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Advances in Social Simulation

Proceedings of the 15th Social Simulation Conference: 23–27 September 2019

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Preface

This book covers the contributions of the 15*th* Social Simulation Conference (SSC) in Mainz, Germany, in September 2019. The annual conferences belong to the key activities of the European Social Simulation Association (ESSA) to promote social simulation and computational social science in Europe and elsewhere providing an international platform for sharing and discussing ideas at the cutting edge of the research field.

Under the general heading *Social Simulation for Social Policy*, the 15*th* SSC featured a special policy focus on *Urban Planning—environmental, economic, demographical and social perspectives*. The conference theme was represented by dedicated keynotes, a plenary policy modelling track, a practitioner round table on federal policies for demographic change, and a modelling challenge for students on air quality policies with local stakeholders from Mainz city planning and urban policy making where students were called to compete for a city simulation award. The focus on "Simulation for Policy" demonstrated the transdisciplinary and practical relevance of the research field as confirmed by the opening speech of the conference held by the State Minister of Social Affairs, Labour, Health and Demography of Rhineland-Palatinate, Sabine Bätzing-Lichtenthäler.

The conference attracted 180 researchers from all over the world. More than 120 conference papers and 23 posters were presented: 57 contributions had been selected for this book. We are grateful to the members of the Conference Scientific Committee who dedicated their time reviewing and selecting the articles for this book.

Following the thematic tracks of the conference, the book contains eleven sections that cover the wide spectrum of research in the field of social simulation. The sections' themes cover work on social simulation theory, methodological issues, and applied research on systems and policy modelling. The theoretical sections address *computational organization theory* with four contributions; two articles focus on the issue of *norms, values, and salience*, and ten contributions concern studies on *artificial sociality*. The methodological sections include a section consisting of four articles dedicated to *modelling synthetic populations*, a section of five contributions on *using qualitative evidence to inform behavioral rules in* *agent-based models*, and six articles on various issues in *methods*, e.g. on the didactics of simulation. Applied research in social simulation is covered by systems and policy modelling. It starts with a section of five articles addressing *socio-cognitive aspects in socio-ecological systems*. The section on *policy modelling* consists of six articles. A section on *tackling climate change and the challenges of the energy transition* contains six contributions. This is followed by a section on *city life* with three contributions. The last section on *simulating mobility* consists of six articles.

The 2019 Mainz conference had been the biggest Social Simulation Conference so far, attracting about 200 visitors from various inter- and transdisciplinary backgrounds. On the one hand, the fact that it was already the 15*th* annual conference of ESSA confirmed that social simulation is an established research field in the meantime successfully growing into maturity. On the other hand, the attraction of so many participants from heterogeneous backgrounds proved that social simulation is an innovative and vibrant research field.

One of the reasons for this success is the fact that social simulation is ideally suited for research questions that require an interdisciplinary approach such as illustrated by the section on systems modelling in sustainability: Research integrates individual cognition and social interaction and locates the human species in the wider frame of the terrestrial ecology. Interdisciplinarity in approach to complex social systems is also reflected by interdisciplinary cooperation in research teams. The high number of contributions in applied policy modelling demonstrates the practical importance of the research field. Social simulation can help decision-makers to understand complex systems and their dynamics. It supports the evaluation of system interventions and the development of better policies in many different domains.

The book provides a broad synopsis of the state of the art in social simulation, both for the established researcher who looks for the latest developments in specific domains and as an informative guide for the newcomer. We wish both audiences a pleasant and exciting reading experience.

Mainz, Germany

Petra Ahrweiler
Martin Neumann

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Part I
Computational Organisation Theory

Chapter 1
Simulation Model of Financial Flows of An Industrial Enterprise

Aleksandra L. Mashkova and Olga A. Savina

Abstract In this paper we present the simulation model of financial flows of an enterprise based on discrete-event approach. The model simulates interactions of an enterprise with customers, suppliers and banks. Financial operations of the enterprise are modeled in the event sections and reflected in accounting statements. The developed model optimizes settlement payment strategy with counterparties and loan repayment scheme, taking into account fluctuations of frequency and volume of orders. Experimental studies are aimed at developing a loan repayment scheme for a medium-sized business, which would ensure the permanent solvency of the enterprise with a minimum cost of working capital attraction. Scenario calculations were compiled for conservative, optimistic and pessimistic prognosis of interest rate and volume of orders during the period.

Keywords Simulation model · Financial management · Financial flows · Accounting methods · Scenario calculations

Introduction

Computer-based financial modeling systems are today gaining much greater acceptance in business organizations [4]. Despite this, a wide gap seems to exist between the information and logic structures programmed into financial models, and the precepts and algorithms derived from a theory of corporate financial management. For the rational organization of financial flows, it is necessary to ensure their quantitative and temporal correspondence to material flows. In organizations this movement is

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rarely synchronous—either an advance payment is made, or payment is delayed as a result of a lack of funds. This leads to difficulties in planning financial flows by traditional econometric methods [2] and determines the need to use stochastic modeling to support decision making [8]. Simulation methods are already widely used in project planning [3, 5] and analysis of financial markets [7]. Simulating financial flows of the organization, their reflection in financial accounting and calculation of financial results based on the received data would lead to effective management of operating capital and reduce its costs.

Structure of the Model

The proposed methodology for simulating financial flows of an enterprise includes the following steps:

1. Reproduction of the initial financial condition of the company (its accounts, assets and liabilities) on the basis of accounting data.
2. Simulation of the receipt of orders and the process of their implementation.
3. Simulation of interactions with the bank and the counterparties.
4. Reflection of operations in the financial statements; determination of the lack of financial resources, cost of their attraction and financial results of the enterprise.

The simulation model of financial flows of an enterprise is based on the discrete-event approach. The sequence of events is reflected in the graph-scheme (Fig. 1.1). Each vertex of the graph corresponds to a certain event [6]. Events are scheduled in the queue, which manages their execution. The sequence of events can be determined

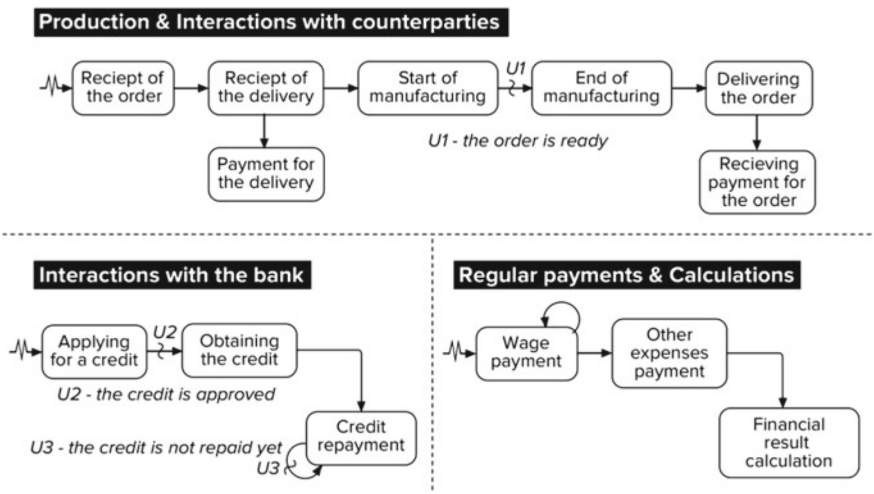

Fig. 1.1 Graph-scheme of the simulation model of financial flows

by conditions U. When the event is executed, changes are reflected in the accounting entries, which ensures the accuracy of the statistics generated as a result of simulation.

The model is based on two assumptions: (1) "just in time" delivery system; (2) sufficiency of the production to fulfill the order without delay. The sequence of actions of the enterprise within each event sections is defined. For example, within the event section "Receipt of order from a customer" a list of materials for production is formed, they are grouped so that each delivery would include materials ordered from one supplier, and the arrival of each delivery is scheduled after a certain period, which is specified by the available information about the supplier.

On the input interface of the model information about previous periods and current activities of the enterprise is loaded: loans, orders, accounts receivable and payable, available cash and production capacities. In the process of modeling, receipt of orders, scheduling of supplies, information about manufactured products and changes in the value of receivables and payables is reflected in the model database. Accounting balance is compiled for the current date; as well as profit and loss statement for the previous period. Accounting is implemented in a simplified form, nevertheless, it is possible to make reliable estimates of profitability, sustainability and other financial indicators of the enterprise on its basis [1].

Modeling Results

The aim of the experiment was to develop a loan repayment scheme for a medium-sized business, which would ensure the permanent solvency of the enterprise with a minimum cost of working capital attraction. Manageable factors in the model are date, period and amount of the credit. Unmanageable scenario parameters are interest rate for the credit, volume of orders from customers during the period and type of orders distribution function. The scenarios were designed for calculations which combine various combinations of these factors. Simulated period was limited to one year, to the level of operative planning.

There are a huge number of combinations of controlled factors, so it is difficult to make an experiment plan in advance. The starting point is identification of requirement for credit resources. The model is run without planning the loan and it is determined when the enterprise lacks working capital and how much cash it needs. After analysis of modeling results, credit options are introduced and changes are observed. After the permanent level of solvency is reached, the volume of credits is optimized. The target function is to minimize the amount of interest paid for using the credit (Table 1.1).

Optimization is based on iterative calculations on the model, and the conditions under which there is lack of funds are excluded from consideration. Results of the experiment for the Scenario #1 (interest rate 25%, volume of orders 220 mil RUR, even distribution of the orders) are shown in Table 1.1. Combination of controlled factors in the experiment number 7 has the best characteristics. In this case, the

Table 1.1 Experimental studies (Scenario #1)

№	Credit calendar (credit #1, #2, #3)			Sum of credit (credit #1, #2, #3), thousand RUR			Credit period, days	Lack of funds	Credit cost, RUR
1	Jan 10	Mar 20	Nov 25	560	420	160	30	Yes	23750
2	Jan 15	Mar 20	Nov 25	560	430	200	30	Yes	24790
3	Jan 10	Mar 20	Sep 20	580	440	200	30	No	25417
4	Jan 10	Apr 1	Sep 20	550	430	170	30	Yes	23956
5	Jan 15	Apr 10	Oct 20	550	430	150	45	No	35312
6	Jan 10	Apr 10	Oct 20	510	360	160	21	Yes	15021
7	Jan 10	Apr 15	Oct 20	550	410	140	30	No	22917
8	Jan 10	Apr 5	Oct 10	540	380	140	30	Yes	22083

enterprise does not lack working capital and the total costs of financial recourses attraction is 22917 RUR. Similar experiments were conducted for other scenarios.

Conclusions

The developed simulation model of financial flows reflects in detail financial operations of an enterprise. Implementing the model for support of financial decisions allows to reduce the cost of working capital by optimizing payment schedule with counteragents and loan repayment scheme. Modeling parameters change in accordance with the market situation within a set of scenarios, which are analyzed through a multivariate analysis of simulation results. The proposed model and algorithms can be implemented both for financial planning support and for reproduction interactions of enterprises in macro-economy simulation models.

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Chapter 2
Drug Trafficking As Illegal Supply Chain—A Social Simulation

Maarten Jensen and Frank Dignum

Abstract Cocaine trafficking is starting to get modeled by supply chain theory. Supply chain theories are described in many economical papers. These theories are however not directly usable in analyzing illegal supply chains. In this paper we investigate the difference between legal and illegal supply chains. Where the difference of the supply chain lies in two factors, these are trust and risk. Here we model a cocaine trafficking supply chain based on legal supply chain theory. This model will be copied and adjusted with theoretical concepts that are inherent to an illegal supply chain. Comparison of the results of the two models showed that differences in those factors lead to differences in the supply chain, such as clustering and efficiency.

Keywords Illegal supply chain · Cocaine trafficking · Trust · Risk

Introduction

The Netherlands is part of the cocaine trafficking business. This is an illegal business that connects cocaine producers in South America to consumers all over the globe. It starts in countries such as Colombia, Peru and Bolivia where coca leaves are farmed and refined to cocaine. This product is transported to various continents, including Europe. The Netherlands and Spain seem to be the main entry points for the drug [15]. The criminals in these countries transport the goods to other European countries

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after importation. Transportation of such large quantities of illicit drugs comes with high criminal activity.

The criminals take advantage of legal transport, real estate and bribe civilians. These undermining actions have a negative effect on public well being and safety. Although less common than in the past, there is still violence among criminals [5]. The strategy applied in the past decades by America had the goal of supply reduction, by eradicating plantations, destroying drugs labs and capturing or killing cartel leaders in South America and Mexico. A positive effect happened in the United States which saw an increase in cocaine price and a decreased drug consumption. However there seem to be more negative effects, as eradicated supply routes have been displaced, creating criminal activities and in some cases more homicides in other regions. The tactic of Mexican police to capture or kill the leading drug dealers, i.e. kingpin strategy, has lead to the fragmentation of large criminal organizations and a massively increased homicide rate [7]. After these events the small number of large criminal groups (cartels), who are based on ethnic ties and are hierarchically structured, broke down into many small independent criminal syndicates who see themselves as entrepreneurs and are based on friendship, kinship and ethnic networks to select partners [5]. These newly formed smaller groups work together to form a supply network that provides drugs all over the globe. In recent decades this market has shifted to Europe and the questions for authorities how to deal with these illegal activities remain. Especially for the Dutch National Police, who are stakeholders in this project, as the Netherlands is a transit country within this illegal supply chain [15, 17]. Knowing more about the illegal supply chain will help authorities make better decisions, when it comes to applying strategies against the criminal world.

To gain insight in the workings of the illegal cocaine trafficking supply chain, we cannot straightaway use current supply chain (SC) theories [2]. These are theories, like the role of trust in SC responsiveness [9] and building a resilient SC [4] that are based on analyses of legal businesses. There are some crucial differences between a legal and an illegal SC. Since there is no official regulatory instance, like contracts or the government, within criminal networks, cooperation is based on other factors such as trust [14]. Performing illicit tasks contains the risk of getting caught by the police, thus risk management strategies are also different in criminal networks [2]. These two factors, trust and risk, will be taken into account for the illegal SC model. We will propose a comparison of two models, one model of cocaine trafficking where the SC component is based on legal supply chain theory. The second is a copy with some adjustments based on theoretical concepts inherent to illegal SCs. These models will then be compared to explain qualitative differences between a legal and illegal SC. Differences regarding the SC growth, dynamics of connections and efficiency.

The next section will describe legal SC theory and a simulation with trust based on legal SC theory. The third section describes the important aspects of cocaine trafficking such as: trafficking, quality, trust and risk. The fourth section describes the proposed model in detail. The fifth section shows results and comparison of the model. In the last section we end with a discussion.

Supply Chain

The term supply chain, although frequently used in contemporary times, is relatively new within economics. It was first coined in the early 1980 as management term. The idea is that individual companies replace the priority of self-interest and personal profits gain, to create an efficient organization with their suppliers and clients [4]. SC management would manage the process from raw materials to delivering the costumer, aiming at an efficient product flow. There are many SC models [11]. However they are not directly the most interesting for this project. They do not take into account the factors of trust and/or risk.

Simulation of a Supply Chain with Trust

Jalbut and Sichman [10] give a simulation of a SC with trust. We will use this simulation as basis for our simulation, as trust is one of the important factors to include in the simulation. Agents in the SC send orders, that take a few steps to arrive, to their supplier. The supplier, upon receiving an order, sends a shipment if he has enough stock. This shipment arrives a few steps later and is received by the client. The trust in the supplier is defined by the historical ratio between the orders placed and the shipment received (Eq. 2.1). In the formula i is the client, j the supplier, the current simulation step is denoted with n, S_{ji} is the shipment received and O_{ji} is the order send. The formula takes into account the time it takes to receive the shipment after sending an order, by mapping the shipments 6 ticks later.

$$Trust_{ij}(n) = \sum_{r=6}^{n} S_{ji}(r) / \sum_{r=1}^{n-6} O_{ij}(r) \tag{2.1}$$

The agents in the simulation search for new suppliers by random chance. They ask their peers for trustworthy suppliers. They will choose suppliers with the highest trustworthiness.

Cocaine Trafficking

The Netherlands As Transit Country

Since the National Dutch Police are stakeholders in this project, we look at the role of the Netherlands in cocaine trafficking. Research states that organized crime in the Netherlands takes the role of a transit-hub (Fig. 2.1).

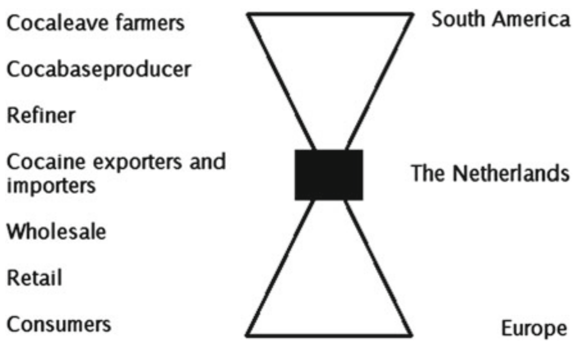

Fig. 2.1 Based on Zaitch [17]

The chain starts in South America where the coca leaves are farmed and refined to cocaine. Most of the pure cocaine for the European market is transported overseas to the Netherlands and Spain. In the Netherlands the cocaine is partly consumed, but the larger amount is distributed to other countries such as Germany, Belgium, United Kingdom and Scandinavia. The form of the figure indicates that the SC starts with many coca leave farmers, who are widespread. The number of people working on it decreases every step from there on. At the cocaine exporters and importers level the number is the smallest and the goods are bundled into larger packages. After import the number of criminals in the process increases and the goods are spread out. Until they reach the consumers who can be all over the continent.

Drugs Trafficking

To create a complex simulation we take quantity, quality and pricing into account. These aspects influence each other as higher quantity usually means higher profits but also higher costs. An increase in quality can also increase the profits but the desired quality may not always be available.

Quantity is dependent on the SC level. Individual farmers only transport a few kilograms. In international transport, ships are mainly used. These ships contain containers filled with hundreds of kilograms of cocaine. Upon arrival in a transit country these shipments can be split among wholesalers, who in turn split it to retailers in even smaller amounts. At the end of the chain, consumers only buy several grams [15].

In the process of trafficking purity of cocaine can be decreased by cutting. Against common beliefs cutting is not performed by retailers, using harmful substances like cleaning products, brick dust and ground glass. Instead it is most often done at production level or at import level, without the goal of harming consumers [3]. According to Broséus [3] the changing of quality, cutting, is performed either at production level or directly after import, at wholesaler level. The purity determines to which countries it can be shipped as customers in different countries are satisfied with different levels of purity [15]. Data from the EMCDDA also indicates highly varying purity in different European countries [6].

Pricing of the cocaine is mainly dependent on the SC level. The price per kilogram increases substantially for each level. After production and refinement in South America a one kg brick of cocaine is worth $800. At international export level in Mexico this price has increased to $34.700 per kg. After import in the country of destination it becomes even higher with $120.000 per kg for the U.S [1]. This difference in pricing should be introduced in the simulation to represent the income of the agents in a more realistic way.

Trust and Risk Assessment

There is a difference between legal and illegal SCs within the concepts of trust and risk. In legal SCs companies can make contracts with each other to form cooperation and prevent risks. In criminal networks formal contracts are not a possibility. Therefore there must be other bases of cooperation. Analysis by Lampe and Johansen [12] on smuggling networks, indicates that cooperation between criminals is highly based on trust. They propose many forms of trust and see the lack of trust as deterring cooperation among criminals, as this increases extortion and threats. In Lotzmann and Neumann [13] we can see a criminal drug dealing group dismantling itself because of the loss of trust among members. There was an event of distrust in a person, this lead to punishing reactions of others. Eventually leading to liquidations.

Risk evaluation is done by criminals in the cocaine trafficking business [16]. One of the main priorities is to not get caught as this leads to personal loss or monetary losses. The risk may prevent criminals from acting immediately and delay their operations. On different levels of the SC there is a varying amount of risk [16]. However this goes out of the scope of this paper. With larger shipments the risk is higher as they are more easily detected and the potential loss is larger. This is different from a legal SC, where the risk of capture by authorities is absent, if the paperwork is fine of course.

Conceptual Model

This section describes the full model in detail. To promote reproducibility the model is available through GitHub[1] and the GitHub contains an Overview, Design concepts, and Details document (ODD) [8]. The model uses the legal SC implementation with trust, by Jalbut and Sichman [10], as a basis. The model's domain is illegal cocaine

[1] https://github.com/maartenjensen/Social-simulation-illicit-supply-chain. Branch: *SSC2019*, commit number *9870ed3*.

trafficking through Europe. From this domain we use qualitative data to provide the model's concepts and quantitative data to provide some parameter settings.

Purpose

The purpose of this model is to give answers to the research question: *What is the difference between a legal and illegal supply chain?* The legal SC is the standard model. We create the illegal SC model by making two adjustments to the standard model. One adjustment is based on trust relations, the other based on risk as these are both prominent factors in an illegal SC. A comparison of the results of both models will be used to answer the question.

Entities, State Variables and Scales

The entities in the simulations are agents, countries, orders and shipments (Fig. 2.2). They are divided in 5 levels in the SC: producers (P), internationals (I) , wholesalers (W), retailers (R) and consumers (C), based on Jalbut and Sichman [10]. *Producers* are their own suppliers and can decide their own production rate. The quality is fixed for a producer, either 40 or 60. The higher quality is sold for 20% more money. *Internationals* have the highest shipment quantities as they send their shipments overseas. *Wholesalers* have the option to convert high quality to low quality, for each high quality they have they get 1.5 low quality. Quality is purity and as an example 2 kg of 60 purity, would leave 3 kg of 40 purity. They perform this cutting whenever they do not have sufficient low quality for an order and have some high quality to cut.

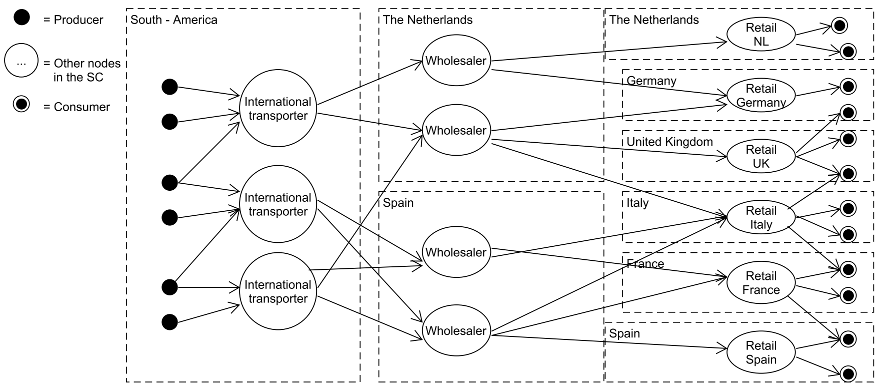

Fig. 2.2 Simulation overview: showing the layout of the entities. Arrows are a supply line and shows the direction of shipments, orders go the other way around

Retailers shipment quantity is the lowest as they send to the consumers. *Consumers* do not have clients as they consume the goods themselves. They have a fixed quality and consumption rate per tick. They are removed from the simulation when they cannot consume for a fixed amount of ticks. All the other agents are removed when they are bankrupt or when an amount of time (104 ticks, 2 years) has passed with no incoming or outgoing shipments for that agent. The pricing grows the further up the chain (towards the consumer). These price differences, *selling price*, are based on the relative price differences in Basu [1]. The general formula for the price of a shipment is represented by $price = selling\ price \cdot (quantity_{q=low} + quantity_{q=high} \cdot 1.2)$, where the high quality is multiplied by 1.2 to represent the 20% increase in price for high quality.

Countries spawn agents of the corresponding SC levels (Fig. 2.2). Since both the Netherlands and Spain are seen as transit countries they contain wholesaler agents. Dependent on the SC level the agents' horizontal position is decided. Their vertical position is dependent on the country. The consumers in European countries crave different amounts of quality [6].

Orders and Shipments take three steps to reach the destination. Orders travel from client to supplier, shipments from supplier to client. They contain the required goods, this is the amount of quantity for each required quality. Shipments also contain the price to be paid by the client. Agents use a learning function to send orders, which makes the orders and shipments arrive in a stream instead of impulsive.

Scheduling

The scheduling of the model is described by pseudocode in Algorithm 1.

Algorithm 1: Model schedule, based on [10]

foreach *tick* **do**
- *Agent:* Pay living cost & removal of bankrupt nodes
- *Country:* Spawning of new agents
- *Shipments:* Move one step further
- *Orders:* Move one step further
- *Agent (consumer):* Receive income
- *Agent:* Choose new suppliers and clients
- *Suppliers:* Receive orders **AND** send shipment to client
- *Consumer:* Consumes
- *Clients:* Send order to supplier
- *Producer:* Create a shipment for himself

end

Design Concepts

The purpose of the model is creating two SCs, a legal and illegal SC that can be compared. The objective of each agent in the SC is to survive by gaining profits. This is done by being able to supply the clients and keeping the stock low. The agents adapt their orders to suppliers based on the amount of goods they require. When there are not enough goods available they will search for new suppliers. When there are sufficient goods available they can search for additional clients. They cannot send shipments directly, however they can connect to new clients. When connected, the clients can start to send orders to the suppliers. A new supplier with directly a good response of shipments can become the main supplier for that client. These micro actions can let a SC emerge since consumers will consume and find out they need suppliers. They find retailers who in turn have to find wholesalers. This process continues until the producers are reached who start producing and send shipments. These shipments eventually reach the consumers. The agents learn from interaction with their suppliers, i.e. how often they send their shipments, this is the definition of trust in this model. The agents only have interaction with neighboring agents, thus only the direct suppliers and clients. For choosing suppliers and clients they look at the trust relation of agents at the same SC level. Stochasticity is used at a few places in the model. The agents are initialized at a random position in their country. New possible clients and suppliers are ordered based on trust but random when they have the same trust level. The possibility of sending a shipment in the illegal SC is stochastic. The starting stock quality and security stock quantity is stochastically determined. For consumers the consumption rate is stochastically determined.

Legal Versus Illegal

Trust The clandestine nature of illegal trafficking makes clients and suppliers not openly visible. While legal suppliers and clients can usually be found through the internet or commercials. The illegal SC agents try to be as discrete as possible. The illegal SC model takes this into account by limiting the visible clients and suppliers. An illegal agent always has the closest supplier and the closest client. The chance of being able to know other suppliers and clients is given by ρ determined by Eq. 2.2. It takes into account the vertical position between the agent y_i and a client or supplier y_j, and divides the distance by the grid height $h = 50$. The minimum returned probability is given by $\alpha = 0.1$. The *probability multiplier* $\beta = 0.5$, decreases the total probability.

$$\rho = max(\alpha, (1 - min\left(1, \frac{1}{\beta} \cdot \frac{abs(y_j - y_i)}{h}\right))) \tag{2.2}$$

Risk One difference between the legal and illegal SC is the possible risk of getting caught by police. This is the case for participants in the illegal SC. Criminals have to wait for the right moment, where they have the right transportation available and when they can evade the police. They cannot send shipments all the time, even when they have enough stock. Therefore a shipment interrupt probability is introduced. It is set at 0.4, this means that there is a 40 percent chance in the illegal SC that an agent can send a shipment. If the agent cannot send a shipment the corresponding order is delayed and added to other delayed orders. The agent sends a shipment when there is no interruption and when there is a new order, this shipment will take all the delayed orders and the new order into account. The client will receive this shipment and compares this with the matching order (6 ticks back). The excessive quantity will be added to the received shipments with a penalty of 0.5.

Results

Simulation Initialization

We show the behavior of the simulation in more detail in this section. We analyze the micro behavior of agents and compare this with the model's design. The SC will form from the consumers to the producers. Since consumers are the first to deplete their stock and crave more goods, they will receive the goods from retailers and then the retailers will not have enough stock. This behavior propagates until it reaches the producers, who will start a production line.

Figure 2.3 shows a part of this process in which an international finds a producer in a legal SC. Figure 2.3a shows tick 11, with orders (blue orbs) coming from the wholesaler in Spain with id:15 (W) to the international with id:8 (I). The orders from wholesaler 15 contain both low quality and high quality requests. In Fig. 2.3b the orders are processed by the internationals (7 and 8) and they send shipments back. Since they both have low quality in their stock and low quality is in the orders, they send a shipment of low quality (dark yellow orb). The next step both internationals (7 and 8) realize they do not have enough stock and search for a producer (P). Likewise the producers search for an international as they have enough stock, thus at Fig. 2.3c we see the connections are made. The connections start with trust 0 indicated by red, a trust of 1 is indicated by a green line. The internationals send an order straight away. After a few ticks (Fig. 2.3d) the orders of the internationals have reached the producers, the producers (1 and 3) send a shipment and start producing shipments for themselves to meet the demand. Producer 3 sends a high quality shipment and produces high quality goods, while producer 1 does this with low quality. These shipments can be seen at the left of the producer and arrive three steps later. This shows the processes of the simulation at micro level, in the next experiment we show the macro level behavior of the model.

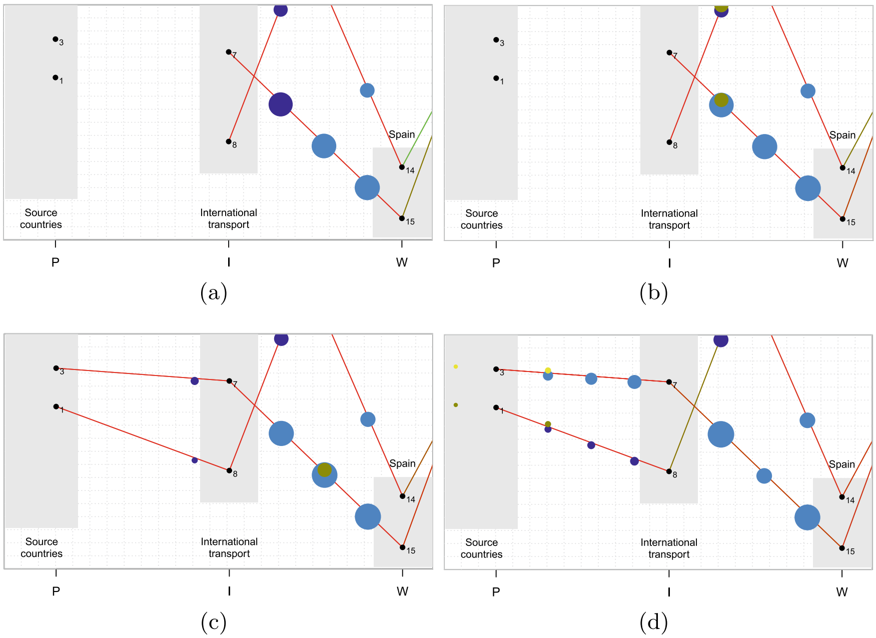

Fig. 2.3 Legal SC initialization: **a** Tick 11; **b** Tick 12; **c** Tick 13; **d** Tick 16 Black dots are agents with their ID displayed, the lines are connection between agents, blue orbs are orders (go to the left) and yellow orbs are shipments (go to the right)

Legal and Illegal Comparison

For the comparison we have run both the legal and illegal model for 1000 ticks. The input parameters are as given by the GitHub code, the same as in the initialization runs. It can be expected that in both runs SC networks will form from producers to consumers. However they most likely differ in composition, with a legal SC network being more spread out and the illegal one more clustered. The trust will most likely be less for the illegal SC as shipments get delayed.

Figures 2.4 and 2.5 show respectively the formed legal SC and illegal SC. An immediate difference that can be seen is the difference in density, where the legal supply chain is much more dense. This has to do with the increase of agents and the increase in connections between those agents (since they are able to make more connections). When we look at the colors for the trust level, we can see that the legal supply chain has many red colored connections. However also brighter colored green connections, indicating higher trust levels. This can be explained by the absence of shipment interruptions, where sending a shipment is only dependent on the stock of a supplier, which makes it easier to send shipments on time. With no interruptions the stock can be maintained relatively easily. When there are interruptions it is harder to keep stock, the clients do not get enough shipments and therefore make larger orders.

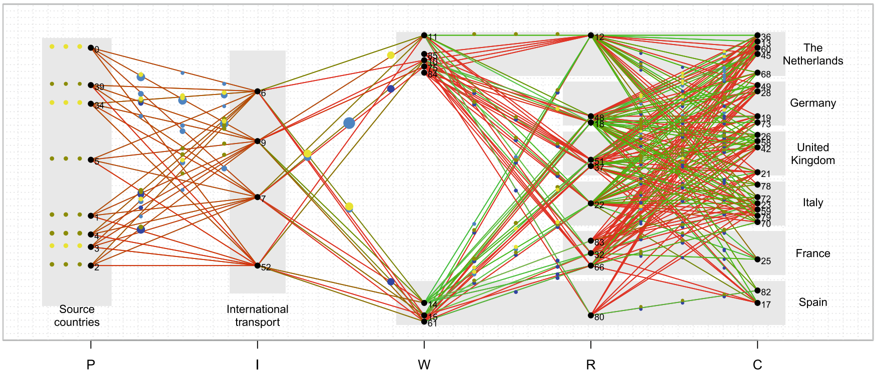

Fig. 2.4 Legal supply chain—At Tick 1000

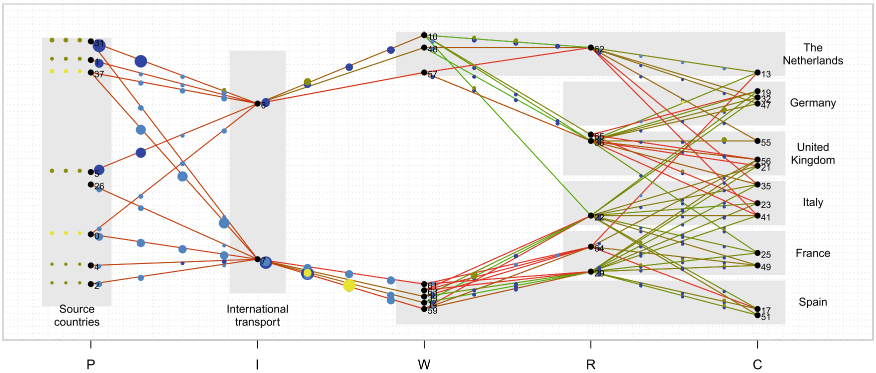

Fig. 2.5 Illegal supply chain—At Tick 1000

This can be seen in the illegal SC between the producers and wholesalers (there are larger blue orbs). The network of the legal SC is more evenly distributed, wholesalers from the Netherlands would deliver to retailers in Spain and vice versa. This does not happen in the illegal SC, where wholesalers of the Netherlands tend to supply retailers from Germany, United Kingdom and Italy. While wholesalers from Spain tend to supply retailers from France, Italy and the United Kingdom. The retailers from their own countries are not there, they became bankrupt at an earlier tick. Possibly by their lower number of *possible clients* as they only have one neighboring country. At the international level the SC is the smallest in terms of number of agents, going left from the wholesalers the number of agents expands. This roughly approaches the hourglass form in Fig. 2.1.

The plots Figs. 2.6 and 2.7 show some differences in the average wealth among agent types. For most SC levels the average money is comparable. Producers have the least money, this is expected since they make the least money from selling. The retail agents earn a bit more, they do have a higher selling price but only sell small

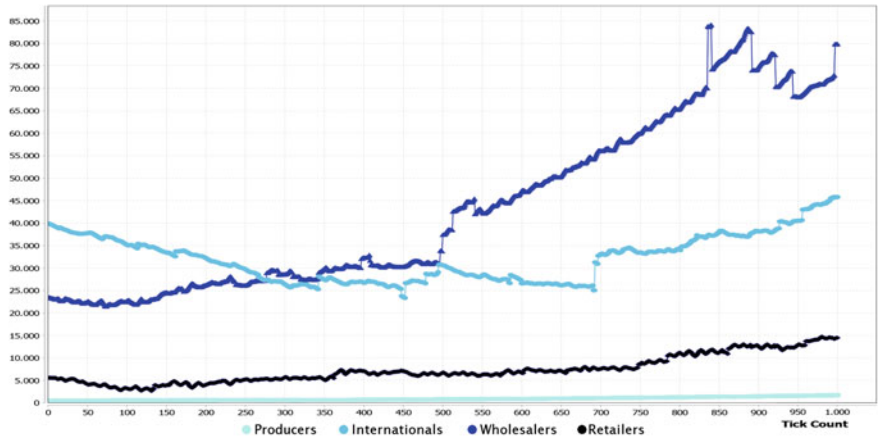

Fig. 2.6 Legal SC money average

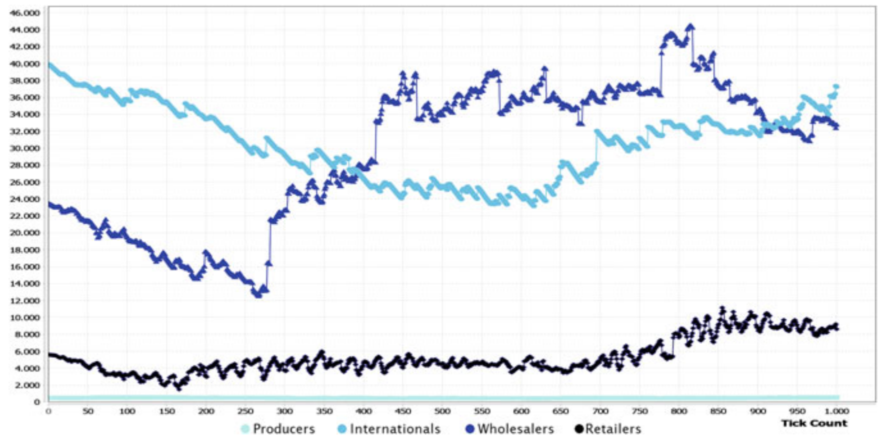

Fig. 2.7 Illegal SC money average

quantities. Combine this with their higher living cost, since labour cost in Europe is higher than in Colombia. The internationals and wholesalers make the most money, as they move large quantities and are in a high selling price. In the legal supply chain we can see the internationals earning a lot of money after tick 500, probably since a stable network has been established. This allows the internationals to have a constant stream of goods from multiple suppliers and able to sell to multiple wholesalers. This does not happen in the illegal SC, probably since it is not stable enough. The illegal average wealth seems to fluctuate more due to a combination of a lower amount of agents and the interruption in shipments. The interruptions in the illegal SC introduce less frequent but higher monetary gains.

Table 2.1 Summary comparison between the legal and illegal SC

Legal SC	Illegal SC
∘ Generally a higher trust level	∘ Generally a lower trust level
∘ Retailers are spread through all countries	∘ Not all countries have retailers
∘ Trade routes are spread out	∘ Trade routes seem to bundle more
∘ More efficient thus it can satisfy more consumers	∘ Less efficient thus it can satisfy less consumers
∘ Few goods are lost because of agent removal	∘ Some goods are lost because of agent removal
∘ Smaller orders thus smaller shipments	∘ Larger orders thus larger shipments

There is also a difference between the legal and illegal SC regarding the produced goods and lost goods. The legal SC has a higher produced goods and consumed goods throughout the run. The amount of removed goods, due to bankrupt agents is relatively low. The illegal SC has lower produced goods and consumed goods and more removed goods than the legal SC. This indicates that the illegal SC has less efficiency. Table 2.1 shows the conceptual results based on the simulation results.

Discussion and Conclusion

By modeling cocaine trafficking as a SC with certain aspects adjusted, a difference in trust and risk. We get the results seen in Table 2.1. The illegal SC seems to reproduce trends of the real world.

The creation of this model brought many possibilities for improvements forward. In the simulation all the agents are syndicates, thus not explicitly modeled as individuals. This would be interesting to see what for example the kingpin strategy [7] would do. The simulation can be adjusted in such a way that agents in the SC can be taken out by the police. For example a large wholesaler that, after a police intervention where they capture the leader, splits up in two smaller wholesalers. Each of the wholesalers having part of the supplier and clients. It would be possible to introduce rivalry or cooperation among these separated wholesalers.

The pricing in the simulation is currently fixed, with variations at different levels and for a higher quality. The agents are not able to vary the prices themselves. Allowing this would show interesting results regarding the tactics used by agents to thrive in the SC. This can be analyzed under different circumstances. Additional tactics could be the choice of shipment size, frequency and concealment level, to prevent detection however increasing costs.

Currently the simulation goods are going through the SC on a demand basis. Since it is based on Jalbut & Sigman's supply chain model [10]. However described by Vermeulen et al. [15] there are cases of an overflow of the drug market. Giving the suppliers the ability to push more quantity may change the behavior of the SC as well.

This means other agents have to search more actively for more clients. With many agents there will be a large amount of competition, which will have other effects, possibly decreasing the prices. Using other economical models we could model this push dynamic.

This model can be used as a basis for illegal SC modeling. However there is still much to do, which is to be seen as it already generates many interesting questions.

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Chapter 3
Influences of Faultlines On Organizational Performance

Fumiko Kumada and Setsuya Kurahashi

Abstract The diversification of employment and work styles in organizations is in progress in Japan, where the labor force is shrinking because of a declining birthrate and an aging population. It is important that we demonstrate how to manage a diversified organization. Using the concept of faultlines, which are hypothetical dividing lines that may split a group into subgroups of people based on their multiple attributes, this paper examines the relationship of influences of an associated diversity (i.e. the faultline strength and the number of subgroups) and a method of communication within an organization. The methods are verified by an agent-based model based on a survey of Japanese organizations. Thus, this paper clarifies that appropriate communication is related to the associated diversity of an organization. Therefore, it is important for a manager to grasp a structure of diversity of an organization and to design communications accordingly.

Keywords Diversity management · Faultlines · Agent-based model

Introduction

Ensuring a stable workforce in Japan is becoming more important, given the country's shrinking labor force due to a declining birth rate and an aging population. Therefore, the acceptance of foreign workers and work-style reforms are in progress, leading to the diversification of workers and work styles. In the field of diversity management, diversity is known to affect organizational performance either positively or negatively. Therefore, clarifying the factors that are positively affected by diversity in Japan is important.

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This paper focuses on the concept of the faultlines perspective defined by Lau and Murnighan [7] to derive one of the solutions to managing a diversified organization to enhance organizational performance. In the following sections, we first introduce previous studies. Second, we explain an agent-based model (ABM) based on the concept of faultlines. Next, we survey Japanese organizations to learn about the attributes of their members. Subsequently, we simulate using the ABM with the results of the survey. We conclude by summarizing the results of the simulations.

Previous Studies

The Field of Diversity Management

Williams and O'Reilly [13] proposed an integrated model that represents how diversity affects organizational performance and explained that diversity could have both positive and negative effects. The integrated model reflects three theories.

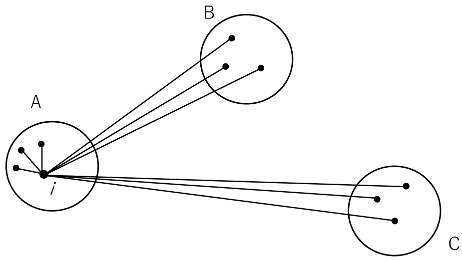
The first theory is the social categorization theory. This theory explains that people categorize themselves and others using demographic attributes, such as age, gender, and others, and that they may experience conflicts in their communications and relationships. The second is the similarity-attraction theory. This theory explains that highly similar individuals feel an attraction to each other and strengthen their solidarity while causing conflict with those who are less similar. The third is the information and decision-making theory. This theory explains that diversity increases knowledge and information types, providing an organization with positive effects. Based on the integrated model, the key point dividing positive from negative may be related to the smoothness of communications.

Faultline Perspective

Lau and Murnighan [7] proposed the concept of faultlines, which are hypothetical dividing lines that split a group into subgroups based on one or more individual attributes to explain the causality of diversity based on attributes of organizational members and conflicts within the organization.

Many previous studies on the faultline perspective reported that they increased conflict. Regarding studies that focused on subgroups, Plzer et al. (2006) reported that an uneven group size could achieve high performance. Carton and Cummings [2] conducted a field survey that showed that three or more subgroups could achieve high performance. In addition, Flache and Mäs [3], Grow and Flache [4] and Mäs et al. [8] revealed the mechanism of the faultline perspective by an agent-based model.

Fig. 3.1 Relationships of elements involved in the computation of *s(i),* where the object *i* belongs to cluster A [11]



Faultline Measurement Methods

Previous studies proposed more than 10 faultline measurement methods. Suzuki et al. [12] stated that the rating scale for cluster analysis proposed by Meyer and Glenz [9], the average of silhouette width (ASW) had various advantages. For example, the ASW could handle continuous and categorical variables and divide target organizations into proper subgroups.

ASW is a rating scale used to evaluate cluster analysis results, as proposed by Rousseeuw [11]. The following items are defined in Fig. 3.1:

– *a(i)*: average dissimilarity of *i* to all other objects of A.
– *d(i, C)*: average dissimilarity of *i* to all other objects of C.

$$s(i) = \frac{b(i) - a(i)}{max\{a(i), b(i)\}} \tag{3.1}$$

Where the smallest value of *d(i, C)* for all the clusters other than A is calculated as *b(i)* according to the above definitions, and cluster B becomes adjacent to A. Equation (3.1) expresses the adequacy of sample *i* to belong to cluster A.

Meyer and Glenz [9] defined this overall mean edge width, $\bar{s}$, as the faultline value. Where the mean edge width is $\bar{s}$ (k) when there are k clusters, for which maximums $\bar{s}$ (k) are selected. The clusters become subgroups, where k is the number of subgroups.

Review of Previous Studies

Only a few prior studies addressed the faultline perspective for Japanese organizations. Therefore, this paper reports on a survey of Japanese organizations on their attributes and indicates diversity by plural dimensions using the faultline perspective. The associated diversity that is defined as the constitution of team members consists of the faultline strength and the number of subgroups because the ASW enables subgroups to extracted to make faultlines stand out in a different dimension from diversity. Moreover, the ABM is used to examine the relationship between the associated diversity and communication. We utilize the ABM because it is appropriate for verifying the influences generated by people's actions toward the entire organization.

Outline of the Proposed Model

In organizational activities, a number of problems occur daily. To solve these problems, both formal communications such as business meetings and informal communications such as chatting occur in an office. Through these communications, members of an organization understand and affect each other. Therefore, the model examines how to influence an entire organization by the associated diversity and communication.

In this model, agents are similar to members of an organization, and they interact with each other to update their evaluation values. Then, the evaluation values of the entire organization (i.e., the sum of the evaluation values of each agent) before and after the interactions are compared to verify the increase or decrease.

Agent Attributes

Each agent has a six-gene array comprised of 0 s and 1 s. This gene array is regarded as the decision-making attitude attribute. Interactions between agents affect each agent's decision-making attitude attribute and update the evaluation value.

The decision-making attributes apply the multi-attribute attitude model of consumer behavior theory. The multi-attribute attitude model describes a scenario in which a consumer evaluates a product, more than one of the attributes receive attention, and all of the evaluations of each attribute result in a comprehensive product evaluation. While replacing products with agents using this concept, the characteristics of how to approach issues are represented by plural attributes, and the sum of the evaluation values of the attributes is regarded as a comprehensive evaluation for solving a problem.

The initial six-gene array of each agent is calculated using the ASW to determine the faultline strength and the number of subgroups. Here, the initial decision-making attitude attribute is assumed to depend on the demographic attributes, such as age and gender, because it reflects before being influenced by other agents.

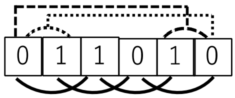


Fig. 3.2 Structure of NK landscape (N = 6, K = 2)

Table 3.1 Example of fitness [5]

Genes	000	001	010	011	100	101	110	111
Fitness	0.141	0.592	0.653	0.589	0.793	0.233	0.842	0.916

Evaluation Function

The NK model by Kauffman and Levin [6] is used as the evaluation function for the decision-making attitude attributes (six-gene array) held by each agent. The NK model is a genetic algorithm that mimics the process by which living organisms evolve and is utilized in various fields, including organizational learning.

The evaluation value of the NK model is referred to as "fitness". The NK model is based on N genes that are related to K genes. Figure 3.2 shows a specific example of N = 6, K = 2, where the evaluation value is expressed as Eq. (3.2).

$$W = \frac{1}{N}\sum\nolimits_{i=1}^{N} w_i \tag{3.2}$$

W_i: The fitness in the fitness function of each gene.

Figure 3.2 shows the case of K = 2. Thus, one evaluation value is calculated with a succession of the agent's genes and the other two genes. There are six sets of genes from the left: (001), (011), (110), (101), (010), and (100) (four sets with a bold line and two sets with dashed lines). The following shows the calculation result of applying the example of adequacy arrays in Table 3.1 based on these six sets. (0.592 + 0.589 + 0.842 + 0.233 + 0.653 + 0.793)/6 = 0.617.

Interaction Method

Initial Method

One organization comprises 18 agents. The six-gene arrays of the 18 agents are evaluated using the ASW. As a result, the faultline strength and the number of subgroups are calculated, and the associated diversity is defined as the constitution of team members. The associated diversity is indicated in Fig. 3.3.

The interaction is defined by "whom" (i.e., the criteria to select an agent), "when" (i.e., the conditions for interaction), and "how" (i.e., the interaction method). The objective of this model is to clarify the type of interactions that have a positive impact

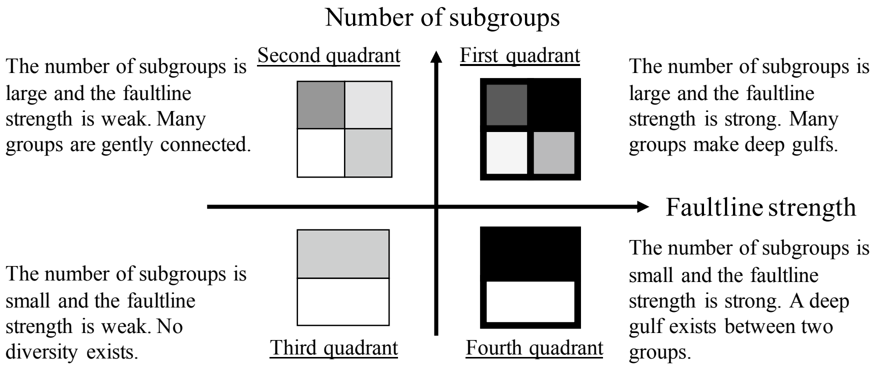


Fig. 3.3 Features of each quadrant in the associated diversity

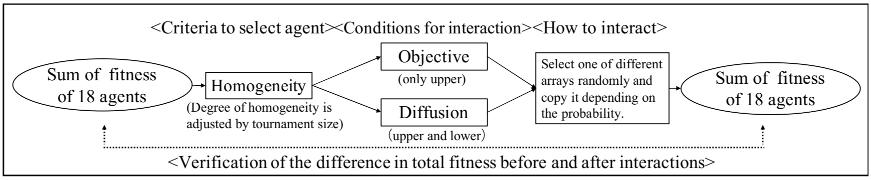


Fig. 3.4 Overall flow of the interaction

on an organization and the quadrant of the associated diversity that effectively affects an organization. Figure 3.4 illustrates the overall flow of the interaction.

Criteria for Selecting An Agent

Williams and O'Reilly [13] reported that the conflict in an organization hinders communication and decreases performance. Thus, a situation of communicating with similar members by conflict is represented, that is named homogeneity selection.

Homogeneity selection comes from the social categorization theory, which is based on the faultline perspective. Similar members gather, and communication is hindered by conflict. The relationship between the degree of homogeneity and organizational performance is verified. As a parameter of homogeneity, tournament size ranges from two to 17. The larger the tournament size, the higher the homogeneity. Figure 3.5 illustrates homogeneity selection process. First, agents are selected randomly according to tournament size. Second, an agent selects another agent with the highest homogeneity (i.e., the closest Hamming distance). Hamming distance is the number of digits of different values at corresponding positions when comparing two values with the same digit number. For example, the Hamming distance between the attitude attributes (011010 and 001010) is 1.

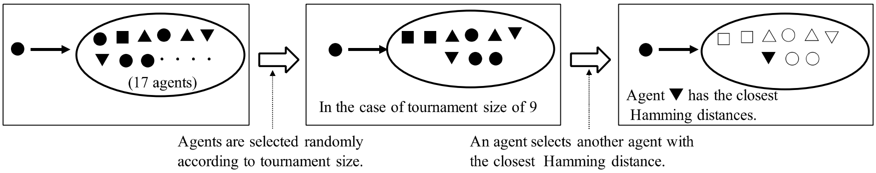


Fig. 3.5 Process of homogeneity selection

Conditions for Interaction

Two conditions for interaction are set for the simulation. The objective type represents each agent attempting to interact with the selected agent when the fitness of a selected agent is higher than that of the agent. In the real social context, it is a situation in which members of an organization communicate to achieve a goal like top-down communications. Business activities usually have goals. Therefore, formal corporate activities are represented by the objective type.

The diffusion type represents each agent's constant attempts to interact with the selected agent regardless of low and high fitness. In the real social context, this type includes, for example, light conversation and information exchange, and lacks goals.

How to Interact

The method of interaction applies the disseminating culture model by Axelrod [1]. This method randomly selected and copied different attributes according to the ratio of the same attributes to the whole. In our model, the ratio of the interaction is set in accordance with the degree of the difference in fitness.

Evaluation Standard

The difference in the fitness of the entire organization before and after interactions serves as the evaluation value. Equation (3.3) shows the evaluation value (E).

$$E = \sum_{i=1}^{n} W_{ei} - \sum_{i=1}^{n} W_{si} \tag{3.3}$$

n: The number of agents.
W_{si}: The fitness of agent$_i$ before the interaction.
W_{ei}: The fitness of agent$_i$ after the interaction.

The evaluation standard is the average of the top 10 out of 100 simulations (except for outliers) as the increasable fitness. Equation (3.4) shows the increasable fitness.

$$Increasable\ Fitness = \frac{1}{10}\sum_{k=1}^{10} E(k) \tag{3.4}$$

E(k): Evaluation value of the top k^{th}.

We observe how the associated diversity and the interaction methods change the increasable fitness, and the relationship between an organizational diversity and performance is clarified.

Simulation for the Verification

To validate the model, we formed six datasets based on the faultline strength and the number of subgroups. The model is valid when faultlines increase conflict and negatively affect organizational performance. In this case, the simulation is performed with the objective type because the faultline is premised as formal communication to obtain a goal within an organization.

Table 3.2 shows the associated diversity of the six datasets and the regression coefficient. The objective variable is the increasable fitness, and the explanatory variable is tournament size. The following two points were reached

– The larger the tournament size, the lower the increasable fitness. A larger tournament size indicates that the degree of homogeneity increases. Therefore, homogeneity selection causes a negative effect on organizational performance.

Table 3.2 Results of simulation for verification

Data set	Faultlne strength	Number of subgroups	Regression cofficient[a]
1	0.687 (strong)	2	−0.395***
2	0.142 (weak)	2	−0.251***
3	0.722 (strong)	3	−0.423***
4	0.308 (weak)	3	−0.264***
5	0.848 (strong)	6	−0.384***
6	0.260 (weak)	6	−0.280***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

[a]The objective variable is the increasable fitness, and the explanatory variable is the tournament size

– When the number of subgroups is the same, the stronger faultline strength results in a larger absolute value of the regression coefficient. Therefore, the strong faultlines have a more negative influence.

This model demonstrates the phenomenon in which conflicts arising from the faultline have negative influences on organizations. The evidence validates the model.

Fact-Finding Survey

We run this model by applying the results of a survey of Japanese organizations to concretely clarify the influence of the associated diversity on organizational performance. Therefore, a survey of Japanese organizations was held to collect the data on the attributes of members.

Survey Overview

The survey subjects were five companies and 14 groups in Japan (three groups in one major company in the real estate industry, one group in one mid-size company that is the investigation firm, seven groups in two startups, and three groups in one emerging company that is a call center agency), for a total of 126 respondents. These groups represent the smallest units that a manager controls. Questions about employee attributes addressed four items: age, gender, service years, and type of employment. By using attribute data, the associated diversity was calculated by ASW.

Survey Results

Table 3.3 shows the associated diversity, and the left side of Fig. 3.6 plots the faultline strength and the number of subgroups of the 14 groups. The results of the regression analysis on the faultline strength and the number of subgroups is as follows:

$$N = 0.687 + 5.721 \times S \quad (3.5)$$

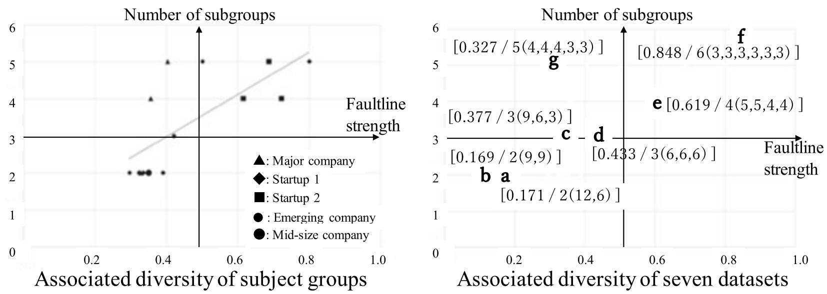
*Coefficient of determination = 0.522, $p < 0.05$.
N: The number of subgroups, S: The faultline strength.
The survey results presented two features

– Half of the groups had less diversity because they were in the third quadrant. Thus, the faultline strength was weak and the number of subgroups was low. However, groups belonging to the fourth quadrant did not exist.

Table 3.3 Associated diversity of subject groups

Subject	N of M[a]	FS[b]	N of SGs[c]	N of M in SG[d]
Major company	8	0.404	5	2,2,2,1,1
	7	0.357	4	3,2,1,1
	10	0.324	2	7,3
Startup 1	6	0.328	2	3,3
	7	0.422	3	3,2,2
	9	0.800	5	2,2,2,2,1
	6	0.336	2	3,3
Startup 2	10	0.686	5	3,2,2,2,1
	10	0.615	4	4,3,2,1
	19	0.722	4	11,5,2,1
Emerging company	4	0.297	2	3,1
	5	0.390	2	4,1
	15	0.502	5	4,3,3,3,2
Mid-size company	10	0.351	2	5,5

[a]Number of members, [b] Faultlien strength, [c] Number of subgroups [d] Number of members in each subgroup



*Number in the right chart: [Faultline strength / Number of subgroups (Number of agents in each subgroup)]

Fig. 3.6 Associated diversity

– Equation (3.5) shows the tendency that stronger faultlines increase the number of subgroups.

Based on Eq. (3.5) six new datasets (a–f), and g, which is in the second quadrant in Fig. 3.3, were formed and simulated. The right side of Fig. 3.6 shows the associated diversity of seven datasets. The survey results confirmed that some groups had an imbalance in the number of subgroup members and some did not. Therefore, datasets were prepared for the case with an imbalance in the number of subgroup members and the case without such an imbalance (a:12,6 and b:9,9; c:9,6,3. and d:6,6,6).

Simulation for Organizational Diversity

To clarify the relationship between an organizational diversity and the various communication methods that actually occur in organizational activities, the simulations are conducted using the datasets based on the survey results. These simulations indicate concretely the influence of the diversity of existing corporate organizations.

The simulation was performed using homogeneity selection as the criteria for selecting an agent, and also the objective type and the diffusion type as the conditions for interaction. Additionally, the evaluation standard applies the increasable fitness, as explained in the third section.

Results of the Objective Type

The results of the objective type with the reproduction of formal corporate activities are indicated in Fig. 3.7 and Table 3.4. At Fig. 3.7, the vertical axis represents the increasable fitness, and the horizontal axis represents the degree of homogeneity in selecting the agent with which to interact. Homogeneity is decreasing toward the right. The following points were clarified

– (b), which has a weak faultline and a few subgroups, is much lower than others when homogeneity is low but is not low when homogeneity is high. This result shows that the possibility of increasing the fitness of an organization with the homogeneity is lower than for an organization with the diversity.

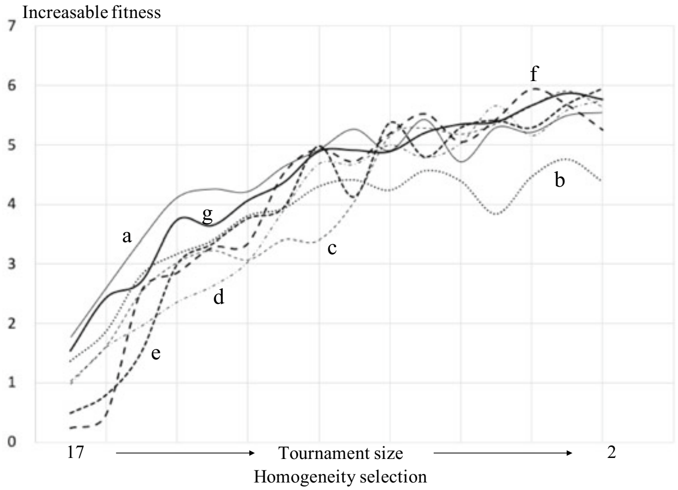


Fig. 3.7 Results of the objective type

Table 3.4 Average and standard deviation of the increasable fitness

		a	b	c	d	e	f	g
Objective type	Average[a]	4.48	3.73	3.97	3.92	3.98	4.06	4.40
	SD[b]	1.05	0.95	1.48	1.54	1.69	1.73	1.25
Diffusion type	Average[a]	2.04	1.93	2.02	1.80	1.77	1.92	2.12
	SD[b]	0.70	0.70	0.94	0.79	0.92	0.94	0.72

[a]The average of the increasable fitness of tournament size from two to 17
[b]The standard deviation of the increasable fitness of tournament size from two to 17

- (e) and (f), which have strong faultlines and numerous subgroups, have the lower increasable fitness than others when homogeneity is high. In contrast, the increasable fitness is higher than others when homogeneity is low.
- (g), which has a medium faultline strength and many subgroups, remains at the middle of seven datasets with the average value and the standard deviation, as in Table 3.4; stability is observed.
- In (a) and (b), the increasable fitness of (b) was always lower than that of (a), despite the faultline strength and the number of subgroups being almost the same. This result confirms that an imbalance in the number of subgroup members affects the organization's performance.

Results of the Diffusion Type

The results of the diffusion type with a reproduction of informal communication such as conversations at lunch and light conversations are provided in Fig. 3.8 and

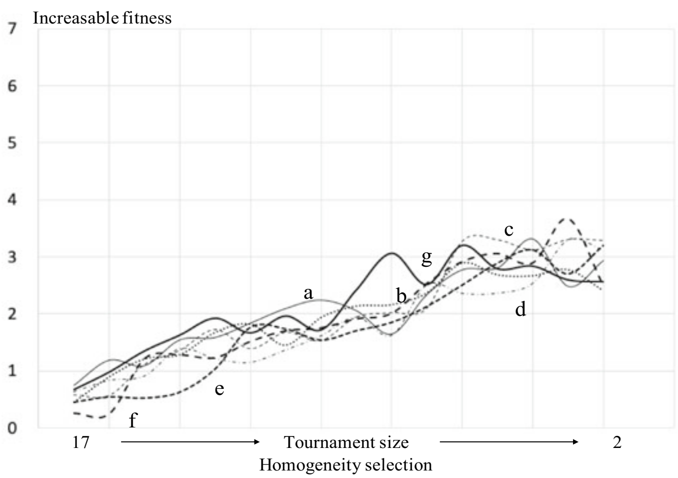


Fig. 3.8 Results of the diffusion type

Table 3.4. At Fig. 3.8, the vertical axis represents the increasable fitness, and the horizontal axis represents the degree of homogeneity when selecting other agents to interact. Homogeneity is decreasing when going to the right. The following points were clarified

– The diffusion type is related to interactions with an agent with lower fitness. Thereby, all increasable fitness averages are lower than for the objective type. In addition, all of the standard deviations are lower relative to the objective type.
– No dataset is much different from the others, such as (b) in the objective type.

Discussion

This paper aims to clarify how to manage diversified organizations to improve performance. Therefore, we indicated diversity through plural dimensions from the faultline perspective. Through the simulation, we validated how the relationship between diversity and communication could affect organizational performance.

The results indicate that the associated diversity influences organizational performance through means of communication. For this reason, a manager needs to grasp the associated diversity and design communication. Based on the simulation results, the characteristics in each quadrant of the associated diversity in Fig. 3.3 are as follows

– In the third quadrant, in which the faultline strength is weak and the number of subgroups is low, half of the survey groups exist. This diversity has the characteristics that communication methods have a weaker influence on organizational performance than the other quadrants. Therefore, the harm caused by the absence of management is small, but the communication design may be less effective.
– In the second quadrant, in which the faultline strength is weak and the number of subgroups is high, few groups of a major company exist. This diversity has the characteristics that different communication methods result in less variation, and stable and high performance is expected. In addition, communication design has the possibility of improving performance.
– In the first quadrant, in which the faultline strength is strong and the number of subgroups is high, some groups of the startups exist. This diversity has the characteristics that the negative effect of communication within extremely homogeneous people is greater than in other quadrants. In contrast, communication design has the possibility of improving performance.
– In the fourth quadrant, in which the faultline strength is strong and the number of subgroups is low, no survey group exists.

Conclusion

This paper clarifies how the associated diversity influences organizational performance through communications through the faultline perspective that indicates diversity by plural dimensions using the ABM. In conclusion, this paper has demonstrated that the influence of diversity makes a difference according to the associated diversity, and grasping the associated diversity and designing ways of communication are essential.

This paper was based on a survey of Japanese organizations, with the frequency of the interactions converted to time using other surveys. Therefore, further studies should conduct a complete survey. In addition, this paper has as subjects the smallest unit of management. Further studies can target a larger organization. Finally, this paper used homogeneity as a parameter. However, using other parameters, for example, cohesiveness and centrality in network analysis are possible. Such studies could clarify the influence of diversity.

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Chapter 4
Agent-Based Model and Empirical Data Integration in Architectural Design Methodology for Corporate Offices

Soungmin Yu and Patrik Schumacher

Abstract This abstract outlines an ongoing research that uses an agent-based crowd simulation model to evaluate the social performance of a spatial design for corporate office environments within the field of architecture. Instead of focusing on the flow of movement which is the common approach in crowd simulation tools, the research described here aims to simulate occupancy behavior. The outlined methodology focuses on model initialization to calibrate the attributes and behavioral rules of the agents with empirical data for an agent based model with utility based decision making framework. The empirical data is gathered through a survey, CCTV camera footages and space observation in a case study, and the data gathering method is designed to capture organization specific occupancy patterns to inform the agent based model. Agents' behavioral rules also consider the findings from research precedents in workplace communication patterns in the field of social science and behavioral and policy sciences. Using the agent-based model, probabilities for social interactions are compared in different design alternatives to evaluate spatial configurations. The initial set of experiments revealed nonlinear relationships between different aspects of design elements and frequency of social encounters.

Keywords Workplace occupancy behavior · Empirical data integration for agent-based model · Architecture design methodology

Introduction

Currently in the building industry, the use of agent-based crowd models are limited to simulating people's flow and movements to evaluate technical function of spatial design such as evacuation strategies. The aim of the research is to simulate how people occupy office environment and their movements and social behaviors during

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the course of a day to inform design decision making process of architectural spaces. The significance of social and behavioral aspect of built environment is noted in design theories that point out the importance of spacio-morphological link in setting the framework for social communication. The complexity of the social processes is said to be embedded within the built environment [7].

Although the research precedents to study the link between spatial forms and behavior tend to accept the fact that the spatial arrangements have influence on occupants' behavior, these studies don't measure and quantify the influences in a conclusive way. Researches on the link between spatial form and collective behavior in the field of architecture focus on the configuration and connectivity of the space based on network analysis to make a positive correlation between the degree of spatial connectivity and the frequency of use which lead to higher social interactions. The research carried out from the late 70's until the late 2000's focused on knowledge intensive workplaces and spatial arrangements to study the factors that enhance communication between employees based on an understanding that increasing unplanned crossed disciplinary communications can promote innovation [2, 4]. These precedent researches have pointed out proximity, propinquity and distribution of attractors within the office space as the main drivers for communication patterns [6]. These studies include analyzing physical distance between employees, frequency of communication, and the impact inter and intra-departmental affiliation as relationships have on the frequency of communications.

Based on the generalizable assumptions that can be made for corporate working environment and precedent researches, an agent-based model is designed with attributes that relate directly to the factors that influence the daily behavior of the employees within a hierarchical organization. Survey questionnaires are developed concurrently with the agent behavioral rules to define the ranges of decision influencing parameters and agent attributes. In the initial test, different office design options based on five varying design parameters are tested and agents' probability to engage in a conversations are measured to compare the design options.

Methodology

Domain and Agent-Based Model Construction

A workplace environment as the domain provides the basis for classifying different action types for the agents. Generalizable assumptions such as having core working hours, scheduled meetings and hierarchical office structure can be made. The agent-based model is constructed using game engine, Unity, with humanoid agents representing individual employees of the office. The decision-making framework is built using utility functions for agents to carry out the actions continuously within a given set. Following the example set out by Allbeck to classify actions into scheduled, opportunistic and aleatoric actions [1], the available actions are divided into scheduled and unscheduled actions. Unscheduled events are triggered based on agent-to-agent and agent-to-environment interactions, agent types, and the probabilities assigned to actions. Based on the techniques used in gaming and animation industries, actions are composed of sequential sub-actions that are carried out once an action is selected based on its utility value. Scheduled actions make up the overall structured daily activities of the office environment such as core working hours. Conversation is one of the unscheduled actions and is used to indicate the likelihood of social interactions taking place. Conversations are triggered depending on the agent's internal state, relationship to the adjacent agents, and the environment. Agent attributes include organization specific information such as team affiliation or rank, and changing internal parameters such as motivation level. All the actions that agents carry out, action time and location are recorded to be used to evaluate the impact of different office design as environment on agents' collective behavior.

Empirical Data and Agent-Base Model Parameters Initialization

In order to initialize the agent-based model with the organization specific behavior, standardized online survey is designed to gather information regarding social tendencies and variations in daily activities including lunch, breaks, and general working patterns such as meeting schedules. The survey results directly inform the probabilities for carrying out certain actions and range values to influence the decision making of the agents. Monte Carlo method is currently being explored to analyze the data gathered to vary the agent population to match the organizational structure based on different behavioral patterns. One-factor-at-a-time sensitivity test of the model is carried out prior to inputting the range values gathered from the survey [3]. An architecture office is used as a pilot case study in order to test the methods for integrating empirical data and agent based model, and the security camera footage of the breakout space in the office is used to observe the informal gathering of the employee interactions. The findings from the camera footage are also used to inform the behavioral rules. Modcam sensors of the same space provide the cumulative density map over time.

Experiments

Several office layout options are used in initial experiments to test the hypothesis that the office layout makes a difference in terms of social interactions of the employees. Agents with same set of behavioral rules and initialized parameters are deployed onto the environments with different design arrangements. Design parameters such

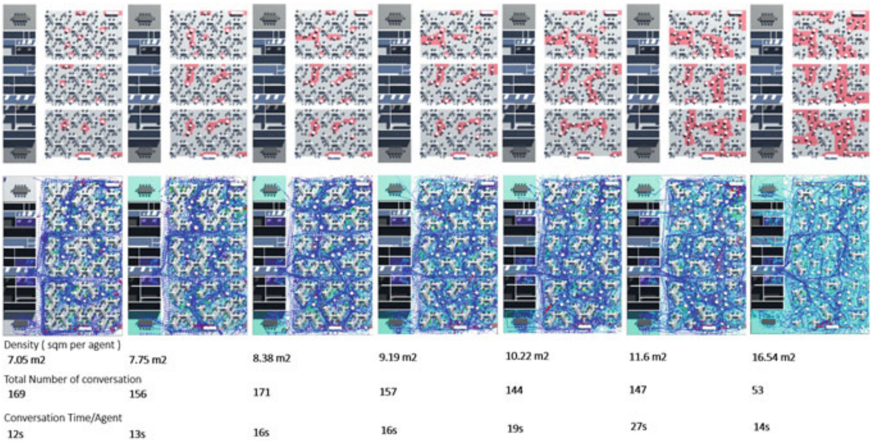

Fig. 4.1 Density (area allocated per person) variations show non-linear relationship with number of conversations agents engage into

as geometric clustering of the furniture layout, density, circulation path, and distribution of attractors are varied in each design options. Total number of conversations carried out by agents and the average conversation length are compared to determine the social potential of different office layouts. One of the experiments showing the variation in density implies non-linear relationship between the social encounters and density variation (Fig. 4.1). The results of this experiment show that the average conversation time per agent can almost double by finding an optimal density of occupants and number of social spaces within the model environment. This suggests that variation in architectural design parameters can potentially increase or decrease the probability of social encounters, and an agent based model capturing an organizational behavior can help evaluate an architectural design based on its potential for social interactions.

Conclusion and Further Development

The non-linear relationship between a design parameter and total number of social interactions of the agents suggest that the agent-based model described in the research can be used to optimize workplace design where the optimum design solution is not obvious to the designer. The research focuses on the calibration of the agent model with empirical data. The validation of the model currently relies on visual identification of the social pattern observed in camera footages and spatial observations carried out in person. Another means of validation method relying on empirical data is desirable but is not within the scope of the research outlined in this paper. The design scenarios in the experiments have been design proposal options. As the next step, real-life case study office environment will be modelled and their employees' behavior will be compared to simulation results.

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Part II
Norms, Values and Salience: Modelling Socio-Economic Behaviour

Chapter 5
Agent Based Model of Cross Media Reach of Advertising

Michał Kot and Bogumił Kamiński

Abstract In this paper we investigate how advertising communication strategy affects consumer buying decisions. We develop an agent based model that allows to compare how effectively different strategies of advertising budget location reach potential consumers. As effectiveness measures we use standard media metrics such as reach and frequency, but we define them for marketing campaigns that utilize many media vehicles (e.g. TV, Radio, Online). Model's parametrization and agents' features are based on results of a dedicated research study in order to obtain results valid for a population of Poland. We emphasize that our model has two unique features that are important in practical applications. Firstly, it allows us to measure not only aggregate reach and frequency but also the effectiveness of communication strategies against narrow sub-populations with high purchase potential. Secondly, one is able to assess and compare the whole distribution of projected reach of communication strategies, and in this way understand not only their expected outcome but also the associated uncertainty.

Keywords Agent based modelling · Media selection · Marketing science

Introduction

There is consent among researchers that marketing communication plays a significant role in influencing consumer decisions regarding product choice. It has been shown that advertising changes tastes in the short term [15] and builds brand equity, that reflects how well-known the brand is, in the long-term perspective [13]. Through brand equity building, advertising informs about product existence extending volume of considered baskets of goods [1] and is able to affect which product features

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customers perceive as especially important, which has an impact on consumer choice function [20]. Strengthening brand equity leads to increased sales [16], brand differentiation [14] or price sensitivity [12].

Due to the importance of marketing communication in terms of affecting consumers emerges problem of assigning the budget to proper marketing techniques. It was a known problem in the beginning of the twentieth century when John Wanamaker formulated his quote ‘I know half the money I spend on advertising is wasted, but I do not know which half’ [22] and has been under researchers’ interest ever since [19], yet with the development of new media vehicles, especially digital ones, the problem got even more complex [11]. Moreover, as marketing expenditure is expected to grow by 5–7% yearly until 2022 totaling 792 billion dollars globally [9] the problem requires comprehensive investigation.

In this paper we develop a simulation based approach for media selection problem. We reproduce the population of agents-customers, assuming their heterogeneity, with a list of parameters describing socio-demographic and customers’ value features. We parametrize the agents and construct their individual media consumption stochastic functions based on data taken from the survey performed for the purpose of this research. As a result we are able to simulate the behaviour of a complex system of agents that is exposed to media communication. Our aim is to compare different media selection strategies in terms of their effectiveness. To evaluate the strategies’ expected outcomes, we use indicators based on reach and frequency among total agents’ population and also among agents with high buying potential reflected in their customer value.

Links between sales and marketing expenditure have been analyzed in the literature. Since Dorfman who has proven that only for non-perfect markets optimal advertising is not null [8] and Nerlove who has proven that in case of log-log model between demand and price optimal advertising should be at constant ratio versus sales [21] researchers focused on econometric inference of advertising to sales relationship. Two comprehensive meta analyses of econometric driven findings can be found in Assmus [2] and Vakratsas [23]. Functional dependency between advertising and sales has also been investigated by Little and Lodish with the usage of MEDIAC system [18], Zufryden with Mean Response function [25] or Liaukonyte with Causal Approach using econometric modelling [17].

A classic approach to media selection problem assumes using deterministic optimization techniques such as linear programming [5, 10], dynamic programming [26], nonlinear programming [3] or treating media selection as a multi choice knapsack problem [24]. In mentioned applications, the problem comes down to constrained maximization of combined media reach among given population. The combined reach formula used in the problem literature (either Sainsbury or Agostini formula) assumes that each media vehicle performs independently [6].

Unlike the literature standards, our approach is derived from the microfoundations. In our model agents have individual features that determine their personal attitude and habits towards advertising and as a result control the intensity of advertising that the agents are exposed to. Based on micro-level data gathered for each agent, our goal is to determine the global system values of variables measuring the absolute effect of the media campaign. This approach has four significant advantages versus classic solutions, e.g.. econometric based, that rely on aggregated metrics.

– *robustness*: It is robust to structural changes and can be used to simulate outcomes of such;
– *exact cross media reach*: It allows to calculate exact combined media reach as each agent has registered a complete history of advertising contacts, thus we are able to capture the interactions in which different media are consumed (we do not need a media independence assumption);
– *sub-population analysis*: It allows detailed analysis of segments of consumers in terms of their buying potential;
– *measurement of uncertainty*: It allows to analyze not only expected value of outcome's measures but also their distribution, thus we are able to capture the risk of different decisions.

In particular, according to our best knowledge and literature research, such an approach, combining the four above mentioned features, has not been used before in the media selection research. However, one should bear in mind that agent based approach is more time consuming as many simulation iterations are required in order to obtain robust results.

Aside from the main objective, we propose a novelty in terms of agent set creation (synthetic population generation) that incorporates the multivariate Bayesian sampling to cover the dependencies between agents' features.

The remainder of the paper is structured as follows: in section Model of Media Consumption we present the model in terms of variables, functional dependencies and mechanisms. In section Simulation Preparation we describe model parametrization and simulation setup and in section Simulation Results we present the results and discuss them in section Concluding Remarks. Due to paper's length limitations, we provide the description of key elements of the proposed model.

Model of Media Consumption

In this section we will cover the model of media consumption's elements, mechanics and configuration.

The model consists of heterogeneous agents that represent the consumers of media communication. All agents use all media vehicles with different frequency and therefore have different opportunity to see the advertisement in each of them. The simulation environment is assumed to consist of 6 media vehicles available, each denoted as M_j for $j \in \{1, \dots, 6\}$, which are: TV, Radio, Print, Digital Display (static media form used in the Internet), Digital Video on Demand (audio-video ad format presented to consumer before the movie is loaded in the Internet) and Social Media (all ad formats used within Internet Social Media networks). Simulation is performed in a discrete time for a period of maximum T steps, with each step reflecting a single

Table 5.1 Agent's features description

Feature group	Feature name	Feature description
SD	Gender	Agent's gender
SD	Age	Agent's age group
SD	Education	Agent's level of completed education
SD	Income	Agent's household's net monthly income
SD	Location	Agent's household's location
MC	Media consumption **MCP**	Agent's probability of consumption of each media vehicle distribution
MC	Weekly frequency **WFC**	Agent's weekly frequency of consumption of each media vehicle distribution
MC	Daily frequency **DFC**	Agent's daily frequency of consumption of each media vehicle distribution
BP	Household size	Agent's household size
BP	Shopping frequency	Agent's frequency of shopping
BP	Ad potential	Agent's susceptibility to advertising
BP	Consumer value	Agent's buying potential

day. The agent set contains N agents each denoted by A_i, for $i \in \{1, \ldots, N\}$. All agents are described by a list of 12 socio-demographic (*SD*), media consumption related (*MC*) and buying potential (*BP*) features, as presented in Table 5.1. Population of agents and their features is initiated at the start of each simulation iteration and remains fixed throughout its duration. Each simulation run is divided into three phases: campaign's setup, campaign's execution and campaign's evaluation.

Campaign's setup phase is introduced by setting the advertising campaign budget B and picking the allocation strategy s_a. We assume B to be a non-negative number, while s_a is a vector of six non-negative numbers that sum up to 1, indicating share of budget assigned to each medium. Based on B and s_a a vector of budget spent on each medium under given strategy $\mathbf{B}(s_a)$ is calculated:

$$\mathbf{B}(s_a) = Bs_a \tag{5.1}$$

Budget assigned to each medium is expressed in terms of number of effective contacts. To obtain the total campaign's contacts vector $\mathbf{C}(s_a)$ we use Hadamard division of $\mathbf{B}(s_a)$ by vector of costs of generating a single contact in each medium $Cost$ (j denotes j-th element of the vector):

$$\mathbf{C}(s_a)_j = \mathbf{B}(s_a)_j / Cost_j \tag{5.2}$$

Having total volume of contacts for the campaign, we compute a plan of contacts for each simulation step $\mathbf{C}(s_a, T)$, which is a matrix. Elements of $\mathbf{C}(s_a, T)$ are denoted as C_{jt} (number of contacts in medium j in time t). In this paper we assume the plan to be a flat allocation of contacts therefore:

$$C_{jt} = \mathbf{C}(s_a)_j / T \tag{5.3}$$

Campaign's execution phase is a simulation of spreading of contacts available in each step and each media vehicle among agents. In order to achieve it, we assign each agent an opportunity-to-see metric, denoted as **M**, that is an array of elements M_{ijt}. Each **M** element is computed based on each agents **MCP**, **WFC** and **DFC** features describing individual media consumption presented in Table 5.1 in line with *MedCons* procedure presented in Algorithm 1. Based on individual computed opportunity-to-see in step t, for each media vehicle j there are C_{jt} agents being sampled with replacement with probability of choosing each agent proportional to M_{ijt}. Therefore, agents with higher media consumption frequency have higher probability to be sampled.

Algorithm 1 Media consumption simulation high-level flow

```
procedure MEDCONS(t, i, j, MCP, WFC, DFC)
    for t = 1 to T do
        for i = 1 to N do
            for j = 1 to 6 do
                Sample MCP_ijt from MCP
                if rand(0, 1) < MCP_ijt then
                    Sample WFC_ijt from WCF
                    if rand(0, 1) < WFC_ijt then
                        Sample M_ijt from DFC
                    end if
                end if
            end for
        end for
    end for
end procedure
```

Campaign's evaluation phase summarizes the campaign performance with a list of effectiveness indicators:

– Multimedia contacts per agent (AC_i)

$$AC_i = \sum_{t=1}^{T} \sum_{j=1}^{M} C_{ijt} \tag{5.4}$$

– Multimedia reach for frequency $F = \{0, 1, 2, 3...\}$ ($MMR(F)$)

$$MMR(F) = 100 \frac{\sum_{i=1}^{N} [AC_i = F]}{N} \tag{5.5}$$

– Cumulative multimedia reach for frequency $F = \{1, 2, 3...\}$ ($CMMR(F)$)

$$CMMR(F) = 100 - \sum_{f=0}^{F-1} MMR(f) \quad (5.6)$$

– Cost per cumulative multimedia reach for frequency $F = \{1, 2, 3...\}$ $(CPCMMR(F))$

$$CPCMMR(F) = \frac{\mathbf{B}}{CMMR(F)} \quad (5.7)$$

In summary section we evaluate the campaign's strategies using indicators $MMR(F)$ and $CPCMMR(F)$ while other presented metrics play supporting role, as they are used to calculate target metrics. For additional information please refer to the ODD: http://bit.ly/2MG34lz.

Simulation Preparation

In this section we discuss model parametrization and the simulation's setup.

Agents' Creation

For agents' creation and parametrization of their features we use data from the dedicated study provided by SW Research, one of the research agencies in Poland. The sample of 1016 respondents' answers has been collected in March 2019. Each respondent has been assigned a population's weight to reflect the structure of Poland's population. Marginal distributions of answers provided for socio-demographic questions have been presented in Table 5.2, all respondents' answers can be found in the ODD.

Each agent's creation process is divided into two phases: sampling of socio-demographic features and sampling of media consumption and buying potential features. We assume that socio-demographic features are sampled first, in line with the Algorithm 2, while features in the second phase are sampled conditionally, based on agents socio-demographic profile.

Due to the fact that socio-demographic features are not independent one should sample them taking into account their cross dependencies. We propose to sample the combination of socio-demographic features instead of sampling each feature independently from the marginal distribution. There exist 270 unique combinations of features (we will refer to those as *cells*), as for mentioned agents' characteristics we have 2, 5, 3, 3 and 3 potential answers available, respectively. However, one should consider the following problem. Firstly, sampling from marginal distribution does not take into account dependencies between features. Secondly, sampling from

Table 5.2 Socio-demographic features' marginal distributions

Variable	Class Id	Answer	Distribution
Gender	1	Male	0.4636
	2	Female	0.5364
Age	1	15–24	0.1772
	2	25–34	0.2776
	3	35–44	0.2323
	4	45–54	0.1378
	5	55+	0.1752
Education	1	Primary and lower	0.0984
	2	Secondary, incl. professional	0.4134
	3	Higher, PhD	0.4882
Income	1	Below 4.000 PLN	0.3189
	2	4.000–8.000 PLN	0.5472
	3	Over 8.000 PLN	0.1339
Location	1	Rural	0.3307
	2	City below 200.000 citizens	0.4183
	3	City over 200.000 citizens	0.2510

the survey data only would prevent us from sampling cells that do not appear in the research study, but may be present in population. To allow both, feature cross dependencies and positive probability of sampling each potential cell we propose using Bayesian sampling in line with the Algorithm 2.

Based on a conducted survey, out of 270 potential cells of features combinations, 215 had at least one respondent assigned, while 55 were null—not observed in the sample. Based on completed cells we have reconstructed the marginal distributions for each feature and as a result the prior probabilities of each cell. Afterwards, we mixed the prior with counts of respondents in each cell and obtained the posterior distribution.

Mixing data into prior has changed the distribution mostly for cells that were missing in the data set and had low prior probability of existence (e.g. combinations of young age and high income and education). Figure 5.1 shows the relation between λ and number of empty cells in the sampled population. We can use λ parameter to balance between importance of prior and survey's information. Note that the proposed algorithm produces the same marginal distributions as observed in the survey data independent on the value of λ, which influences only the level of cross-dependency between features.

Algorithm 2 Agent set sampling

1: Use Dirichlet distribution as a prior with K parameters indicating number of unique feature combinations and α_i, for $i = 1, 2, ..., K$ being concentration parameters calculated from marginal feature distributions, treated as independent variables

$$\alpha_i = \prod_{j=1}^{F} P(f_j) \in (0, 1)$$

$$\boldsymbol{\alpha} = (\alpha_1, ..., \alpha_K)$$

Dirichlet distribution, $Dir(K, \boldsymbol{\alpha})$ with density function given as

$$f(x_1, ...x_K, \boldsymbol{\alpha}) = \frac{1}{B(\boldsymbol{\alpha})} \prod_{i=1}^{K} x_i^{\alpha_i - 1}$$

$$B(\boldsymbol{\alpha}) = \frac{\prod_{i=1}^{K} \Gamma(\alpha_i)}{\Gamma(\sum_{i=1}^{K} \alpha_i)}$$

2: Use survey data to update prior distribution with observed counts of each class β_i.

3: Obtain posterior distribution that is conjugate Dirichlet distribution with concentration hyper-parameter $\boldsymbol{\theta}$. θ_i expected value is specified as

$$E(\theta_i) = \frac{\lambda\alpha_i + \beta_i}{\sum_{i=1}^{K} \lambda\alpha_i + \beta_i} \in (0, 1)$$

$$\boldsymbol{\theta} = (\theta_1, ..., \theta_K)$$

Where λ indicates the importance of prior in construction of posterior distribution (higher λ results in posterior identical to prior distribution)

4: Sample $\hat{\theta}_i$ from posterior distribution $Dir(K, \boldsymbol{\theta})$

5: Sample agents' population based on $\hat{\theta}_i$ realization

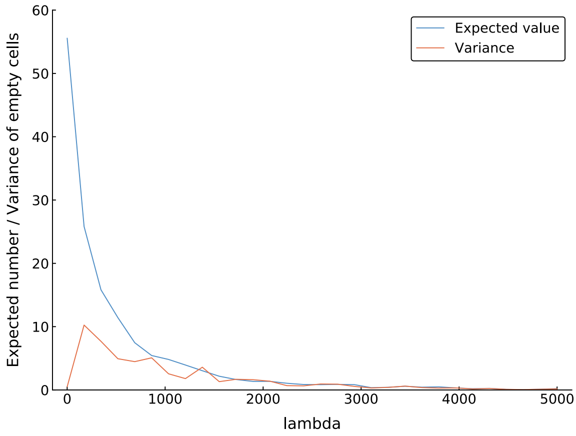

Fig. 5.1 Number of empty cells sampled from posterior distribution versus lambda

Table 5.3 Simulation parameters

Variable	Range
N	1000
T	30
B	[2000, 4000, 6000, 8000, 10000]
λ	1000
Cost	[5, 10]

Simulation Setup

Simulation algorithm has been tested using parameters presented in Table 5.3.

Parameters presented in Table 5.3 play supporting role in evaluation of allocation strategies s_a. We have created 126 s_a vectors that met the restrictions that each element is either 0.0, 0.25, 0.50, 0.75, 1.0 and sum of all vector's elements is equal to 1.0. Moreover, we created cost vectors as all possible combinations of 5 and 10 for each media vehicle, resulting in 64 vectors. Based on simulation setup there exist 40,320 potential combinations of variable values. Each combination has been iterated 5 times for 3 randomly created agents' populations which leads to a total number of simulations equal to 604,800. All computations have been evaluated using Julia language [4].

Simulation Results

In this section we present results of simulation described in Sects. Model of Media Consumption and Simulation Preparation.

Tables 5.4 and 5.5 present best five strategies in terms of building average effective reach $CMMR(1)$ and $CMMR(3)$, respectively. All strategies have been presented as a combination of a form of % of allocated budget (TV, Radio, Print, Display, VOD, Social Media) and refer to total budget equal to 8000. Results prove that TV shall remain a primary medium in the media mix, as all top strategies in terms of expected level of reach assume at least 50% of budget assigned to this media vehicle. However, results differ in case of $CMMR(1)$ and $CMMR(3)$, because in case of $CMMR(1)$ one should use wider media mix, with 2 or 3 media vehicles in media split, while to build $CMMR(3)$ one shall focus on 1 or 2 media vehicles.

The presented approach is robust of structural changes. It allows to predict the outcome of a strategy that has never been used before, e.g. adding digital media into media mix with the total budget increased by 50% as presented on Fig. 5.2. We emphasize that all strategies have been analyzed in terms of results' variability, measured by standard deviation. The analysis of uncertainty allows to draw the

Table 5.4 Best strategies in terms of generating CMMR(1)

Strategy	E(CMMR(1))	S(CMMR(1))
(50, 0, 0, 25, 0, 25)	37.85	1.37
(75, 0, 0, 0, 0, 25)	36.56	1.04
(75, 0, 0, 25, 0, 0)	35.65	1.36
(50, 25, 0, 0, 0, 25)	36.65	1.29
(50, 0, 0, 0, 25, 25)	34.84	0.98

Table 5.5 Best strategies in terms of generating CMMR(3)

Strategy	E(CMMR(3))	S(CMMR(3))
(100, 0, 0, 0, 0, 0)	28.12	0.73
(75, 0, 0, 0, 0, 25)	26.27	0.76
(75, 0, 0, 25, 0, 0)	25.71	0.68
(75, 25, 0, 0, 0, 0)	23.23	0.50
(75, 0, 25, 0, 0, 0)	22.93	0.59

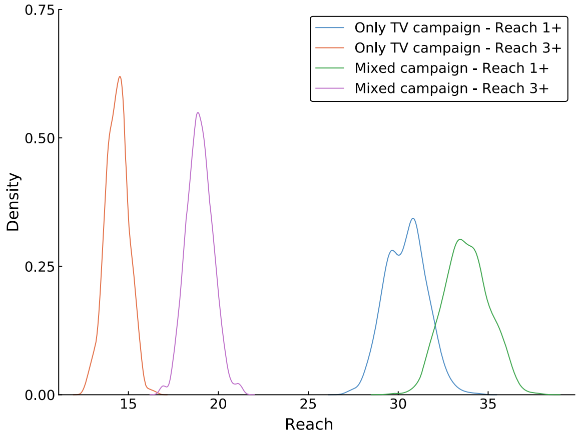

Fig. 5.2 What-if scenario evaluation example

conclusion that on average strategies generating higher levels of reach are more volatile than their less effective counterparts as shown on Fig. 5.3.

From the target group's perspective, agent based model allows to identify narrow subgroups with high buying potential to focus communication on them. A simplified presentation of such analysis is presented in Fig. 5.4, where on X axis we present agents' features combination: Education—Income—Location (e.g. 111 stands for Primary education and household net income below 2000 PLN and rural household location) and on Y axis we present Gender—Age combination (e.g. 11 stands for Male and age 15–24). Colours indicate buying potential index of a given cell and vary from dark violet (low) to yellow (high buying potential).

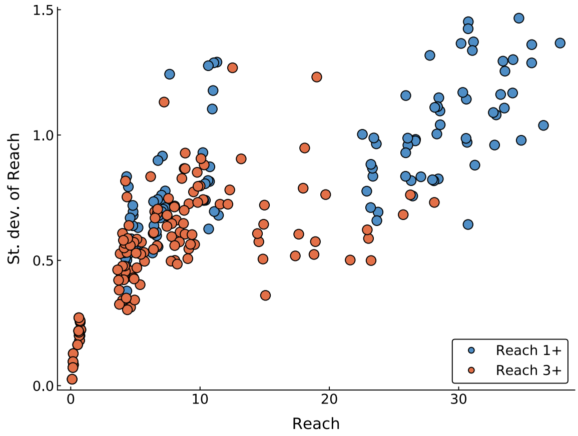

Fig. 5.3 Strategies mean reach versus st. dev. of reach

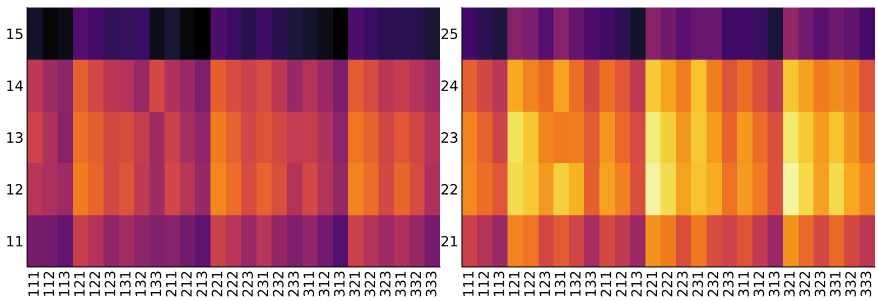

Fig. 5.4 Heatmap of target group based on buying potential(left—men, right—women)

Table 5.6 Cost of generating reach point per budget size

Budget	CPCMMR(1)	CPCMMR(3)
2000	258.22	1139.1
4000	366.10	1134.8
6000	460.28	1191.2
8000	551.24	1246.3
10000	644.55	1300.8

From the cost effectiveness's perspective each budget increase has diminishing impact on generated reach. On average, media budget of 2000 generates $CMMR(3)$ for 258 per reach point, while budget of 10,000 performs less effectively, for 665 per reach point. Detailed results have been presented in Table 5.6.

Concluding Remarks

In this paper we have presented an agent based model of media communication that allows to simulate potential advertising campaign's outcomes. Based on dedicated survey we have parametrized our model and obtained results which confirmed that campaign results in terms of media metrics are strongly dependent on the strategy of budget allocation. We have investigated population of agents seeking for especially important, from the buying potential perspective, subgroups. We plan to develop further our model with the strongest focus on:

– Extending media strategy scope with a possibility of non-flat budget assignment over time and setting longer campaign duration;
– Adding a possibility of targeting agents belonging to the desired target group;
– Extending analysis by adding value of media contacts, reflecting the fact that certain media contacts may be more persuasive than the others [7];
– Extending analysis with more complex uncertainty measures;
– Extending analysis how lambda parameter in agent sampling impacts results;
– Presenting the population of agents in a form of a network. Adding connections between agents and allowing them to communicate.

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Chapter 6
Social Identity in Agent-Based Models—Exploring the State of the Art

Geeske Scholz, Tobias Eberhard, Robin Ostrowski, and Nanda Wijermans

Abstract A key challenge in social simulation is how to represent human behavior, specifically in its social context. The Social Identity approach (SIA) reflects a promising potential as it describes how people behave while being part of a group, how groups interact and how these interactions and 'appropriate group behaviors' can change over time. SIA is used in a variety of fields and increasingly implemented in agent-based models. A systematic review and comparison of SIA formalizations and implementations is so far missing. We present our impressions from a pre-review of the current state of SIA models, such as what key SIA concepts have been formalized and how their formalization compares. We found a diversity of application areas of models that use (parts of) SIA. We further noted differences in how parts of SIA have been formalized and used, e.g. the widespread use of the emergence of group norms and behavior, while other SIA aspects such as different strategies to positive self-esteem received little attention.

Keywords Social identity theory · Agent-based model · Modeling human behavior

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Introduction

A key challenge for designing an agent-based model (ABM) is to represent human behavior in a way that is contextually and psychologically plausible. While the social sciences and social psychology offer numerous theories to explain human behavior in specific contexts, the hurdles involved in selecting a reasonable theory and implementing such a theory in an ABM are high [1]. One particular need and challenge is formalizing human behavior and decision making in its social context—representing how people might decide what to do within a specific context and social-physical situation. Part of the reason for this difficulty is the complex relationship between the individual's identity and the social situation they happen to be in. One combination of theories with the explanatory potential to be of use here is the Social Identity approach (SIA), referring to the Social Identity Theory (SIT) [2] and the Self-Categorization Theory (SCT) [3, 4]. SIA proposes that people derive a significant part of their self-concept from the social groups they belong to [2, 3, 5], thereby presenting a promising theory of an important social situation: group behavior.

SIA describes how people behave while being (psychologically) part of a group, how groups interact and how these interactions and 'appropriate group behaviors' can change over time. When a social identity is salient, group membership becomes an important factor in peoples' beliefs and behavior. What is important for the group becomes important for the individual. Moreover, groups have social norms and expected behaviors, so when a particular social identity is salient the group members are expected to act within the norms. SIA is used in a variety of fields that relate to the building of group belonging or exclusion of others, e.g. social psychology, organizational psychology, cultural studies, political psychology, and politics. The broad application context is reflected in the diversity of application domains, e.g. decisions on sustainable agricultural practices [6], differing perceptions of history [7], leadership in groups [8], party identification [9], and environmental behavior [10]. In social simulation, the richness of SIA has been recognized as well [11], e.g. with models that use SIA to explore inter-ethnic conflicts [12] or the emergence of riots [13].

While SIA seems to hold great promise for diverse application cases of models, a systematic review and comparison of SIA formalizations and implementations is missing. For the crowd modelling literature, a systematic literature review revealed that none of the models analyzed adequately incorporated the theoretical underpinnings of social identification [14]. By providing a comprehensive theory on how individuals behave in a social context, SIA seems to be applicable for diverse model applications, while being challenging to specify and formalize. How a theory is understood and implemented is crucial, as even subtly different assumptions of how to represent human behavior may result in very different model results [15, 16]. We aim to make a step towards exploring the state of the art of SIA formalizations in ABMs. To this end, we conducted a pre-review of the current state of SIA models using Google Scholar, and compared key SIA concepts of selected models. In this extended abstract we share our impressions and present possible ways forward.

Pre-review of the Current State of SIA Models

To get an impression of the availability and current state of Social Identity models, we executed a pre-review. In a Google-Scholar search (on 21-10-2017), using "agent-based model" AND "social identity theory" as search terms, we found 54 papers that actually concerned ABMs that mentioned using the Social Identity Theory. Our pre-review concerns 38 (of 54) model papers that were accessible to us, which were each read by at least one of the authors. We inductively discussed and developed categories for which we analyzed models further. In this extended abstract, we discuss the first impression we gained and present examples from some of the models we reviewed.

The ABMs in this review cover a diversity of research areas. The most predominant research area is generically concerned with social science, e.g. [17–19], whereas others are more domain specific, such as models from social psychology, e.g. [20], crowd simulation, e.g. [21], peace and conflict research, e.g. [22], business management, e.g. [23], and environmental system science [24]. The usage of the aspects or parts of SIT differs from one model to the other. We found only two models—of which one is built upon the other—that tried to implement all aspects of the social identity theory [20, 25]. Most models use aspects of SIT concerned with:

- Explaining the emergence of group norms and behavioral differences between social groups, e.g. [26, 27];
- In-group favoritism or out-group devaluation, e.g. [13]; and/or
- The possibility of multiple social identities of one agent in different occurring social situations, e.g. [28].

Only few models implemented strict explanations for the agent's motivation for acting on SIT, i.e. namely the need for a positive self-esteem, e.g. [29]. Of which only some modelled the theoretical possibility of agents having different strategies to contain or enhance positive self-esteem, e.g. [20]. Lastly, we found models that relate to SIT by mentioning it only in the simulation results section, e.g. [30].

To highlight the differences in formalizations of SIA in ABMs, we will zoom in on a few formalizations of key SIA concepts, namely (a) identity and self-concept of an agent and (b) processes of social categorization and group formation.

Identity and Self-concept. Models that formalize identity or self-concept focus on formalizing aspects of the SCT, which describes the self-concept as a structure that comprises personal and social identities. Depending on the situational context, different aspects can be salient and influence an individual's behavior. Salience is defined as the product of relative accessibility and situational fit of a social categorization [31]. An equivalent formula can be found in some models, e.g. [32]: Salience = Accessibility $\times$ Fit. Hereby, accessibility is determined by an individual's experience and situational motivations. Some models focus on the cognitive aspect of accessibility using (un-)certainty (e.g. "bounded confidence", [29]), while other models focus on the emotional component of accessibility using the concept of emotional valence (e.g. [32]). The situational fit refers to a normative as well as a comparative component. Normative fit evaluates the extent to which an observed behavior matches the perceiver's stereotypical expectations. Hence, it refers to the relative accessibility of known categorizations. The normative fit has been formalized in [32] by determining which social groups are present in the current context and then comparing them with already known social categorizations. If there is no match, an agent's known categories don't fit and the agent has to adapt. The comparative fit is equivalent to the meta-contrast ratio, which we describe in the next paragraph.

Social categorization and group formation. In SCT, the process of social categorization is closely connected to the process of social comparison (meta-contrast principle, [3]). As the comparative categorization of perceived group-membership as well as the perception of typical group-members or behavior is precisely described, it is no wonder that we found similar formalizations. Thereby, the following formula is used to formalize the meta-contrast ratio modeling "prototypicality" [33, 34]:

$$P(x_p, X) = \alpha * d_{inter}(x_p, X) - (1 - \alpha) * d_{intra}(x_p, X) \quad (6.1)$$

Here, the agents calculate the comparative fit of a social categorization by determining the difference of the perceived distance between groups (inter-group similarity d_{inter}) and perceived intra-group similarity (d_{intra}). Available categorizations are determined by an individual's representation (x_p) in a perceived context (X). Results are weighted by a factor (α) that is parameterized. Finally, the number of available social categorizations is determined by the number of maxima of the function $P(x_p,X)$ which can be interpreted as a social group's "Prototypes" [33, 34] or "Centroids" [32].

Preliminary Conclusion and Ways Forward

The diverse application areas of the models in our pre-review confirm the great promise we see in SIA. Furthermore, the use of SIA in models is on the rise. However, how SIA is used differs a lot, with some aspects being widespread (e.g. the emergence of group norms and behavior) and other parts (e.g. different strategies to positive self-esteem) receiving little attention. Our brief comparison of the formalizations of key SIA concepts in models points to some components that are formalized in a similar way (e.g. the principle of meta-contrast ratio), while other components of SIA are formalized in different ways (e.g., the accessibility).

SIA is not directly translatable into program code. Like most non-formal theories, some aspects have to be interpreted and filled in by assumptions that are not made by the theory [35], leading towards differences in and plurality of models. While differing model foci and application cases might create the need for different formalizations, transparency and a comparison of different options and their consequences would facilitate an informed choice for a specific option.

Although we understand the presented work as useful to get an impression on whether SIA is used in models as well as how, more work is needed to gain a full picture of the state of the art. To this end, we have started a more in-depth review. Several new models have been published in the last year, including doctoral theses that make serious attempts to use SIA for model applications. To gain a full picture of the state of the art, we will move beyond the work presented here, including systematic and more detailed comparisons of SIA formalizations in ABMs. More specifically, we envision (i) a more systematic and in-depth review, (ii) replications of ABMs using SIA, and finally (iii) a widely available intuitive and psychologically plausible formalization of SIA that is applicable for diverse application contexts/cases.

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Part III
Artificial Sociality

Chapter 7
Towards Fundamental Models of Radicalization

Mijke van den Hurk and Frank Dignum

Abstract This paper proposes a multi-agent based model of radicalization, based on the theoretical framework from [1]. The model combines the need for significance with ideology and social group theory, in order to create radical behavior. With this model a first attempt is made for a fundamental model that can be used to get better insights in the mechanism behind radicalization. Results show that agents do radicalize and that this leads to the formation of isolated social groups. Furthermore, results show that radicalization does not just depend on a deviating mental attitude, but is a combination of individual and context characteristics.

Keywords Radicalization · Terrorism · Need for significance · Ideology · Social groups · Social simulation.

Introduction

Within the field of research on terrorism one of the major questions is why and how people become terrorists.

Finding the answer is not easy, because there is no clear definition of what terrorism is [2]. The main reason for lacking a definition is pointed out in the famous saying "one man's terrorist, is another man's freedom fighter", i.e. the description on what

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terrorism is depends on the context and who answers the question. Furthermore, it is also not clear when someone can be labeled as a terrorist. For example, is a suicide bomber a same kind of terrorist as someone who supports a terrorist organization, but does not participate in their activities? Can someone, who once was a terrorist, get rid of this label? Or is he a terrorist for the rest of his life? The lack of a definition for the term ‘terrorist’ influences the understanding of radicalization and the knowledge about how and if a terrorist can deradicalize.

This paper is a first attempt towards a model of radicalization, in order to get better insights in the process of why and how people become terrorists. The why in this question is focused on the motivation of terrorist. People are not born as terrorist, so they must be driven by some type of motivation [3]. The how refers to the process of radicalization towards terrorism, since one does not become a terrorist in a day.

A lot of research has been done on the motivational aspects and the process of radicalization. Most research concentrates on personal factors or circumstances that trigger the radicalization, like age, education level or socioeconomic status [3]. However, these factors do not take personal drivers into account, nor do they provide an insight into the mechanism of radicalization.

In [1] a theoretical framework is proposed that shows how the combination of personal motivation and social context triggers the process of radicalization, which can eventually lead to violent behavior or terrorism.

Not just is terrorism an example of radical behavior, so are suicide, anorexia and severe crime. Within the framework of [1], radical behavior is explained as behavior that helps reaching one personal goal, the focal goal, but at the same time undermines goals that matter to other people. Where normal behavior tries to find a balance between reaching different goals, radical behavior is typically focused on one goal, which is called a motivational imbalance.

Anorexia is an example of motivational imbalance. In general, a lot of people want to look good by losing weight, and are willing to sometimes skip dessert or go to the gym instead of hanging out with friends. But anorexia is a radicalized form of that behavior, as someone stops eating at all and consistently ignores the goal of being healthy.

According to [1] looking at radical behavior in this way has two important implications. First of all degrees of radicalism can be measured by the difference in commitment on the focal goal and the undermining of other goals, i.e. motivational imbalance. Now radicalization can be explained as the process of becoming radical, from a low degree of motivational imbalance towards a higher degree. Within this process the commitment towards a focal goal becomes stronger and people are more and more willing to perform extreme or even violent actions.

Secondly, the subjective manner on what is radical behavior is captured by seeing radicalism as motivational imbalance. The definition of what is important or normal depends on the norms and values of social group, i.e. a family, company or a nation. For instance, in the Netherlands democracy and protecting it is one of the core values of the nation. However, this does not hold for all nations. This means that anti-democratic behavior is seen as radicalism in the Netherlands, but not in all countries.

Using this definition of radicalism, clearly terrorism is an example, with the undermined goals being protecting the democratic order [4], killing others or even killing oneself. Now, the question of why someone becomes a terrorist is a matter of finding the personal focal goal that is shared among terrorists. Although the goal of an extremist group is mostly politically motivated, this is mostly not the personal motivation of people that leads to radicalization.

According to [5] the personal goal of a terrorist is the need for significance, which can become a focal goal and create a motivational imbalance. This need is an abstract, universal drive in people that makes that individuals want to achieve something or do something good with others acknowledging this. If someone experiences a big loss in this feeling of being significant or important he wants to do something to get this feeling back. Only when the commitment towards regaining significance is extremely high, someone becomes willing to perform radical and even violent behavior [1, 6].

A gain in significance as a goal is not enough to radicalize. An ideology functions as a means to reach that goal, as it describes which actions are appreciated and will give someone significance. If an ideology supports extreme behavior in order to earn acknowledgement, it might lead to radical behavior.

A person will not commit to a new ideology without some connection with a member of the group practicing that ideology. This means that social groups and relations are an important factor in the process of radicalization too.

To summarize, the combination of a need for significance as goal, an ideology as a means to reach that goal and the connections with a social group supporting that ideology might trigger radicalization. In order to get a better insight on how these three components influence radicalization, a multi-agent based model is proposed that, with the use of a simulation, can test the above theoretical framework and help understanding the mechanism behind radicalism. In Chap. 2 a broader theory of the concepts is given. Chapter 3 discusses related work and Chap. 4 describes the proposed model. Chapter 5 contains the validation with some results and the paper is ended with conclusion and discussion.

Theoretical Background

Need for Significance

According to [1, 7] the need for significance is a universal drive in people to actually be someone, to create a legacy or to be acknowledged by others.

Kruglanski et al. [7] mentions that this drive can be interpreted as the concept of self-love, introduced by Jean-Jacques Rousseau. This self-love is in contrast with love of the self, which is about taking care of yourself. According to Maslow's pyramid of human needs, the personal care is a higher need than the need for significance. However, [7] argues that these two needs are equally important.

A loss in significance can be caused by an individual experience, like a divorce or infertility, but also in a social context, for example when a group someone feels related to gets publicly humiliated.

A gain in significance can be received in different ways. Acknowledgement is obtained when one acts according to the norms of the group. The feeling of being someone can be obtained by performing actions that results in a positive outcome for the group. This can be something like volunteering in an animal shelter. At the same time, the more unique the actions, the more appreciation. Having the right skill or wanting to do something no one else wants, can lead to a gain in significance. An example is providing bread as a baker since people need bread and cannot make it themselves.

Since someone can only get the feeling of significance from others, performing these actions need to be noticed by other people, even if it is in the long run.

Ideology

Ideology is a collection of values, attitudes and behavior [8]. On one hand it prioritizes some values and make some of them absolutely preferred. The latter are called sacred values [6], where people are even willingly to make irrational choices and sacrifice themselves in order to protect this value.

On the other hand an ideology describes what types of behavior are accepted or rejected, in order to live according to those values. This means that the same actions can be interpreted in different ways depending on the ideology. For example, looking at veganism and the Islam as ideologies, the action eating pork is not done and is therefore negatively evaluated in both. Eating chicken is still not done as a vegan, but within the Islam this is a neutral action.

It is possible that people live according to different ideologies, as long as the behavior of one ideology is not in conflict with the other ideology. For example, a conservative will not easily switch to being a liberal, since not only his social group of conservatives will reject him when he changes his behavior, but also people from the liberal party will not easily include him because he used to do actions that are against their norms and values.

Social Groups

A social group is a group of people that interact with each other and behave in a similar manner, according to the norms and values of that group. Social groups come in all kinds sizes, as long as all its members share a same group identity [9]. Examples are one's family, friends, school or nation.

People belong to multiple groups and have therefore different social identities. Depending on the context, one's identity and the corresponding behavior will become active. For example, someone will behave differently within a group of friends than at work since the rules of how to behave are different. Although people belong to different groups, mostly these groups share common values to avoid conflicting behavior.

When looking at a group as a circle, members can be located at the core or more at the periphery of the group. At the periphery it is easier for a member to switch to other social groups and thereby its behavior. When situated at the core, one is surrounded by other members all behaving in the same way. In that case it will be harder to leave that group, since actions deviating from the norms will be more visible and, possibly, rejected by the core of the group.

Once a social group is surrounded by different groups, its members tend to favor other members of the same group, its ingroup, over members of other groups, the outgroup. This is known as the ingroup outgroup bias. Research shows that this effect of ‘us’ versus ‘them’ can emerge already when people who do not know each other on forehand are divided in different groups. This effect makes that people will not easily switch from one’s ingroup to the outgroup.

In extreme situations the ingroup outgroup bias makes that a ingroup becomes isolated. They are convinced that only their norms and values are correct and the members of the other groups are the enemy. In this case there is no periphery in the group with people switching between identities. This strong ‘us’ versus ‘them’ effect is a common feeling of members of an extremist group [3].

Finally, according to [6, 10] joining a new group and adapting to its norms, values and behavior is a process itself, where the identity of an individual becomes fused with the group identity. In case of radicalism, the personal identity is fully replaced by the identity of the group. This could explain why people are willing to sacrifice themselves for the group, like suicide bombers, since they only see themselves as part of that group.

Related Work

In [11] the same theoretical framework is used to build an agent-based model in order to get a better understanding of violent extremism. Although all three concepts of the theoretical framework mentioned in [1] are taken into account, the actual implementation of them differ from the one proposed in this paper. First of all, the research question is focused on understanding how violent extremism, i.e. a high degree of radicalization, emerges from motivational imbalance.

Secondly, the model assumes that only when the motivational imbalance is below a significance quest threshold, the agent will look for a means to gain significance. However, [7] explains the need for significance as a need that everyone has, besides the need of taking care of oneself. This means that everybody has some motivation for gaining significance, albeit less committed than others. This can potentially lead to motivational imbalance, rather than the significance quest being a consequence of motivational imbalance.

Finally, gaining significance is directly modelled, instead of through actions and the social surrounding influencing the choice of actions. Since ideology and social groups have a major impact on behavior, this should be taken into account too.

The Model

This model is a first step towards implementing the radicalization process by using the three concepts need for significance, ideology driven behavior and social groups. The purpose of the model is to show that the combination of a high need for significance, a radical ideology and a social group acting according to that ideology can start the process of radicalization, i.e. let agents perform actions that undermine goals or values that are important to other agents, and will lead to the formation of isolated social groups.

The implementation is a simplification of the theoretical concepts described in Sect. "Theoretical Background".

Description

The agents in this model are living in a world where the goal is keeping its level of significance as high as possible. The agent can gain significance by performing actions and getting acknowledgement by his social surrounding. How actions can give a gain in significance is defined in two different ideologies. Every agent belongs to a group that acts according to an ideology. In extreme cases the agent can switch to the other group with the other ideology. The social network of an agent consists of the agents' direct neighbors, i.e. between 0 and 8 agents, where its ingroup consists of agents that act according to the same ideology and the out group of agents that act according to the opposite ideology.

The described process is visualized in Fig. 7.1.

The level of significance S varies between 0 and 1. A low value of significance can be interpreted as somebody feeling depressed. During the simulation the significance level will be randomly dropped. With a probability of $\frac{1}{5}$ the level will be multiplied with a random value between 0 and 0.8. This resembles real-life events that have a negative influence on one's feeling of significance, like a break-up or getting fired.

The two ideologies I_0 and I_1 available for each agent are an abstract representation of values, norms, cultural traditions and habits. For every available action the possible gain or loss of significance is defined within the ideology. This corresponds to an ideology describing what is good and bad behavior, but also being the means to gain significance. Each ideology describes how much gain one can obtain by performing that action or how much it is rejected, which is represented by matrix M, shown in Fig. 7.2.

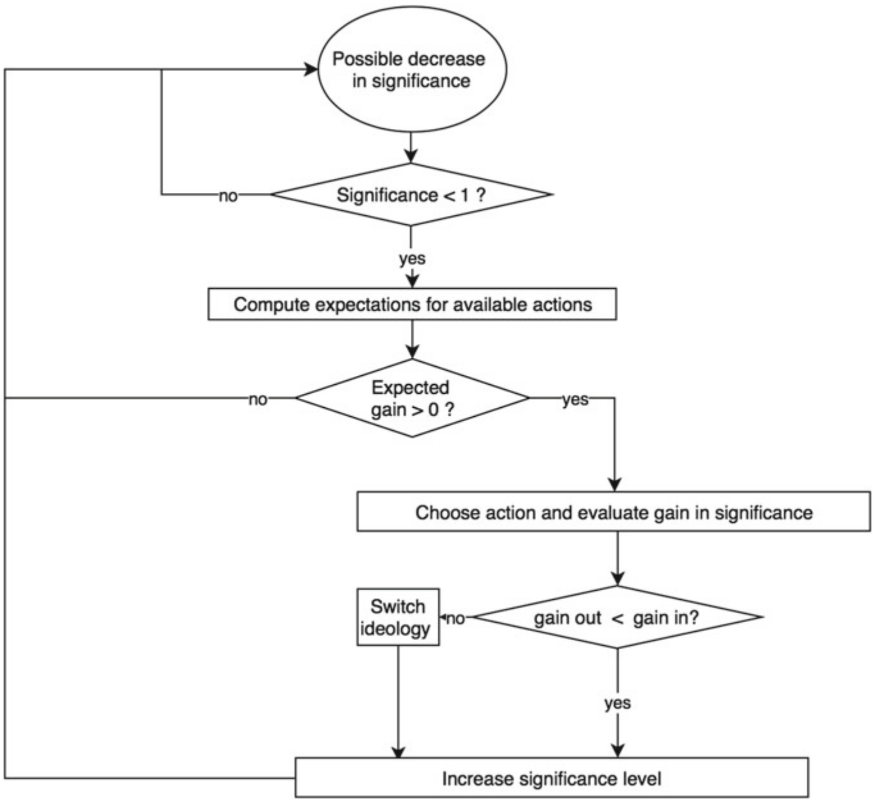


Fig. 7.1 Model description

$$M = \begin{array}{c} \\ I_0 \\ I_1 \end{array} \begin{array}{c} \begin{array}{ccccccccccc} a_0 & a_1 & a_2 & a_3 & a_4 & a_5 & a_6 & a_7 & a_8 & a_9 & a_{10} \end{array} \\ \begin{bmatrix} 1 & 0.8 & 0.6 & 0.4 & 0.2 & 0 & -0.2 & -0.4 & -0.6 & -0.8 & -1 \\ -1 & -0.8 & -0.6 & -0.4 & -0.2 & 0 & 0.2 & 0.4 & 0.6 & 0.8 & 1 \end{bmatrix} \end{array}$$

Fig. 7.2 Two ideologies describing the interpretation of actions

In total there are 11 actions available for the agents, such that it is possible to show the process of shifting towards more extreme actions, but keeping the total number of actions within bounds. The two ideologies are opposites from each other, where the action with the most gain in I_0 gets the highest rejection from I_1 and the other way around. Action a_5 is a default action, i.e. no gain but also no rejection by both ideologies. The ideologies and their actions can be interpreted in many ways. Taking right wing extremists versus liberals for instance, a_0 can be interpreted as hurting foreigners, a_3 defaming them, a_8 giving them jobs, and a_{10} help them fully integrate. Note that in real life there are actions that are positive interpreted in multiple ideologies, but since this model is about radicalization the focus will here be on radical actions and opposite ideologies.

The agent chooses the action with the highest expected gain. The expectations are computed using the rewards within each ideology, combined with a ingroup and outgroup bias. These two bias values are a combination of the number of agents in their ingroup or outgroup and their level of need for significance, and are computed as follows:

$$w_{in} = n_{in} * (S/2) \tag{7.1}$$

$$w_{out} = n_{out} * (1 - S/2), \tag{7.2}$$

with S the level of significance and n_i the number of agents in the ingroup and outgroup respectively. Note that $n_{in} + n_{out} = 8$. The lower the level of significance of the agent, the less positive bias he has towards his ingroup and the more he will look at the number of agents of the two different groups that can give him a significance gain. This correspond to an agent suppressing the norms and values of his ingroup when his need for significance becomes high enough.

The expected gain for action i of agent a is then computed by

$$E_i = w_{in} \times M_{i,I_{in}}/n_{a_i,in} + w_{out} \times M_{i,I_{out}}/n_{a_i,out}.$$

Here, $M_{i,I_{in}}$ and $M_{i,I_{out}}$ are entries in M of action i and the ideology of the in or out group, i.e. the gain or loss of action i defined by the ideologies. Further, w is the group bias and n_{a_i} the number of agents of the ingroup or outgroup that do the same action, which corresponds to more gain in significance in case of a relative unique action.

To make sure that agents do not choose actions that are in conflict with their previous behavior, they can only choose from the actions that have a maximum distance of two on the scale of radical actions. For example, if an agent performed action a_2, with a 0.6 evaluation within his ingroup and a -0.6 from his outgroup, the next possible actions are within the set a_0, ..., a_4.

In case all actions that an agent can choose from have a negative expected outcome, the agent will perform no action.

Once chosen, the agent will perform that action. In this model this is a trivial step, since action are always successful. Next, the satisfaction level of significance is increased. The gain is computed as follows:

$$\Delta S = 0.1 \times (w_{in} \times M_{i,I_{in}}/n_{a_i,in} + w_{out} \times M_{i,I_{out}}/n_{a_i,out}),$$

which corresponds to the computed expectation. However, the outcome is multiplied by a factor of 0.1 in order to limit the gain in significance by performing one action.

When the need for significance is high enough, i.e. his level of satisfaction is too low, his ingroup bias and therefor acting according to the norms and values of his group are suppressed. An agent will perceive the gain in significance of the ingroup as important as the gain of the outgroup. In that case, the actual gain only depends on the number of agents in each of the group and the number of agents actually performing that action. If the increase of significance by the outgroup is higher than that of the ingroup, i.e. if

$$\Delta S_{out} > \Delta S_{in},$$

the agent will switch from group.

Results

The above described model is implemented in Netlogo. By running the model, radical behavior should emerge. In this context, radical behavior means agents that perform actions that gives them a major gain in significance, but at the same those actions are rejected by others. Furthermore, the population of agents will split in groups, where agents will be mostly surrounded by other agents belonging to the same group.

Implementation and Initialization

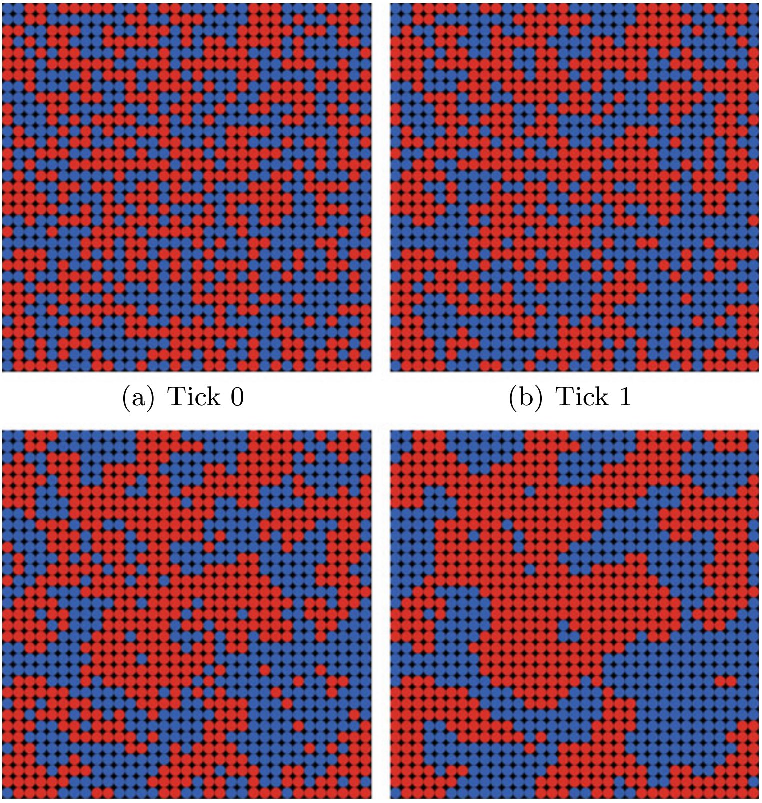
Here, every action can be performed by every agent and will always be performed successfully. Besides increasing the level of satisfaction of agents, the actions in this model do not have any impact on the environment. At the start of the simulation, the agents are equally divided between the two groups and randomly placed in the grid. The first action of the agents is set to a moderate one, i.e. action a_4 for group 0 and a_6 for group 1, where a gain of 0.2 can be obtained according to their ideology, and -0.2 according to the other ideology. All agents start with a value of significance $S = 1$.

Simulation

In Fig. 7.3 the results of the simulation are shown. The blue agents are agents that act according to ideology I_0 and the red ones according to I_1.

The chosen ideology of the agents has converged and they do not switch from group anymore. Clearly, groups of agents have emerged that all act according to the same ideology. This corresponds two the fact that people tend to surround themselves with others who think and act the same.

Agents do not switch anymore, because their actions are too distant from the actions of the other group. This corresponds to two opposing groups whose behavior is so different that it creates so-called social bubbles.



(a) Tick 0 (b) Tick 1

(c) Tick 4 (d) Tick 14

Fig. 7.3 Runs at tick 0 (upper left), 2, 4 and 14 (bottom right)

In order to get a better understanding of the behavior of the agents, Fig. 7.4 zooms in on different individual scenarios.

Figure (a) show a blue agent with no agents from his own group and figure (b) shows a red agent with only two neighbours from his own group. Looking at their actions over time, they have radicalized in the sense that they eventually picked the most radical action. In particular the agent at (a) can not gain any significance since there are no other blue agents in his surrounding and has therefor a significance level of 0. However, he can not switch to the red group to gain significance from them, because his radical action deviates to much from the actions from the red group. This situation is similar to someone being stuck in a situation without having the possibility to escape.

Agents at (c) and (d) are mostly surrounded by agents of the same ideology. The agent at (d) switched from the blue group to the red group. Compared to the agents at (a) and (b) their actions are more moderate. This can be explained by the fact that they get enough significance from their surrounding and do not need to fully

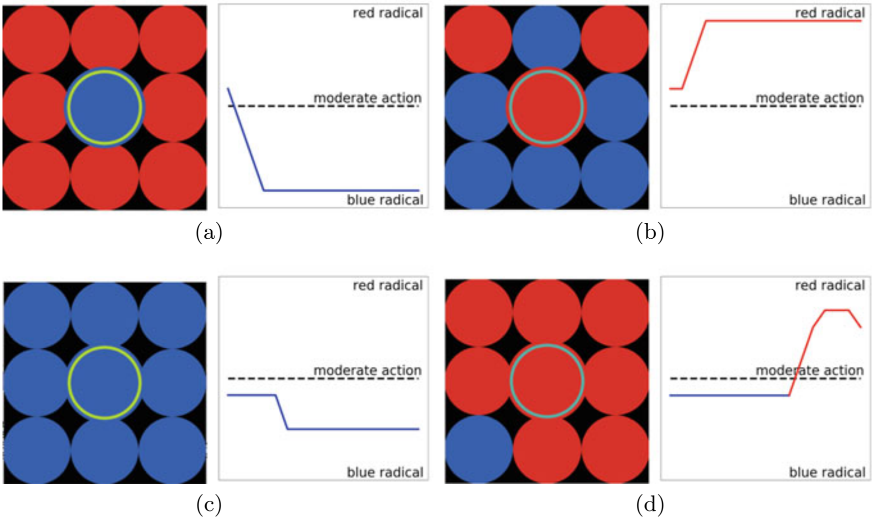


Fig. 7.4 Different scenarios of four individuals with their final social surrounding at the end of the simulation and their chosen actions over time

radicalize. At the same time their actions are mostly seen as positive, since there is (almost) no agent of the other group to reject those actions.

The above results show the start of a radicalization process in the sense that agents choose more radical actions and isolated group emerge, where agents are not able to switch to the other group. Also, it shows that the circumstances of the social surrounding of the agent play an important role in radicalizing or not and keeping his significance level high enough. If not in the right condition, agents get stuck and are neither able to gain significance according to their own ideology nor switching to the other group.

Conclusion and Discussion

The model in this work is a first implementation of the theoretical framework from [1], where it is argued that the combination of three concepts lead to radicalization, namely a high need for significance, an ideology that will function as a means to gain significance and connection to the group that acts according to that ideology.

The results show that groups of radical agents emerge, where radicalizing individuals lead to the formation of isolated social bubbles. It shows the importance of a social surrounding in order to start the radicalization. Furthermore, the circumstances of the agent seem to be important as not all agents with a low level of significance are able to gain this significance back. These results increase understanding of the radicalization process and can give insights on why deradicalization is not straightforward as someone can not easily escape their social group.

In the described model the essential concepts of significance, ideology and social groups from [1] are implemented within a simplified framework with actions, goals and values. However, extensions should be made in order to create a better representation of the real world.

First of all, the set of needs of agents should be extended, for example with the need for survival, as mentioned in [7]. Secondly, in this model the need for significance is fulfilled by acting according to the norms of a social surrounding and therefore 'doing good' and doing something unique. The latter requires that agents have skills that are not commonly shared, such that not all agents have the opportunity to perform every action. Furthermore, actions have no consequences in the current model. However, a lot of actions do affect others, directly or indirectly, and positively or negatively. Finally, each agent should have an internal representation of what good behavior is. For example, being healthy is a value shared among people, but how to keep oneself healthy depends on the interpretation of the individual. [12] introduces a framework in which multiple needs, actions and values combined.

Extending the existing model with the above mentioned concepts it is possible to gain significance in a non-radical matter and let different degrees of radicalization emerge. Furthermore, other phenomena related to radicalism, like sacrificing oneself for the group and identity fusion, can be studied and this will give a better understanding of the mechanism underlying radicalization.

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Chapter 8
InCREDulity in Artificial Societies

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Abstract This paper describes an artificial society in which the simulated agents behave and interact based on a computational architecture informed by insights from one of the leading social psychological theories in the scientific study of secularization and religion: "credibility-enhancing displays" (or CREDs) theory. After introducing the key elements of the theory and outlining the computational architecture of our CRED model, we present some of our initial simulation results. These efforts are intended to advance the quest within social simulation for more authentic artificial societies and more plausible human-like agents with complex interactive and interpretative capacities.

Keywords Artificial societies · Agent-based model · CRED · Supernatural beliefs · Personality · Worldview · Religion

Introduction

The use of agent-based modeling to construct artificial societies in which social scientists and policy professionals can explore and test their hypotheses has been growing rapidly in recent years. These tools have proven themselves useful for demonstrating the emergence of macro-level social patterns from micro-level agent behaviors and

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interactions, even when the latter are relatively simple. The next step for computational modeling and simulation is to develop best practices for creating agent architectures and artificial societies that more adequately incorporate insights about human behavior from disciplines such as cognitive science, social psychology, sociology, and economics. To this end, the present paper presents an artificial society whose simulated agents have variables related to the sorts of emotional attitudes, norms, and identity markers that we believe will be required for adequate representations of "sociality" in multi-agent artificial intelligence models.

More specifically, the artificial society described below attempts to implement some of the empirically driven theoretical insights into human sociality derived from research on the role of "credibility-enhancing displays" (CREDs) on the growth or decline of religiosity in human cultures. CRED theory was first outlined in 2009 by Joseph Henrich [1], who argued that a primary predictor for the expansion of religiosity is the extent to which an individual's social environment is characterized by costly behavioral displays of belief, which signal that ostensibly incredible beliefs (e.g., the existence of hidden supernatural agents) are in fact truly believed. CREDS, in other words, provide social legitimacy to worldviews that contain elements that are not particularly self-evident or obvious. This hypothesis has received support from several empirical studies, including some on the factors that contribute to theism [2] and the spread of secularization [3]. Other studies have shown that CREDs seem to be an important factor in differentiating religious believers from non-believers [4] and in predicting the age at which individuals embrace atheism [5]. More recently, scholars have explored the role of credibility-*undermining* displays, CRUDs (behaviors inconsistent with one's belief) which seem to weaken the power of religion in human populations, as illustrated in research on the response to pedophilia scandals in the Roman Catholic Church in Ireland [6]. CRUDs, in other words, signal the illegitimacy, immorality, hypocrisy, or inefficacy of aspects of a worldview. It is important to emphasize that CREDs and CRUDs are intentionally or unintentionally transmitted, two sides of the same coin, and not necessarily religious. Other sorts of displays, such as the adoption of veganism (a CRED indicating the belief in animal welfare) or a widely publicized fraudulent charity (a CRUD undermining the belief in donations and/or humanitarian aid), can affect the diffusion of non-normative public goods [7]. This suggests the potential policy relevance of this research, and further motivates our interest in constructing an artificial society in which we experiment with the role of CREDs in shaping human behavior.

The aim of the CRED model is to explore the conditions under which—and the mechanisms by which—(non) religious beliefs and behaviors increase or decrease in an artificial society designed to represent a contemporary Western city.

Methods

The CRED Model

The CRED model described here is an extension of the Simulation of Extended Time Integration (SETI) model [8]. The Artificial Society Analytics Platform on which both of these models are based has been outlined in more detail elsewhere [9]. A complete ODD + D protocol for the CRED model can be found online at: https://github.com/ivanpugagonzalez/CRED_Model. Here we provide a brief description of the main features and procedures of the model affecting the worldview (WV) values and religious affiliation of agents.

Agents. The artificial society represented in the CRED model is inhabited by individual human agents who attend school, work (get hired and fired), marry, and reproduce. They are categorized as belonging to a majority or a minority group. They have variables related to demography (age, majority/minority group, education, employment, etc.); to personality (the HEXACO factors plus charisma, susceptibility, frustration, motivation to join a club (MTC) and club tolerance (CT)); to worldview (WV; from secular to religious on a continuum between [0,1]); and to religious affiliation. Religious clubs are membership organizations that exist to support agents with a religious WV; each club has a leader, defined as the agent with the highest charisma value. Agents affiliated to a religious club tend to have WV values in the religious spectrum (0.5, 1.0]; but agents with a secular WV may also affiliate with religious clubs. Agents have memories of interpersonal encounters and the cognitive capacity to evaluate the (in)consistency of CREDs displayed by others. Due to CRED interactions, agents may change their WV and (dis)affiliate with/from religious clubs.

On initialization, agents are assigned variables drawn from suitable distributions that vary according to the group they belong to (majority or minority). Agents attend school for at least 16 years (with a maximum determined by their total education variable) and then move to the work force. The likelihood of employment depends on agents' sex and group category; and on enforced antidiscrimination for agents from the minority (22–29 in Table 8.1). Agents die with a certain probability or if they reach their life span. Agents may get married after reaching an age threshold; to marry, agents must satisfy age, education, and worldview compatibility conditions. Once married, agents may have children; newly born agents inherit the HEXACO personality traits of their parents. Other personality traits such as worldview, charisma, susceptibility, frustration, etc., are derived from the inherited HEXACO personality values (Fig. 8.1).

CRED Interactions. On a weekly basis (52 times a year), agents encounter a CRED interaction with a randomly selected agent from each of its three different social networks: family (mother and father), worldview club (if affiliated), and neighborhood. Agents must be 12 years or older to interact. In club interactions, agents have a higher likelihood of interacting with the leader of the club than with any other club member. CRED displays have values ranging on a continuum between

Table 8.1 Parameter range values in the CRED model

Parameter	Range
CRED Importance related:	
(1) Importance of a CRED display by a leader of a given club	[0.05, 1]
(2) Importance of a CRED display by a leader of my club	[0.05, 1]
(3) Importance of a CRED display by a religious agent	[0.05, 1]
(4) Importance of a CRED display by a secular agent	[0.05, 1]
CRED Impact related:	
(5) Effect of being affiliated to a religious club on CRED impact	[0.05, 1]
CRED consistency related:	
(6) Effect of conscientiousness on CRED consistency	[0.5, 9]
(7) Effect of frustration on CRED consistency	[0.5, 9]
(8) Sigmoidal curve determining effect of club and world view conflict on consistency	[0.4, 0.6]
(9) Error of display consistency of credibility enhancing display (CRED)	[0.25, 0.75]
Other CRED related:	
(10) Probability of interpreting a CRED as a CRUD	[1, 40]
(11) Dampening effect of the leader of a club on the increase of an agent's frustration	[1, 10]
Affiliation related:	
(12) Probability of joining a religious club when holding a secular world view	[1, 60]
(13) Minimum hypocrisy threshold value	[0.5, 0.9]
(14) Minimum joining threshold value	[0.5, 0.9]
Society related:	
(15) Number of adults in initial population	[500–1000]
(16) Initial percentage of agents from the majority group in population	[0.6, 0.9]
(17) Number of religious clubs from majority	[5–15]
(18) Number of religious clubs from minority	[5–15]
(19) Initial percentage of population affiliated to a religious club	[0.1, 0.9]
(20) Human Development Index	[0.25, 1]
(21) Family Impact on Pluralism Index	[0.1, 1]
Employment related:	
(22) Number of Employers	[5, 15]
(23) Percentage of females from the majority employed	[0.75, 0.95]
(24) Percentage of females from the minority employed	[0.75, 0.95]
(25) Percentage of males from the majority employed	[0.75, 0.95]
(26) Percentage of males from the minority employed	[0.75, 0.95]
(27) Probability of losing employment majority	[0.05, 0.15]
(28) Employers' minority friendly (mode)	[0, 0.9]
(29) Enforced Antidiscrimination	[0, 0.9]

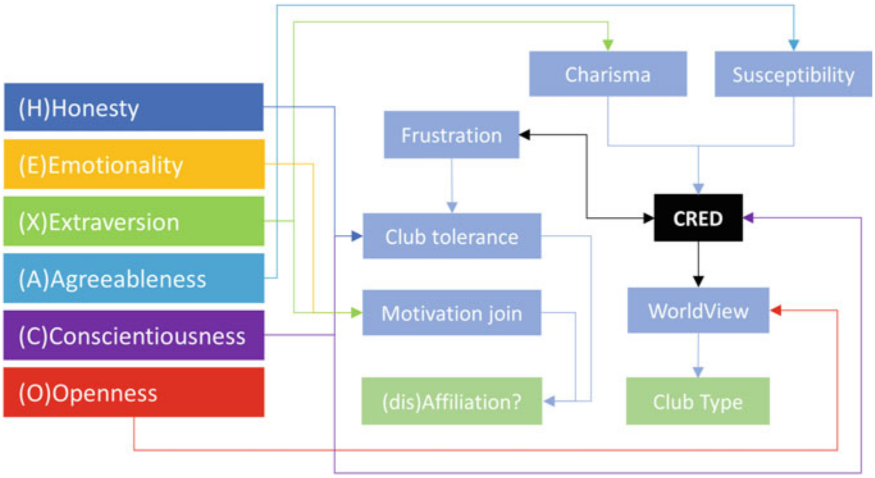

Fig. 8.1 Relation between HEXACO personality factors, CRED displays, WV values, and (dis)affiliation with/from religious clubs. Openness influences initial WV value of the agent; agreeableness influences susceptibility; extraversion influences charisma; honesty and conscientiousness influence club tolerance (CT); emotionality and extraversion influence motivation to join a club (MJC); and conscientiousness and frustration influence CRED consistency. Observing others display CREDs may change/reinforce agent's WV values and may increase /decrease their frustration. High frustration may lead to club disaffiliation and/or reaffiliation via CT and MJC

$[-1,1]$. Thus, CRED displays can be positive/credibility enhancing (CRED) or negative/credibility undermining (CRUD). The value of the display depends on an additive composite equation with three main factors: display importance, display impact, and display consistency. Display importance depends on whether the "exemplar" (agent displaying the CRED) is the leader of a club, and on the type of WV (religious or secular) of the exemplar. In the latter case, we distinguish between the importance of secular and religious WV. Leaders of a club enhance the importance of the display (1–4 in Table 8.1). Display impact depends on the exemplar's charisma, the observer's susceptibility (based on personality variables) and age, as well as the age difference between exemplar and observer. CRED/CRUD impact, then, reflects the tendency of charismatic agents to be more influential than others, the tendency of susceptible agents to be more easily impacted, and the role of age and age difference on the displayed CRED/CRUD (5 in Table 8.1). Display consistency depends on the exemplar's conscientiousness, frustration, worldview, and club affiliation. Exemplars who are not frustrated, highly conscientious, religious, and affiliated with a club will tend to display consistent CREDs. Exemplars who are very frustrated and low in conscientiousness, as well as agents with a secular WV affiliated with a religious club will tend to send inconsistent CREDs (i.e. CRUDs) (6–9 in Table 8.1). Additionally, secular agents ($WV < 0.5$) may interpret CREDs from religious agents ($WV > 0.5$) as CRUDs. The likelihood of this happening is determined by the degree of secularism of the agent and a parameter (10 in Table 8.1).

Modulators of CRED intensity After the exemplar has displayed a CRED or a CRUD to an observer, two other factors further modulate the intensity of the display: pluralism and existential security indexes. The pluralism index [0,1] represents the heterogeneity of WV values an agent experiences in its close (family) and broader (neighborhood) environment. The importance given to the family (Q) and neighborhood (1-Q) may vary (21 in Table 8.1). Indexes with values close to 0 represent homogenous WV values and will have no effect on the CRED display. Values close to 1 represent a heterogenous WV environment and will mute the intensity of the display by a maximum of 50%. The existential security index may not only mute but also amplify the intensity of a display. Importantly, this enhancement/dampening occurs only on displays from religious exemplars that are CREDs (not CRUDs). The existential security index is calculated from a composite equation involving two elements: the income class of the agent adjusted by the human development index (HDI) of the society (20 in Table 8.1), and the degree to which an agent perceives social threats (expressed by the agent's variables for shared norms (between minority and majority) and out-group suspicion). The HDI moderates the effect of income on an agent's existential security index: the existential security of low-income agents is higher in a society with high HDI (e.g. ~ 0.83 in Norway) compared to a society with a low HDI (~0.212 in the Central African Republic). The existential security index varies between [0.5,1.5], meaning that at its lowest value religious CREDs will be amplified by 50%, and at its highest value religious CREDs will be dampened by 50%.

Effect of CREDs/CRUDs on agents' WV and frustration. After the exemplar makes a display to the observer, the observer's WV and frustration are updated according to the paths followed in two decision trees, one for religious agents and another for secular agents (Fig. 8 in ODD + D protocol). Both decision trees consider whether the observer and exemplar are affiliated with a club and the WV value of the exemplar. In addition, when the observer is religious, the decision tree considers whether the openness personality trait of the observer is high or low, and the type of religious club (majority or minority) with which the exemplar is affiliated. The leaves of each tree illustrate the effect that a CRED or a CRUD has on the WV and frustration variables of the observer. Updates may increase, decrease or leave equal the WV and frustration values of the observer. Further, when the observer's frustration increases, the increment in frustration is smaller when the observer is affiliated with a club. This dampening effect is proportional to the leader's degree of charisma (11 in Table 8.1) such that the more charismatic the religious club leader, the lower the increase in frustration of the observer.

(Dis)Affiliation with/from religious clubs. Religious clubs are the only type of club included in the model. When the increase in frustration is so high that it surpasses the agent's hypocrisy threshold (Fig. 8.1; 13 in Table 8.1), the agent disaffiliates from its current religious club. Further, if the agent's frustration is higher than the agent's specific motivation to join a club (Fig. 8.1; 14 in Table 8.1), the agent joins a new religious club. The club that the agent joins is the one from which it remembers the most intense CRED display. When the agent is secular, there is still a probability for the agent to join a religious club. This probability is inversely proportional to the agent's degree of secularism. In other words, the closer the agent's WV value to the religious spectrum (~0.5), the higher its likelihood of joining a religious club. Again, the club that the agent joins is the one from which it remembers the most intense CRED display.

Simulations, Parameter Variation and Data Collection

Social processes related to education, income, and marriage were parameterized according to demographic data from the city of London and are not explored in the present study. The ranges of values for variables related to CRED display and effects (Table 8.1) were proposed by our subject matter experts. We sampled the parameter space (Table 8.1) using Latin hypercube sampling [10] with the 'lhs' r library [11]. We simulated each parameter combination once but swept the parameter space in some detail (1,500 combinations). Each simulation lasted 30 simulation years and every year consisted of 52 weeks. In every simulation year, we recorded the average *WV* values of (a) the whole population, (b) the majority group, and (c) the minority group. In addition, we recorded the average percentage of agents affiliated with a religious club at (a) the population level, among the (b) majority and (c) minority groups, and among agents holding a (d) secular or (e) religious worldview.

Statistical Analysis

Before analyzing the data, we visually inspected each of the response variables (average WV and percentage of affiliated agents) to corroborate that the input parameters indeed produced appropriate variation in the response. Then, to analyze the data we used R statistical software version 3.5.1 [12], proceeding as follows. We first built a correlation matrix between each response variable (average *WV* values: (a) population, (b) majority, (c) minority; percentage of affiliation: (a) population, (b) majority, (c) minority, (d) secular (e) religious) and all input parameters (Table 8.1) plus simulation year. From these correlation matrices we identified 1) whether input parameters were strongly correlated with each other and 2) whether the input parameters were significantly correlated with the response variable. Then we ran GLM models for each response variable. The input parameters included as predictors in each of the GLM (Generalized Linear Model) models were selected according to the following criteria. First, if inputs were highly correlated among each other ($r > 0.5$), then the input with the highest correlation with the response variable was kept and all others were excluded since keeping them may produce collinearity problems. Second, when the correlation coefficient between two input parameters was higher than the correlation coefficients between these inputs and the response variable, the input with the highest correlation with the response was kept and the other was excluded since keeping both may also produce collinearity problems. Third, if the correlation coefficient between the input and the response variable was below 0.05, then the input was excluded. A correlation coefficient of 0.05 means that the input explains only 0.25% of the variance. Thus, our threshold was liberal, since we included inputs with a potentially low explanatory value. With the selected inputs we ran seven GLM models (one per response variable).

Results

The combination of input parameters produced large variation in average WV value and percentage of agents affiliated with a club at year 30 (Fig. 8.2). Values ranged from [0.1–0.9] and from [0.03–0.94] at the society, majority, and minority group level for average WV and percentage of individuals affiliated, respectively (Fig. 8.2). The percentage of club affiliation among secular agents was low in most simulations and the reverse was true for agents with a religious WV (Fig. 8.2). Nevertheless, variation was still moderately high: [0–0.5] and [0.12–0.85] for secular and religious agents respectively (Fig. 8.2).

GLM Models Predicting Average WV Value

After exploring the data visually and selecting potential predictors, we used the *leaps* library and *regsubsets* function to perform multi-model inference. Based on the adjusted R^2 values, the best model at the society level is shown in Table 8.2. The model explained ~ 54% of the variance of the average WV values and included 9 predictors (results for the majority/minority groups are qualitatively similar, except that in the minority model simulation year was not significant). From the nine predictors included in the final model, only a few explained most of the variance (Table 8.3).

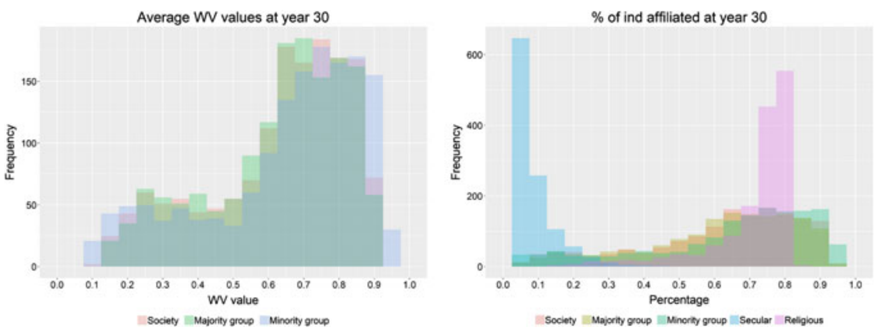

Fig. 8.2 Histograms of average WV and percentage of individuals affiliated with club at year 30

Table 8.2 Best GLM model predicting average WV values at the society level, and percentage of the total variance ($R^2 = 0.54$) explained by each predictor (var exp). In **bold** predictors explaining at least 1% of the total variance

	Est. (SE)	t-value	P-value	Var exp
(Intercept)	0.124 (0.01)	23.47	<0.001	–
Effect of conscientiousness on CRED consistency	0.034 (0.00)	166.03	<0.001	0.56
Effect of frustration on CRED consistency	0.020 (0.00)	98.63	<0.001	0.19
Initial % of Population Affiliated	0.228 (0.00)	104.75	<0.001	0.20
Simulation Year	0.002 (0.00)	28.92	<0.001	0.02
Probability of interpreting CRED as CRUD	0.001 (0.00)	27.22	<0.001	0.02
Effect of club and world view conflict on consistency	0.178 (0.01)	20.69	<0.001	<0.01
Minority friendly	−0.008 (0.00)	−4.14	<0.001	<0.01
Human development index	−0.024 (0.00)	−10.34	<0.001	<0.01
Family weight on Pluralism index	0.008 (0.00)	4.32	<0.001	<0.01
Adjusted R^2: 0.54. F-stat: 5772 on 9 and 44,988 DF. p-value: <0.001				

The effect of conscientiousness and frustration on CRED consistency explained ~ 56% and ~ 19% of the total variance, respectively (Table 8.2). These parameters determined CRED consistency: the higher their value, the more consistent the CRED (see Fig. 4 in ODD + D protocol) and the higher the increase in worldview religiosity. Further, the initial percentage of the population being affiliated explained ~ 20% of the total variance; the higher this percentage, the higher the increase in worldview religiosity. Finally, simulation year and the probability of interpreting a CRED as a CRUD explain ~ 2% of the variance each. All other predictors explain less than 1% of the variance.

GLM Models Predicting Percentage of Affiliation

Based on the adjusted R^2 values, the best models are shown in Tables 8.3–8.5. All models explained > = 73% of the variance. Final models included the same 12 predictors; however, the percentage of variance explained by each predictor varied substantially.

For the model predicting affiliation at the society level, four predictors explained 99% of the total variance (Table 8.3). Not surprisingly, the initial percentage of population being affiliated was the best predictor, followed by the effect of agents'

Table 8.3 Best GLM models predicting percentage of affiliation at the society level and percentage of the total variance ($R^2 = 0.73$) explained by each predictor (var exp). In **bold** predictors explaining at least 1% of the total variance

	Est. (SE)	t-value	P-value	Var exp
(Intercept)	0.074 (0.01)	10.19	<0.001	–
Initial Percentage of Population Affiliated	0.646 (0.00)	290.99	<0.001	0.68
Effect of conscientiousness on CRED consistency	0.031 (0.00)	149.86	<0.001	0.21
Effect of frustration on CRED consistency	0.019 (0.00)	90.68	<0.001	0.07
Simulation Year	0.003 (0.00)	56.47	<0.001	0.02
Minimum joining threshold value	−0.171 (0.00)	−38.74	<0.001	0.01
Human development index	0.018 (0.00)	−7.85	<0.001	<0.01
Minority friendly	−0.012 (0.00)	−5.96	<0.001	<0.01
Effect of being affiliated to a religious club on CRED impact	0.028 (0.00)	10.96	<0.001	<0.01
Importance of a CRED being display by a religious agent	0.022 (0.00)	8.73	<0.001	<0.01
Minimum hypocrisy threshold value	0.059 (0.00)	13.28	<0.001	<0.01
Dampening effect of leader on the increase of frustration	0.002 (0.00)	−9.87	<0.001	<0.01
Initial percentage of agents from the majority group	−0.049 (0.01)	−8.29	<0.001	<0.01
Adjusted R^2: 0.73. F-stat: 10,070 on 12 and 44,985 DF. p-value: <0.001				

conscientiousness and frustration on CRED consistency. All predictors had a positive effect on affiliation except minimum joining threshold. This is expected, since the higher the minimum joining threshold the more frustrated the agent must be before trying to join a club.

For the model predicting affiliation among religious agents, simulation year explained most of the total variance followed by the initial percentage of the population affiliated and the effect of conscientiousness and frustration on the consistency of the CRED. All these predictors had a positive effect on affiliation (Table 8.4).

Finally, for the model predicting affiliation among secular agents, simulation year explained 78% of the variance (Table 8.5). In this case, however, year had a negative effect, meaning that as time goes by the percentage of secular agents affiliated with a religious club decreases. Initial percentage of population being affiliated was the second-best predictor and four other predictors were the third-best (Table 8.5). Three of these predictors had a negative effect: minimum joining threshold, effect of religious club on CRED impact, and importance of the exemplar being religious. Minimum hypocrisy threshold had a positive effect.

Table 8.4 Best GLM models predicting percentage of affiliation among religious agents and percentage of the total variance ($R^2 = 0.74$) explained by each predictor (var exp). In **bold:** predictors explaining at least 1% of the total variance

	Est. (SE)	t value	P value	Var exp
(Intercept)	0.015 (0.01)	2.01	0.04	–
Simulation Year	0.019 (0.00)	301.72	<0.001	0.69
Initial Percentage of Population Affiliated	0.386 (0.00)	166.14	<0.001	0.22
Effect of conscientiousness and CRED consistency	0.019 (0.00)	85.82	<0.001	0.06
Effect of frustration and CRED consistency	0.012 (0.00)	53.80	<0.001	0.03
Human development index	−0.004 (0.00)	−1.51	0.13	<0.01
Minority friendly	−0.015 (0.00)	−7.18	<0.001	<0.01
Minimum joining threshold value	−0.104 (0.00)	−22.45	<0.001	<0.01
Effect of being affiliated to a religious club on CRED impact	0.063 (0.00)	23.54	<0.001	<0.01
Importance of a CRED being display by a religious agent	0.063 (0.00)	23.60	<0.001	<0.01
Minimum hypocrisy threshold value	0.010 (0.00)	2.12	0.03	<0.01
Dampening effect of leader on the increase of frustration	0.001 (0.00)	2.62	0.01	<0.01
Initial percentage of agents from the majority group	−0.054 (0.01)	−8.74	<0.001	<0.01
Adjusted R^2: 0.74, F-statistic: 10,900 on 12 and 44,985 DF, p-value: <0.001				

Discussion

The goal of this CRED model was to explore the conditions under which—and the mechanisms by which—religious beliefs and behaviors increase or decrease in an artificial society designed to represent a contemporary Western city. Two main insights stand out from our initial simulation experiments. First, the consistency of CREDs (shaped by conscientiousness and frustration) seems to drive both the increase in religiosity and the percentage of agents affiliated with a club at the population level. However, whereas consistency is the main driver of the increase in religiosity (Table 8.2), this is not the case for percentage of affiliation. The initial percentage of agents affiliated appears more important for the latter than CRED consistency (Table 8.3).

Second, the percentage of affiliation among agents holding either a secular or religious worldview is mainly driven by time (simulation year). Time has a positive effect among religious agents but a negative one among secular agents (Tables 8.4 and 8.5). This result, however, may be an artifact of the way the model is initialized. At initialization, HEXACO personality values are drawn from a normal distribution ($\mu = 0.5$, $sd = 0.25$). Because openness influences the agents' worldview, at initialization populations will have an average of 50–50% of agents with a religious and secular

Table 8.5 Best GLM models predicting percentage of affiliation among secular agents and percentage of the total variance ($R^2 = 0.76$) explained by each predictor (var exp). In **bold:** predictors explaining at least 1% of the total variance

	Est. (SE)	t value	P value	Var exp
(Intercept)	0.069 (0.00)	19.55	<0.001	–
Simulation Year	−0.004 (0.00)	−144.50	<0.001	0.78
Initial Percentage of Population Affiliated	0.356 (0.00)	331.74	<0.001	0.14
Minimum joining threshold value	−0.100 (0.00)	−47.67	<0.001	0.02
Minimum hypocrisy threshold value	0.103 (0.00)	47.94	<0.001	0.02
Effect of being affiliated to a religious club on CRED impact	−0.047 (0.00)	−38.18	<0.001	0.01
Importance of a CRED being display by a religious agent	−0.045 (0.00)	−36.52	<0.001	0.01
Effect of conscientiousness and CRED consistency	−0.003 (0.00)	−29.68	<0.001	<0.01
Effect of frustration and CRED consistency	−0.002 (0.00)	−17.35	<0.001	<0.01
Human development index	0.003 (0.00)	2.22	0.03	<0.01
Minority friendly	0.003 (0.00)	3.62	<0.001	<0.01
Dampening effect of leader on the increase of frustration	−0.003 (0.00)	−31.06	<0.001	<0.01
Initial percentage of agents from the majority group	0.080 (0.00)	28.06	<0.001	<0.01
Adjusted R^2: 0.76, F-statistic: 11,770 on 12 and 44,985 DF, p-value: <0.001				

worldview. Thus, when the initial percentage of agents affiliated is above 50%, some of those who are affiliated will have a secular WV and therefore will tend to disaffiliate with time. And vice versa, in populations initialized with a low percentage of agents affiliated, agents with religious WV will tend to affiliate with time. This would then explain the positive/negative effect of time on the percentage of affiliation among religious/secular agents respectively. Hence, in future work, we will explore the dynamics that emerge when we fix the initial percentage of affiliated agents and the percentage of agents with a religious worldview at high or low values at the initialization of simulation runs.

Conclusion

Overall, the model highlights the role of initial affiliation and consistency of CREDs on religiosity. These results are also consistent with the theory and other empirical findings. In contexts where there is a large initial percentage of religiously affiliated individuals in a population, it takes time for secularization to occur, and this is slowed down by a high number of consistent religious CREDs. When consistency is low, on the other hand, religiosity may decline more rapidly, as shown in a study investigating the effect of pedophilia scandals on people's religiosity [6].

The CRED model was intended to elucidate a social-psychological theory of religiosity, and in doing so it advanced the quest within social simulation for more authentic artificial societies and more plausible human-like agents with complex interactive and interpretative capacities. The model successfully simulates the processes of religious affiliation and disaffiliation observed within most western cities and does so through complex agent signaling and interpretation dynamics that conform closely to the theoretical and experimental literature on costly signaling. Hence, the model captures and reproduces the theory. Although in the present study no new insights were generated, in the future we plan to run optimization experiments to produce new insights, for instance, into the factors necessary for secularization to occur in the face of consistent CREDs.

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Chapter 9
How Does Social Status in the Classroom Influence Classroom Community Formation?—Verification Using Multi-Agent Simulation

Ayano Kuwahara, Fujio Toriumi, and Isao Yagi

Abstract School bullying is a serious problem for education sites. One cause of bullying is the social status of school. The social status of school is called "social status in the classroom" in Japan. Previous studies against bullying include investigations of classroom community formation and which students in a certain caste tend to suffer from bullying. However it has not been considered that students' social status in the classroom changes dynamically. In this paper, as a preliminary step, we develop a simulation model of school community formation based on the fluctuation in the status of social status in the classroom and friend groups. As a result, student behavior conscious of social status in the classroom and friend groups is suggested to reduce student isolation.

Keywords Multi-agent model · Social status in the classroom · Communication · Community formation · Artificial society

Introduction

School bullying is a serious problem for education sites. One cause of bullying is the social status of school which means the hierarchical relationship between students in the class. This status is called "social status in the classroom (hereinafter called "SSC")".

Many empirical studies discussing bullying in the classroom have been conducted. For example, Chaux et al. [1] investigated the characteristic of regions and schools where bullying is likely to occur. Ahmed and Braithwaite [2] described the role of family variables and school variables in discriminating between non-bullies/non-victims, victims, and bullies. Kowalski and Limber [3] examined the difference

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between the factors that cause cyberbullying and traditional bullying. However, it is difficult for empirical studies to ascertain which factors actually affect bullying because various factors affect the actual classroom at the same time. Multi-agent simulation may be effective in the investigation of classroom community formation, such as simulation of SSC and causes of bullying, because we can simulate and observe which factors affect the classroom.

Some previous studies used multi-agent simulation to model group dynamics [4], friendship networks [5], or a combination theory [6]. Toriumi and Ishii [7] found that students who observe the situation emerged. Ono et al. [8] investigated which SSC had students who were victims of bullying.

In the present study, we focus on classroom community formation, which is necessary in order to consider bullying problems, and investigate attitudes of students who are conscious of SSC and friend groups that affect classroom community formation through multi-agent simulation. While the status of a student in a SSC was fixed in the previous paper [7], the statuses of students in the proposed model change during the simulation. Friend groups are formed by student actions based on the statuses of the students in the SSC system. We also introduce the proposed model, which includes two types of student personalities where the student tries to increase his/her status in the SSC system or the student tries to maintain friends with members of the group to which he/she belongs. We observe how the classroom community is formed by changing the ratio of the number of students with the former personality to the number of students with the latter personality.

Proposed Model

Model Overview

In the present study, we constructed a model based on Toriumi and Ishii's classroom model [7]. However, we removed teacher intervention and added the status of SSC and friend groups so as to accurately grasp the influence of student behavior based on improving the status of SSC and stabilizing friend groups. In addition, we adopt the agent's personality and behavioral strategies so that student agents know the status of SSC and human relations in friend groups and act to improve and stabilize their surrounding environment.

Classroom Community Model

We build our model as one class of junior high school and conduct experiments. There are thirty student agents in the classroom. Agents within the same classroom have a favorability rating for each classmate. The favorability rating is randomly assigned at the start of the simulation. The favorability rating changes through communication. The agent can set friend links for up to five agents whose favorability rating exceeds 0.0. The rank of the total favorability rating is defined as the rank SSC. The agent believes that belonging to a SSC of higher rank is a good thing. The SSC rank is an indicator of the decision to make friend groups and to select conversation partners. All agents belong to one friend group. Friend groups are created at the start of the simulation, that consists of all agents linked by friend links to the group leader of each friend group, and they are changed by communication. A friend group consists of a group leader and other group members. The number of friend group members ranges from one to thirty. The agent might leave one friend group and join a new friend group. After all agents have finished communicating, we update friend links and status of SSC.

Communication

An agent communicates and changes relations. The conversation partner of the agent is another agent belonging to the same classroom. The topic subject when the agent communicates is an agent in the same classroom other than himself/herself and the conversation partner. The agent selects a communication method based on a behavioral strategy. The behavioral strategy depends on the personality of the agent. There are two patterns of personality: improvementism and pacifism. Personality is fixed to the value assigned at the start of the simulation. After communication is complete, the agent updates the favorability rating of the conversation partner and topic subject. Renewal of the favorability rating is based on the theory, which extends Heider's balance theory [9]. Heider's balance theory is as follows. The attitude of a person toward a certain thing is determined by the emotional relationship among the person himself/herself, the conversation partner, and the topic subject. Assuming that these emotional relationships are favorable (+) or unfavorable (-). If the product of the three emotional relationships is positive, the state is equilibrium. And if the product is negative, the state is unbalanced.

Behavioral Strategy

Student agents have a behavioral strategy to show how they behave in the classroom. There are two strategies: the improvement strategy and the pacifist strategy. The agent selects either behavioral strategy for each strategy-fixed turn. Agents who are assigned improvementism tends to choose the improvement strategy. Agents who are assigned pacifism tends to choose the pacifist strategy. The agent who selects the improvement strategy acts to increase the position in the SSC system and increase the position of the friend group in the SSC system. An agent who selected a pacifist strategy mainly attempt to improve friendships among group members by communicating among the friend groups to which they belong.

Experiment and Considerations

Experimental Settings

We compare two classrooms that differ with respect to how student agents select their conversation partners. One of the classrooms to be compared is a classroom in which student agents take actions to stabilize friend groups and improve their status of SSC. We call this classroom a classroom with a behavioral strategy. Another classroom is a classroom in which student agents are not conscious of friend groups or the SSC system. We call this classroom a classroom without a behavioral strategy. Let the minimum unit of communication within a classroom be one turn. This corresponds to communication conducted in the real world before or after class. The number of communication turns for one day is approximately 10. Since the number of days that junior high school students attend school is approximately 200, one turn of the experiment corresponds to 2,000 communication turns, representing approximately one year. The average of 100 trials is given as a result.

Under the above conditions, interpersonal relationships between students since classroom creation are reproduced in experiments. The formed community is evaluated by the following three parameters: number of isolated agents, number of fringe agents and the rate of interlinkage. Isolated agents are agents that do not have any friend links from/to anyone. Fringe agents are not isolated agents and are agents that does not have interlinkage that means mutual friend links are established. The presence of an agent in this state is undesirable for classroom management. The rate of interlinkage is the rate at which mutual friend links are established among all friend links established in the classroom. When the rate of interlinking is high, the proportion of students who believe that they are friends with each other is large. Such a classroom is desirable for classroom management.

Experimental Results

Next, we compare the classroom community formation of a classroom with a behavioral strategy and that of a classroom without a behavioral strategy. The results are shown in Table 9.1.

Discussion

Using the behavioral strategy, the number of isolated agents and the number of fringe agents decreased. Repeated communication within a friend group through a pacifist strategy and actions that were taken to create new friend links through improvement strategies are considered to be factors. Using the behavioral strategy, the

Table 9.1 Impact of existence of a behavioral strategy on classroom community formation

	Isolated agent	Fringe agent	Rate of interlinkage
Classroom without a behavioral strategy	0.76	2.98	0.38
Classroom with a behavioral strategy	0.33	1.77	0.43

Table 9.2 Average number of friend groups

	Without a behavioral strategy	With a behavioral strategy
At the start of the simulation	11.13	11.18
At the end of the simulation	10.45 (–0.68)	5.87 (–5.31)

student agents acted to make friendships stronger. In the classroom with a behavioral strategy, the rate of interlinkage is increasing. This is considered to be a factor by repeated communication within a friend group through a pacifist strategy. Therefore, conversations that takes friend groups and the status of a SSC into consideration influences the generation of one-to-one friend relationships. The number of generated friend groups was 10.45 in the case without a behavioral strategy and was 5.87 in the case with a behavioral strategy. Since there is no large difference in the number of friend groups that were originally generated, in the case with a behavioral strategy, many group mergers were conducted through communication. Since there are friend groups with only one member, such single-person groups decreased due to group merger. As such, students acting while conscious of friend groups and school castes had a positive effect on class-room community formation. Table 9.2 shows the number of groups. On the other hand, a certain agent repeatedly alternates between an isolated state and a non-isolated state at the beginning of the simulation. The isolated state was resolved as the simulation turn progressed. However, an agent that had been isolated for several turns did not leave the isolated state. If an isolated student exists, it is vital for the teacher to assist the students in communicating in order to resolve the isolated situation.

Conclusion

In the present study, we added the friend group, the SSC, and the behavioral strategy to the classroom community formation simulation model carried out in previous research. Evaluation of classroom community formation was conducted using the number of isolated agents, the number of fringe agents, and the rate of interlinkage. As a result, in the case of a classroom in which friend groups and SSC are manifest, we found that it is difficult for isolated agents to turn up. Using behavioral strategies, agents will enhance each other's favorability rating within a friend group in order to strengthen the unity of friend groups and will talk to students other than friends in order to raise their status of SSC.

However, an agent that had been isolated for several turns did not leave the isolated state. If an isolated student exists, it is vital for the teacher to assist the students in communicating in order to resolve the isolated situation. One of the future task is to change the current behavioral strategy to the other various things.

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Chapter 10
Agent-Based Simulation of Policies to Reconnect a City and the Countryside

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Abstract An agent-based model was created to capture the spatio-temporal dynamics of the economy at the level of a Dutch province. After 1945, Noord-Brabant has been subject to an active program of economic development through the stimulation of pig husbandry. This has had far-reaching effects on its economy, landscape, and environment. The simulation is at institutional level, with typical stakeholder groups, lobbies, and political parties playing a role in determining policies that in turn determine economic, spatial and ecological outcomes. It allows to experiment with alternative scenarios based on two political dimensions: local versus global issues, and economic versus social responsibility priorities. The paper describes the model and presents examples of outcomes showing disconnect and reconnect. The model shows very strong sensitivity to political context. It can serve as a reference model for other cases where "artificial institutional economy" is attempted.

Keywords institutions · Regional policy · Livestock farming · Livelihood

Introduction

In the past centuries, industrialization has changed the way food systems are coordinated. Thanks to great advancements in logistics, local food systems are increasingly linked to global food systems. Cities are no longer dependent on their 'country-sides' for food system services. One of the consequences is a disconnect between cities and the countryside. This poses a threat to the sustainability and resilience of the food system at different levels [1].

Local food systems used to have tight feedback loops. Consumers and producers, as well as externalities, were closely linked within local food systems. These direct

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feedback loops were fundamental to the resilience of the food system in coping with perturbations from nature and the market. With globalization, more direct feedback loops need to be replaced by other institutionalized ways of feedback arrangements to avoid disconnects and enhance the resilience.

Based on Cumming et al. [1], Termeer et al. [6] elaborated on the importance of rules and traditions to maintain ecosystem services and connects between urban and agricultural systems. Their analytical framework seeks to explain the dynamic processes of institutional change, the strategies and interactions of powerful players in the system and their embeddedness in political systems. This framework was used to re-examine a historical case: the intensification of the livestock sector in Southern Netherlands (the Province Noord-Brabant) from the 19th century until today. Their conception of institutions centers on two aspects: rules and power. Institutions can be seen as formal and informal rules that shape patterns of political, economic and social interactions, without determining them. Such rules guide the behavior of governments, markets and civil society actors operating at multiple scales. The importance of power is due to the fact that rules are often results of negotiations between powerful and less power actors. While these two aspects greatly contribute to conceptual understanding of the dynamics of the livestock sector, the institutional mechanisms remain rather abstract and elusive due to the complexity of the situation and the large amount of stakeholders involved. This makes it difficult to conduce policy analysis on alternative institutional arrangements.

Inspired by the theoretical framework and historical analysis developed by Termeer et al. [6], this paper describes an agent-based simulation model that aims to operationalize the concepts and mechanisms from the bottom up, and enable policy analysis. In particular, the paper seeks to build an ontology of institutional mechanisms by developing reference models for actors and their interactions. The ontology aims to be generic across cases, with Noord-Brabant as the example and for calibration.

In the sections that follow, the model is first described in detail, followed by selected results that illustrate possible outcomes of different policy intervention. The paper concludes on the applicability, limitation and future developments of the model developed.

The Agent-Based Simulation Model

This section describes the simulation, following the revised ODD protocol [3]. The simulation is programmed in NetLogo. Source code, data, and sensitivity analysis are available from the CoMSES OpenABM model library under the title "Policies to reconnect a city and the countryside" (https://www.comses.net/).

Purpose The simulation supports regional policy making with respect to the relation between city and countryside, in a democratic polity. To this end it enables the exploration of potential consequences of alternative interventions, and counterfactuals, i.e., situations that could have emerged under different courses of events. As an example a region is simulated where a rapidly expanding high-tech industry in the city and an intensive livestock industry in the countryside compete for space for housing, farming, and leisure. Tensions arise between the traditionally powerful agricultural sector and environmental and animal-welfare movements and the high-tech industry. The latter require clean production locations and a healthy, safe, attractive, living environment in order to recruit and sustain highly qualified staff.

The purpose of the simulation is to make clear how regional policies and material, monetary, migration, and information flows can affect each other under pressure from lobbies, public opinion, and national and EU-policies.

Entities, state variables, and scales Figure 10.1 depicts the entities represented in the simulation. Several types of agents act in an environment comprising plots with different types of land use. Three sets of plots represent urban, countryside, and village areas. One of the urban plots represents the city center, where offices are located. The other plots can be used for housing or farming. Maximal population density and cost of living depend on the land use type. An urban plot can typically house up to 25 individual households, a village 10, and a countryside plot only one. The countryside typically has the highest cost of living; villages are the cheapest. Livestock keeping can be restricted to particular areas in the countryside. Furthermore, the air around livestock farms can be polluted and health hazards may be effective in case of disease outbreaks.

Households are the main actors in the simulation, where a household stands for an individual with some economic activity and the household depending on that activity. Households are assumed to have a single economic activity or inactivity. They may either be farmers or workers in the agri-industry, or high-tech workers, or be unemployed or disabled. The economic activity generates incoming and outgoing monetary flows, resulting in a cash balance. A farmers' income results from exploitation of a production capacity; the others receive a salary or some form of support. Farmers generate flows of manure, bad air, and, in case of disease outbreaks, infection risk. Other individuals can be affected by these flows. Some country dwellers in financial trouble engage (irreversibly) in criminal activities, such as growing Indian hemp or facilitating drug-labs.

Individuals' actions are assumed to be governed by norms that depend on reference group memberships (Table 10.1). A reference group is here defined as a group who are expected to act according to a set of common rules (norms). Membership of some reference groups can be chosen by individuals if the norms correspond with their opinions, some can be left if the norms no longer correspond. Membership of some groups is forced by circumstances, such as unemployed and disabled. Membership can be bound by conditions for joining, leaving, or remaining; for instance a farmer has to leave the reference group farmers when bankrupt. Some groups are mutually exclusive, such as farmers and unemployed. Public administration serves as a reference group of which all individuals are members. Its norms apply to all individuals. Emigration is the only way to escape from it.

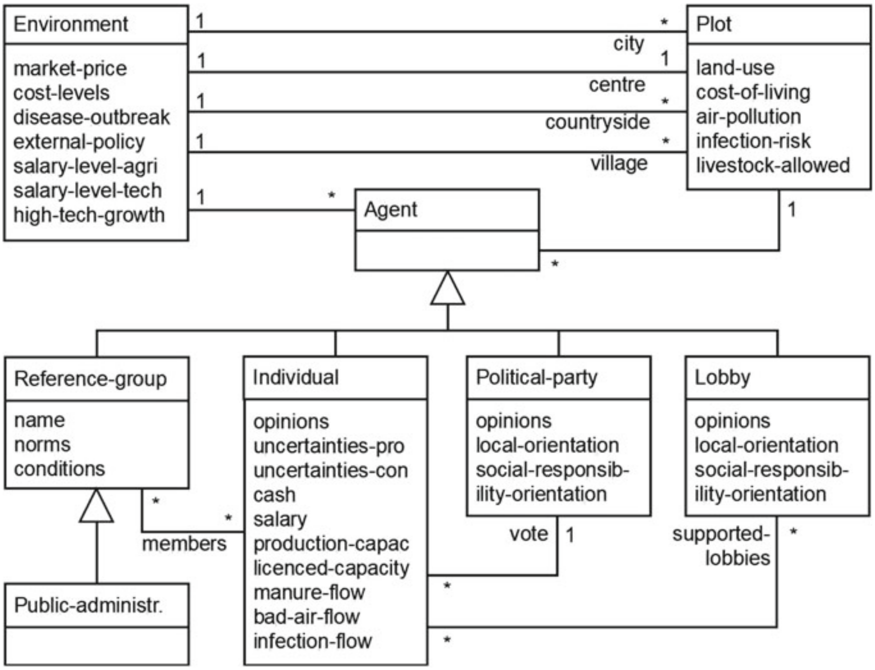

Fig. 10.1 Class diagram representing the entities in the simulation

Table 10.1 Lists of reference groups, lobbies, and norms currently represented

Reference groups	Lobbies	Norms
Farmers	Livestock-lobby	Invest in livestock farming
Countryside-criminals	High-tech-lobby	Care for the local environment
Agri-workers	Global-responsibility-lobby	Care for the global environment
High-tech-workers	Local-responsibility-lobby	Foster agri sector
Unemployed		Foster high-tech industry
Villagers		Work in agri industry
Urbanites		Work in high-tech industry
Commuters		Live in the countryside
Patients		Live in a village
Locally-involved		Live in the city
Globally-involved		Licence required for livestock
Public-administration		No livestock near populated areas
		Freeze production capacity
		No more licences
		Engage in criminal activities

Political parties and lobbies participate in the formulation of norms to be applied by the public administration, such as conditions for farming licenses. Individuals vote for political parties in periodic elections. An individual's vote is assumed to be based on the distance between its opinions vector and those of the parties (the "party programs"). Public administration implements the norms for which a sufficiently positive opinion exists among the parties, weighed by the number of votes. Between elections, party programs may change. Parties are characterized by two dimensions: an orientation towards local problems versus global problems, and an orientation towards economic issues versus social responsibility issues. Lobbies (see Table 10.1) try and affect the party programs. Their success is assumed to depend on the extent to which their orientations match and on the economic relevance of their supporters, which is measured as the sum of salaries plus farmers' cash flows of individuals.

Furthermore, lobbies try and affect the public opinion. The simulation applies mechanisms of opinion dynamics [4]. The opinions concern norms (see Table 10.1 for a list of currently implemented norms). Opinions express a positive or negative stance regarding a particular norm, which can be affected by communications from lobbies or discussions with other reference group members. The extent to which an opinion can be affected depends on an individual's uncertainty about the issue. Uncertainty may be aroused by information flows and events like disease outbreaks. These mechanisms are further discussed under "Submodels". With respect to lobbies, it must be noted that they have another role than the reference groups: reference groups set norms for their members; lobbies try and set norms for others.

The simulation proceeds in an abstract world of 33 by 33 patches, with initially mostly countryside patches where farmers dwell and produce pigs, a village area inhabited by agri-industry workers, and a city populated by workers in the high-tech industry. The industries are assumed to not only comprise the core activities, but also input supply, processing, transport, and services such as finance, accounting, veterinary, construction, maintenance, legal, catering, etc. The simulation typically spans a period of fifty years, in time steps of one year.

Process overview and scheduling The simulation starts with initialization by assigning plots to city, countryside, and village areas, and populating the plots: reference groups, lobbies, political parties, and public administration in the city center, high-tech workers in the other city plots, farmers in the countryside, and agri-workers in the village areas. Then the simulation runs for a number of time steps, each representing a year. Figure 10.2 depicts the process flow per step.

External influences are generated: the market price for fattened pigs is generated at random between a lower and upper bound set in the user interface. The production cost is increased by a percentage due to national and international environmental and animal welfare policies and quality restrictions. Disease outbreaks are generated with a frequency set in the user interface.

Individuals generate flows. They spend a particular cost of living, depending on the type of plot they live on. Farmers produce pigs, manure, bad air, and infection risks (the latter in case of a disease outbreak), and sell pigs. When they have sufficient capital and licenses, they invest in capacity extension. If they have capital

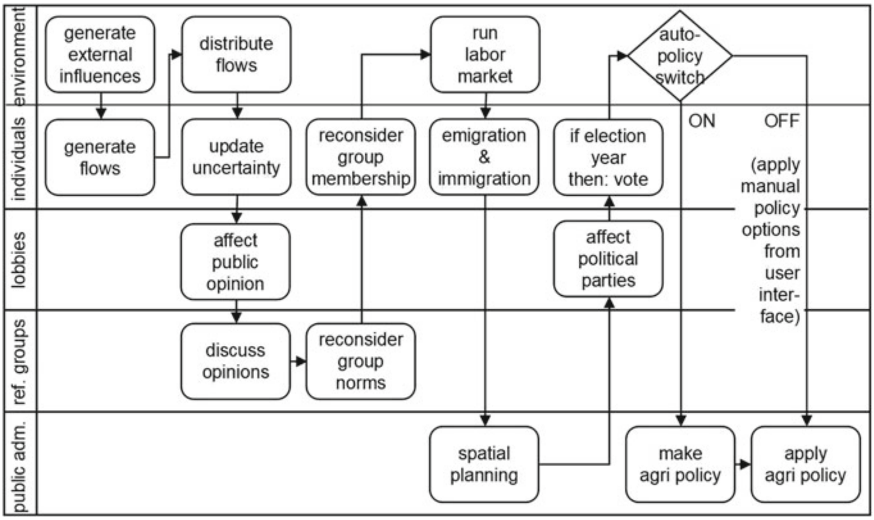

Fig. 10.2 Process flow in a single, one year, time step

but no license, they apply for it. Workers in high-tech and agri industry receive a salary. Unemployed and patients receive support for the cost of living. Some farmers complete their incomes by facilitating criminal activities.

Flows are distributed through the environment. Manure is accumulated in the environment. Bad air and infection risk spread locally and can cause serious nuisance or disable people. Data on economic growth, population, production, employment, environment, and disease outbreaks become available to all agents.

Flows and aspects of their current situation can affect individuals' uncertainties about their current opinions. For instance, for a farmer a high profit is desirable, but great manure flows may reinforce others' doubts about farming. Bad air may make people uncertain whether they are living in the right place or not. Disease outbreaks may make the public opinion susceptible to campaigns to restrict farming.

Lobbies try and affect the public opinion through communication campaigns, addressing particular uncertainties. Individuals discuss opinions in their reference groups, which generally leads to convergence of opinions. As a result of opinion shifts, a group's norms may be adapted.

Individuals may reconsider their reference group memberships and leave or join groups. These decisions are governed by opinions about the norms, and by membership conditions. Some changes are voluntary; for instance, high-tech workers who want to live in the countryside can leave the urbanites and join the commuters, if they have sufficient capital and a plot is available. They can move back if they don't like it anymore. Changes can also be forced, e.g., farmers who no longer have sufficient cash or licenses must quit, sell their farm, become villagers or urbanites, and join the unemployed.

In the labor market, employment in the agri-industry depends on total pig production in the region; employment in the high-tech industry is assumed to depend on an externally determined growth, which is generated at random within some bounds in each time step. Tight conditions in the labor market induce immigration. On the other hand, long-term unemployment stimulates individuals to emigrate from the region.

Public administration can extend city and village areas in case of population growth. To this end, country dwellers on the edges are expropriated. Depending on current agricultural policy, new licenses may granted to expropriated farmers, or they may just be bought out.

Lobbies try and affect political parties' opinions, which are voiced in the party programs. Lobbies can affect policy not only through affecting public opinion before elections. Lobbying continues between election years. The policies implemented by public administration depend on the parties' opinions, weighed by the votes from the recent election. When the parties' opinions change under the influence of lobbies, new policies can be implemented.

Examples of policies directed to livestock farming are investment support (to increase livestock production) and binding livestock keeping by licensing (to achieve the opposite). Licensing enables freezing the total production capacity in the region, reducing total livestock by restricted licensing and buy-out, or restricting livestock farming to particular areas, or combinations of these policies.

Design concepts *Basic principles* of the model are opinion dynamics [4] and rule-following decision-making [5] by individuals and a public administration under a democratic polity, which can constrain farmers' decisions through licensing and buy-out. Land use planning by the public administration prioritizes other industries and housing over agricultural land use and expropriates country dwellers when space is required. The modeled entities and processes are based on historical research on the region and expert data on current politics.

Emergence: Potentially emerging phenomena are the growth or collapse of economic sectors, urbanization, pressure on the environment, public support for particular policies, consequences of policies, and the effects from lobbies and arousing events on policies.

Adaptation: Individuals may adapt their opinions and change their reference group memberships, and their support for lobbies and political parties. Public policy may change under pressure from lobbies and public opinion.

Objectives: The only actors pursuing objectives are the lobbies. Other actors are affected by them, but are modeled as rule-following decision makers.

Learning: Based on experience and information, individuals can (based on changed opinions or forced by circumstances) change their reference group memberships and then apply different decision rules. However, they simply follow new rules and do not make or use *Predictions*.

Sensing: Individuals can sense the condition of their environment, can receive information flows reporting on consequences of others' actions, and are aware of others' opinions.

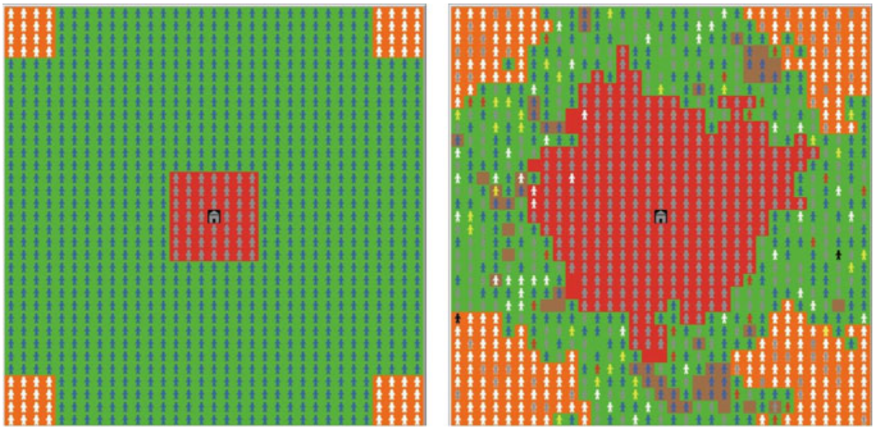

Fig. 10.3 Examples of the simulated world view, after initialization and a (counterfactual) situation 50 years later, illustrating the effect of urbanization (area color legend: green—countryside; red—city; orange—village; brown—high pressure on the environment)

Interaction: Interactions between individuals in reference groups, between lobbies and individuals and between lobbies and political parties are based on opinion dynamics [4]. Individuals' uncertainty (susceptibility to others' opinions) depends on personal experience, uncertainty arousing events, and information on developments in their environment.

Stochasticity: Variation of simulation outcomes results from random fluctuations in pig price, high-tech industry growth, disease outbreaks and, to a lesser extent, randomly generated expropriation decisions, encounters during opinion exchange, opportunities to move, and the distribution of initialized agent traits (production capacity, salary).

Collectives: Agents are members of reference groups, in which they maintain common norms and discuss opinions.

Observation: The main question is: will the intensive livestock industry collapse or survive? Main observables in this respect are the number of farms, total annual pig production, and employment in the livestock complex. An additional question is: if the livestock sector survives, is that possible without hindering the evolution of the high-tech industry? Observables for this purpose are high-tech employment and emigration of high-tech staff. Furthermore, it is useful to observe the strengths of the different lobbies, general indicators such as population growth and employment, and urbanization (see Fig. 10.3; the red area is the city).

Initialization and input data The simulation is initialized as a world of 33 by 33 patches. Reference groups, lobbies, political parties, and public administration are located on the central patch (see Fig. 10.3). Around the patch a city is populated with 25 households of high-tech workers per patch, with a salary generated at random around the average, set in the user interface. The countryside is populated with one farm household per patch, with a production capacity generated at random around

Table 10.2 Inputs and other parameters with their default settings

Parameter	Value	Unit	Parameter	Value	Unit
Simulation-time	50	y	Country-cost-of-living	30000	/y
Mean-initial-capacity	500	pigs/y	City-cost-of-living	25000	/y
Price-upper-bound	130	/pig	Village-cost-of-living	20000	/y
Price-lower-bound	110	/pig	Farm-estate-value	1000000	
Initial-production-cos	70	/pig	Opinion-dynamics-mu	0.2	
External-policy-effect	0.042	/y	Initial-uncertainty-min	0.4	
Capacity-investment-cost	200		Initial-uncertainty-max	0.6	
Outbreak-frequency	0.04	/y	Interaction-partners	2	/y
Criminal-susceptibility	0		Norm-adoption-threshold	0.83	
Mean-salary-agri	40000	/y	Policy-threshold	0.5	
Agri-complex-employment	0.001	/pig/y	Lobby-effectiveness	0.3	
Mean-salary-tech	30000	/y	Election-period	4	y
Tech-industry-growth	3.3	%/y	Unemployed-emigration-factor	0.1	/y
Bad-air-limit	30000	pigs/y			

the average, set in the user interface. Village areas are populated with 10 agri-sector workers per patch, with a salary generated at random around the average, set in the user interface.

Further inputs and parameters (see Table 10.2) can all be set in the user interface. The inputs are calibrated against data obtained from statistics and experts on the pig production evolution in Noord-Brabant and the Netherlands in general. Details and sensitivity analysis are available on CoMSES/OpenABM.

Submodels The rules that the individuals follow are based on the norms of reference groups to which they belong. Individuals have opinions on the norms of their own reference groups and those of other groups. Opinions on norms are represented as a vector **x**; each element x_i represents an opinion on a particular norm as a real number on a scale from 0 (negative opinion) to 1 (positive opinion). Individual's opinions are initialized $x_i = 1$ for the norms of their reference groups, $x_i = 0.5$ (indifferent) for other norms. Lobbies' opinions are initialized as $x_i = 1$ for the norms they promote, $x_i = 0$ for the norms they oppose, $x_i = 0.5$ for the other norms. For political parties, all norms are initialized as $x_i = 0.5$.

Lobbies do not change their opinions, but affect those of political parties and individuals. Their effect on opinions in political party programs is computed as:

$$x_i(t+1) = x_i(t) + \epsilon\sigma\delta(x_i' - x_i(t)), \tag{10.1}$$

where x_i' stands for a lobby's opinion on norm i and lobby effectiveness ϵ is a global parameter set in the user interface; $0 < \epsilon < 1$. A lobby's strength σ is computed as the sum of salaries plus farmers' cash flows of individuals who support the lobby, divided by the sum of salaries plus farmers' cash flows of all individuals. The ideological distance $\delta = (|\lambda_\mathrm{p} - \lambda_\mathrm{l}| + |\rho_\mathrm{p} - \rho_\mathrm{l}|)/2$, where λ_p, λ_l, ρ_p, and ρ_l stand for local versus global and social responsibility versus economy orientations of party and lobby, all as real variables in [0...1].

An individual's opinion can be affected by another agent, such as a lobby, according to the individual's left-hand (y_i) and right-hand (z_i) uncertainties:

$$x_i(t+1) = \begin{cases} x_i(t) + \mu(x_i'(t) - x_i(t)), & \text{if } -y_i \le x_i'(t) - x_i(t) \le z_i \\ x_i(t), & \text{otherwise,} \end{cases} \tag{10.2}$$

where μ is the opinion dynamics convergence parameter, $0 \le \mu \le 0.5$.

Individuals discuss opinions in their reference groups. The number of interactions they seek per time step in each of their reference groups is set in the user interface. When two members of a reference group meet and discuss norm, both update their opinions according to Eq. 10.2.

The elements of uncertainty vectors **y** and **z** are initialized to a default value between 0 and 1, set in the user interface. Uncertainties are set to a value of 1.0 in case of a negative (left-hand) or positive (right-hand) experience resulting from a particular norm, and return to the default value in the next time step.

An individual joins a reference group when its average opinion on the group's norms exceeds a threshold τ and if the individual satisfies the membership conditions. An individual leaves when its average opinion is less than $1 - \tau$ and satisfies the conditions to leave, or when it no longer satisfies the membership conditions.

In elections, individuals vote so that they minimize the Manhattan distance between a party's and their own opinion vectors. Then, in the policy process, policies are installed or changed when the average opinion of parties, weighed by the number of votes, exceeds a threshold, set in the user interface.

A reference group adopts a new norm when the average opinion of its members about the norm exceeds the threshold τ that can be set in the user interface. A

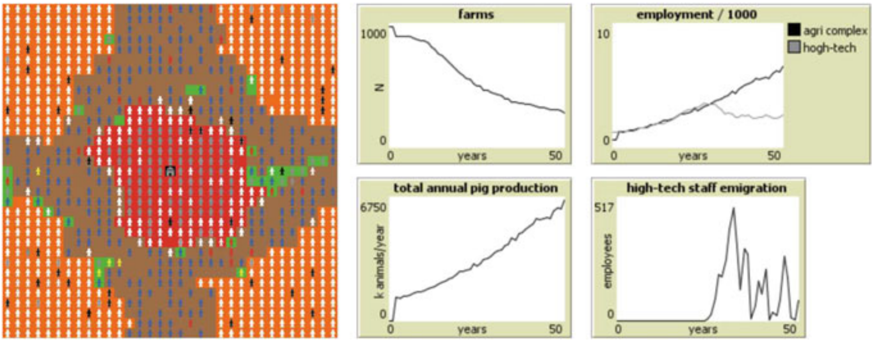

Fig. 10.4 Outcomes from a run without regional livestock policies (legend: see Fig. 10.3)

reference group rejects a current norm when the average opinion of its members about the norm is less than $1 - \tau$.

Examples: Disconnect and Reconnect as Stylized Trends

Figure 10.4 depicts outcomes from a default run, where no regional policies are applied to regulate livestock farming. A spatial planning policy is in place to enable the housing of immigrating employees of the agricultural complex and the high-tech industry by expropriating farmers and expanding city and village areas. Furthermore, external policies increase pig production cost by environmental, animal welfare, and quality regulations. The outcome of this scenario is an economy dominated by the agricultural complex, with a strong increase of export-directed livestock production, disconnected from the city, with serious environmental effects and problems to fulfill staff requirements from the high-tech industry.

The situation depicted in Fig. 10.4 is counterfactual. Policies at the regional level, restricting the location of farms and growth of the livestock, have been in effect since the second half of the 1980s. Currently, additional measures are demanded by several lobbies and pressure groups and particular policies are being discussed to further restrict the livestock industry in Noord-Brabant. As analyzed by Termeer et al. [6], the institutions simulated in the present model are at work and reduce the influence from the agri-complex on regional politics.

Figure 10.5 presents an example of outcomes from a simulation where the institutions of the polity are in effect and reconnect city and countryside. In the first decades, livestock and the high-tech are both growing, while the livestock lobby dominates the politics. Environmental pressure increases and makes the growing population more susceptible to the social responsibility lobbies. Together with the high-tech lobby, they put pressure on political parties and enforce a policy to buy-out farms near populated areas. When pig production grows again due to increasing farm size,

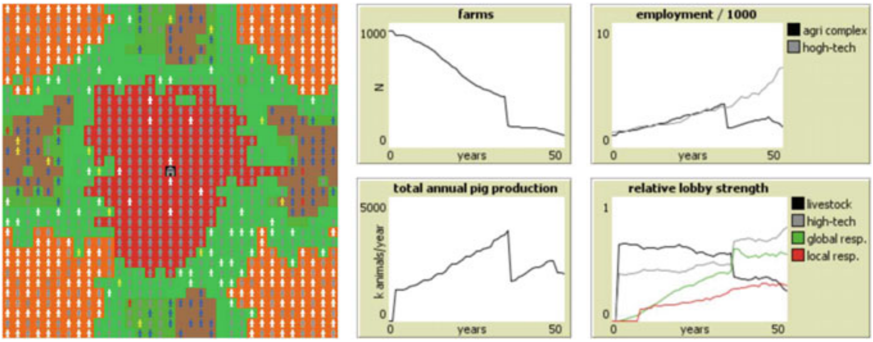

Fig. 10.5 Outcomes from a run where a democratic multi-party polity realizes feedback

a more restrictive licensing policy is enforced by the now powerful social responsibility lobbies. As a result, employment in the livestock industry declines and its influence on politics decreases further. The example shows how institutions matter to keep city and countryside connected.

Conclusion

Model concepts From an ontological point of view, the ambition of this model is to find a middle ground between, on the one hand, "artificial sociality" models that center on relational processes, and on the other hand, economic models that have simple utility-maximizing agents. We attempted to construct an institutional/political world. We believe that we struck a workable balance between ontological simplicity and plausibility. The combined use of reference groups, lobbies and political parties has potential and can serve as a canvas for other simulations. The model would allow for improvements on the "artificial sociality" side, for instance, by varying the strength of certain reference groups, or by basing voting behavior more on reference group membership and less on opinions.

Validation For a model of this kind, validation is a thorny issue. It implements ideas from institutional economics in an eclectic way, since no theory offers clear guidance; the theories were not invented for that purpose. This means that the model cannot be "validated against theory". On the other hand, it is too stylized to exactly represent the province of Noord-Brabant that served as its source of inspiration and calibration. We therefore aim for no more than face validation based on second-order effects in the simulation. Considered from this perspective the model performs well. The actual state of Noord-Brabant is marked by the pressures shown in Fig. 10.4, where the disconnected livestock industry prevails, Fig. 10.5, where the reconnect is being realized through the institutions of a democratic polity.

In line with the above, the purpose of this model cannot be to predict, nor even to closely "backcast" what has already happened. Instead it is an illustration of the main issues driving the economic history of the system. It can serve as a boundary object to inform policy, to be used in imagining various futures for the region. It can be useful, provided it is not used out of context or with too many validity claims [2].

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Chapter 11
A Study of Group Formation Using Agent-Based Modeling

Lucy McGowan and Randall Westgren

Abstract This work uses agent-based modeling to model three philosophical accounts of group formation and subsequent group agency. Each account proposes the presence of collective intentionality, a product of either I-intentionality or we-intentionality as its foundation. The successful modeling of all three types of group formation was completed in NetLogo utilizing a common uniform landscape.

Keywords Group formation · Group agency · Agent-based modeling

Introduction

Social ontology, or the study of shaped mental states, provides a unique contrast to individual intention as a basis for group formation discussion. To use social ontology to explain group agency we must first assume two things: (1) that an individual acting through group behavior is an observer-relative observation that is critical to group formation and (2) that there is a provision in the concept of social ontology to account for small groups that provide similar strength of identity as strong institutions [1]. Through these assumptions we are able use social ontology to model the modes of action of individuals, starting with collective intention, to form small groups and create sociality.

Collective intentionality "is the power of minds to be jointly directed at objects, matters of fact, state of affairs, goals or values" [2] to achieve group 'sociality'. Historically, intentionality is associated with an individual and it is natural to assume that collective intention is the summation of individuals' intentions at the aggregate level. This is not the case; collective intention can be modeled with either (a) jointness of action to achieve multiple individually-held goals, given mutual understanding

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that collective action is required; or (b) goals are held jointly and collective agency results in achievement of the collective goal. Traditionally, collective intentionality is associated with commitment. The intention of an individual is subsidiary to the group when the individuals commit to joint action. Again, it seems natural to assume that collective intention becomes the commitment of the group as a whole rather than the commitment of individuals to one common commitment. However, individuals retain ownership of their intention and commitment, and therefore their course of action [2]. The behavior observed because of this form of collective intentionality is a result of a group of individuals, individual collective intention.

Collective intention, the outcome of we-intentionality, acts through the individual in several modes; shared intention, joint intention, shared belief, collective acceptance, and collective emotion [2]. The study of group formation around collective intention requires defining the boundary between shared intention and joint intention. Shared intention removes intention from the individual and places in between individuals to achieve collective goals. Joint intention is a stronger form of we-intentionality for plural agents. Tuomela's account defines that this as the basis for cooperation, where the agents only act for group goals [3].

We use agent-based modeling to demonstrate three mechanisms of collective intentionality through the mode of shared intention or joint intention: Michael Bratman's shared intention and planning agency [4], Margaret Gilbert's plural subject of joint commitment [5], and Raimo Tuomela's we-intentionality [3]. Each author's account is an explanation of group phenomena of sociality but each perspective differs from the others.

This research uses agent-based modeling (ABM) to illustrate the relationship between individuals, collective intentionality, and group agency in the formation of groups (i.e. the accounts of Bratman, Gilbert, and Tuomela). The use of ABM allows one to examine the outcomes of alternative decision-making rules for individuals and alternative interaction behaviors among individuals. Agent-based modeling allows for a model simulation of group behavior and emergent phenomena given varied initial conditions and behavioral changes from interactions between agents, subject to a common environment. The individual agent will be adapting, sensing, and changing to the environment with the intention of success—whether it be the success for the good of the individual or of the social group. In order to monitor both the status of the individual and the existence of groups a research method that can monitor the 'interrelations between individual traits and system dynamics' is critical [6].

Theories to Achieve Group Formation

Michael Bratman views planning structures as 'basic to our individual agency', and uses the existence of individual planning structures to develop a thesis for *modest sociality* via intentionality. Planning structures are the internal forces in place to execute plans of action [4]. For a group to exhibit sociality it must first share an intention. Bratman, determines that (because of the planning theory) each individual can and will choose an activity, of which all group members agree upon. The plan state then morphs from the individual intending that they go alone to the group intending that they go together [4]. The creation of a 'master plan' through the 'meshing' together of individual sub-plans is sufficient to achieve the intended joint activity. All the sub-plans together must 'successfully execute' the joint action of the individuals in order for the intended meshing to be achieved [4]. The outcome is group agency. In the modeling for Bratman group formation, formation begins when agents unite based on intentions, in order for groups to exhibit sociality they must first share an intention. Bratman, determines agents can only link with agents that are not like them. If each of the agents has the same type of intention then the agents begin to 'mesh' their sub-plans. If the incorrect type of meshing occurs the group dissolves. The formation of the 'master plan' is the indication of group agency.

In Margaret Gilbert's account of groups, she uses a plural subject approach to propose connection via prior commitment, to drive we-intentionality. This commitment or mutual obligation is the glue that holds together the plural subjects via shared intention. The commitment present is adequate in the presence of three criteria: disjunction, concurrence, and obligation [5]. The two key factors in representing Gilbert's approach are commitment and intention. In Gilbert's account, she proposes that prior commitment is present first, before intention. It is the obligation imposed by the commitment that forces concurrence on the intention to be completed [5]. In the modeling of Gilbert group formation, formation begins when agents unite based on prior commitments in place, agents can only link with agents that are not like them. The group then brings intention to a consensus. The sign of intention then triggers group agency.

Bratman and Gilbert could not find room for both the individual's intention and the group's intention inside a social group. However, Raimo Tuomela can only justify group action through the view of both the individual's intentionality and the group's intentionality. Tuomela's unique account results from an extensive list of qualifiers for group reason, collectivity, and collective commitment serving to unify the group around "constitutive goals, values, and purposes to which the group life is dedicated" also known as shared ethos [3]. An individual's agency provides the framework for each individual to perform intentional action on behalf of the group [3]. Tuomela is concerned by the motivating factors to achieve group action. If group reason motivates individuals to act together and collectivity embodies cooperation, then collective commitment follows. Collective commitment acts through joint-intention. In modeling Tuomela group formation, the presence of we-intention is the driving trait that spurs group formation. Agents are only allowed to form groups with agents that are in different roles than themselves and but share the same ethos, intention, and believe that each member will contribute to the success of the share ethos (represented as belief in the model). For Tuomela it is the existence of the shared belief that the accumulation of all parameters will accomplish the we-intention that triggers group agency.

The mechanisms described by Bratman, Gilbert, and Tuomela can be summarized in two categories: (1) individual-based and (2) group-based. Bratman relies upon the intentions of individuals to motivate group formation. Gilbert and Tuomela perceive the existence of we-intention (or at least the awareness of we-intention) as the beginning of the pathway to group formation. Each model has an agent attribute that prompts the action to search for potential group members within a specific search radius. Then agents access the surrounding environment in search of potential group members based on specific attributes. For each model the order attributes are searched for differs, this coding difference is the illustration for the different social ontological views.

Agent-Based Modeling of Group Formation

The agent-based model of potential group formation structures is a unique, comprehensive model of the three proposed approaches (Bratman, Gilbert, and Tuomela) individuals use for group formation to achieve group agency. From an agent-based modeling perspective (via NetLogo) this does not seem revolutionary, but the application of a formal modeling approach to a field that typically uses thought experiments is impactful. This approach allows for an analysis of the group agency while systematically analyzing the consequences of the implied individual and group behaviors.

Individuals use a certain set of heuristics for their decision-making processes. When combining these heuristics (and consequent interactions) with the behavior rules from the three accounts of group intentionality and agency, one obtains the group-forming processes. These test the model that Ruef proposes for group entrepreneurship (formation and sustained agency) [7]: What is the "social glue" that holds entrepreneurial teams together? Ruef suggests that the group that an entrepreneur chooses to work with is a consequence of "relational demography", a structural account rather than the behavioral account embedded in the agent-based model. Our paper explores the implications for future work on the small teams that populate the entrepreneurial ecosystem.

It is the formality of agent-based modeling that allows theoretical discussion around sociality of team formation and action to advance. Inside the boundaries of agent-based modeling different experiments will make explicit the processes individuals take to form groups. Additional complexity can be added to the models by adding an environment in which specific activity and impact can occur. The flexibility of agent-based modeling to provide a framework to support individual attributes, and therefore the social ontological perspective, a global environment, the economic environment in which entrepreneurial groups act, and the all of the possible interactions (agents with agents and agents with the environment) makes it the preferred mechanisms to complete foundational research relating to sociality.

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Chapter 12
Combining Crowd Sensing and Social Data Mining with Agent-Based Simulation Using Mobile Agents Towards Augmented Virtuality

Stefan Bosse and Uwe H. Engel

Abstract Augmented reality is well known for extending the real world by adding computer-generated perceptual information and overlaid sensory information. In contrast, simulation worlds are commonly closed and rely on artificial social behaviour and synthetic sensory information generated by the simulator program or using data collected off-line by surveys. Agent-based modelling used for investigation and evaluation of social interaction and networking relies on parameterisable models. Finding accurate and representative parameter settings can be a challenge. In this work, a new simulation paradigm is introduced, providing augmented virtuality by coupling crowd sensing and social data mining with simulation worlds in real-time by using mobile agents in an unified way. A simple social network analysis case-study based on the Sakoda social interaction model and mobile crowd sensing demonstrates the capabilities of the new hybrid simulation method and the impact of collected real-world data on social simulation.

Keywords Agent-based modelling · Agent-based simulation · Agents · Mobile crowd sensing · Agent platforms

Introduction

The key concept of this work is the consideration of humans as sensors and the seamless integration of real-world sensors in social simulation. This concept is highly interdisciplinary and is a merit of social and computer science if the human sensor data will be coupled with social interaction and networking models. Social interaction has

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a high impact on the control and evolution of complex social systems, which should be addressed in this work.

Agent-based methods are established for modelling and studying of complex dynamic systems and for implementing distributed intelligent systems, e.g., in traffic and transportation control (see [1, 2]). Therefore, agent-based methods can be divided into the following main classes and paradigm [3]:

1. Agent-based Modelling (ABM)—Modelling of complex dynamic systems by using the agent behaviour and interaction model ⇒ **Physical agents**
2. Agent-based Computing (ABC)—Distributed and parallel computing using mobile agents related to mobile software processes ⇒ **Computational agents**
3. Agent-based Simulation (ABS)—Simulation of agents or using agents for simulation
4. Hybrid Agent-based Computation, Modelling, and Simulation (ABX) ⇒ **Combining physical and computational agents**.

The fourth paradigm is the novelty introduced in this work with application to social mobility and network simulation.

ABS is suitable for studying complex social systems with respect to interaction between individual entities, manipulation of the world, spatial movement, and emergence effects of groups of entities. The main advantage is the bottom-up modelling approach composing large-scale complex systems by simple entity models. The main disadvantage of ABM is the (over-) simplified entity behaviour and simplification of the world the entities acting in. Commonly, simulation bases on synthetic data or data retrieved by field studies. Many simulations and models lacking of diversity that are existing in real world. Commonly, sensor and model data (parameters) used in simulations (virtual world) is retrieved from experiments or field studies (real world), shown in Fig. 12.1. But there is neither a feedback from the virtual to the real world nor an interaction of the real world with the virtual world. ABC is mainly used to implement adaptive and self-organising distributed computing. In this work, a different simulation approach combining ABM, ABC, and ABS methodologies (ABX), is used deploying the widely used programming language JavaScript. JavaScript is an easy to learn programming language that was used originally in WEB development, but is increasingly used as a generic programming language and for ABS [4].

The *NetLogo* simulator is an established agent-based simulation tool used in social and natural sciences [5]. NetLogo bases on an observer-centered global bottom-up model, i.e., there is one script representing an observer that controls the entire simulation and the implements the agent behaviour. The *NetLogo* programming language (that is domain-specific) consists basically of sets and set iterator statements performing computations. In this work, a different simulation approach combining ABM, ABC, and ABS methodologies, is used deploying the widely used programming language JavaScript. JavaScript is an easy to learn programming language that was used originally in WEB development, but is increasingly used as a generic programming language and for ABS [4, 6].

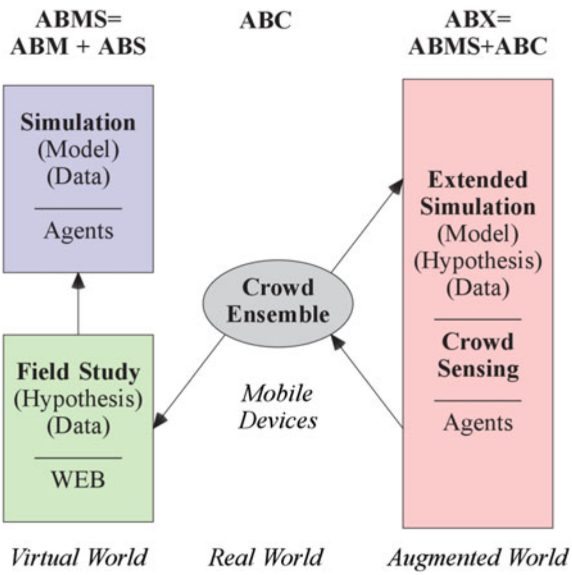

Fig. 12.1 (Left) Traditional ABMS with separate field studies (Right) New ABX combining modelling, simulation, and field studies via crowd sensing

Today administration and management of public services and infrastructure relies more and more on user data collected by many domestic and private devices including smart phones and Internet services. Simulation is increasingly used to study emergence effects of complex distributed systems. User data and user decision making has a large impact on public decision making processes, for example, plan-based traffic flow control. Furthermore, intelligent behaviour, i.e., cognitive, knowledge-based, adaptive, and self-organizing behaviour based on learning, emerges rapidly in today's machines and environments. Social science itself exerts influence on public opinion formation. We observe a rise of Artificial Intelligence (AI) in the shape of computational methods of analysis of data and meta data extracted, e.g., from the web. This statement alludes to the rise of "computational social science" (CSS), the accompanying shift from survey methods to computational methods and possible implications of this development: usage of different data, different methods, exposition to different threats to data quality (concerning sampling, selection effects, measurement effects, data analysis), and different rules of inference are likely to result in comparably different conclusions, public reports, and hence in different input to public opinion formation.

ABM and ABS relies on parameterisable behaviour models. The selection of appropriate and representative parameter sets are crucial for modelling real-world scenarios.

Mobile devices like smart phones are valuable sources for social data [7], either by participatory crowd sensing with explicit participation of users providing first class data (e.g., performing surveys or polls) or implicitly by opportunistic crowd sensing collecting secondary class data, i.e., traces of device sensor data delivering, e.g., actual position, ambient conditions, network connectivity, digital media interaction, and so on. Crowd sensing and Social Data Mining as a data source contribute more and more to investigations of digital traces in large-scale machine-human environments characterised by complex interactions and causalities between perception and action (decision making).

It is difficult to study such large-scale data collection, data mining, and their effect on societies and social interaction in field studies due to a lack of data. Agent-based modelling of socio-technical systems is well established [8], however commonly applied in an artificial world., i.e., a simulation is performed in virtual reality worlds only to derive and proof models under hard limitations. In this work, a new concept and framework for augmented virtual reality simulation is introduced, suitable, but not limited to, to investigate large-scale socio-technical systems. Mobile agents are used already successfully in-field crowd sensing [9]. In this work, mobile agents are used to combine in-field ubiquitous crowd sensing, e.g., performed by mobile devices, with simulation.

Crowd sensing (CWS) can be considered as part of field studies [9], either performed in a participatory or opportunistic way. A challenge in crowd sensing as well as classical field studies is user motivation in participation and incentive mechanisms. Opportunistic crowd sensing on mobile and ubiquitous devices requires self-organising and adaptation capabilities, which cannot be satisfied by classical and centralised WEB-based services. Mobile agents (ABC) as mobile software processes can overcome limitations occurring in centralised WEB infrastructures [9]. Mobile agents provide a seamless interface between real and virtual worlds (ABMS).

Agent-Based Crowd Sensing, Chat Bots, and Digital Twins

Classical field studies are commonly serviced by a central WEB server and WEB-based content management. These field studies address usually participative crowd sensing. Opportunistic crowd sensing can extend user classes and user numbers significantly. One promising approach supporting the human-as-sensor concept is the deployment of autonomous or semi-autonomous chat bot agents that can interact with humans on a wide range of devices, media, and social platforms. Mobile agents feature self-organising and self-adaptation. Commonly, simulation is performed with artificial agent models derived from theoretical considerations or experimental data. Augmented virtuality enables dynamic simulations with agents representing real humans (or crowds). By using crowd sensing it is possible to create digital twins of real humans based on a parameterisable behaviour and interaction model. The parameters of artificial humans in the simulation represented by agents are collected by sensor data, i.e., surveys optionally fusioned with physical sensors like GPS.

It is assumed that there is a parameterisable behaviour model M of individual entities, i.e., a model of social interaction, which is used to model digital twins representing individual real humans (P: Parameter set, S: Sensor set, A: Action set):

$$M(S, P) : S \times P \rightarrow A \tag{12.1}$$

The individual behaviour model will result in a specific system behaviour showing emergence effects (e.g., segregation and group formation).

Mobile chat bot agents fulfill two tasks in crowd sensing: (I) Sensing of data from the user and user devices and (II) Negotiation between the crowd sourcer and the user.

Extended Simulation Architecture

The software framework couples virtual and real worlds by using computational agents (chat bots) operating in virtual and real worlds and physical agents in simulation. The chat bot agents are the interface between humans and simulation.

The entire crowd sensing and simulation architecture consists of the following components:

1. Crowd sensing software (Mobile App and WEB Browser)
2. Unified agent processing platform based on JavaScript (JavaScript Agent Machine, *JAM*)
3. Agent-based simulation with Internet connectivity providing two different agent types:
   - **Physical agents** representing individual artificial humans or any other physical entity in the simulation world;
   - **Computational agents** representing mobile software, i.e., used for distributed data processing and digital communication, and implementing chat bots, available in the simulation and the Internet;
4. Chat dialogues, Chat bots and Mobile agents (computational);
5. Knowledge-based Question–Answer Systems.

The principle system architecture is shown in Fig. 12.2. Details can be found in [4]. *JAM* platform nodes exist in the simulator, in Internet relays used for the inter-connectivity of CWS and simulation, and application programs for crowd sensing operating, e.g., on mobile devices. The simulation world consists of a set of virtual *JAM* platforms that are controlled by a physical *JAM* node. A physical *JAM* node can be connected to the Internet, virtual nodes can be connected with each other (simulating communication).

In the simulation model, there is no significant difference between physical and computational agents. The main difference is mobility (in the simulation world). Physical agents are bound to a virtual *JAM* node (*vJAM*), and the agent is mobile by its platform, whereas computational agents can migrate between platforms and between virtual and real worlds. Physical agents can access an extended programming interface (API) similar to the well-known *NetLogo* simulation model providing agent control like agent creation, movement or visual changes. An expressive *ask* operator is provided, too.

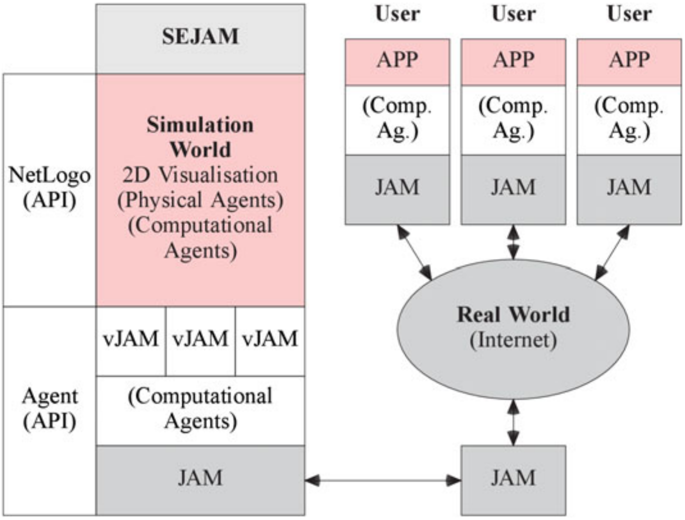

Fig. 12.2 Principle concept of closed-loop simulation for augmented virtuality: (Left) Simulation framework based on the JAM platform (Right) Mobile and non-mobile devices executing the JAM platform connected with the virtual simulation world (via the Internet)

Social Interaction and Segregation with the Sakoda Model

To demonstrate the augmented virtuality approach combining agent-based simulation with agent-based crowd sensing the *Sakoda* model [10] was chosen as a simple social interaction and behaviour model between groups of individual humans. It poses self-organising behaviour (emergence) and structures of social groups by segregation.

For the sake of simplicity, there is a two-dimensional grid world that consists of places at discrete locations (x, y). An artificial agent occupies one place of the grid. Maximal one agent can occupy a place. The agents can move on the grid and can change their living position.

It is assumed that there are two groups related to the classes a and b of individuals. The social interaction is characterised by different attitudes [10] of an individual between different and among same groups given by four parameters:

$$S_{ab} = (s_{aa}, s_{ab}, s_{ba}, s_{bb}),\ S_{abcd} = \begin{pmatrix} s_{aa} & s_{ab} & s_{ac} & s_{ad} \\ s_{ba} & s_{bb} & s_{bc} & s_{bd} \\ s_{ca} & s_{cb} & s_{cc} & s_{cd} \\ s_{da} & s_{db} & s_{dc} & s_{dd} \end{pmatrix} \quad (12.2)$$

The model is not limited to two groups of individuals. The S vector can be extended to four or more groups (or generalised) by a n-dimensional matrix. Here, the S vector or matrix is the model parameter set $M(P)$ that can be used to create diverse digital twins based on surveys and crowd sensing.

The world model consists of N places x_i. Each place can be occupied by none or one agent either of group α or β, expressed by the variable $x_i = \{0, -1, 1\}$, or generalised $x_i = \{0, 1, 2, 3, 4,...,n\}$ with n groups. The social expectation of an individual i at place x_i is given by:

$$f_i(x_i) = \sum_{k=1}^{N} J_{ik}\delta_s(x_i, x_k) \tag{12.3}$$

The parameter J_{ik} is a measure of the social distance (equal one for Moore neighbourhood with distance one), decreasing for longer distances. The parameter δ expresses the attitude to a neighbour place, given by (for the general case of n different groups):

$$\delta_s(x_i, x_k) = \begin{cases} s_{\alpha\beta} \text{ , if } x_i \neq 0 \text{ and } x_k \neq 0 \text{ with } \alpha = x_i,\ \beta = x_k \\ 0 \quad \text{, otherwise} \end{cases} \tag{12.4}$$

An individual agent ag_i of group α or β is able to change its position by migrating from an actual place x_i to another place x_q if this place is not occupied ($x_q = 0$) and if $f_i(x_q) > f_i(x_i)$. The computation of the neighbouring social expectation f values is opportunistic, i.e., if f is computed for a neighbouring place, it is assumed that the agent occupies this neighbour place if the place is free, and the current original place x_i is omitted for this computation. Any other already occupied places are kept unchanged for the computation of a particular f value. From the set of neighbouring places and their particular social expectations for the specific agent the best place is chosen for migration (if there is a better place than the current with the above condition). In this work, spatial social distances in the range 1–30 place units are considered.

Originally, the entire world consists of individual agents interacting in the world based on one specific set of attitude parameters S. In this work, the model is generalised by assigning individual entities its own set S retrieved from real humans by crowd sensing, or at least different configurations of the S vector classifying social behaviour among the groups. Furthermore, the set of entities can be extended by humans and bots (intelligent machines) belonging to a group class, too.

Model Parameters and Crowd Sensing

Creation of virtual digital twins is the aim of the crowd sensing. The crowd sensing is performed with chat bot agents. One stationary agent is operating on a user device, e.g., a smart phone, and another mobile agent is responsible to perform a survey (either participatory with a former negotiation or opportunistic ad-hoc).

The results of the survey, a set of questions, are used to derive the following simulation model parameters:

```
parameters = {
  group : string "a"|"b",
  social-distance: number [1-100],
  social-attitudes : [saa,sab,sba,sbb] ,
  mobility : number [0-1],
  position : {x:number,y:number}
}
```

The *group* parameter sorts the user in one of two classes *a*/*b*, the *social-distance* parameter is an estimation of the social interaction distance, the *social-attitudes* parameter is the *S* vector, but limited to a sub-set of all possible *S* vector combinations (discussed below), and the *mobility* parameter is a probability to migrate from one place to another. The position (in cartesian coordinates) is derived from the living centre of the user (global position data, GPS) and mapped on the simulation world (x, y). The *S* vector parameter determines the spatial social organisation structure. Typical examples of the *S* vectors with relation to social behaviour are [10]:

- (1, −1, −1, 1): Typical segregation with strong and isolated group clusters
- (0, −1, −1, 0): Mutual suspicion
- (1, −1, 1, −1): Social climbers
- (1, 1, −1, −1): Social workers
- (1, 1, 1, 1): Inclusion.

Experiment and Evaluation

The initial simulation was carried out with a unified $S = (1, -1, -1, 1)$ setting for all agents of both classes leading to classical segregation structures (strong isolated clusters), shown in Fig. 12.3. The social interaction distance was fixed $r = 3$; In a second run, digital twins retrieved form crowd sensing surveys were added to the simulation dynamically. Some results are shown in Fig. 12.4. Now, the *S* vector and the social distance r depend on the answers given by the (real) humans, which can differ from the initial *S* setting and the social interaction distance r. These agents (if their *S* differs from the basic model) create a disturbance in the segregation patterns. Agents with $s_{\alpha\beta} = 1$ and $s_{\alpha\alpha} = 1$ can be integrated in both groups and are able to bind different groups close together (see the development and movement of the blue and red clusters inside the red circle in Fig. 12.4).

The crowd sensing extends the simulation with the following dynamics and changes:

1. Disturbance of the synthetic simulation with digital twins not conforming to an initial parameterisation of the artificial individuals (affecting *S* vector, spatial social interaction distance, mobility)
2. Adaptation and change of the fraction of different groups (commonly a equally distributed fraction from each group is assumed)
3. Convergence and divergence of the emergent behaviour of group formation (spatial organisation structures).

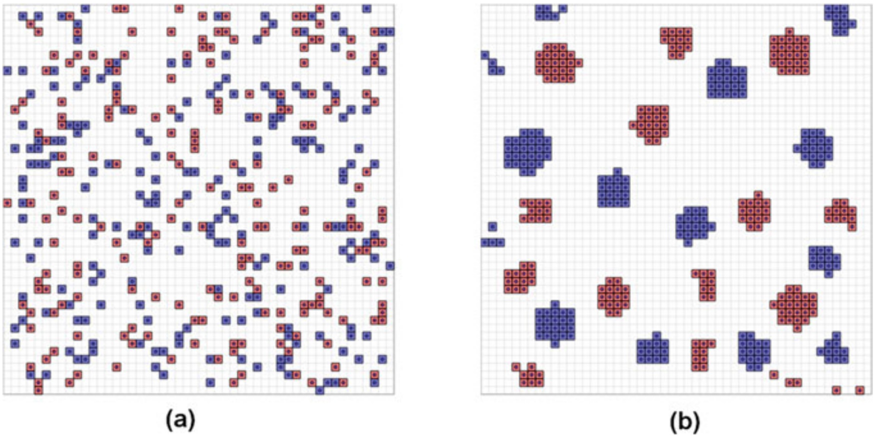

Fig. 12.3 **a** Simulation world consisting of 200/200 artificial agents of class a/b (blue/red squares), randomly distributed **b** Simulation world after social organisation based on mobility forming strong isolated homogeneous clusters with S = (1, −1, −1, 1) and r = 3 interaction radius after 200 simulation steps

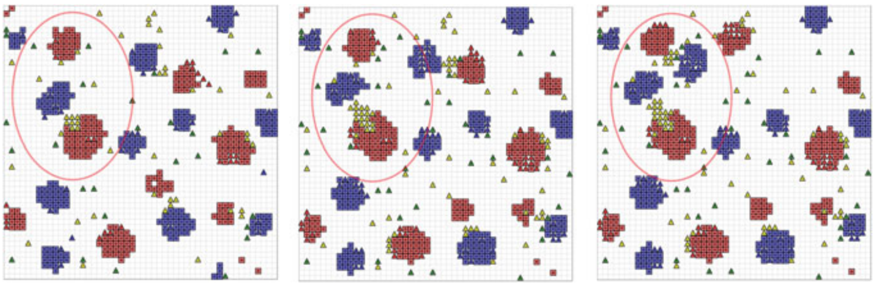

Fig. 12.4 Simulation world at different simulation times (500/1000/1500 steps) consisting of 200/200 a/b class agents (blue/red squares) all with S = (1, −1, −1, 1) and r = 3 parameter settings and additionally up to 200 digital twins (triangles with colour based on individual S/r parameters)

The comparison of the simulation with the single and the multi-parameter social behaviour derived by CWS is shown in Table 12.1. The mean distance between group *a* and *b* clusters (in mesh grid units measured between the center points of group clusters) show no significant difference, but the mean distance between clusters of same group increase by about 20% as well as an increased variance in the distance (increased disturbance).

Remarkable is the creation of heterogeneous clusters (group *a* and *b*) by digital twin agents with a variation of social behaviour. The mean cluster size of these meta clusters are 4 times larger than the mean size of single clusters. The mean distance gap of *a* to *b* groups in such meta clusters is about 5 grid units and much lower than the mean distance in other areas.

Table 12.1 Comparison of the mean distance of blue (group a) and red (group b) clusters (ab) and the mean distance of same group distances (aa, bb) without[1] and with[2] social behaviour variations by CWS

Group	Mean	Variance	Min	Max	#Clust	Mean(cs)
ab[1]	10.6	3.7	5.6	20.8	–	–
aa[1]	14.5	2.9	10.4	18.5	11	16
bb[1]	12.4	2.2	8.5	16.9	13	15
ab[2]	11.7	3.7	6.9	20.3	4 (11)	64
aa[2]	17.0	5.5	9.9	28.5	11	18
bb[2]	16.9	3.9	10.8	22.5	10	21

Finally, the injection of the digital twins with behaviour variations leads to a broader and scattered area coverage, weakening segregation.

Conclusion

The MAS simulation framework, introduced in this work, is suitable to combine social and computational simulations with real-world interaction at run-time by integrating crowd sensing and by using mobile agents. A simple use-case demonstrated social interaction and social structure formation based on a parametrisable Sakoda model extended with digital twins retrieved by agent-based crowd sensing integrated in and extending agent-based simulation. The crowd sensing surveys performed by mobile agents is used to create digital twins of real humans in the simulation world (with respect to the social interaction model and mobility) based on individual surveys via a chat bot dialogue. The injected twins posing behaviour variance introduce disturbance in the simulation and the emergence outcome.

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Chapter 13
Towards An Understanding of Opinion Formation on the Internet

Using a Latent Process Model to Understand the Spread of Information on Social Media

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Abstract Understanding what drives the process of opinion formation has been studied since the 1960s. With the advent of the social web, this process has drastically changed, as everyone can easily reach out to the global public. However, not everyone expresses their opinion on social media. Understanding what governs this process is crucial to understanding the spread of information on the Internet. We use a latent process model to simulate opinion formation using agent-based modeling. By creating an artificial social network with artificial users and content, we simulate the reaction of users to content and the resulting spread of information. We inform our model from a questionnaire survey study that indicates that actual sharing is rare for a large proportion of users. Our findings indicate that deep network penetration can not be explained by user behavior alone and that "minority effects" might require large scale simulations to be seen. Future research should thus incorporate simulated algorithms and larger populations.

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Introduction

Facebook, Instagram, Twitter, and WhatsApp are integrated into everyday life. More and more people use social networks to look for information, to form opinions, but also to disseminate opinions [3, 6]. However, what information is shown to whom, depends largely on the users' interactions with content.

In the past, social networks also played a major role in debates about how opinions were deliberately influenced to manipulate political outcomes. It is therefore important to better understand and predict opinion-forming processes. Research is concerned with how the use of social networks influences user behaviour [13]. An example for such effects is the so-called "minority effect", where a small determined fringe minority changes the opinion discourse of an entire group [4, 8].

In our research, we try to apply the *Latent-Process Model* of opinion formation in an agent-based model to understand how users react to different types of content. We inform our model using a questionnaire survey. We then use the model to simulate how agreement with content yields different interaction strategies, which in turn yields different network penetrations. Overall, we try to understand whether a complex model such as the latent-process helps to determine the spread of information in social networks.

Related Work

We look at the attitude of users of online social networks. Therefore, we first define the term *attitude*. As a person's attitudes and actions are closely interrelated, we then present the *Latent Process Model* that is used to explain the construction and components of attitudes. From these attitudes behavior is derived using social response theory (see Fig. 13.1).

Attitude

Several understandings of *attitude* exist. For some, *opinion* and *attitude* are synonymous and interchangeable, whereas others regard them as different aspects of a related process. So far, there is no uniform definition of attitudes [10, 12]. Nevertheless, attempts to define *attitude* have showed similarities. Using these and following the definition of Oskamp and Schultz, we understand the term as a tendency to evaluate an object of attitude positively or negatively and to react to it if necessary.

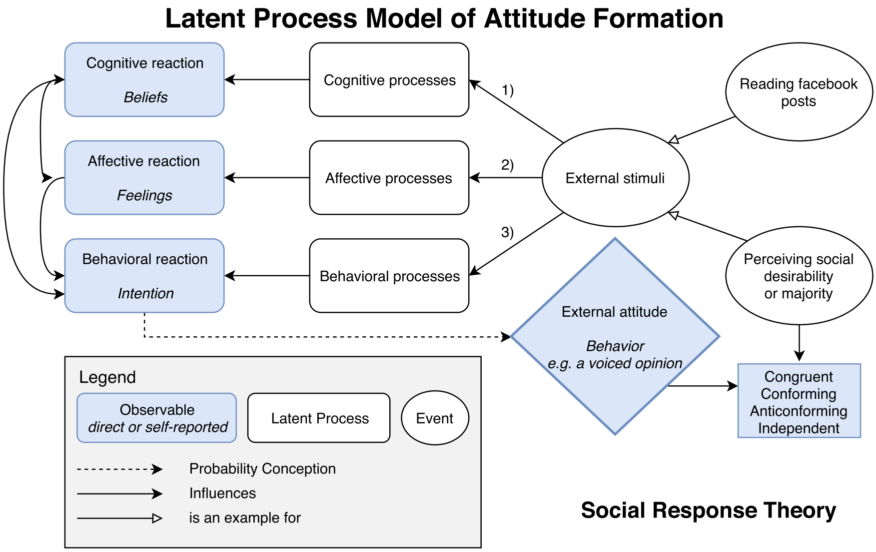

Fig. 13.1 Latent Process Model of Attitude Formation. Individual Events can have different influences on each processes (see 1, 2, and 3). The external behavior (opinion voicing) is then guided by social response theory

Attitude research. Research on attitudes assumes that attitudes consist of a cognitive, affective, and behavioral component [12]. The cognitive component is a person's thought about an attitude object, often referred to as *beliefs*. The affective component relates to the *feelings* or emotions towards the adjustment object. The behavioural component refers to concrete intentions and an actual behaviour towards an object [2, 5, 12]. The affective component is important, as emotions are usually motivating and drive behaviour more strongly [12] than cognition.

There is also criticism of this rather established three-component model [2, 9]. It is unclear how the components are interconnected and whether the components actually say the same thing or whether they differ enough to be divided into three different entities. It is also doubted whether an attitude always consists of all three components [12]. Here, two views have emerged: On the one hand the proponents of the so-called *Consistency Theorem*, on the other hand those who reject this theorem (*Separate Entities Model*).

Latent-Process-Model

The *latent process model* [7] arose from criticism of the *Consistency Theorem* and the *Separate Entities Model*. All models try to explain the emergence of attitudes. DeFleur and Westie criticize that the models assume a consistency between action and attitude. Still, they believe that an inner process mediates between external stimulus and behaviour. The other two models try to explain this inner process, which cannot be observed through visible behavior, but—according to DeFleur and Westie—behavior cannot be equated with this inner process. They further believe that behaviour is influenced by other factors such as social desirability, not only attitude. For them, attitude is a theoretical construct that must be considered as unknown. The theoretical construct is a link to describe the relationship between object and action. For the attitude itself, there is the antecedent unobservable process of attitude formation and a subsequent reaction. However, they assume that there is a stimulus that triggers cognitive and affective processing and the process of behavioral intentions. The three processes then together or individually form the latent attitude, which manifest through a cognitive or affective reaction or behavior. Here, DeFleur and Westie speak of a probability conception, i.e., how probable it is that a person behaves towards an object in a similar way as in the past. An advantage of the model is that the attitude does not have to be seen as an explanation for a person's behaviour, but rather as the regularity of certain behaviour patterns. A further advantage of the *Latent Process Model* is that no connection between the individual components within the model is assumed, but they can arise in the model from one to three process types [7, 12].

Another model of social interaction is the diamond model or four-dimensions of social response by Nail et al. [11]. This model states that the actual opinion voicing of a person in a social setting of majorities and minorities can be of four types. Behavior can be *congruent*, which means that their external attitude (or voiced opinion) matches that of the majority. *Conforming* individuals show an external attitude that also matches the majority, but is opposing the internal attitude. Anticonforming individuals share the minority opinion (internally) and voice it (externally). And independent individuals may or may not share the majority opinion (internally), but refrain from sharing in either case—they stay externally neutral. Which behavior is shown depends on the strength of internal attitudes and the strength of the externally perceived majority opinion. Different thresholds induce different behaviors.

Research Aim

The goal of our research is thus to utilize the latent-process model and the four dimensions of social response to understand how opinion formation—and even hidden opinion change—spread in social network structures. Different from previous research (e.g. [1]), we include a theory of social response.

Method

To achieve this aim, we build an agent-based model that simulates opinion formation using a *latent process model* based on three pillars. First, our model uses message sending. Our messages are of different types, addressing either cognitive or affective processes in the agents. Second, the agents opinion formation is simulated using cognitive, affective, and also behavioral processes. Lastly, each agent may behave in accordance to the four-dimensions of social response. Since such a model has a plethora of possible parameter configurations, we limit the simulation experiments by informing the model using data from a survey.

In this survey we measure both the distribution of different agent-types and different content-types. This means two things. First, it means that we determine if users react differently to cognitive and affective stimuli. From this, we determine the distribution of different reaction of our agents. Second, it means that we ask users about their reactions to different contents, using real life social media posts, to determine what processes in the latent-process model are addressed.

Online Questionnaire

As mentioned before, expressing one's opinion on social media depends on unobservable antecedent processes. Therefore, we concentrate on the observable external opinion or behavioural reaction. The survey was sent via individual social networks (i.e., Facebook, Twitter, etc.) between December 2018 and February 2019 using convenience sampling.

Survey Materials. The survey consisted of two parts. In the first part, we asked for gender and age as demographics. We further looked at the experience with and the knowledge about online social networks. we asked, how large their biggest chat-group was and with how many users they were connected.

For part two, we first introduced a scenario: Here, the participants should think of an online social network with a similar structure and functionality as Facebook. Then, we presented four different *contents* and asked questions about each of them (more details in the following paragraph). These questions measured the cognitive and affective *value* of these example news posts using a semantic differential (more details in the next paragraph). We further asked the users, how they would react to this content (more details in the last paragraph of this section). Lastly, we asked whether the content helped them form an opinion, whether it supported their opinion, and whether they perceived it as polarizing.

Contents used in our study. To cover a breath of different affective and cognitive values we used four different content variations: first, a serious article (1. *Zeit Online article*) and second, a polarizing article (2. *Bild Online article*). For these two, we used a report on an EU survey on anti-Semitism, which was published on both websites. We further used an emotional promotional item (3. *Instagram post*) and an unemotional promotional item (4. *online evaluation*). Both contents advertise for a Berlin bar (BRYK).

Measuring cognitive and affective value. After the presentation of each content, we asked the participants to evaluate the content with 12 adjectives on a semantic differential. This was done to capture the affective and cognitive value for the latent process model presented in Sect. "Latent-Process-Model".

Measuring behavioral value. Afterwards, we presented the same content again (to see a possible influence on opinion formation) to the participants and asked them how much they would agree with the content and how they would react (share, comment, like, ignore), if they were to encounter it in a social network. These questions deal with the *behavioral dimension* of the latent process model and were also be integrated into the agent-based model.

Results of the Online Survey

As a first step of this study, we analyzed the data of the online survey using SPSS. As a second step, building on these results, we created an agent-based model (see Sect. "Method: Agent-Based Model") and analyzed the data using SPSS and Netlogo. Following, we present the results of the online survey, starting with a short sample description.

Sample Description. Of the 105 participants 63 were female and 42 were male. The participants were on average 31.7 years old ($SD = 11.5$). From the four different social networks/messaging-apps most participants use WhatsApp (97%), followed by Facebook (87%) and Instagram (52%), the least participants use Twitter (13%). The largest chat group for most participants consists of *10 to 20* (34%), *more than 20* (34%) or *5 to 10* (26%) people. In social networks, many participants are connected with *more than 300* (34%) users. On the other hand, many also stated that they are connected with *less than 50* (16%) users.

Four different contents Following, regarding the *contents*, we look at the correlations of the *cognitive*, *affective* and *behavior-reaction* and their influence in the *opinion formation*, the support readiness (*support*), the reinforcement of the conviction (*conviction*) through other people and the polarizing overall impression (*polarizing*).

For *Zeit online* the *cognitive reaction* showed a positive influence on the *willingness to share the content* and an negative influence on the *intention to ignore* the content. The *cognitive reaction* further correlated positively with the *opinion formation* and *support*, but negatively with the evaluation how *polarizing* a content is. As can be seen in table 13.1, calculated linear regressions with the *cognitive reaction* as independent variable confirmed the influence on the dependent variables.

Comparison of the four different contents Comparing the contents (see Fig. 13.2), the participants perceive *Bild online* as most polarizing. Further, less participants would include the *Instagram post* in their opinion formation. In contrast, most participants would include the *online evaluation*. Matching, the most participants share the *online evaluation* to support a person in their network.

Table 13.1 Regression results for Zeit online with the cognitive reaction

Dependent variable	Regression results	Corr. r^2
Sharing	$F(1, 103) = 19.07$, $p < 0.001$	$r^2 = 0.15$
Ignoring	$F(1, 103) = 13.31$, $p < 0.001$	$r^2 = 0.11$
Opinion formation	$F(1, 103) = 90.05$, $p < 0.001$	$r^2 = 0.46$
Support	$F(1, 103) = 52.12$, $p < 0.001$	$r^2 = 0.33$
Polarizing	$F(1, 103) = 18.58$, $p < 0.001$	$r^2 = 0.15$

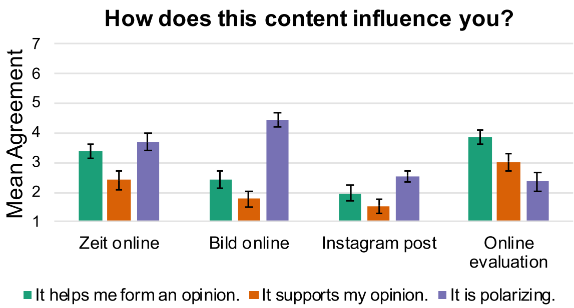

Fig. 13.2 Means for the comparison of the four different contents. Error bars denote 95% confidence interval

Method: Agent-Based Model

Using the online survey results, we have developed an agent-based simulation, which we from now on call the *o-formation model*.[1] For the methodical implementation we used the multi-agent programming language Netlogo in version 6.0.1, developed by Uri Wilensky [16]. NetLogo provides a user interface to agent-based modeling and allows to run several hundreds of simulations using a batch mode.

O-Formation Model: Before the Simulation Starts

Based on the reported average size of a network we set the network size for all simulation runs to 100 agents. To reduce the complexity of the model and to enable a comparability of the results, we fixed some settings from the beginning, that we describe following and are visible in Table 13.2.

Modelling attitude As mentioned earlier, each agent has an *internal* and *external attitude* on a certain topic. Each agent can have a positive or negative *internal attitude* or have **not yet formed** an attitude (see Table 13.2 positive and negative proportion). The attitude is stored as a number.

[1] As in opinion formation.

Table 13.2 Initially adjusted parameter settings for the agents of the model

Parameter	Value	Parameter	Value	Parameter	Value
Agent count	100	Positive proportion	10%	Negative proportion	10%
Proportion seen	10%	Clustering-coefficient	0.14	Initial opinion	100%
Conformity rate	50%				
Congruence rate	50%	Anticonformity rate	50%		
Independence rate	50 %				

Initially 10% of the 100 agents in the network see the content (*proportion seen*). Of all agents, 10% each have a *positive* or a *negative* internal attitude towards the content (see Table 13.2 *positive proportion* and *negative proportion*).

The *internal attitude* is only known by the agent itself. In contrast, the *external attitude* or external opinion is a public disclosure of the opinion. It therefore describes whether an agent has already made a positive or negative statement on the topic by sharing the message. Neutral agents have not yet shared the message.

An agent may also have an *external attitude* different from their *internal* one. How internal and external attitude relate to each other is governed by social response theory. Depending on the direction and strength of the attitude as well as the attitude of other agents different thresholds apply for determining the external attitude. We fixed the rates of the different *social response types* (congruence, anticonformity, conformity, independence) to 50%. For example, if an agent has the same attitude as the majority—thus *a congruent social response*—it decreases the threshold to share the content by 50%. Inversely, if an agent hold the minority attitude—thus *an anticongruent social response*—the threshold is increased by 50% (see Table 13.2 *rates*).

The *internal attitude* and *external opinion* of an agent can change through the exchange with other contents or other agents.

Generating the Artificial Network

Since we looked at user behavior on Facebook in the survey, we also wanted to look at a network similar to Facebook in agent-based modeling. We opted for a easy to generate but classical small world network, the Watts-Strogatz model [15]. In this network, agents can see and share content from friends connected to them. There are close friendships or more distant acquaintances. Therefore, we weighted

Table 13.3 Initial parameter settings of the four different contents

Parameter	Zeit	Bild	Instagram	Evaluation
Cognitive-impact	0.4	0.3	0.22	0.23
Affective-impact	0.06	0	0	0
Influence-likelihood on agents if it agrees	0.69	0.39	0.34	0.72
Influence-likelihood on agent if rejects	0.14	0.26	0.09	0.26
Sharing threshold	16	14	14	11

the connections between the agents by assigning a random value between 0 and 3 to each edge.

In their study, Ugander et al. analyzed the structure of Facebook and found that with a circle of friends of 100, the clustering coefficient is 0.14 on average. We used the results of this study as a basis for our model, and therefore adjusted the *neighborhood-size* to 2 and the parameter *rewire-probability* to 35%, what generates a *clustering coefficient* of 0.14 [14]. We then performed 1800 simulation runs to verify that the parameter settings lead to the desired average *clustering coefficient* ($M = 0.14$, $SD = 0.23$).

Modelling messages In the model, a topic (or message) is one configuration randomly chosen from the four contents of the online questionnaire.

Additionally to the initial adjustment of the parameters, we have created templates for the four *contents* of the online survey. Here, we defined the influence of the *cognitive* and *affective component* of the *latent process model* (see Sect. "Latent-Process-Model"). We designed the parameter settings of the four *contents* according to the results of the online survey, as can be seen in Table 13.3.

Opinion Distributions At the Beginning

At the beginning of the simulation we adjusted four *different opinion distributions*. In the beginning of the *first distribution* (*Neutral*), only 10% of the agents have a positive and 10% a negative attitude towards the topic of the content. In contrast, in the *second distribution* (*Polarized*) every person has an attitude towards the topic of the content. Here, 50% of the agents have a positive and 50% a negative attitude. The *third distribution* considers an already widely accepted issue. The content proponents are in the majority (*proponents*). Here 60% of the agents have a positive and 10% of the agents have a negative attitude towards the content. Mirror-inverted in the *last distribution* (*Opposition*) are 60% agents with a negative and 10% agents with a positive attitude towards the content.

Transfer of the Results to the O-Formation Model

The linear regression results described in Sect. “Results of the Online Survey” form the basis of our *o-formation model*. The *opinion formation* by agents is influenced by how important the cognitive or affective aspect of the subject is to them. It is also possible that an agent is affectively/emotionally convinced of a topic, but cognitively or logically rejects it. The importance of the *affective* and *cognitive component* is initially determined on a scale of −3 to 3 (to match the survey data). The distribution of values depends on the *type of person*. Agents with a *public point of view* randomly receive a value between 2 and 3 for positive attitude and -3 and -2 for negative attitude, agents with a *hidden point of view* randomly receive a value between 1 and 3 for positive attitude and −3 and −1 for negative attitude and zero for agents with a *neutral* attitude.

In addition to the agent, a content and the relative stance of the content (positive or negative) are defined at the beginning. The content also has a cognitive (range: −3 to 3) and affective (range: −3 to 3) component. In addition, we have determined how strongly an agent evaluates the content according to the *affective-impact* and *cognitive-impact* components. The content remains the same in the network, whereas the agents can change their internal and external attitude through exposure to content.

In addition, we variate in the model how many people include content corresponding to their attitude in their *opinion formation* and, based on the results of the survey, how many include content contradicting their attitude in their opinion formation (see also rows 3 and 4 in Table 13.3).

Decision algorithms. When the simulation starts, the agents form their internal attitude by comparing their own *cognitive component* with the *cognitive component* of the content they see. The calculation depends on the *type of person* the agent belongs to. If the cognitive value for the agent and the content is positive and the cognitive value of the content is higher than that of the agent, a 3 is returned as the value. The value is smaller if the cognitive content is equal to or smaller than the value of the agent. The value indicates how much the agent matches the *cognitive component* of the content. The content can thus convince the agent more convincingly than its own logical arguments or less convincingly. For agents with a negative cognitive value, the calculation is analogous. Agents with a cognitive value of 0 can only be flipped by very convincing contents (>1.99 or negative). Analogously, each agent also compares his own *affective component* with the *affective component* of the content.

Following the model of DeFleur and Westie, the cognitive and affective value together form the *latent attitude* [7] by multiplying the *cognitive component* by the *cognitive-impact*. Here, it is calculated to what extent the content convinces a person cognitively, i.e., with logical arguments, and how much importance he attaches to the aspect of opinion formation. The same calculation is performed for the *affective component* and multiplied by 2, since the *affective component* is considered to be more important [12]. The *affective* and *cognitive components* thus form the *latent*

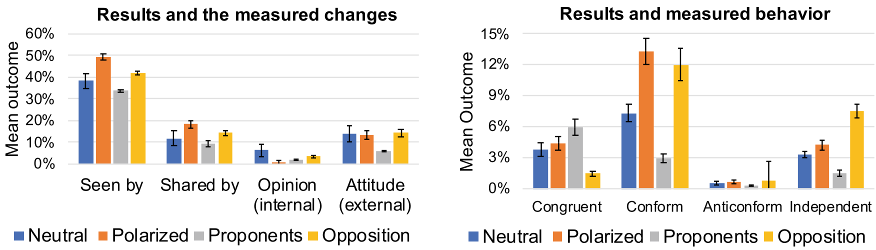

Fig. 13.3 Averaged outcomes at the end of the simulations for the four initial opinion distributions and the respective measured changes for the example content Zeit online over all simulations (left) and behavior classification (right). Error bars denote 95% confidence interval

attitude in the model. If the *latent attitude* is positive, the person agrees with the opinion of the content. If the latent attitude is negative, the person rejects the content.

However, not all agents include the content in their own opinion forming. The *internal opinion* is important for the selection of agents who include the content in the opinion forming process. At this point, the model filters for agents who see the content for the first time and for a percentage of agents with a positive *internal opinion*, the content is included in the opinion forming process. These agents then adopt the content as their own *internal opinion*, provided the opinions differ. Agents with a negative *internal opinion* also go through the same process, albeit with a lower likelihood.

After the agents have formed their *internal opinion*, the agents who see the content for the first time are again filtered out and assigned a behavior. Agents who have the same opinion as the content and who exceed the *sharing threshold* (set at the beginning) share the content.

How Do Starting Conditions Affect the Model?

We exemplary show the results for *Zeit online* and all initial opinion distributions. We see that almost no user behaves *anticonforming* during the simulation runs(see Fig. 13.3). The biggest change occurred for users, that themselves *conform*. In the *proponents* distribution only three users adapt themselves to the opinion ($M = 2.96$, $SD = 2.3$). Further, we see that external attitude changes are larger than internal opinion changes (see Fig. 13.3), although changes remain small.

Discussion

Using the agent-based simulation we found four main results. First, the network penetration of the four contents is small for all four initial distributions and in no simulation do all agents see the contents at the end. It can therefore be assumed that users who agree with the opinion of the content do not see any incentive to share the content. Secondly, the content has only a minor influence on the formation of attitudes and the expression of opinions. This reflects the passivity of the participants reported in the questionnaire. Thirdly, the social influence has only a small influence on the behaviour of the agents. An oppositional distribution increases the conformity of the persons, which could be due to the fact that persons receive particularly little social support in this distribution and would therefore rather adapt to the opinions of others. Fourthly, the content was mainly shared when a person acted in conformity with the opinion and influence of their friends.

Conclusion and Outlook

First of all, we can argue that the differences in using social networks influences how people react to online content. Our results have shown that the cognitive response, i.e., the logical evaluation, has an influence on the type of reaction, opinion-forming, and willingness to support others. The affective reaction, i.e., the emotional evaluation, also has a partial influence on the formation of opinion and willingness to support and strongly influences conviction.

Although sharing is considered to be the strongest form of participation, overall most users, regardless of the type of content, are passive and unwilling to promote opinion-forming by sharing contributions. Due to the low activity, over a third of users, at least in our model, do not see the contributions and the social impact has almost no impact. Users seem most likely to share content in order to conform to their friends. Given that users actually do see content that intends to shape opinions, large network effects seem to be at play, that require additional investigation. Our small 100 agent simulation might underestimate the effect of the determined minority in social networks. Furthermore, other malicious types of content were not simulated (e.g., click-bait, spam, fake news). These could have resulted in different outcomes as well. Lastly, a large component of the spread of information in social networks are algorithms. They determine how the behavior of individuals leads to actual exposure. In our simulation, we assumed that sharing equates exposure. This is not the case in real social networks. The research could be extended be integrating evaluations and simulations of recommender systems and their effects of opinion formation.

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Chapter 14
Modeling the Culture of Online Collaborative Groups with Affect Control Theory

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Abstract We review Affect Control Theory (ACT) as a promising basis for equipping computational agents in social simulations with a sense of sociality. ACT is a computational theory that integrates sociological insights about the symbolic construction of the social order with psychological knowledge about cognitive-affective mechanisms. After explaining the theoretical foundations of ACT and applications of the theory at the dyadic and group level, we describe a case study applying the theory from an ongoing research project examining self-organized online collaboration in software development.

Keywords Culture · Affect · Group dynamics · Digital collaboration

Modeling Culture: A Challenge for Social Simulation

Much recent discussion has revolved around the question of aligning social simulation with relevant theories in psychology and sociology. One aspect of this debate is how to implement behavior rules and decision-making algorithms that reflect psychological knowledge about bounded rationality, heuristics, emotions etc. [e.g., 1–3]. A second problem relates to sociality; i.e., modeling the emergence of a social order out of agent interactions, reflecting properties of human and primate groups such as fights about status, identity, group cohesion, or cultural rules about appropriate relationships [cf. 4].

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In this paper, we outline how Affect Control Theory (ACT), an established social psychological theory of social interaction as emerging from an emotional desire to align one's identity with culturally shared beliefs about the social order [5, 6], can be used to equip artificial computational agents with a sense of sociality. ACT, with its dual roots in psychology and sociology, speaks to the problems of psychologically realistic decision making and artificial sociality alike. We briefly review the theory and some of its applications before we describe ACT-based simulations of group dynamics in online collaborative networks. These simulations emphasize the aspect of hierarchical versus egalitarian structures in such groups, an important and ubiquitous facet of work culture [7]. The goal of this paper is thus twofold: (1) to make the community of social simulation scholars aware of a theoretical tradition that we think very useful for grounding agents in social psychology; and (2) to contribute toward understanding through social simulation contemporary, and increasingly relevant, forms of digital collaboration.

Affect Control Theory (ACT)

Intellectual Roots and Theoretical Components of the Theory

ACT links social perception with identity, behavior, and emotion in social interactions. The theory draws on *symbolic interactionism* [6, 8–10], proposing that people rely on culturally shared meanings for social concepts to efficiently interpret and respond to social events and anticipate the behavior and emotions of others [5, 6]. We internalize these meanings as we are socialized into our culture, through language acquisition and our encounters with others, and they have tremendous influence on our interpretations of and responses to the world around us. We are motivated to maintain alignment between our interpersonal behavior and this basic cultural knowledge, and tend to behave in ways that are culturally appropriate.

The cognitive mechanism that produces alignment of interpersonal behavior with cultural meanings, according to ACT, is our desire to maintain *coherent mental representations*, a core psychological motive according to well-known classical theories of balance, cognitive dissonance, and -nowadays- parallel constraint satisfaction [11–14]. While these theories differ in scope and detail, the common denominator is that humans are assumed to seek states of mind where all elements of their cognitive representations have a good mutual semantic fit, while inconsistent mental models are perceived as aversive and motivate either reappraisals or changes of the situation.

From modern neuroscience we know that cognition is inseparable from affect [14, 15]. Accordingly, ACT assumes that the alignment of social behavior with cultural norms is a subtle process, driven by *affective processes and intuition* more than by conscious thought. The theory uses cultural affective meanings associated with identity, behavior, and emotion labels to model how humans interpret and respond to social events. Meanings are measured on three universal semantic dimensions (referred to collectively as EPA) [16]: evaluation (good versus bad), potency (weak versus strong), and activity (calm versus excited), corresponding to the basic dimensionality of human emotion and social interaction [17, 18].

Unlike most other, predominantly qualitative, symbolic interactionist approaches, ACT employs *mathematical formalization.* Affective meanings are represented as vectors in the affective EPA space, based on empirical measures in large-scale surveys using an established semantic-differential technique [16]. Shared cultural knowledge expressed on EPA dimensions describes and differentiates social concepts, which possess characteristic patterns of affective meaning known as fundamental sentiments ($\mathbf{f}$). These reflect how good, powerful, and active particular identities, behaviors, or emotions seem in general, outside of the context of social events. Perceptions shift, however, when concepts appear together within social events. Event-contextualized EPA meanings, known as transient impressions ($\boldsymbol{\tau}$) and modeled with regression equations [5], capture our interpretation of actors, behaviors, and other elements of a situation and predict our behavioral and emotional responses to unfolding events.

Our social actions are planned and carried out to either maintain situational meanings or to bring them back into *alignment with cultural expectations* about appropriate behavior and emotions for the identities involved in an event. When expectations are violated, we experience *deflection* (D), a sort of tension about the situation that signals a discrepancy between our current experiences and cultural expectations. In line with cognitive consistency theories (see above), people seek to minimize deflection by acting in ways that maintain cultural expectations about the situation. Deflection is calculated, in ACT, as the sum of the squared Euclidean distances between transient impressions $\boldsymbol{\tau}$ of the identities and behaviors emerging from a situation (between a given "actor" and "object-person") and fundamental sentiments $\mathbf{f}$ for these event elements summed over EPA dimensions (with weights w_i):

$$D = \sum_i w_i (f_i - \tau_i)^2 \tag{14.1}$$

ACT's predictions accurately reflect behaviors and emotions experienced in a variety of real-world social interactions, including sentiments and social behavior in domestic partnerships [19], support groups [20], social movement organizations [21], and other interactional contexts. Scholars have found that the motivation to align situational behavior with cultural meanings explains phenomena as diverse as deference patterns based on persons' relative occupational prestige [22], leader responses to employee behavior [23], and the preference for interaction partners that provide identity-consistent feedback [24]—even patterns of interaction among nations [25].

Social Simulation Based On ACT

Given the mathematical formalization of ACT with linear algebra [5], using the theory as a basis for defining computational agents is straightforward. A variety of ACT-based computational models have been developed and applied in the past. ACT's classic simulation model, known as *INTERACT* [26], predicts the culture-specific social dynamics that arise from cultural meanings for identities and behavior by means of empirically parameterized regression models in conjunction with repositories of cultural sentiment data, generating testable predictions about behavioral and emotional responses to social events. Model predictions have been supported by survey, experimental, and naturalistic evidence from a research program spanning several decades [e.g., 23–25].

BayesACT is a more recent probabilistic generalization that combines the ideas and empirical strategies of the ACT research program with a Bayesian approach from artificial intelligence, modeling social dynamics as a partially observable Markov decision process [2, 27]. BayesACT agents can represent uncertain knowledge about identities as probability distributions in EPA affective space, model multiple identities in one person, and make improved inferences about identity as interactions unfold. Simulations show that even with large initial amounts of uncertainty, stable and orderly patterns of social interaction emerge after a few rounds of interaction, showing that affective coherence mechanisms can explain human interactions even in the absence of consensual symbolic knowledge about the social order [27].

Group Simulator is a turn-based ABM (implemented in Netlogo) that extends ACT to model group interactions [28, 29]. Users can set up identity profiles for each group member and model task groups of sizes ranging from three to twenty-five members. Inheriting INTERACT's social-dynamics equations, Group Simulator predicts group members' behavioral and emotional responses to unfolding events based on the assumption that the agent experiencing the most social tension (i.e., deflection as per Eq. 14.1) will tend to be the next to act. It then calculates the most likely interaction partner by optimizing for the agent that will best confirm the sentiments associated with the actor's self-identity, the object-person's self-identity, and the behavior. In other words, the model simulates a relational process of mutually compatible meaning-making based on deflection-minimization as the optimization mechanism. Besides such identity-based tie formation, Group Simulator predicts the distribution of interpersonal behaviors across Interaction Process Analysis categories, a well-known taxonomy of group behavior [30]. Heise [28, 29] validated Group Simulator's applicability for task groups by replicating empirical findings from a classic study of mock jury deliberations [31].

Studying Online Collaboration With ACT

Hierarchy Versus Equality in Online Collaboration

As part of a larger, ongoing project aimed at studying open-source software development with ACT [2], we model the influence of work cultures on online collaborations using Group Simulator. The portrayal of online groups in the literature is conflicted. Some scholars emphasize the reputedly consensus-driven, egalitarian nature of open-source groups [32]; others note that successful online collaborations tend to be hierarchical and are often unable to reconcile the ideological expectations of egalitarian co-dependent collaboration with the reality of developing versatile, reliable, and profitable applications [33, 34]. We contribute to the growing literature studying the power dynamics of online groups by examining how roles, identities, and relational norms such as the level of reciprocity and distribution of group member contributions simultaneously influence the expectations and behaviors of group members. In particular, we are interested in comparing the social tension (deflection as per Eq. 14.1) experienced in hierarchical versus egalitarian groups. We hypothesize that more egalitarian groups create more deflection because they lack the clear expectations and relational structures implied by the supervisor-subordinate role-sets [cf. 35] given in hierarchical settings. In contrast, egalitarian groups must repeatedly renegotiate who will take a leading role in the interaction, yielding more potential for the affective expectations of group members to be violated. Preliminary simulations with Group Simulator reported in [2] were in line with our hypothesis, here we expand on these results by studying in more detail how role identities are expressed over repeated group interactions. For example, does an agent broadcast their guidance to the entire group, work through a trusted intermediary, or through a series pairwise interactions? While reciprocation implies greater accessibility and, thus, a shallower power gradient between team members, the ability to address the group for prolonged periods underscores the social distance between the supervisor and her subordinates [36]. Consequently, when considering how a work culture is likely to influence interactions, we need to consider both the meanings of the work identities defining that culture (i.e., their evaluation, potency, and activity) and the impact of the relational norms governing turn-taking.

Procedure: Simulation Experiments

To examine how role configurations and relational norms influence the power dynamics of groups, we conducted two simulation experiments where we compared two role configurations. We refer to these group types as egalitarian and hierarchical, respectively. We address the role configurations featured in each experiment first. As implied by their names, the types differ from each other with respect to the group members' relative potency. We kept the evaluation and activity of the group members

Table 14.1 Simulation description, parameter settings for study 1 and 2

Group	E	P	A	Label	Addressing Group %	Reciprocity %
Egalitarian	1	1.5	1	Man (3)	*Varying*	0.8
Hierarchical	1	2.5	1	Boss (1)	*Varying*	0.8
	1	0.5	1	Client (2)		
Egalitarian	1	1.5	1	Man (3)	0.4	*Varying*
Hierarchical	1	2.5	1	Boss (1)	0.4	*Varying*
	1	0.5	1	Client (2)		

Note The identity labels come from U.S. sentiment data collected between 2002 and 2004 [26]

in both groups constant at a value of 1 to isolate the effects that relational norms have on power dynamics [but see 38]. The resulting egalitarian and hierarchical groups consist of identities roughly corresponding to EPA ratings for the identity *man* on one hand and the identities *boss* and *client* on the other, based on data from a U.S. cultural context [26].

We compared the effect of addressing the group (as opposed to an individual group member) and reciprocation by conducting two simulation experiments. Specifically, we employed a 2X2X11 design, comparing two group types (egalitarian and hierarchical) with respect to two factors (the proportion of actions directed towards the group and the proportion of actions reciprocated by group members), across eleven settings (one for each 10th percentile difference in the two rates). We conducted 200 simulations of each group type with respect to each factor for each percentile. Each simulation consisted of 500 turns. In the simulations where we varied the address-the-group rate, reciprocity was held constant at 0.8 for these experiments, simulating commonly observed rates of reciprocity in discussion groups [37]. In the simulation experiments varying reciprocity, we kept the percentage of actions directed at the group constant at 0.4. For both experiments, we held group size constant at three; all other parameters were set at their default values as per [28]. Table 14.1 summarizes the role configurations (identity label and number of agents of this type), address-the-group percentages, and reciprocity rates featured in each experiment.

Results

We analyze the results of our simulation experiments in two ways. First, we provide a high-level description of changes in group behavior in response to changes in relational norms by comparing the relative proportions of behaviors in egalitarian and hierarchical groups that fall into four broad types of group behavior identified by Robert Bales and colleagues over the course of a thirty-year research program [28, 30]. These types include: positive socio-emotive (e.g., raving about a repository's app), active task (e.g., reviewing pull requests), passive task (e.g., watching), and negative socio-emotive behaviors (e.g., rejecting pull requests) enacted by group

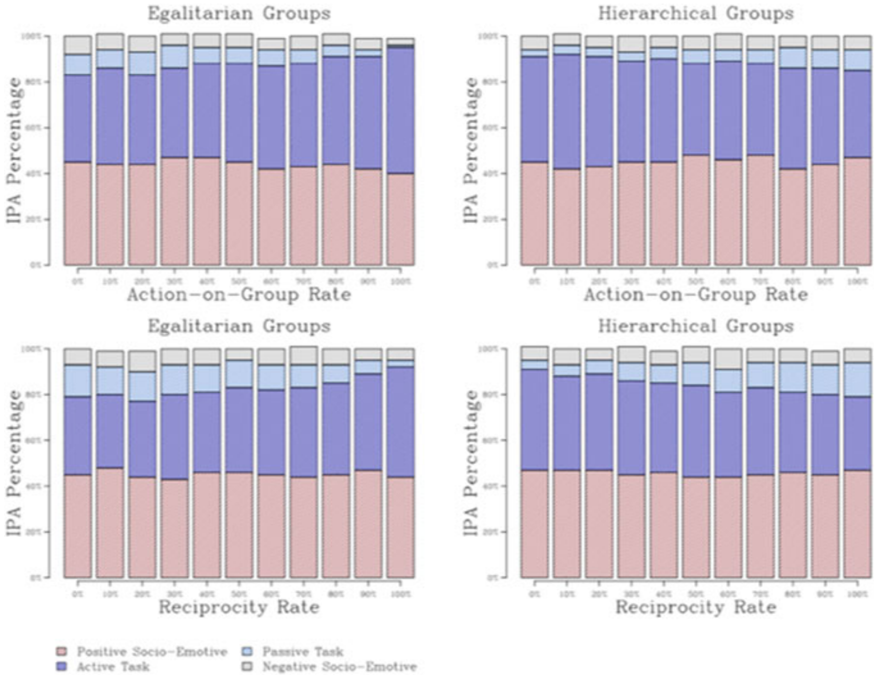

Fig. 14.1 Predicted percentages of socio-emotive and task behaviors as the percentage of actions addressed to the group and reciprocity change

members. Second, we examine how changes in relational norms influence the median level of deflection experienced by group members. These analyses allow us to demonstrate the varying degree of identity maintenance allowed by the different types of group norms.

Types of Activities. Figure 14.1 compares the proportions of behaviors in each category enacted by egalitarian and hierarchical groups (the left and right columns respectively). The figure's rows correspond to changes in the percentage of behaviors addressed to the group, and the percentage of reciprocated behaviors (the top and bottom rows respectively). The x-axis indicates the percentage of behaviors addressed to the group or reciprocated. The y-axis indicates the percentage of behaviors in each behavior category, with the shading indicating the proportion of behaviors in that category. E.g., the second bar in the top left-hand quadrant indicates that groups of men who addressed the group approximately 1 out of 10 times tended to exhibit relatively few negative socio-emotive behaviors and passive task behaviors (7% and 8%, respectively), and many more active task behaviors and positive socio-emotive behaviors (42% and 44%, respectively).

We find that, for both egalitarian and hierarchical groups, the proportion of negative socio-emotive and passive task behaviors shrinks as the percentage of actions directed to the group increases, while the proportion of active task behaviors tends to grow. For hierarchical groups, the proportion of both negative socio-emotive and passive task behaviors tends to be greater than that of egalitarian groups. These trends are fairly intuitive when considering a few factors.

First, the two groups' role configurations directly influence the likelihood of each behavior type. In egalitarian groups, members' moderately positive identity profile makes more potent negative behaviors such as defying and arguing unlikely because these behaviors tend to be quite negatively evaluated. In contrast, the power difference between clients and bosses makes it more likely that clients will both consult with bosses and, when acted on in ways perceived as aggressive, ignore and evade them.

Second, although the group's role configuration sets basic expectations, the increasing percentage of behaviors directed towards the group also affects the proportion of behaviors in each category. Group members have fewer opportunities to immediately and efficiently resolve interpersonal tensions as the percentage of behaviors directed towards the group increases. Consequently, the agent must act primarily in ways that affirm the entire group's identity. If we evaluate the group as being good and potent, then we will tend to act in ways that support this collective identity. As a result, we see increasingly homogenous behaviors because the identity demands of the group begin to supersede the identity demands of any particular group member.

Figure 14.1 also indicates that norms governing reciprocity also influence the likelihood of different types of behaviors occurring during the group interaction. The bottom two graphs suggest that groups with a stronger expectation that actions will be immediately reciprocated tend to exhibit more diverse sets of behaviors than groups with lower reciprocation rates, with hierarchical groups tending to exhibit greater diversity than egalitarian ones because a greater variety of behavior affirms the group members' respective identities. Bosses can affirm their identity by joking with, directing, or advising the group; clients by asking questions and consulting. In contrast, men affirm their identity by doing the same things: joking with, directing, and generally thumping each other on the back. This difference in the variety of behaviors that affirm the role expectations of the group is indicated in Fig. 14.1 by the relative distribution of behaviors in each category.

Although Fig. 14.1 indicates that strong reciprocation norms have generally the opposite effect of strong norms to direct actions towards the group, it also indicates that norms governing reciprocity can have an even greater impact on the variety of behaviors enacted by the groups. Reciprocity influences the variety of behavior sequences a group is likely to enact because reciprocation norms govern a wider range of potential alters. While norms governing the proportion of actions directed towards the group influence how many actions are directed towards one potential alter (the group), reciprocation norms influence who else the agent will interact with.

As the norm to reciprocate approaches 100%, there is a greater likelihood that the interaction will be dominated by chains of relatively homogeneous reciprocated events. Examples from daily life include chains of seemingly unending pleasantries, affirmations, questions and responses and, more alarmingly, escalating patterns of abuse. Because our egalitarian and hierarchical groups consist of good and at least

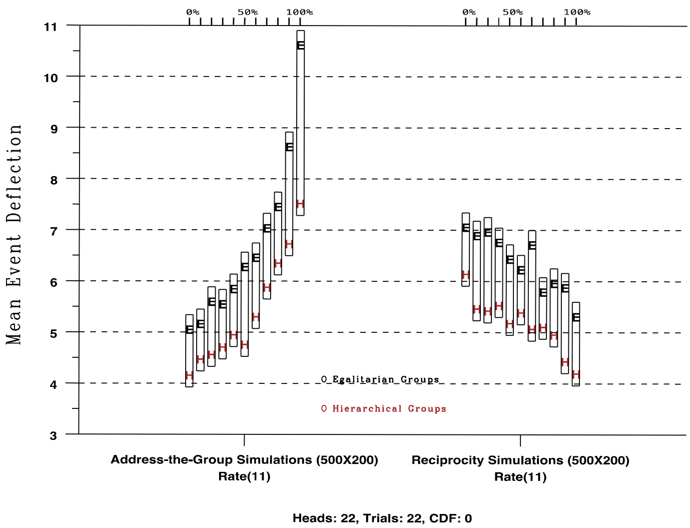

Fig. 14.2 Predicted event deflection for egalitarian and hierarchical groups controlling for different address-the-group rates and reciprocity rates (22 Binomial Trials)

moderately potent identities, the majority of behaviors even at high rates of reciprocity are positive socio-emotive and active task behaviors in the simulations presented here.

Identity Maintenance: We next analyze Group Simulator's predictions about the level of deflection experienced by the group to establish the link between the patterns we observed in Fig. 14.1 and the symbolic identity-maintenance processes that generated them. We focus on deflection because deflection minimization is the driving mechanism behind Group Simulator's predictions. Recall that deflection arises from the discrepancy between our expectations of a situation and our impressions of it.

Figure 14.2 compares egalitarian and hierarchical groups with respect to the mean event deflection experienced by group members. Event deflection is a measure of the tension generated by an event such as the boss addressing the group. The figure compares simulation experiments where we varied the address-the-group rate to experiments where we varied the reciprocity rate. The blocks in the figure indicate each unique combination of factors (the mean deflection experienced in each group type at each rate over 500 turns in 200 simulations). The group means are indicated by the letters H and E for hierarchical and egalitarian groups respectively. For example, the mean deflection of groups where no one addresses the group is 4.2 for hierarchical groups and 5.1 for egalitarian ones. The block lengths, thus, indicate effect size, with larger blocks indicating a greater difference between the groups. The pattern across the blocks is also meaningful. Treating each block as its own experiment, we find that in all 22 simulations egalitarian groups experienced more deflection than hierarchical ones, making it highly improbable that this effect is due to chance.

We find that the address-the-group rate influences deflection, but that the reciprocity rate diminishes this effect. Egalitarian groups experience more deflection because it is more deflecting to be acted upon by an equally potent person than by a more potent one. Increasing the address-the-group rate generates deflection by ensuring that a higher percentage of actions will be addressed towards the group rather than some other object, even if another object would better minimize the agent's deflection. A norm to address-the-group, however, also breaks negative action sequences by providing a new more positively evaluated object of interaction. Nevertheless, the increasing level of deflection as the address-the-group rate increases suggests that a strong norm to address the group is likely to result in accumulating levels of deflection that addressing the group cannot resolve. Higher reciprocity rates weaken the effect of the address-the-group rate because fewer of the actions are directed towards the group, and more actions are addressed towards the agents' last interaction partner which often is the agent that most minimizes the actor's deflection.

Lower group-level event deflection; however, does not necessarily mean that agents in hierarchical groups are all experiencing less deflection, just that most of the group most of time is experiencing less deflection. We next examine patterns at the agent-level to get a better sense of how the agent's role identities influence the level of tension they experience.

Figure 14.3 compares the level of deflection experienced by actors and object-persons in egalitarian and hierarchical groups. The x-axis indicates the percentage of behaviors either addressed to the group (the top panels) or reciprocated (the bottom panels) in egalitarian and hierarchical groups (the left and right panels respectively). The y-axis indicates the median level of deflection experienced by each group member. The solid lines indicate when agents are actors; the dashed lines when they are object-persons.[1]

We find that object persons experience more deflection than actors in both egalitarian and hierarchical groups. We also find that role differentiation leads to different outcomes. Bosses when actors, but particularly when object-persons, experience more deflection than clients or men. Although the agent traces in hierarchical groups are generally more closely grouped and lower than those in the egalitarian groups, bosses when the object of an interaction experience far more deflection than agents in other roles and settings.

These patterns arise from interaction norms encoded in affect control theory's interaction effects. Expectations regarding how we should be treated given our role's evaluation and potency govern the exercise of power in groups. The expectation that people will act in ways that are attuned to the potency of the person with whom they are interacting is an important interaction norm in groups. Good people are not bullies. There is also a strong expectation that powerful people will act in powerful ways. Although being the object of an interaction generally results in a loss of perceived potency, this loss is less if the actor plays an important role in the group. ACT researchers have identified these norms and others, evident as interaction terms in the

[1] The object-person agent traces end at 90% in the address-the-group rate experiments because at a 100% address-the-group rate all actions are directed at the group rather than to the agents.

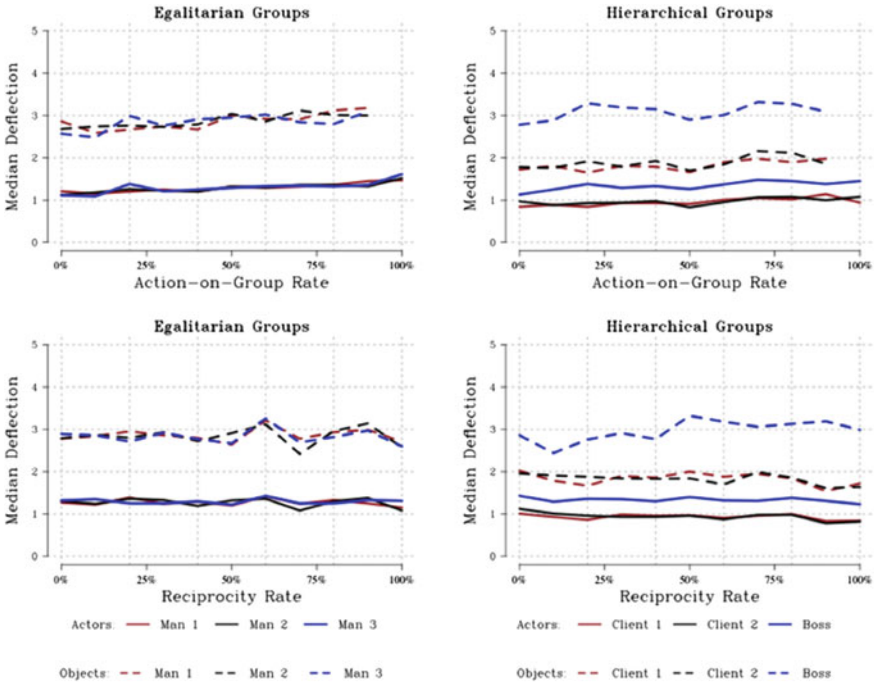

Fig. 14.3 Predicted median group member deflection as the percentage of actions addressed to the group and reciprocity change when being actors and object-persons

theory's impression change equations, repeatedly in empirical studies of impression formation [5, 38].

These cultural expectations largely explain observed differences in the level of deflection experienced by actors and object-persons in egalitarian versus hierarchical groups. Greater potency comes with greater risk of deflection. Bosses must not only act in powerful ways leading to a loss in potency when they are the object but also in legitimate ones leading to losses in evaluation when they are the actor. The moderating influence of the actor's potency also largely explains why agents in egalitarian groups experience more deflection under most conditions. Our simulated men experience slightly more deflection from acting in dominant ways towards peers, and significantly more deflection from being acted upon in a dominant way.

Discussion

Our simulations demonstrate how role configurations and relational norms influence group behavior by setting role expectations and moderating the extent to which group members can affirm their roles. We find that hierarchical groups tend to experience less event deflection, but that actors in dominant roles are likely to experience more deflection than others because they confront more complicated norms pertaining to the exercise of their power. In addition, we find that relational norms allow group members to efficiently resolve deflection through reciprocation, while also allowing them to disrupt sequences of disconfirming behaviors by addressing the group or another group member. These norms are likely to be particularly important in egalitarian groups where there are no clear role expectations establishing dominance patterns.

It is important to note that although there is decades worth of research examining the operation and maintenance of status hierarchies [39], there are far fewer generative models of these dynamics [40], and no other model to our knowledge that applies an identity maintenance perspective. This work highlights two avenues of future research. First, although hierarchical groups may make interactions more predictable, they do not necessarily make them more fulfilling. Preliminary simulation results indicate that, in many instances, people experience more negative emotions in hierarchical groups, suggesting new questions regarding the relationship between identity maintenance and emotion in groups. Second, although promising, affect control theory's emphasis on interaction at the dyadic level limits its ability to model groups. The theory predicts how people respond to being the actor or object-person in an event but not an observer. This has implications for our findings, especially our reciprocity findings, because while these findings likely reflect the state of the agents acting and reciprocating, we have no predictions about the state of the other agents, and thus of the group as a whole. Consequently, a more robust application of the theory will need to consider the deflection experienced by actors and object-persons as well as observers.

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Chapter 15
Integrating CAFCA—A Lens to Interpret Social Phenomena

Corinna Elsenbroich and Harko Verhagen

Abstract As social context becomes a more central concept for social simulation, different approaches to context have been developed. We discuss four of these with the help of an overall Contextual Action Framework for Computational Agents (CAFCA). More in particular, we describe how the consumat model, social norms, collective reasoning, and social practices can be related to each other using CAFCA. Following this we show how these approaches than can co-exist in the analysis and simulation of social phenomena rather than compete or be seen as mutually exclusive.

Keywords Agent-based modelling framework · Collective dilemmas · Context · Action theory · Social ontology

Introduction

Over the last decade a new focus has emerged in the social simulation community: the recognition of the essential importance of social context [1]. Although social science is aware of context in the analysis of social life, it is either stripped away in quantitative studies often leading to over-generalisation, or overemphasised in qualitative studies, undermining generalisation.

Agent-based modelling has often been heralded as a method capable of combining qualitative and quantitative data [2, 3]. This ability to combine highly contextual and highly generic data makes it particularly suited to support investigation into context. Firstly, simulation methods model processes. By modelling change over time ABM can model contexts changing, changes in reactions of agents to contexts and

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changing contexts through individuals adapting behaviours collectively. Secondly, the possibility of modelling heterogeneity in ABM allows for the implementation of different contexts, different understandings of contexts and different reactions of agents to contexts. Thirdly, ABM can model emergence, allowing for the emergence of contexts from aggregations of individual behaviours. Finally, ABM can model tipping points or path dependencies, modelling changes and persistence in contexts. When people understand a situation one way or another, they put a chain of events into motion, dragging others with them.

This paper discusses four particular approaches of existing context focussed work and produces links between them to advance the possibility of implementing context in socially relevant ways into ABM. The links and approaches are systemized with the help of the Contextual Action Framework for Computational Agents (CAFCA) [4]. CAFCA is a framework developed to structure the variety of different contexts along the two dimensions of Level of Sociality and Mode of Reasoning respectively. A context, according to CAFCA, is thus defined as a combination (a tuple) of **who** (the relevant social context) and **how** can an agent (choose to) react. Each dimension has 3 values: (1) individual, (2) social, and (3) collective and (a) automatic, (b) strategic, and (c) normative respectively. Each of the nine combinations can be seen as a particular context configuration which demands a particular behavioural response. Figure 15.1 represents the CAFCA framework.

	Individual	**Social**	**Collective**
Habitual	repetition	imitation	joining-in
Strategic	rational choice	game theory	team reasoning
Normative	(institutional) rules	(social) norms	(moral) values

Fig. 15.1 The CAFCA framework

Approaches to Context

In this section we will present four different approaches to (modelling of) aspects of social context that have been used in agent-based social simulation model.

Consumat

The Consumat [5, 6] is an agent architecture focussed on modelling consumer behaviour in a context sensitive way along the dimensions of aspiration and uncertainty tolerance. Based on several psychological theories, both dimensions have 2 levels resulting in 4 modes of decision-making. Agents who are satisfied and certain repeat their behaviour. A deviation from satisfaction, keeping certainty, agents start to deliberate rationally about their options, aspiring to find higher levels of satisfaction. If agents are satisfied but uncertain, they look around and start imitating other agents' behaviours. If both dissatisfied and uncertain agents start applying strategic social comparison. The driving force behind the Consumat is minimising cognitive effort, which increases from repetition to imitation to social comparison to rational deliberation. The latter, 2012 version adds social networks to the equation as a means to decide whom to imitate or socially compare to. Even with this addition, the social level is minimally developed as the focus stays on the individual agent. The model is perhaps too teleological to cover daily life processes but works well for the types of contexts for which it was originally developed (consumer decisions).

Social Norms

Social norms have often been seen as the explanatory concept to be invoked to go beyond purely rational behaviour, i.e. beyond the homo economicus. However, social norms are not a well-defined concept, neither in the social sciences themselves nor in computational social science [7, 8]. One advancement of the study and use of social norms in the latter were the developments of the "Emergence in the Loop" architecture (EMIL-A) and simulator (EMIL-S) [9]. The major advancement of EMIL is that it develops normative reasoning in parallel to rational reasoning, allowing for context dependency of reasoning modes. The architecture includes modules for norm recognition, adoption and internalisation, in addition to normal Belief-Desire-Intention (BDI) components. Reasoning modules are activated depending on whether the agent understands the situation as rational or normative. Given the choice for BDI as the base level of deliberation, one can say that this model is overly teleological as well.

Collective Reasoning

Collective reasoning is a wide field of research spanning several disciplines, in particular philosophy, law, psychology and sociology. These approaches to analyse collective dilemmas include institutions [10], norms of fairness [11], collective identity and group belonging [12] or collective reasoning [13]. They investigate how combined decisions of individuals can be interpreted, whether in the form of opinion aggregation, group dynamics, or the understanding of others' intentions. One particular version of collective reasoning, team reasoning, has been developed as a response to conundrums of game theory. Team reasoning stipulates that sometimes people recognise a situation as collective and maximise utility for the team rather than themselves as an individual. There are now some models using collective decision making in the contexts of extortion racketeering [14] or social dilemma games [15, 16].

Social Practices

Social practices have been used in ABM to model behaviour change, in particular in the contexts of consumer behaviour and household energy use (e.g., [17]). Social practices take the idea of habitual behaviour seriously, allowing for actions to result through the partaking of individuals in (shared) social practices. It is important to note that there is no deliberate selection in which practices to partake in and which to desist from. Rather an individual's partaking in practices co-evolves with its other behaviours and with the evolution of the practices themselves.

CAFCA and the Four Approaches

Using CAFCA we can compare these four approaches with each other with respect to the 2 CAFCA dimensions. This results in the matrix depicted in Fig. 15.2.

Let us now discuss what CAFCA might contribute to agent-based modelling given two examples of context dependent actions.

Example 1: innovation diffusion

There are several implementations of innovation diffusion using agent-based modelling. Most often diffusion ABM use very simple decision rules. Kiesling et al. [18] discuss several approaches used for decision making in diffusion models, covering threshold, utilitarian, state transition and opinion dynamics models. For all of these the heterogeneity leading to the variance in the time of adoption lies in the agents themselves (e.g. varying thresholds, varying utility functions). The Consumat goes beyond these simple behaviour models, using several modes of reasoning to explain a particular agent's adoption as agents find themselves in different levels

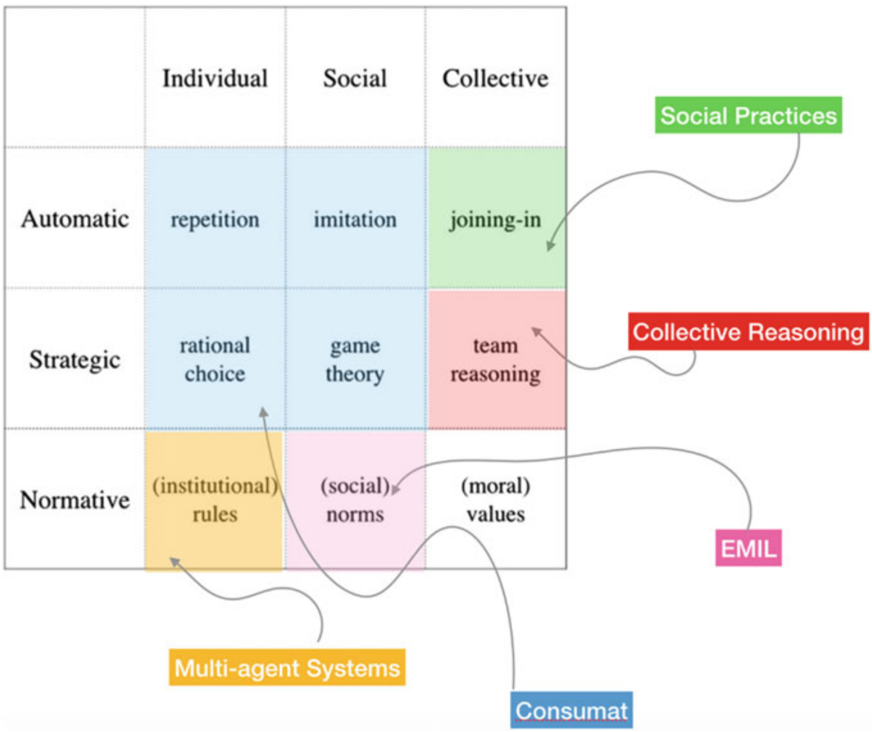

Fig. 15.2 The CAFCA framework populated by the four approaches

of satisfaction and certainty. Following this idea of integrating modes of reasoning, CAFCA could model innovation adoption as a set of different interpretations of the social and reasoning mode context: we start off with some individuals that make a rational choice to adopt, followed by some imitation behaviour (the cool dude has a mobile phone and I want one too), followed by joining in (being part of the phone crowd), followed by social norms (one just has to have a mobile phone). This goes beyond just having agent heterogeneity along one variable (e.g. threshold value). This means interpreting a simple situation which is usually modelled in a unified way as a situation with high levels of heterogeneity in terms of agents finding themselves in different contexts and behaving in line with their interpretation of the context. The question in putting the model together moves from "what is the distribution of threshold values?" to "which different contexts are at play in the target system we want to model?".

Example 2: public good games

Models of public goods games (PGG) are often modelled using a population consisting of cooperators and defectors. Usually the models take into account some reaction to past experiences, so that agents defect as a reaction to defection by others (a version of the tit-for-tat strategy, see [19]). Sometimes normative considerations are implemented to safe cooperators from becoming suckers. These considerations might be detection of trustworthiness of other agents, gossip to warn agents about defectors or punishment regimes [17]. TreaColD (short for Team Reasoning in Collective Dilemmas) is a model moving away from this setup, implementing a context dependent switch between strategic social and collective reasoning. Agents still react to past experiences but they consider the behaviour of the team as relevant rather than individuals. As long as agents interpret the context as one of a collective endeavor, they apply team reasoning, once this interpretation ceases agents become likely to defect.

Discussion

The plethora of social theories and models makes the need for a framework to relate and compare them to each other pertinent. CAFCA is an attempt at such a framework. Taking social practices on board we think that CAFCA is an important contribution to clarifying different contexts in which agents make decisions but equally important in broadening our vocabulary for talking about these contexts. Far from limiting ourselves to one or two modes of reasoning—for example strategic and normative as in EMIL, CAFCA allows us to take a wider scope of context dependent behaviours into account, including a construction of contexts. This way we see CAFCA as a systematisation of existing frameworks, allowing for these to not compete but coexist as descriptions of behaviours in different contexts. As Warren Thorngate [20] said in his review of “Minding Norms” [9], “Sequel Anyone?”.

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Chapter 16
Computational Demography of Religion: A Proposal

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Abstract This paper proposes a new approach to the demography of religion and non-religion that builds on and expands agent-based modeling and social simulation techniques developed in prior work by the research teams led by the authors. Traditional demographic approaches to religion and non-religion understandably focus attention on self-reports of religious identity or affiliation, where longitudinal data is most readily available, and they employ a cohort-component methodology to make projections. We argue that demographic projections of religion and non-religion could be enhanced by using multi-agent artificial intelligence models of societies. After artificial societies with suitably cognitively complex agents are validated using existing demographic data, projections of religion and non-religion could be made by measuring religiosity within the artificial society not only as affiliation but also in three other dimensions: belief, service attendance, and private religious practices. Artificial-society religious demographic projection could also take account of nonlinear feedback loops and interaction of variables, produce narrower error estimates, and integrate a rich array of disciplinary insights relevant to religious and nonreligious identity and change—all of which are weaknesses in traditional religious demographic projections.

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An Old Problem and a New Kind of Solution

Sociologists of religion have observed that, contrary to mid-20th-century predictions, religious adherence worldwide is on the rise in the twenty-first century [1, 2]. With the fall of Communism in Eastern Europe and increased openness of China, previously atheist and agnostic individuals are returning to the religious traditions of their ancestors or adopting a new religion entirely, from Orthodox Christianity to Mahayana Buddhism. At the same time, Christians continue to leave churches in Europe and North America, despite the rapid rise of Pentecostal and Evangelical Christianity in Asia, Africa, and Latin America. Migration is moving millions to new places, bringing their religious preferences and practices with them. Ecological pressures related to water, air, and food are confronting large populations. Governments are increasingly aware of the importance of religion and religious change for public policy, national security, and inter-national relations. It is critical to have a firm grasp on the changing landscape of religion and non-religion for policy and planning purposes. Understanding religious and non-religious identity and change also takes researchers right to the heart of problems central to the academic study of religion and non-religion—problems focusing on the origins and functions of the beliefs, behaviors, and experiences associated with religion and non-religion in our time.

The state of the art in social-scientific methods for projecting future religious adherence is a cohort-component methodology. This method proceeds in several steps.

Step 1: On a national level, religious adherence changes in six ways: births, deaths, conversion in, conversion out, immigration, and emigration [3]. Each of the six dynamics must be considered to truly understand the ways in which religion and non-religion are changing, and how religion and non-religion might continue to shape public policy, national security, and international relations. Fertility typically has the most significant influence on the absolute and relative sizes of religious groups. It is widely known that natural growth is primarily a matter of socio-economic conditions on the national level. Thus, tracking fertility rates and the movement of people across borders are standard demographic practices [3]. Indeed, switching (conversion) in and out of religion is—in most places, most of the time—relatively unimportant for the future of religious and non-religious adherence in a given country; rather, birth rates are typically the major driver of religious change [4]. Yet there are situations where fertility fails to tell the whole story. In certain times and places, religious switching and economic and environmental feedback systems impacting fertility rates become dominant factors in religious and non-religious change. Thus, data is needed for all six ways in which religious adherence can change.

Step 2: The data to be collected should be broken into age-cohorts—five-year blocks are typically accepted as sufficiently fine-grained. For example, fertility data is needed for women aged 0–4, 5–9, 10–14, 15–19, 20–24, 25–29, 30–34, etc. And the same break-down is needed for deaths, migration in and out of the nation in question, and religious switching.

Step 3: The data to be collected needs to be broken down further by religious grouping. Here it is most important to capture the large religious and non-religious groups, between which fertility rates often vary quite dramatically. Smaller religious groupings and various categories of non-religious people (e.g. atheists versus agnostics versus no-affiliation) can also be important depending on the purpose of the demographic projections.

Step 4: The dimension of religiosity to be measured is also a critical decision. Traditional demography focuses on self-identified religious adherence because census data covers that for many countries whereas solid longitudinal data on other dimensions of religiosity can be difficult to find. When the data is available, however, other measures are also potentially important, such as religious service attendance, private religious practices, and personal religious beliefs. This decision about what to measure matters because the story about religion in a given country can be very different depending on what is measured. In Norway, for example, census-based religious adherence data suggests that Norway is a very religious country with over 70% of the population in the national Lutheran church and around 80% identifying as members of a religious group. Yet regular church attendance rates are well below 5%, with some estimates as low as 1.5%, and the rate of belief in God is now below 25%.

This yields a five-dimensional dataset: nations, source of population change, age cohorts, religion and non-religion components, and aspect of religion measured; as noted, religious demographic projections typically collapse the fifth dimension and focus solely on religious self-identification, which simplifies matters somewhat. Projections are then based on running cohorts out into the future in five-year steps (or whatever size was used for age cohorts). Some dynamism can be incorporated by linking fertility rates to projected economic conditions, but the modeling process is relatively straightforward once the formidable dataset has been constructed.

This is the method employed by both the World Religions Database [5, 6] and the Pew Research Center in their religion projections [1, 7]. Those projections differ mainly because of different estimates about fertility and switching—for example, Pew has Muslims at a higher proportion of the world's population than WRD.

Unsurprisingly, assumptions about fertility and switching are critical considerations in making sound religious population projections. For example, Africa's massive 20th-century shift from traditional religion to Christianity and Islam went unrecognized by sociologists using standard methodologies. It was only by considering the crucial role of religious switching that, in 1970, sociologist David Barrett reasonably anticipated the massive increase of Christian and Muslim populations in sub-Saharan Africa by the year 2000 [8, 9]. Barrett went beyond standard demographic tools in his research to uncover a new way to understand religious change in the modern world.

We propose to do the same: to go beyond standard demographic tools to uncover a new way to understand religious change in the modern world. Specifically, we envisage the incorporation of computer modeling and simulation (M&S) to transform religious demographic projections from employing cohort-component procedures to actually measuring religious and non-religious populations in artificial societies.

Religious Demographic Projection Using Artificial Societies

M&S tools are widely used in the sciences, including the social sciences within what is now called social simulation, but have only recently been applied to the sociological study of religion and non-religion [10–19]. Applying M&S to religious demographic projections should be feasible and has the potential to revolutionize the way we think about religious demographics. In cohort-component methods, the projections themselves are relatively easy to produce after the formidably difficult datasets are constructed. In artificial-society projection, by contrast, both the datasets (used for calibration) and the artificial societies are extremely difficult to produce. The payoff for the additional work of building and validating artificial societies is an important consideration in assessing the value of this new approach. In what follows, we consider these potential benefits as we discuss the procedures for generating religious demographic projections from simulation experiments on artificial societies.

Big-Theory Integration

To create computational simulations of religious and non-religious identity and change, it is critical to adopt a big-theory approach that integrates multiple disciplines relevant for explaining the complexities of social change, including demographics and social psychology, cognitive science and psychology of religion, political economy and environmental sociology—in short, and in principle, all known factors that significantly impact religious and non-religious switching, fertility, and migration.

Big-theory integration transcends the problems of internecine disciplinary battles and inter-disciplinary neglect to generate a causal architecture for religious and non-religious identity and change that shows how theories enjoying some degree of empirical support can, when properly limited to avoid contradictions with other theories, complement one another, strengthening and deepening the resultant interpretation. This big-theory integration is essential for any artificial society in which the agents are cognitively complex enough to make decisions about religious affiliation, religious service attendance, private religious practices, and religious beliefs.

The agents in an artificial society are individuals that live virtual lives, interact with others, make decisions, and define their own identities over time. Implementing fertility, migration, and especially switching dynamics in an artificial society of intelligent religious agents is a natural application of M&S and needs to make use of what is known from sociological, psychological, and other disciplines about theories and data related to demographic forecasts. Thus, a big-data approach to M&S using artificial societies supports the expression of ambiguities of religious and non-religious self-identification, and how those shades-of-grey realities get reduced to black-and-white answers on a census form.

Multiple Dimensions of Religiosity

Demographers of religion tend to approach their tasks using a selection of tried-and-tested methods. They attempt to measure religious and non-religious affiliation, beliefs, attitudes, and practices, but they know full well that they struggle to get at the core issues related to identity. Human identity, including in public and private acts of self-identification, is often complex, multifaceted, vague, and partially hidden. It can be difficult to identify the real significance of demographic projections, given the gap between public self-identification and private thoughts, feelings, and behaviors. Demography itself does not directly address how people think and talk about themselves as individuals in society, nor how they relate to wider group dynamics that determine attitudes to questions about belonging. Further, demographers struggle to evaluate how these dynamics stand, or do not stand, in relationship with one another. Religious identity is inherently messy and complicated. The agents express the complexity and ambiguity of religious and non-religious identity, and they make judgment calls when they boil all that messy nuance down to a census checkbox just as human beings do. This is not news to demographers, of course, who fully understand these challenges and are sharply aware of the measurement assumptions they make.

A suitably designed artificial society for religious demographic projections would not have to choose among the various dimensions of religiosity. Validating such a model for all four dimensions of religious affiliation, religious service attendance, private religious practices, and religious beliefs could be accomplished using census data where possible and other surveys where census data is not available. The spottiness of the survey data on service attendance, practices, and beliefs would be less problematic for calibrating and validating a model of this kind than in the cohort-component methodology, so long as there is some longitudinal aspect to the data, which there is for many countries.

Thus, religious demographic projections using artificial societies could be made in all four dimensions of religiosity simultaneously: religious self-identification and adherence, religious service attendance, private religious practices, and religious or non-religious beliefs. These projections could be placed alongside one another, visually representing the complexity of religious and non-religious change in the contemporary world. This is far preferable to seeing only one dimension of religiosity projected forward and far more likely to fend off misunderstandings.

Demographic Assumptions as an Asset for Experimentation

Artificial-society religious demographic projections share an important virtue with all multi-agent artificial intelligence models: they parametrize many assumptions. In cohort-component demographic projections, assumptions tend to be buried in the fascinating footnotes, which therefore make for unusually juicy reading. Those same assumptions would be part of the experimental platform produced using a computational model, which would include parameter sweeps, optimization experiments, and the testing of hypotheses.

Of course, an artificial society makes many design assumptions that are not parametrized. One of the purposes of the validation process is to test those assumptions and the involvement of subject-matter experts greatly lowers the likelihood that faulty assumptions will survive long enough to need to be detected during validation. But all traditional assumptions debated in the footnotes of reports on religious demographic projection using the cohort-component method can be parametrized in the artificial-society method.

The Puzzle of Error Projection

Traditional cohort-component demographic projections typically project errors in the same way they predict population cohorts: project out the lowest bound of the error range separately from the highest bound of the error range. Because these errors accumulate quickly, the result is typically vast errors, making the projections almost impossible to refute. Artificial-society religious demographic projections can calculate error along the way, resulting in much tighter confidence intervals and making conflict between the projections and real-world data easier to produce.

This is an illustration of what we take to be a virtue in scientific work: energetically seeking conditions for correcting and improving scientific results.

The Virtues of Comparison

Artificial-society religious demographic projections should be able to identify the parameter conditions under which the cohort-component projections are replicated—which, we note in passing, is itself an important kind of validation. And the same system can produce many different forecasts based on explicit assumptions about measurement and uncertainty, thereby managing the on-the-ground realities of multiple religious identity and public–private differences on religious and non-religious self-identification. Tuned one way, the system can produce forecasts that match existing projections for religious and non-religious adherence in the future; tuned a different way, with different assumptions, the forecasts change as well.

We think of the result as an assumption-relative demographic forecasting system. The underlying computational simulations internalize both the ambiguity of human identity and self-description, and the boiled-down, sometimes misleadingly clear, realities of how people describe themselves on census forms. The system would treat forecasts as useful, simplifying abstractions from real-world complexity, and supply a prismatic way of peering into the future, with multiple forecasts explicitly dependent on measurement assumptions, visualized within an easy-to-use web-based tool. All of this is grounded in computational simulations whose causal architectures reflect state-of-the-art knowledge about religious and non-religious identity and change.

Taming Non-Linearity

Consider the world's two largest religions: Christianity and Islam. Presently, Muslims typically have younger populations and higher fertility rates than Christians, and some projections indicate that Muslims might outnumber Christians by the year 2050 [7]. However, investigation using different kinds of source material and methods could in principle uncover an alternative picture. It is difficult to study the role of religious switching and the role of economic and environmental feedback processes that alter the dynamics of birth and death, which sometimes occur in non-linear ways. Tracking religious switching is particularly difficult today in large countries such as China and India—places where qualitative research and on-the-ground reports claim that switching is occurring from atheism, agnosticism, and Hinduism to Christianity, Buddhism, and other East Asian religions [20–23]. If switching and fertility-impacting feedback mechanisms are underrepresented in demographic modeling—both potentially highly non-linear processes—then the models no longer reflect the de facto situation of religion on the ground in a significant way. If models and forecasts are substantially out of step with reality, then they are insufficient for planning purposes.

Big-theory integration joined with computational M&S in an assumption-relative demographic forecasting tool offers leverage against the kinds of non-linear feedback that can defeat cohort-component projection methodologies. Artificial-society religious demographic projections naturally pair robust theoretical analysis of religious and non-religious identity with fertility-impacting economic and environmental feedback mechanisms. The product is a big-theory integration of the relevant empirically robust considerations bearing on religious and non-religious identity and change, arcing across multiple disciplines, specific to each country considered, and sensitive to the possibility of non-linearity in snowballing processes of social change.

Let's get a little more specific about this. Ideally, fertility takes account of economic, cultural, and environmental factors; longevity takes account of medical technologies, public health standards, and social support; and migration takes account of labor-oriented migration, refugees, and family reunification. The interactions among these factors can be extremely complex and non-linear. For example, several factors impact a nation's fertility rate, from local factors such as a woman's alcohol intake and individual contraceptive use to larger factors such as economic uncertainty, expansion of higher education, social interaction, and other social norms [24, 25]. Social scientists and demographers have, on many occasions, observed these mechanisms at play throughout history and in the contemporary period. For instance, the domestication of plants and animals in the Paleolithic period had substantial impacts on hunter-gatherer economies and, thus, fertility. Among other factors, more reliable food sources helped shorten birth intervals [26]. A direct fertility-agriculture link was also made in rural Turkey, where fertility rates were reportedly higher in wheat-growing areas in the southeast and northeast parts of the country [27]. Pairing environmental and economic feedback mechanisms with the role of religion in social life produces a more nuanced picture of the impact of religion on fertility rates. For example, Nigerians seek religious solutions to most social and economic problems, but religion affects childbearing indicators to varying degrees in different religions—Christian women report lower fertility rates than their Muslim counterparts [28]. Another example is Mongolia, where fertility rates between religious traditions were nearly identical in the socialist period (ending in 1991). However, at the beginning of the democratic period in that country (early 2000s), religion began to have an influence on fertility and Buddhist women reported lower rates than women from non-religious households [29].

Non-linear feedback loops and interactions are a significant challenge to cohort-component demographic projection, second only to collecting the data required to make demographic projection of any kind possible. But non-linear feedback loops and interactions between variables are the very stuff of computational models. Thus, the proposed new method of artificial-society religious demographic projections has great promise.

Technical Challenges

Beyond the challenges of collecting data (in which traditional demography is frankly amazingly good) and managing big-theory integration of multiple disciplines relevant to religious identity and change in the construction of artificial societies (in which our research group is quite experienced; e.g., [16–18, 30–35]), the task of developing artificial-society religious demographic projection also faces significant technical challenges. These challenges include the following.

- These artificial societies are complex so there is a need to understand them at the level of their agents. For this purpose, a simulated empathy framework should prove useful [36, 37].
- The assumption-relative demographic forecasting system needs to be a web-based system that allows users to interact with the simulation model, artificial intelligence modules, and related datasets. It needs to have a layered architecture that relies on modularity, anticipation, crowdsourcing, and artificial intelligence.

- The complexity of agents in these artificial societies stems, in part, from the high fidelity of their artificial minds. It is not possible to "simplify" the agents to reduce computation time and memory requirements, and it is important to aim at 1:1 ratio of agents to real persons if possible. The associated challenge is how to maintain the complexity of each individual agent while making computation tractable. This might be achievable by providing sophisticated implementations of communication among agents and distributing agent functions across multiple computing nodes in a cluster with distributed (i.e., non-shared) memories.

A final challenge relates to the fact that building these artificial societies is a major task in and of itself, both in relation to characterizing social processes and in relation to building the complex agent minds needed to populate the society. The kinds of artificial societies useful for religious demographic projections can't be built overnight. The incremental nature of our group's research program is expressed in Fig. 16.1, which also describes our proposed Modeling Religious Change (MRC) project.

Our artificial societies started out as simple as meaningfully possible for a demographic application (SimLan) and have been carefully extended systematically to include social elements that are critical for applications in specifically religious demography. These incremental extensions are as follows.

- SimLan is the baseline of the society including birth, death, marriage, employment and social networks.

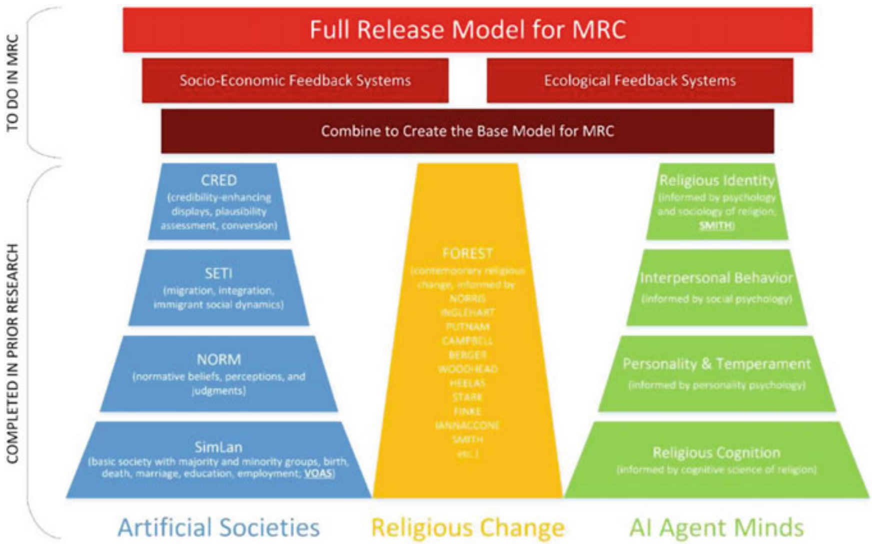

Fig. 16.1 MRC modeling tasks in relation to research already completed. The first of the new tasks—combine everything to create a base model for MRC—is particularly challenging. The entire process must be completed for each targeted country, but we plan to take advantage of relevant similarities among countries when possible

- NORM introduces social effects of normative beliefs, perceptions, and judgments [17].
- SETI introduces social elements related to the majority-minority structure of the population in SimLan's artificial society, including migration, integration, and the associated social dynamics [35].
- CRED introduces the social dimensions of credibility-enhancing displays, mutual evaluation of the sincerity and authenticity of AI agents, and the evaluation of the plausibility of religious and non-religious worldviews [38].

Likewise, the AI agent minds started out as simple as possible to express basic religious cognition. We then incrementally extended the complexity of agent minds in a variety of ways necessary to work towards the kinds of agents that undergo worldview switching, differences between private and public religious and non-religious identity, different behavioral patterns depending on personality and temperament, and so on. The various models involving the less and more complex agent minds are individually validated but not yet integrated, and that is one challenge for MRC. Integrating agent minds in a matching artificial society is another challenge. A third challenge is accounting for the dynamics of religious change. A preliminary integrated theory of the dynamics of religious change, at least for contemporary western contexts, is expressed in the "Future of Religious and Secular Transitions" (FOReST) system-dynamics model [39]. The research incorporated into FOReST needs to be integrated in the artificial society for MRC. Other challenges are to introduce socio-economic and ecological feedback systems that impact fertility rates and other dynamics within MRC's artificial society, to the extent necessary for producing population projections for individual religious groups.

Conclusion

The computational M&S approach to religious demography proposed here is intended as a complement to traditional demographic approaches in the scientific study of religion and non-religion. While the latter produce forecasts that rely primarily on survey self-reports of religious affiliation, artificial-society religious demographic projection can make forecasts in several dimensions of religion and non-religion simultaneously, as well as take account of non-linear looping and interaction dynamics that are problematic for cohort-component demographic methodologies. Building on and expanding M&S techniques developed in prior work, we are developing new tools that we hope will improve the capacity of demographers to interpret religious and non-religious identity and change in human populations.

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Part IV
Modelling Synthetic Populations

Chapter 17
Generating Synthetic Population for the Agent-Based Model of the Russian Federation Spatial Development

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Abstract In our research we generate synthetic population for the agent model of the Russian Federation spatial development according to sample-based approach. The initial data source is All-Russian population census 2010. Within procedure of generation we fill the model database with objects of the model (agents and households) and set interconnections among them. Simulation results show variation of the generated synthetic population from the original Census data.

Keywords Synthetic population · Sample-based approach · Agent model · Census data

Introduction

In the socio-economic system of Russia in the spatial aspect there is a bright disproportion: overpopulation of some regions, causing environmental, housing and transport problems in them; and, conversely, outflow of population from others. The goal of the Strategy of the Russian Federation spatial development is to overcome these problems by smoothing socio-economic differences between regions and improving interregional infrastructure, which would improve resettlement of population and centers of economic activity.

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Our research is aimed at developing a tool for evaluating alternative actions in tax, monetary and investment policies within aims of the Strategy. The model of the Russian Federation spatial development, which is being developed in our research, would reflect sex-age structure, composition of households and spatial distribution of Russian population; infrastructure, production capacities, educational and administrative institutions in different regions. The structure of the model is presented in [6].

In this article we present initial modeling data structures and sources and algorithms of population synthesis for the model. We have selected sample-based approach for this task, because large arrays of detailed information about population and composition of households in different regions of the Russian Federation are available from results of the All-Russian Population Census 2010 [1]. The population is reconstructed as records of individuals in a household in the model database so that attributes of the resulting synthetic population match as closely as possible the distributions in the census data, as it was proposed by Beckman for U.S. census data structure [3] and further implemented for the UK, Switzerland, Australia, Canada, Belgium [2, 7] and other countries. Since the Strategy of the Russian Federation spatial development considers regions as a geographic scale, there is no need to use sample-free techniques to simulate population of small geographic objects [4, 5] for this task.

Algorithm for Generating Synthetic Population

The algorithm is based on a number of tables from the collections of All-Russian Population Census 2010 [2], which is the most recent source with very detailed information. The main initial data tables used for generating population of the Russian Federation are Age-sex structure of population in different regions (1), Marriage status of residents (2), Number of private households (3), Number of residents in collective and homeless households (4), Age-sex composition of private households (5), Age structure of the married couples (6), Number of children in intact and single-parent families (7), Distribution of private households by number of residents (8).

The first step is to set geographical structure of the Russian Federation (Fig. 17.1). After that the original generation of agents is created, in accordance with the sex-age structure of population in each region (1). One agent in the model corresponds to 100 people of the same sex-age group. The created agents are assigned with status "single", "married", "divorced" or "widower" according to the table (2). The required number of private households is created (3), one model household corresponding to 100 real-world households; and also one collective household that represents prisons, shelters, monasteries, nursing homes, and one household of homeless people in each region.

The most complex task in population synthesis is distribution of agents by households, which we do in the following sequence:

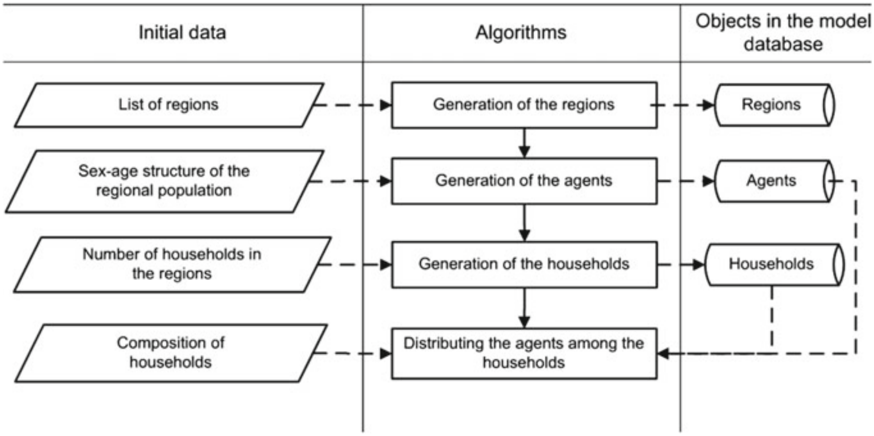

Fig. 17.1 Sequence of population synthesis in the model

1. The specified number of agents is fixed for the collective household and the homeless household (4). Agents associated with collective or homeless households are excluded from further consideration.
2. Adult agents with status “single”, “divorced” or “widower” are distributed one by one to a given number of single private households, according to sex-age structure of their residents (5).
3. The specified number of married couples (2) is created, choosing male and female agents with status “married” in accordance with the age structure of the married couples (6). Created couples are assigned one by one to private households.
4. The given number of children is attached to intact families (7), respecting difference between mothers and children in the range of 16 to 45 years.
5. Single-parent families are created and the given number of children (7) is attached to them, sticking to the agreed age difference. Single parents are selected from adult agents with status “single”, “divorced” or “widower”. Each single-parent family is distributed to a separate private household.
6. Remaining adult agents are randomly distributed by two into empty private households.
7. Number of agents in private households is brought up in accordance with (8) by settling the remaining agents into created private households.

Generated population is stored in a database for later use in scenario calculations on the further stages.

Table 17.1 Simulation results

Parameter	Census data	Modeling data	Variation
Number of residents	142,856,536	1,428,565	$2{,}52 * 10^{-5}\%$
Number of households	54,560,627	545,606	$4{,}95 * 10^{-5}\%$
Married couples	33,206,726	332,067	$7{,}83 * 10^{-5}\%$
Residents of collective households	1,832,386	18,324	$7{,}64 * 10^{-4}\%$
Children in intact families	16,996,690	169,967	$5{,}88 * 10^{-5}\%$

Simulation Results

The model of the Russian Federation spatial development is being programmed on C# in Microsoft Visual Studio 2015. Results of the generation procedure are stored in the model database, access to them is provided by SQL-queries. Table 17.1 presents variation of characteristics of the generated population of the Russian Federation in 2010 from the original Census data. To cope with computational complexity of generating synthetic population of 142 million of residents we have reduced number of agents (100 to 1), the opposite operation was made to modeling data for calculating variation of results.

Conclusions

In this article we presented results of the first stage of development of an agent-based computer model of the Russian Federation spatial development. The model is a tool for assessing control actions aimed at eliminating imbalances in population distribution, economic achievements and quality of life in various regions. At this stage we reconstructed population of different regions and their distribution among households in accordance with information from All-Russian Population Census 2010.

The purpose of the generation procedure was to create objects of the model (population and households) and reflect their interconnections in the model database. In the process of program implementation, agents and organizations were aggregated: one agent in the model corresponds to 100 residents. Simulation results show very small variation from Census data due to used sample-based technique: the number of created objects is pre-determined and only their distribution is stochastic. Meanwhile, the obtained results show validity of the proposed population synthesis algorithms and their program implementation.

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Chapter 18
Gen*: An Integrated Tool for Realistic Agent Population Synthesis

Kevin Chapuis, Patrick Taillandier, Benoit Gaudou, Frédéric Amblard, and Samuel Thiriot

Abstract In recent years, the use of agent-based modeling to tackle complex societal issue has led to the massive use of data to better represent the targeted system. A key question in the development of such models is the definition of the initial population. If many tools and methods already exist to generate a synthetic population from global and sample data, very few are really used in the social simulation field. One of the major reason for this fact is the difficulty of use of the existing tools and the lack of integrated tools in the modeling platforms used by modelers. To tackle this issue, we present in this paper a new generic tool, called Gen*, allowing to generate, localize and structure by a social network a synthetic population, directly usable in the GAMA agent-based modeling and simulation platform through its modeling language. The paper presents in details the three components of Gen* (generation, localization, structuring) as well as their use in the GAMA platform.

Keywords Synthetic population generation · Population localization · Social network generation · Gama platform

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Introduction

Agent-based modeling has become a major approach to study complex social systems and is now used in more and more domains (e.g. geography, ecology, sociology, economy). This boom has also led to the development of more grounded models, passing from a KISS [1] to a KIDS [2] approach. This transition was also favored by the availability of data. Indeed, we are now in the Era of Big Open Data where the quantity and the diversity of data like demographic data, GIS data and social network data is quickly growing. It is now possible to follow a Data-driven simulation approach [3] which aims at building the model from the available data. However, using such an approach requires to have tools to ease the creation, replication and exploration of descriptive social system models.

The paper focuses on a specific aspect of the integration of data in simulations that concerns the initialization of the simulation, and more particularly the generation of the initial population of agents. In order to be more realistic, agent-based models need to integrate agent population that more precisely represent target population. The question of the representativeness of the synthetic population (SP) does not only concern the distribution of the entities attributes, but also the entity localization as well as their connection between each other. Unfortunately, generating a structured and spatialized population of agents from diverse sources of data is a complex task that is out of scope of the main modeling platforms. We aim thus at filling this lack by proposing a new tool, called Gen*, integrated in the GAMA platform, that makes it possible to easily generate a synthetic population that reflect the distribution of attributes, spatial distribution and connection between entities.

The paper is organized as follows: section "Realistic Synthetic Population for Agent-Based Simulation" presents the context of this work, i.e. the generation of synthetic populations. section "Principles of Agent Population Synthesis Using Gen*" is dedicated to the presentation of the general principles of the Gen* tools and section "Integration into the GAMA Platform" to its integration in the GAMA platform. Lastly, section "Conclusion" concludes and presents perspectives.

Realistic Synthetic Population for Agent-Based Simulation

Synthetic Population Generation

The approach that have been most studied is based on the idea of Synthetic Reconstruction (SR) [4] and consists in building populations through the random generation of individual characteristics. The created entity is then seen as a vector of values—e.g. $\{blue, 1.75, 35, male\}$—that represents the individual characteristics for each attribute—e.g. color of the eye, height, age and gender respectively. This process is usually conducted by drawing attribute values either from the available distributions [5] or from an estimated joint-distribution based on techniques such as the Iterative

Proportional Fitting (IPF) algorithm [6], simulated Markove-Chain [7] or bayesian-based estimation techniques [8]. The available data to based distribution upon, as well as the algorithm used to sample characteristics, will decide whether individual vectors are drawn at once or by gathering separately drawn characteristics.

When a sample of the target population is available, the generation process can take the form of a replication of individual records. The created population is then made of duplicated vector of characteristics taken from real individuals. This second approach is referred to as Combinatorial Optimization (CO) [9]. The process usually starts with a random initial set of individual records and then add and/or swap individual(s) drawn from the sample any number of time needed to fit required final states [10]. In fact, the replication of known real individuals is driven so to fit macroscopic descriptors, which can be the required size of the population or available aggregated data e.g. a certain proportion of male and female or a certain distribution of age. Any kind of optimization algorithm can be used to manage the selection of newly drawn entities of the population, and several have already been used, e.g. greedy heuristics [11] or genetic algorithms [12].

Synthetic Population Localization

The localization of synthetic entities in agent-based simulation model is a concern as far as the goal is to put them into a realistic spatial word. To this extends, modelers must rely on GIS to create the context to locate agents in. Dealing with spatial data, several methods are classically used to desegregate population distribution of attributes to any number of scattered sub-zones. Most of them have been developed in the context of aggregated demographic data at regional level that has to be ventilated across smaller scale areas. To this purpose, census centroid data [13], dasymetric modeling [14] or a combination of those methods [15] have been mostly used.

To sum up, two main steps can be used to address the localization problem: the first one referred to as *Areal interpolation*, consists in translating data from aggregated areas to more precise ones. This type of method uses ancillary data to refine aggregated data originally given at a coarser level [16]: entities characteristics are put into correlation with spatial characteristics, making satellite imagery, land use or land cover explanatory variables of the spatial distribution of entities attributes. For example, [17] use dasymetric mapping to study U.S. wide racial segregation at a high resolution ($90\,m^2$ cells) combining population density at district level, and fine grained ancillary satellite imagery and land cover. The second step referred to as *Explicit localization*, consists in providing individuals with a precise location, that could be a coordinate (x, y) or a geographical object (e.g. a building). Very few has been done on this aspect, as mention in [18].

Synthetic Population Social Network

According to a recent survey in the social simulation field [19], most models proposed in the domain that actually include a social network component to organize the agent population are using very simple and abstract models, i.e. regular, random (ER), Small-world, Scale-free. Two evident reasons for this concern are, on the one hand, the lack of available data concerning social networks on the targeted system (such data are expensive to acquire), and on the other hand such simple models are quite easy to implement and control through a limited number of parameters. Therefore, and even if several advanced social network generators, that could be appropriately used to generate synthetic social networks (such as [20, 21]) exist, they are not sufficiently solicited due mainly to the learning cost to master such tools. Therefore, whereas it is largely acknowledged that simple models are a poor approximation of real social networks [22], they are still largely used. The evident alternative to these models concerns the implementation of ad hoc networks including hypotheses specific to the modelled domain. Following this trend, one of the most advanced initiative concerns contact networks in the field of epidemiology and are strongly dependent on the previous steps in the synthetic population generation: links in the network corresponds to significant properties to interact (i.e. propagate the virus) which is assumed to depend on household relations, schools and workplaces which are generally generated at the localization step.

Principles of Agent Population Synthesis Using Gen*

In this section we present the capabilities of the open-source Gen* library.[1] The main repository is made of four components: the core API that define the main concepts and overall meta-model of population, entity, attribute and value; the gospl API that encapsulate data harmonization, generation algorithms and synthetic population validation indicators; the spll API responsible of synthetic entity localization, including areal interpolation, explicit localization and spatial binding; and finally, the spin API that contains network generation algorithm between synthetic entities.

The framework have been design so that each API only rely on main concepts define in the core library, makes it possible for users to work only with generation, localization or network creation independently. Furthermore, the library contains a repository with example applications to previously generated population for the city of Rouen and Bangkok.

[1] https://github.com/ANRGenstar.

Generation of Synthetic Population

Gen* makes it possible to generate a SP from samples and/or aggregated data. Before the generation process per se, and because demographic data can be diversely recorded, the available input information need to be harmonized [23]. Hence, using a unified representation of data about synthetic population, algorithms can be used in order to make the best of available information: in fact, Gen* makes it possible to generate a synthetic population from any type of data, with or without a sample, only based on aggregated data or a mixed between aggregated and sample data. At the end of the generation process, Gen* provides several indicators to asses SP quality.

Data harmonization Our proposal consider two types of input data: aggregated frequency or contingency and sample of population. The first one is transposed into a sparse multi-dimensional matrix with one dimension for each described attribute. The second source of data is considered to be a population of entity and can be treated as a SP, making a sample readily usable as an initial population of agent.

Both type of data are manipulated through input files in csv or excel format. In order for Gen* to read data, modelers needs to create a configuration. The library provide several features to build and store it in a JSON file that includes: input data files path, type of data for each and a description of all attributes (type of value, encoded form).

To ease the accessibility of data, Gen* provide a *dictionary* template in order to directly read data from known sources. We can find two templates that allows to ease the use of data from IPUMS (data-base of demographic data for more than 100 country around the world) and INSEE (french national institute of statistics). The schema can be extended to include any kind of pre-formated demographic data simply by defining the proper dictionary for Gen* to directly read files from any sources.

Methods Gen* has support for SR and CO based algorithms. They have classically be split into sample–free and sample–based techniques, mainly because the later needs as a stringent requirement a sample while the former only needs it when performing joint-distribution estimation.

For the first category, as default method, we provide direct sampling from known distribution, or as a refinement a hierarchical sampling that organized attributes in a graphical model with the ability to tune parameters of the Bayesian network [24]. When a sample of the population is available, modelers can use the IPF procedure to estimate the underlying joint distribution to be used in the sampling phase (see [25] for a recent critical review of the techniques and implementation issues). In all cases, we provide three sampling algorithms either linear, binary or alias search to draw individual vector of characteristic from the conditional, hierarchical or joint distribution respectively.

The alternative CO based techniques is also available with several optimization algorithms to choose from. In order to setup CO algorithms one must define several meta-parameters. First for the starting population, modelers can choose either to use the sample or to draw a defined number of records from the sample. Next, we consider a synthetic population to be a solution and searching through neighbor solutions involve swapping any number of individual. Modelers can choose either to elicit records randomly or in order to shift on one dimension of the distribution of attribute (e.g. swap two individual record that only differ on one attribute). At the end, modelers must define the fitness function that can rely on any quality indicators define in section Indicators. Ultimately, Gen* provides several optimization algorithms that can be used to monitor the CO process: random search, hill climbing, tabu search and simulated annealing.

Indicators Basic principles of quality assessment of generated SP implies a comparison between output population aggregated data and available data about targeted real population. Gen* provides state of the art indicators that can be split into two types of distance metrics: the index focusing on categorical distance and those that target continuous distance. In the first category we can mention the Total Absolute Error that count the number of misclassified records [9]. It is used thanks to its simplicity of computation, and also preferred in CO algorithm to compute fitness [10]. The second type of indicator features classical average indicator, namely Relative Average Percentage Difference and Standard Root Mean Square Error that focus on aggregating relative distances over the distribution of attributes [26]. Last, we implement an indicator that does the trade off between categorical and continuous distance metric: Relative Sum of Square modified Z score [27]. This index is based on the $\mathcal{X}^2$ and take into account both misclassified entities as well as relative difference in the distribution of attributes.

Localization of Synthetic Population

Gen* provides as well many tools to localize a synthetic population. We describes here the main principles of this localization, but more details can be found in [18]. The synthetic population localization tool of Gen* comprises two different while close processes: the first one, called *nesting process*, concerns the actual localization of each entity, e.g. assigning to each entity a "home place", i.e. a geographical object (building, area, etc.) referred as a *nest* and a coordinate in this *nest*; the second process, called *biding process*, enables to associate different spatial objects to the entities of an already localized population (e.g. a workplace).

Data requirements The only mandatory data to provide is a geographic file specifying the geographic objects on which Gen* will locate the entities (*nesting*). We have made the choice to explicitly locate the entities in spatial objects so that each user can define the location best suited to the needs of the model: the *nest* can be buildings, cells of a raster file or even simply a polygon representing the limits of the studied system. The modeler can also provide other data to the localization process, such as "mapping" data, to create a link between the population entities and geographical objects, e.g. the number of people per administrative region. As a refinement, it is possible to input any kind of spatialized data that will monitor the areal interpolation methods. Those data are commonly refereed as *ancillary data* and can be raw satellite imagery, land use or land cover, either raster or vector data.

Methods

Nesting process: The *nesting* process consists of connecting each entity of the population with a *nest*, and to define a location in this *nest*. In order to achieve a more realistic specialization of the entities, Gen* allows the modeler to define spatial constraints to filter possible *nests*. Gen* integrates three basic types of spatial constraints: geometric, contingency and density. In addition, Gen* enables as well to define spatial constraints on the location of entities, such as a maximum distance from roads or point of interest (POI). If the constraints do not find an appropriate *nest* (over-constrained), they can be released. More precisely, for each constraint, a relaxation process can be defined as well as a maximum relaxation function which defines to what extent the stress can be relaxed. When multiple *nests* satisfy all the constraints for an entity, Gen* uses a distribution function to choose one. Gen* provides the modeler with three predefined distribution functions: uniform distribution, area distribution and capacity distribution.

In addition, in order to facilitate the localization process, Gen* provides the modeler with a tool to generate a contingency map or a density map from raw input data or by using statistical learning techniques such as regression. Available areal interpolation techniques make possible to infer a spatial distribution of entities and attributes from the initial mapping data and any ancillary data. Then, it can be used to allocate entities according to it, together with the aforementioned constraints.

Spatial binding: Gen* enables to link a set of geographic objects to each entity. This linking process is very close to the *nesting* process: the principle is to choose for each type of link (for example, workplace, school) a geographical object among a set of possible places. To do this, Gen* uses a combination of spatial constraints and a spatial distribution function. Since it is often necessary to link features with geographical objects close to their place of residence, Gen* offers the possibility of defining a distribution function according to the distance between the entity's location and the spatial objects such as the gravity model. Distribution function can also take into account the attributes of agent and places to bind them according to user define Bayesian rules.

Social Network in Synthetic Population

Following the observed situation in the social simulation domain [19] that is that 69 percent of the published papers using social networks generation were actually relying on basic abstract models. Gen* enables modellers to access such generic generation models. More precisely, Gen* integrates methods to generate:

- regular lattices: either 1D or 2D lattices, with the possibility to adjust the degree of the nodes in the 1D case;

– random networks: following the Erdös-Rényi model and enabling to play on the probability of connection among individuals that actually controls the network density as well as the average degree of the network;
– small-World networks: using the beta-model of Watts [28] that has two main parameters, the degree of the 1D lattice used as the starting structure and the noise beta added to the lattice. The latter corresponds to the probability of randomly rewiring a link in the network;
– scale-free networks: using the preferential attachment model [29] that allows to control the network density as well as the slope of its power-law distribution of degrees.

Apart of such solutions, Gen* facilitates the building of *ad hoc* networks. Indeed, it provides access to the properties of each generated individual and their location (following the preceding steps in the generation process of the synthetic population) enabling therefore to build spatial networks (based on the location of individuals) or p1 social networks [30] (based on the individuals' attributes and homophilic rules).

Integration into the GAMA Platform

The main motivation of the Gen* project has been to provide tools to generate a synthetic population for agent-based models. Reviews of the literature in the JASSS[2] journal have shown both for synthetic population [31] but also for synthetic networks [19] that synthetic populations are rarely used in agent-based models for social simulation. When it is the case, the algorithms used are often very basic. We argue that a reason is that these tools are not easily accessible for modelers, in particular when they are not computer scientists or mathematicians. We thus argue that it is necessary to integrate such a tool inside an agent-based modeling tool to ease its use. In this paper, we choose to extend the GAMA modeling and simulation platform[3] [32, 33]; we choose this platform as it manages very well the spatial data and because it is particularly well-suited to develop large-scale models, in which the synthetic population generator library Gen* is particularly relevant.

The GAMA platform is a generic agent-based modeling and simulation tools which provides a dedicated modeling language (GAML) specifically designed for any modeler to build his/her own model. Its main features are to integrate very easily spatial data (vector and raster), to be natively multi-level and designed to support large-scale models with a huge amount of data. It also provides many tools to design participative simulations [34]. It benefits for a very dynamics community of developers and users and is used worldwide.

[2] http://jasss.soc.surrey.ac.uk/.
[3] http://gama-platform.org/.

```
// Define the population generator
gen_population_generator pop_gen;

// Set the generation algorithm
// Here it will be the Direct Sampling
pop_gen <- pop_gen with_generation_algo "IS";

// Set the individuals attributes and their possible values or range of values
// Here indivduals have an age (integer value) and a couple status (among single or couple)
pop_gen <- pop_gen add_attribute("Age", gen_range, ["0 to 17", "18 to 110"]);
pop_gen <- pop_gen add_attribute("CoupleStatus", string, ["single", "couple"]);

// Set the constraints in terms of localization
// Here agents will be located in buildings
pop_gen <- pop_gen localize_on_geometries("../data/shp/buildings.shp");

// Set the social networks linking individuals
// Here the neighbourhood network is generated as a spatial proximity graph
pop_gen <- pop_gen add_network("neighbours","spatial",500.0);

// Creation of 100 (localized) agents from this population generator
create people from: pop_gen number: 100 ;

// Generate the graph of neighbours
pop_gen <- pop_gen associate_population_agents(people);
graph<people> graph_neighbours <- pop_gen get_network("neighbours");
```

Fig. 18.1 Example of GAML code illustrating the three aspects of the Gen* population generation

We developed an extension to the GAMA platform,[4] which extends the GAML language to allow modelers to create the synthetic population, to locate it and to structure it in a social network directly using the modeling language. An example of code is provided in Fig. 18.1 and the Fig. 18.2 illustrates a more complex generated population (agents with 5 attributes, located in buildings, mapped using IRIS demographic data, and structured using two social networks). The principles of the integration are the following ones:

1. Creation of the population generator and its configuration with a generation algorithm (Direct Sampling in the example), the individual attributes of the population to be generated (age and sex in the example), the constraints in terms of localization (in buildings in the example) and the social networks that can be generated (a spatial network in the example);
2. Creation of a chosen number of agents of a given species[5] generated and located using the population generator;
3. Creation of the social network(s), once this population of agents is created.

We argue that providing such a tool directly in an Agent-based platform will ease the use of SP in agent-based social simulation. Modelers will thus be able to generate a population within modeling environment and to make use of it directly in the simulations. Furthermore, it can help the modelers to run batch exploration over the synthetic populations in order to assess its impact on the simulation results: e.g. to analyze the effect of population size keeping distribution of attributes constant

[4]The extension can be directly downloaded from GAMA 1.8 at the https://www.irit.fr/genstar/p2updatesite/.

[5]`Species` is the GAML keyword representing a kind or a class of agents.

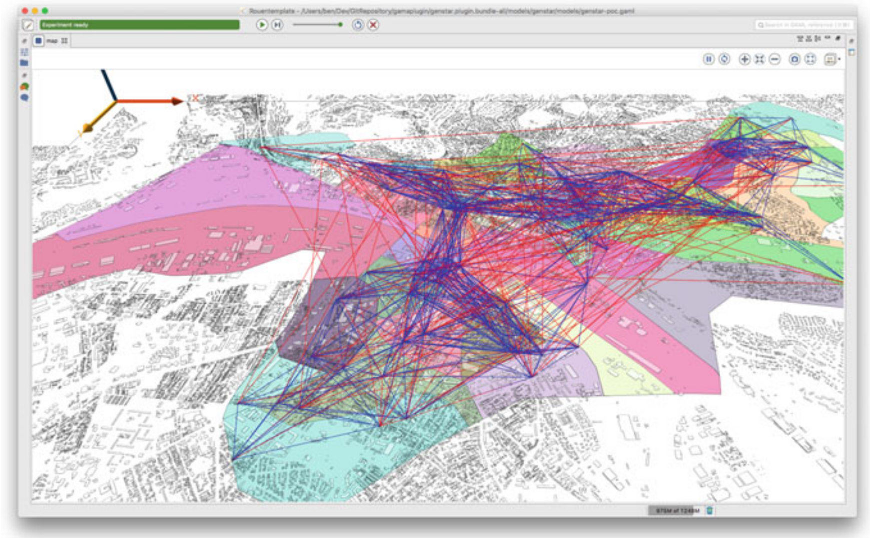

Fig. 18.2 Example of a population composed of 100 agents generated with 5 attributes (age, CSP, sex, couple and iris) from INSEE data, localized on IRIS inside buildings and linked through 2 social networks (a random network and a proximity network)

or tune the structure of the population according to user define hypothesis on the distribution of attribute.

Conclusion

In this paper, we presented Gen*, an integrated synthetic population generation tool, that can be used in the generic agent-based modeling and simulation GAMA platform. We tried with Gen* and the GAMA plug-in to provide a powerful tool, but at the same time, an easy one to use and adapt to many applications, either in terms of entities to generate or in terms of data used. A first encouraging result is that Gen* is already used in several projects dealing with different applications: evacuation of an urban area evacuation facing hazards [35], diffusion of vegetarian diets, study of urban congestion and pollution emission in the city of Dijon [36], etc.

In terms of perspectives, many new features are already planned. The first one concerns the possibility to define multi-level populations (e.g. households composed of individuals). Indeed, in its current version, Gen* does not enable to generate such populations whereas many case-studies require to take several levels into account. To face this issue, we plan to implement several new algorithms: some that rely on a layer flattening process coupled with classical SR methods (e.g. IPU [37] or HIPF

[38]) or using mixed strategies that make use of CO algorithm to match up layers of SR based generated entities [39, 40].

Another perspective concerns the definition of more complex social network, mixing classic structures (small-world, scale-free, etc.) with other information such as the agent attributes and their localization.

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Chapter 19
Towards the Evolution of Synthetic Population in Continuous Time

Johan Barthélemy, Morgane Dumont, and Timoteo Carletti

Abstract Synthetic populations are tools widely spread in the agent-based community for representing a baseline population of interest whose dynamics and evolution will be simulated and studied. The dynamic evolution of the synthetic population has been typically performed using a discrete and fixed time step. A continuous approach based on the Gillespie algorithm is proposed in this research. Preliminary experiments illustrate the potential of the new method before future work are discussed.

Keywords Synthetic population · Continuous evolution · Gillespie algorithm

Introduction

Synthetic populations are tools widely spread in the agent-based community for representing a baseline population of interest whose dynamics and evolution will be simulated and studied using microsimulations. Using synthetic populations typically consists of two steps. The first one is the generation of the synthetic population statistically as similar as the population of interest. This problem has been extensively studied since the seminal work of [1]. As such, many different methods are available in the literature. Selecting the right one depends on the data available for the generation process [2–5]. We refer the reader to [5, 6] and [7] for a review of existing approaches.

The dynamic evolution of the synthetic population to forecast the future population is the second step. This is done by feeding the microsimulation with the baseline synthetic population generated in the previous step and apply a set of models and rules to its agents in order to simulate the dynamics of the population. Recent large

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Springer Proceedings in Complexity,
https://doi.org/10.1007/978-3-030-61503-1_19

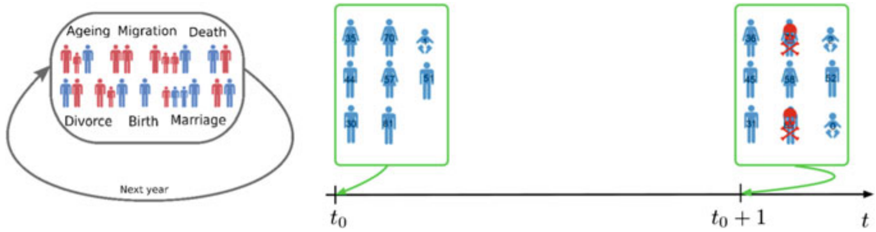


Fig. 19.1 Conventional approach to evolve synthetic population in TransMob. Each simulated year t_i the following sequence of models is applied to obtain the synthetic population in t_{i+1}: ageing, dying, divorcing, wedding, births

microsimulation based on this approach include ILUTE [8], MOBLOC [9], VirtualBelgium [10] and its extension VirtualBelgium in Health [11] and TransMob [12].

Usually, the simulation of population's evolution is driven by a large number of models defining the interactions of the agents between them and/or their environments. Even though each model can have its own time-scale, the conventional approach to simulate the evolution of a population is to use a global time step, e.g. one year, to evaluate all the model in a given predefined sequence. This situation is depicted in Fig. 19.1.

Despite having produced satisfactory results in many different applications, this approach is not ideal. Indeed, the generated population is sensitive to the ordering of models used in the evolution, i.e. different sequences of models will result in significantly different populations. To mitigate this issue, a calendar-based approach has been recently proposed [13], but still relies on a fixed time step. In addition, it is usually impossible to simulate processes evolving on short time scales due to the typically large time step used.

The goal of this research is to propose a framework to evolve a synthetic population solving both aforementioned issues, i.e. without a fixed order for the models and with a dynamic time step. The proposed evolution scheme relies on Gillespie algorithm (Gillespie 1977) originally made to stochastically simulate coupled chemical reactions and is briefly detailed hereunder.

Continuous Evolution Scheme

Let us denote by $P = \{d_1, \ldots, \in d_K\}$ the synthetic population of size K, and $M = \{m_1, \ldots, m_l\}$ the set of l models used to evolve P until a given time horizon t_f is reached. The main steps of the proposed algorithm are:

1. **Initialization**: initialize the baseline population P at time $t = t_0$.
2. **Monte-Carlo step**: determine the most probable $m_s \in M$ as well as τ, the most probable time step at which m_s will occur.

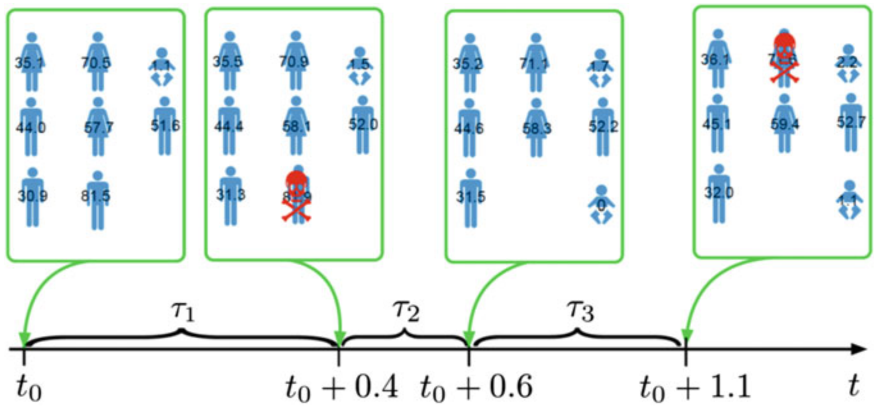


Fig. 19.2 Schematic representation of a continuous time evolution. At each iteration, the most probable time step and model are selected. In this example, the following sequence of models is applied: ageing and death, ageing and birth, ageing and death

3. **Update**: m_s is applied to P and $t \leftarrow t + \tau$. The transition probabilities of every $m_i \in M$ are also updated.
4. **Iterate**: go back to 2 while $t < t_f$.

This evolution scheme is illustrated in Fig. 19.2.

The first step to assess the potential of this new methodology is to compare it against validated ones. We thus simulate the evolution of a small synthetic population of 15,000 individuals using a limited set of models (ageing, birth, death) using the recent calendar-based approach as well as a conventional one relying on a fixed (discrete) time step.

Initial results indicate that the approaches produce comparable results. For instance, Fig. 19.3 shows that the evolution of the average population size and the average age of the individuals over time are similar.

The proposed approach also allows the use in the models of non-constant probabilities over time to take into account seasonality effects. For instance, let us assume that the natality rate can follows one of the two the probability distributions represented in Fig. 19.4, i.e., either uniform or non-constant. The outcomes of those two distributions on the number of births over time in the population are illustrated in Fig. 19.5, where the seasonality induced by the non-uniform can be clearly seen.

From those early experiments, it can be seen that the proposed approach has potential to simulate realistic synthetic population evolution as it does not assume any a priori sequence of models to apply, nor a fixed time step.

Nonetheless, this method is computationally intensive and not well suited to large population. Indeed, as the simulated population grows, τ decreases and can become very small, thus increasing the number of steps to reach t_f. Consequently, improving the scalability of this approach will be investigated.

Finally, and more importantly, future development will also focus on adapting this approach to synthetic populations made of individuals gathered in households.

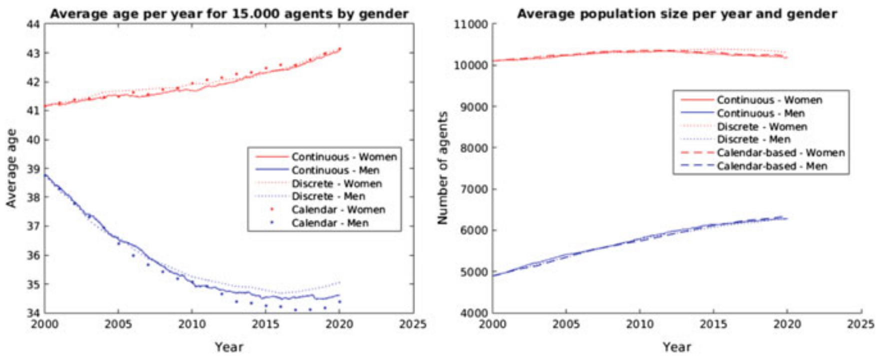
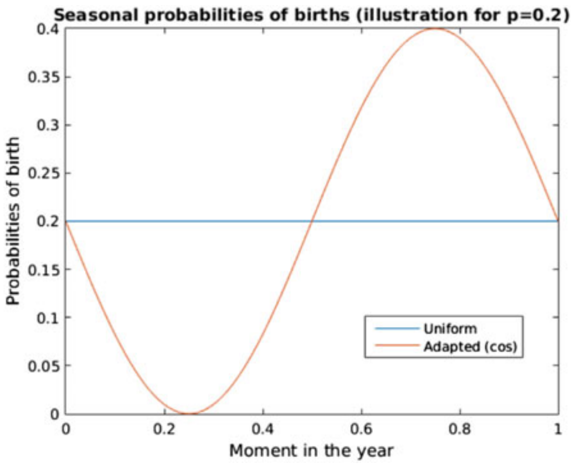


Fig. 19.3 Evolution of the average year of the individuals per gender (left panel) and population size per gender (right panel) for different evolution algorithms. It can be seen that the algorithms produce similar evolution curves

Fig. 19.4 Birth probability distribution functions: uniform (blue), non-uniform (red)



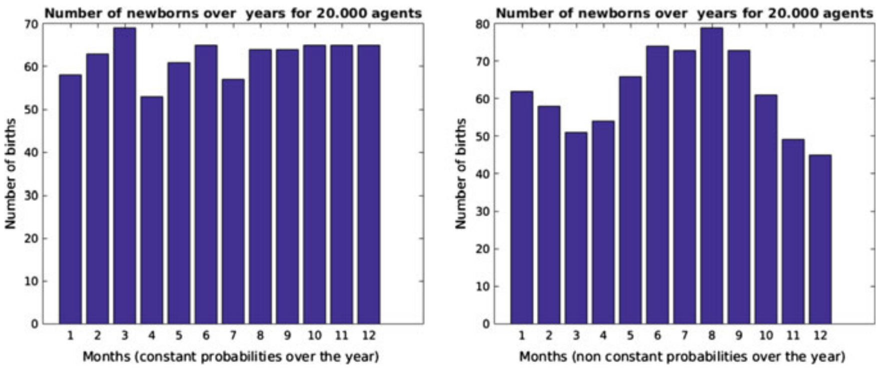


Fig. 19.5 Number of births per month assuming a constant uniform probability distribution over the year (left panel) and a non-uniform probability distribution (right panel)

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Chapter 20
Using Mobility Profiles for Synthetic Population Generation

Alperen Bektas and René Schumann

Abstract Agent-based modeling (ABM) is a wide-spread technique that can be utilized as an artificial laboratory for in-silico experiments of real-case studies of different domains such as mobility. To initialize agent/environment attributes and their relationships, disaggregated (individual level) micro-data is required as an input. However, having such data is not often possible due to several reasons such as privacy concerns. To bridge the gap, generating realistic synthetic data (from census/survey data) becomes an initial and essential step of agent-based modeling. In this piece of research, we employ the mobility profiles of the Swiss population for generating synthetic populations along with their mobility activities. To validate the synthetic data, an agent-based model, which is already calibrated to the empirical data, is re-run with a sample and the generated synthetic data. Accumulated decisions of agents in both cases are compared. In addition, marginal frequencies of control attributes are benchmarked. The first obtained results demonstrate that increasing size of the generated population decreases the difference between simulation results of the synthesized data and the real data.

Keywords Synthetic population generation · Agent-based modeling · Mobility profiles · Cluster analysis · Demand modeling

Introduction

In recent years, the demand for methods/paradigms, which require individual level data (micro-data), has significantly risen. This increase can be attributed to various determinants such as developments in computational power, easier data collection or

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increasing trend of capturing heterogeneity. One of these paradigms is agent-based modeling (ABM). It is considerably useful to reflect individual behaviors as well as environmental and demographic attributes. It provides a flexible platform where various disciplines (e.g. sociology, psychology, computer science) blend together as one. Agent interactions with each other and with the environment, decision-making mechanism and collective outcomes can be modeled by using theories of these disciplines. Thus, agent-based models can be used as artificial laboratories for in silico experiments of real-case studies. Through a calibrated and validated agent-based model, future scenarios can be explored before implementation.

To depict real world dynamics in a bottom-up designed agent-based model, disaggregated (individual level) micro-data is required. Except for a few exceptions such data is not often available due to several reasons such as privacy concerns [7]. Even if such data is available for one-to-one matching with agents, this is not favorable because of the strong dependency to the data source. Due to these reasons, generating realistic synthetic populations of simulated areas has become an initial and essential step for agent-based models. A synthetic population is a microscopic representation of a real population [1]. It is not one-to-one identical to the real population. Instead, it mimics, regarding some specific attributes by having similar statistical distributions. It is statistically close enough to the real population to be used in models such as an agent-based simulation.

As a case study of agent-based modeling, we are currently undertaking modeling heterogeneous mobility demand by an agent-based model called BedDeM (Behavior Driven Demand Model) that is explained detailedly in section Behavior-Driven Demand Model (BedDeM). Rather than routing (exact coordinates), we investigate potential determinants, which in principle can influence mobility behaviors of individuals in particular modal choices (e.g. car, train, soft mobility modes). To make decisions of agents in the model as realistic as possible, we use a decision making mechanism from psychology called Theory of Interpersonal behavior (TIB) [13]. So far we've been using a sample from a joint table of two data sets (Micro-census (MTMC) [2] 2015 and Swiss Household Energy Demand Survey (SHEDS)[17]) to initialize the agent population in our previous experiments. Characteristics of the data are explained in section Characteristics of the Data. Since dependence to real data sets is not favored, in this research we aim to generate realistic synthetic data for our model. Another reason is that being dependent on data-sets does not allow us to expand the number of agents more than the number of respondents (e.g., to have a high resolution). In the previous research, we clustered the Swiss population based on their mobility related features such as the modal choice to obtain mobility profiles [4]. Narrowed down intra-cluster distributions were obtained along with the medoids of each cluster (i.e. profile). Through an optimization process, intra-cluster cohesion and inter-cluster separation were enhanced that leads to less variation (intra-cluster). The idea of this piece of research is generating synthetic data profile by profile according to shrunk intra-profile distributions (i.e. less variation) and then merging them properly to obtain the final synthetic data (see section Generation Procedure—Synthesizer). As validation, BedDeM simulation is employed with a sample from real (empirical) data and 3 synthetic data sets (with different population sizes) separately.

Simulation results of the real and the synthetic data are compared in section Evaluation. Besides, marginal frequencies of control attributes are benchmarked. In the next section, we explain some other related studies. The paper ends with limitations and conclusion sections.

Related Work

There are various approaches for synthetic population generation. This study is related to most of them in terms of the problem rather than the methodology. Two of the approaches Synthetic Reconstruction (SR) and Combinatorial Optimization (CO) come to the forefront with their variations [10].

SR methods consist of two steps; fitting and generation. These methods are generally based on Iterative Proportional Fitting (IPF) technique (it was first established by Deming and Stephan [6]), that generates a multivariate table of conditional probabilities, which are derived from cross-tabulations of the desired attributes of the base population. In the fitting stage, cells in the table are fitted to sub-totals that are gained through survey/census data. After that, in the generation step, joint probabilities obtained in the fitting stage are utilized to expand micro level sample data to the full population. Frick's paper gives a good insight into how to use the IPF for categorical variables [8]. In that study, a synthetic population with hectare based level resolution is generated. Farooq et al. touch on shortcomings of the IPF [7]. The paper states dependency on the sample data is essentially blowing up of the sample rather than reproducing it from the heterogeneous points in the attribute space. Limitation to categorical variables is another shortcoming that the paper taps. It introduces a Markov Chain Monte Carlo (MCMC) simulation-based technique that can overcome the shortcomings. It benchmarks the simulation-based approach with the IPF technique via the standard root mean square error (SRMSE). Even in the worst case, the simulation-based approach overcomes. The technique in the paper is restricted to non-hierarchical data that is underlined by Casati et al. [5]. They introduce an extended version of MCMC called, hierarchical MCMC (hMCMC) to overcome that restriction. In the paper, hMCMC is combined with generalized ranking (GR). Jeong et al. also underline the IPF's dependence structure of the reference joint table [12]. The paper introduces a novel capula-based joint fitting (CBJF) approach. It compares the CBJF technique against the IPF. In most cases, the CBJF is superior to the IPF. One of the limitations if the CBJF seems that it can be applied only to ordinal variables. Antoni et al. use a population synthesizer tool, called MobiSim, which generates agents and distributes them to households according to demographics data [1]. In another study, the performance of two synthesizer tools PopSynWin and PopGen are compared [11]. Both use SR techniques. PopGen performs better in generating population at the individual level. The authors argue that the performance of tools varies according to variation in household and person characteristics of a particular geography. Similar SR based synthesizer tools are addressed such as ILUTE, FSUMTS CEMDAP, ALBATROSS, etc. in other studies [3, 14–16]. Another comparison research was done by Harland et al. [9]. The study compares three techniques; deterministic re-weighting, conditional probability, and simulated annealing algorithm. Synthetic populations are generated by them for the city of Leeds in the UK. Simulated annealing was found the best performing one among them.

CO techniques (introduced by Williamson [18]) are concerned with finding an optimal or close to optimal solution among a finite collection of possibilities (joint distribution pools). They involve the random selection of a group of individuals from disaggregated data so that it matches the population size of the small area. Huynh et al. present a paper that can be useful to understand the concept of CO. They use the CO technique to generate a synthetic population of Sydney for their agent-based model [10]. The paper depicts a methodology to initialize and evolve a synthetic population in the model. The initial population is synthesized over aggregated data of demographic distributions and attributes of agents evolve in time endogenously (aging, dying, marriage, divorce, etc.) in the model within a time series (2006–2011).

In brief, there are several validated approaches. We aimed to obtain mobility profiles by clustering in the previous research according to our needs (e.g., exploring mobility profiles, using these profiles to calibrate our model [4]). In this piece of research, we utilize already obtained profiles (i.e. as a milestone) for synthetic population generation. So, we've not used one of the validated approaches that are explained above although some of them are very successful.

Characteristics of the Data

In this section, we look close to the real (empirical) data that is utilized by the model so far as to simulate heterogeneous mobility demand in Switzerland. Two qualitative data sources, a census (MTMC [2]) and a survey (SHEDS [17]), were combined to obtain three tables (subsets of the data); the population (agent/individual attributes), the schedule (trips/activities), and the correspondence (vehicle and resource attributions) [13]. This study aims to generate synthetic versions of these tables that mimic the real ones statistically. The population table consists of 180 individual attributes (of respondents) [13]. The table contains mixed-type attributes (i.e. categorical, numeric). The MTMC is utilized to obtain socio-demographic attributes (e.g. age, income level, household size, canton, municipality type, education level, etc.) while the SHEDS is mainly used for psycho-social values (e.g. environment friendliness, mobility preferences, habits, emotions, etc.) to map the decision-making mechanism of agents. A detailed description of how to map the survey data to the decision-making mechanism can be found in [13].

The schedule table contains mobility activities (trips) of the respondents (in the population table). It contains 8 attributes that determine characteristics of trips such as `departure_time`, `distance_of_trip` and `purpose_of_the_trip`. The number of entities in the schedule table depends on the population table. Because the population table has the `number_of_trips` (daily) attribute, which is aggregated to find the length of the schedule table (see Eq. 20.1).

$$Schedule\ length = \sum_{i=1}^{n} A_{i,number\_of\_trips} \tag{20.1}$$

Vehicles and resources of the respondents are located in the correspondence table. It has 3 attributes; `ID` (respondent's ID), `type_of_vehicle` and `type of_resource`. The `type_of_vehicle` consists of vehicles (e.g. car, bike, motorbike) with various power-trains (e.g. diesel, gasoline, hybrid, electric). The `type_of_resource` attribute contains mobility resources of agents (e.g. travel-cards, driving license, etc.). When trips are performed, the correspondence table is checked to see available mobility modes for a modal choice.

Behavior-Driven Demand Model (BedDeM)

BedDeM is an agent-based model (simulation), which aims to capture the heterogeneity of individual demand. In this piece of research, it is calibrated with the mobility data as described above. Thus, it becomes a core tool to model heterogeneous mobility demand in Switzerland [13]. Agents perform their trips based on a decision making mechanism inspired by Triandis' Theory of Interpersonal Behaviour (TIB) [13]. The theory involves various psycho-socio and economic determinants such as emotions, habits, monetary cost, social learning, etc. that influence mobility behaviors of agents. After reasoning, agents chose one of the available mobility modes (e.g. car, train, bus, tram, etc.) to perform their trips, called modal-choice.

At the current milestone, we utilize the qualitative data (MTMC and SHEDS) that are described in the previous section. To initialize the model, first, we took a representative sample of respondents from the population table. Individuals in that sample are matched with agents in the model. Basically, each agent employs the real attributes of a respondent. The sampled population consist of 3080 individuals along with 180 attributes. Each individual has a `weight_to_universe` value, which is utilized to fit results to the whole population (i.e. scaling). Some of the attributes are used actively by the simulation whilst some others stay descriptive (transitive). Descriptive attributes are mostly used for the post-processing phase to makes analyses (e.g. describing who are soft-mobility users). Trips of selected respondents are obtained through filtering by respondent IDs. In the same vein, vehicles and resources of the selected respondents are gained (in the correspondence table). Then agents begin to perform their trips in the schedule table simultaneously. They take into account their vehicles such as car and their resources such as public transportation subscriptions in the correspondence table while reasoning. After that, they decide on one of the available mobility modes. Thus, BedDeM generates individual mobility demands of selected respondents (i.e. with which mobility mode they perform their trips). These demands are accumulated to obtain macro-patterns (along with total kilometers) over which the model is calibrated [13]. They should be consistent with real (empirical) data sources. For instance, ca. 22% of trips in Switzerland are performed by train (yearly) [2]. It should be reflected in the macro-patterns that BedDeM generates. Parameters that are used actively in the decision-making mechanism of agents are tuned after several iterations. Detailed information about the calibration process can be found in our recent paper [13].

Generation Procedure—Synthesizer

In this section, the method that is followed to generate realistic synthetic data is introduced (see Fig. 20.1). The idea is generating synthetic data for each mobility profile separately based on narrowed down intra-profile distributions (i.e. smaller attribute spaces) and merging them. In this study, BedDeM is employed with both the real and the synthetic data separately to compare results. This comparison gives an idea about how well the generated synthetic data mimics to the real data. Thanks to the calibration process, macro-patterns that BedDeM generates with the sample data are in line with the macro-patterns in the real data. In other words, accumulated decisions of agents are similar to the respondents'. Hence, comparing simulation results of the real data against the synthetic data illustrates their closeness.

We are currently developing a module, called `Synthesizer` (see Fig. 20.1). It is initialized by the desired population size (the number of agents). According to this input, first, it distributes the entered population size to the mobility profiles according to their sizes, which were obtained in the previous study [4]. Because proportions of the profiles are heterogeneous. Synthetic population, schedule and correspondence tables are generated iteratively for each profile. Generation of categorical attributes hinges on intra-profile marginal frequencies (distributions) except for location attributes, for which conditional distributions (constraints) are maintained due to legal constraints. For instance, we have two location attributes for the population; `canton` and `type_of_municipality` (according to the definition of the Swiss Statistical Office [2]). Constraints are applied (via cross-tabulations) for them because some municipality types do not exist in some cantons. Therefore, using only marginal distributions might lead to assign some agents in unrealistic places. To generate numeric attributes firstly the type of fitting distribution is detected by statistical tests. For instance the `distance_of_trip` in the schedule table. Firstly, its fitting distribution is detected according to the Cullen and Frey graph (see. Fig. 20.2).

The kurtosis and squared skewness of the real data is plotted along with the bootstrapped values. It seems that possible fitting distributions are the Gamma and the Weibull. After comparing empirical and theoretical values like in Fig. 20.3, the synthetic values are fitted to the Weibull distribution. This figure compares empirical values against theoretical values in terms of four evaluations; densities, Q-Q (quantile-quantile) plot, cumulative distribution functions (CDFs), and P-P plot (p-value plot). These statistical evaluations give an idea about how fit empirical values to the theoretical ones (i.e. how good is the fitting distribution). Although these three distributions are quite close to each other, the Weibull was better judged by Q-Q plot.

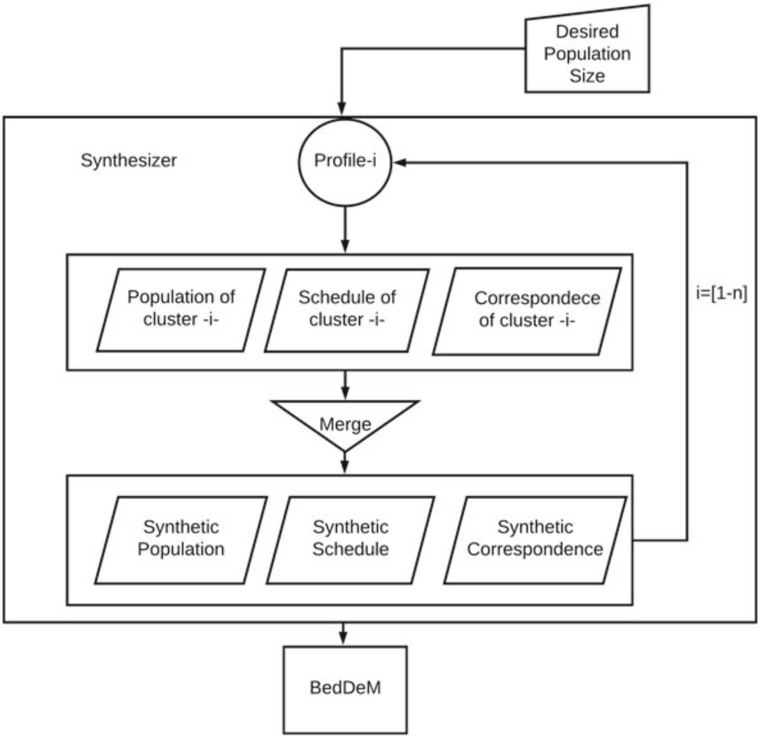
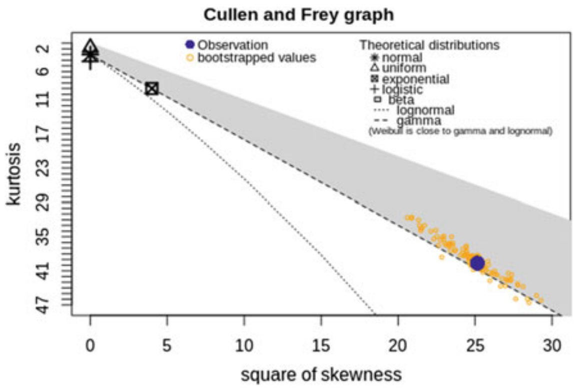


Fig. 20.1 Architecture of the Synthesizer (n = number of profiles)

Fig. 20.2 Illustration of bootstrapped values and fitting distributions



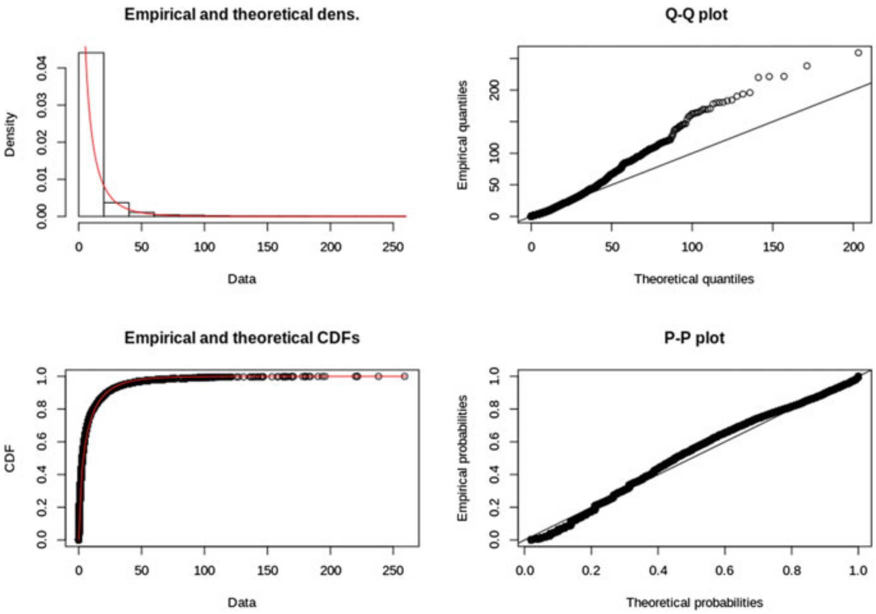


Fig. 20.3 Comparison of empirical and theoretical values

These tests are applied for each numeric column. Basically, the fitting distribution of each numeric column is detected and the Synthesizer is configured accordingly. Then, random numeric values within the boundaries of each profile, which follow the detected fitting distribution, are generated by the Synthesizer. Thus, generated values mimic the same density distribution of the real ones.

We obtained 13 mobility profiles and their medoids in the previous study [4]. Basically, respondents in the empirical data were clustered based on their mobility related attributes (i.e. characteristics) to obtain these profiles, which are used for this study as a milestone. The Synthesizer takes the first profile and generates its synthetic data. Then in a loop, all profiles' data is generated successively. Generated synthetic data is merged to obtain the final one. Since attributes (i.e. column names) of generated data of each profile are identical, the merging process (i.e merging synthetic data of each profile) is just aggregating rows to each other. Instead of generation as a whole, the Synthesizer generates data profile by profile (modularity) to benefit less variation (i.e. similar respondents are clustered in the same profile). Once the Synthesizer generates all synthetic data, it re-weights synthetic individuals for scaling. In the MTMC, each respondent has a `weight_to_universe` attribute that indicates how many people are represented by the corresponding individual in the real world. This attribute matters when individual demands are accumulated to obtain macro-patterns. Numbers (e.g. kilometers) of each individual is multiplied by its weight_to_universe value to fit whole Swiss population. Therefore, weight_to_universe values of synthetic individuals should be re-calculated according to the entered population size (i.e. weight_to_universe values are different for 10k and for 100k population sizes due to the difference in resolution). The Synthesizer uses the linear regression as in Eq. 20.2 to assigns weight_to_universe values for the synthetic individuals based on the following attributes.

$$\begin{aligned}\text{Weight\_to\_universe}_t = \alpha &+ \beta_1 \text{Canton}_t \\ &+ \beta_2 \text{Municipality\_type}_t \\ &+ \beta_3 \text{Household\_size}_t \\ &+ \beta_4 \text{Income\_level}_t \\ &+ \beta_5 \text{Education\_level}_t + \epsilon\end{aligned} \tag{20.2}$$

These attributes are selected based on a regression analysis. After new values are assigned to synthetic individuals (i.e. according to the entered population size), generated synthetic data become ready to be used by the simulation.

Evaluation

We generate three synthetic populations (along with their schedule and correspondence) with different sizes; 2000, 10000, and 20000 individuals. As has been mentioned, the real data (sample) contains 3080 individuals. BedDeM employs the synthetic and real populations separately (i.e. four different configurations) to check how well the synthetic data mimics the real data (reference). Since The Synthesizer adjusts weight_to_universe values according to population sizes (i.e. to fit whole Swiss population), macro-patterns and total kilometers become comparable. As we can see in Fig. 20.4, the dissimilarity between the simulation outputs of the real and the synthetic data shrinks with increasing population size (the bars are sorted according to the error rates). It means that the synthetic data become more realistic with increasing population size. Both macro-patterns and total kilometers are in line with the reference.

In Table 20.1, the absolute differences (errors) between the synthetic and the real populations are illustrated numerically. The error in total kilometers decrease with increasing population size. It shows that the Synthesizer is quite successful to generate synthetic distances for trips (in the schedule table). Both the detection of the fitting distribution and the data generation accordingly seem satisfactory. The error between macro-patterns (mode by mode comparison) looks higher than the total kilometers. The reason might be attribution of vehicles and resources in the synthetic correspondence table.

In addition to comparing the simulation results, marginal frequencies of the randomly chosen control attributes are displayed in Table 20.2. The proportions of the categories seem quite close. There is no significant difference between there synthetic populations. But some categories with very few proportions, disappear with

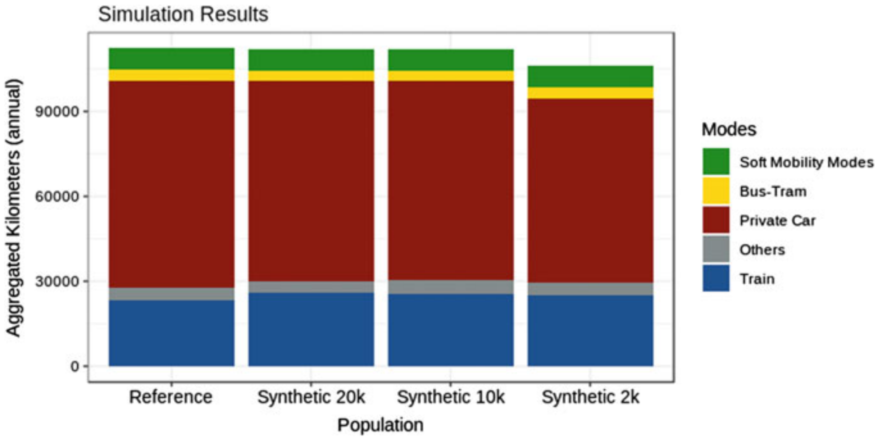


Fig. 20.4 Outputs of BedDeM with different configurations (The kilometers in the y-axis are million kilometers)

Table 20.1 Error rates of different synthetic population sizes

Population Size	Error in Total Kilometers (%)	Error in Macro-patterns (%)
2k	5.6	8.9
10k	0.5	5.4
20k	0.4	5.0

decreasing population size. The results show that generated synthetic data mimic the real data pleasingly already at this early stage of development. The study is quite open for future extensions that are discussed in the future work section.

Conclusion

In this piece of research, we generate synthetic populations along with mobility activities. Mobility profiles are utilized for data generation. Through profiling (clustering), attribute distributions are narrowed down (i.e. the variation in the clusters is shrunk). We've developed a module called Synthesizer, which generates synthetic data for each mobility profile separately. Then the generated data is merged to obtain the final synthetic data. The Synthesizer utilizes fitting distributions (first detect, then generate) for numeric attributes. For categorical attributes, univariate marginal frequencies (intra-cluster/profile) are employed. 3 synthetic populations with activities are generated with different population sizes. The model employs both the real and the synthetic data for validation. The first results show that increasing population size makes synthetic populations more realistic. Marginal frequencies of control attributes

Table 20.2 Comparison of the marginal frequencies (proportions)

Marginal Frequencies of the Control Attributes					
	Categories	2k	10k	20k	Reference
Household_size	1	0.265	0.260	0.259	0.263
	2	0.402	0.416	0.413	0.414
	3	0.139	0.136	0.138	0.137
	4	0.149	0.139	0.142	0.141
	5	0.037	0.040	0.039	0.038
	6	0.005	0.005	0.005	0.005
	7	0.000	0.001	0.003	0.003
Income_level	1	0.019	0.027	0.026	0.022
	2	0.090	0.092	0.093	0.091
	3	0.200	0.195	0.187	0.184
	4	0.301	0.281	0.284	0.274
	5	0.144	0.139	0.143	0.141
	6	0.098	0.101	0.105	0.108
	7	0.057	0.063	0.061	0.061
	8	0.033	0.040	0.038	0.045
	9	0.054	0.058	0.058	0.069
Number_of_cars	0	0.175	0.172	0.168	0.218
	1	0.515	0.505	0.511	0.510
	2	0.268	0.269	0266	0.235
	3	0.038	0.039	0.040	0.337
	4	0.005	0.009	0.008	0.006
	5	0.003	0.001	0.001	0.001

are also checked. Heterogeneity of individuals is maintained. The frequencies are in line with real data. In conclusion, generated data through mobility profiles mimic real data fairly well.

Limitations—Future Work

When categorical attributes are generated, only univariate marginal frequencies are considered (except for location attributes). In other words, constraints among attributes are ignored. In the next step of our developments, these constraints can be maintained to improve the results. For numeric attributes, detection of fitting distributions is made manually. Distributions are detected, then the Synthesizer is configured accordingly. In the next steps, it can be fully automatic. The Synthesizer detects the most appropriate fitting distribution automatically based on some statistical tests and generates synthetic data accordingly. Although numerical attributes are generated randomly based on detected fitting distributions, categorical ones are still fitted to marginal frequencies. It is still a kind of cloning. Generating reasonable and realistic white noises around medoids of profiles might help to overcome that problem in the future work.

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Part V
Using Qualitative Data to Inform Behavioral Rules in Agent-Based Models

Chapter 21
Building a Data-Driven Model of Peer Review: The Case of Science Foundation Ireland

Thomas Feliciani, Pablo Lucas, Junwen Luo, and Kalpana Shankar

Abstract Research has long questioned the validity and reliability of peer review, the process for selecting manuscripts for publication and research proposals for funding. For example, scholars have shown that reviewers do not interpret evaluation criteria in the same way [1] and produce inconsistent ratings [2], and that peer review is subject to gender, ethnicity, seniority, and reputation biases [8, 11].

Keywords Peer review · Research funding · Agent-based modeling

Modeling Peer Review

Research has long questioned the validity and reliability of peer review, the process for selecting manuscripts for publication and research proposals for funding. For example, scholars have shown that reviewers do not interpret evaluation criteria in the same way [1] and produce inconsistent ratings (Bornmann et al. [2], and that peer review is subject to gender, ethnicity, seniority, and reputation biases [9, 12].

Social simulation and agent-based models in particular have proven valuable tools to study the causes of-and seek remedies for- the issues with peer review [16]. This is due to three factors: (1) the complex nature of peer review systems, which are characterized by non-linear interdependencies between applicants, reviewers, and

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the institutions in which they are embedded; (2) the typically high cost and risk of testing interventions; and (3) the notorious scarcity of available data on peer review systems [8, 15].

Since 1969, when scholars have first turned to formal and computational modeling to study peer review [17], 44 modeling papers have been published on the subject. The current state-of-the art shows two lacunae: limited model integration and limited empirical calibration and validation [4].

This paper reports on work in progress aimed at filling in these gaps. In the context of a larger, mixed-method project on the peer review process at Science Foundation Ireland (SFI), we are integrating and building on existing simulation models of peer review to compare them and better connect them to empirical reality. In our work we focus on different aspects of peer review, one of which are aggregation rules. These rules define how the assessment by different reviewers and/or on different evaluation criteria can be combined into an aggregated score, a number which captures the overall worth of a submission. We will present our ongoing work on aggregation rules as example to illustrate the typical lacunae in simulation studies, and how a mixed-methods approach can help solve them.

Aggregation Rules in Simulation Literature

Several simulation studies have explicitly modeled aggregation rules. A complete review is provided in Feliciani et al. [4]; here we mention a few examples. In some models the aggregated score can be the median of the different review scores [11]; some other models take the mean of the scores—the mean can be weighted by the reviewers' reputation [13] or complemented with information on the standard deviation of the individual scores [10].

First Issue: Limited Model Integration

The existing literature consists of an abundance of competing assumptions, alternative implementations, and unconnected findings, which result in the fragmentation of the landscape. The literature on aggregation rules is a prime example: only a few papers have compared more than one aggregation rule (the examples above have), and no one has attempted to implement aggregation rules proposed in previous work. This lack of integration among models and further development of existing models raises important concerns about their generalizability.

The way we are addressing this issue is by implementing the aggregation rules from the literature into our simulation model. By aligning these rules within a common simulation framework, we can test them against one another and find which ones (and under what conditions) are the best at maximizing common outcome metrics of peer review, like efficacy (i.e. the capability to filter out poor quality submissions) and efficiency (i.e. reducing costs).

Second Issue: Limited Use of Empirical Calibration and Validation

Despite many researchers advocating for more empirically calibrated and validated models [7], few have incorporated empirical evidence of peer review in their work. With a few exceptions (e.g. [5]), only a few models of peer review (or of aggregation rules specifically) have been calibrated or validated.

This may be due to different reasons. One reason could be the aforementioned scarcity of data on peer review systems. A second reason could be that, even when data are available, they often are of the qualitative kind, and there is no consensus on what are good practices in using qualitative data source to calibrate and validate models.

We argue that the use of both qualitative and quantitative evidence is necessary for the study of peer review; as such data is necessary to understand the formal rules and the actual practices of the peer review process. Further to that, quantitative data can be deployed for empirical testing of models' predictions [6].

In our study of aggregation rules, we can rely on qualitative and quantitative data on the peer review process in two funding schemes at Science Foundation Ireland. We are using these data in two ways: first, to reproduce the conditions found in a real peer review process, and second, to test the effects of competing aggregation rules against empirically observable outcomes.

The data sources we have are at different levels of aggregation (funding calls, proposals, individual applicants and reviewers) with mixed quantitative and qualitative components (e.g. call documents, instructions, textual reviews, interviews with applicants, and so on). The use of qualitative data sources in particular leads to some challenges which are of common interest for modelers who work with these data types.

Use of Qualitative Data Sources

The first challenge concerns the formalization of the model—that is, the initial phase of model building where the modeler translates an informal description of a process into a formal system. In our case, formalization means translating reviewer guidelines and SFI regulation and guidance documents into code for the agent-based model.

The literature offers few examples of protocols or methods to produce code based on some kinds of qualitative data. One example is the Engineering Agent Based Social Simulation framework (EABSS), which demonstrates how model development can be driven by a focus group [14]. Others had interview data as starting point: interviews can be used to draw cognitive maps, and cognitive maps are implemented in the simulation environment to guide agents' behavior [3].

A second challenge concerns the use of qualitative data for empirical validation of a simulation model. To our knowledge, the only way of testing numerically-expressed model predictions against qualitative data (e.g. a report by the chair of a SFI sitting panel) is to convert the qualitative data into quantities. For textual inputs (like reviews) we can do the conversion with a combination of manual coding and computational methods (e.g. natural language processing)—this, at least, is the approach we are taking to translate textual reviews into input for the empirical calibration of a simulation model of aggregation rules.

Conclusion

By taking our ongoing study of aggregation rules in peer review as an example, we have illustrated two common gaps in the modeling literature, why it is important that we address them, and how we can do it. One of the two gaps concerns the insufficient interface between models and the real world: we have argued that the use of mixed data sources can alleviate the issue, and we have summarized our strategies for implementing diverse data sources in the empirical calibration and validation of a simulation model.

To conclude, our modeling work on the peer review process at SFI has two ambitious objectives: (1) to test competing assumptions and modeling strategies, and (2) to pioneer the integration of qualitative evidence into a simulation model, for which standards have yet to emerge.

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Chapter 22
Building a Bridge from Qualitative Analysis to a Simulation of the Arab Spring Protests

Stephanie Dornschneider and Bruce Edmonds

Abstract This paper builds a 'bridge' between a qualitative analysis and the design of an agent-based simulation by applying the CSNE framework, which distinguishes between context, scope and narrative elements. Qualitative data were constructed from ethnographic interviews on the Arab Spring in Egypt and Morocco. To identify narrative elements, the data were analysed by coding procedures from grounded theory and a computational analysis. Through a series of conversations and structured questions, the scope and context, which were largely implicit in the data, were specified, and a simulation was produced in a process akin to 'rapid prototyping'. The aim was to produce the design for a simulation that included the key elements and behaviours identified from the qualitative data and as few other elements as possible. This paper describes this process, the CSNE framework, as well as the simulation that resulted. The lessons learned for such an exercise are reported.

Keywords Protests · Arab spring · Egypt · Morocco · Interviews · Qualitative analysis · Context · Scope · Agent-based simulation · Qual2rule

Introduction

It is (or, at least, *should* be) a principle of science that one does not ignore evidence (at least not without a very, *very* good reason). If one accepts this then one should not ignore either qualitative or quantitative evidence. All kinds of evidence have their own difficulties—and qualitative data is no exception—but that is no reason to ignore it. On the other hand, agent-based simulation is flexible enough to integrate a wide range of kinds of evidence and can provide a well-founded way of integrating qualitative and quantitative data [1]. There is a lot of valuable qualitative evidence

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available, and if there were an accepted, systematic and transparent method for going from qualitative data to elements of a simulation, then more modellers might utilize it [2]. This work is meant to contribute towards developing such methods.

Here, we present a collaborative research project between an agent-based modeller and a qualitative researcher. The collaboration is inspired by a research project investigating the question what motivated people to participate in the Arab uprisings, large-scale protests against autocratic regimes in the Middle East between 2011 and 2012. The aim of this paper is to experience and explore the process of bridging between qualitative analysis and elements of an agent-based simulation, as well as to illustrate the possibilities.

Constructing Data About the Arab Spring

The Arab Spring were mass uprisings in the Middle East that were triggered by the self-immolation of a street vendor in central Tunisia in December 2010. The uprisings involved millions of protestors throughout the Middle East and had unprecedented consequences, leading to the ouster of President Ben ‘Ali in Tunisia, President Mubarak in Egypt, and President Saleh in Yemen, the death of Colonel Gaddafi in Libya, and civil war in Syria. Nevertheless, many Arab countries returned to autocratic rule soon after.

The Arab Spring had different trajectories across the Middle East. To avoid focusing on the trajectory of one particular country, two settings with opposite experiences of the uprisings were chosen for the qualitative study—Egypt and Morocco. In Morocco, the main Arab Spring protests happened on February 20, 2011. They forced King Muhammad VI, who remains in power until today, to introduce constitutional changes, which were confirmed by a referendum in July 2011. In Egypt, the main Arab Spring protests happened on January 25, 2011. They led to the resignation of President Mubarak in February 2011 and were followed by the first free elections in Egyptian history, which brought the Muslim Brotherhood into power. A year later, the military took over and a new, autocratic President, al-Sisi, was inaugurated.

We constructed data from ethnographic interviews with individuals who participated in the Arab Spring protests, as well as with individuals who stayed at home instead. In Morocco, interviewees came from Rabat, Sale, Casablanca, and Marrakech. In Egypt, interviewees came from Cairo and Alexandria. The sample included 65 males and 28 females. Most of the interviewees (81%) were adults aged between 20 and 50. We also constructed data from Facebook posts. We focused only on posts in which individuals responded to the calls for the main protests. The Facebook groups that issued the calls for these protests are *Kulana Khalid Sa’id* (Egypt) and *Mouvement du 20 Février* (Morocco). Hundreds of individuals responded to these calls, from which 19 posts by individuals who were planning to participate in the protests were selected for the qualitative analysis. By contrast, posts that consisted of emojis, poems, or statements that did not express an intention to participate in the protests, were not included in the study.

From Qualitative Data to Simulation Elements

Analytic Framework

To construct and analyse data, we apply the CSNE analysis framework [3]. C stands for Context and addresses the kind of situation one is in that determines the 'bundle' of knowledge that is relevant to that kind of situation (in our case the Arab Spring protests). S stands for Scope. It addresses what is and is not possible given the current situation and observations. NE stands for Narrative Elements. It refers to the narrative elements that are mentioned assuming the context and scope. The hope is that such a framework combines a number of characteristics that make it suitable for this task. It has roots in cognitive science/AI and thus may reflect some of the realities of how humans construct and communicate narratives. It results in structures that have computational correlates within an agent in a simulation. Finally, it is sufficiently flexible to accommodate some of the variety of recorded narrative. We started with this framework in mind when we attempted the bridging process.

Constructing Narratives

To construct qualitative data from which we can develop an agent-based model, we first coded the interview transcripts and Facebook entries into Narrative Elements. In this analysis, we applied qualitative coding procedures developed by Strauss and Corbin [4]. This analysis broke down the individuals' direct speech into three main components: (1) the factors that constitute the narrative, both external and internal (beliefs), (2) direct and indirect connections that link these factors into a narrative (inferences), and (3) the ending of the narrative (decisions to protest or to stay at home). Factors and endings represent the semantics of the narrative elements, whereas inferences represent the narratives' structure. In total, we constructed 121 narratives about participation in the Arab Spring. 102 narratives were identified from interviews and 19 from Facebook posts.

To break down direct speech into factors that constitute the narrative (beliefs), we applied open coding [4, p. 61] and grouped parts of sentences (words, sub-clauses, main-clauses) or entire sentences according to similar and different factors addressed by their propositional contents. In this way, we identified 145 separable beliefs that constituted protest narratives. We then used elements from axial coding [4, p. 96] to create types based on the factors they addressed. When assigning codes, we used the actors' own vocabulary to help preserve meaning ("in vivo" codes [4, p. 69]). For example, one belief about improving living conditions was identified from quotes such as: "People in the villages have better salaries now," and "Life is much better now."

To identify structural elements of the narrative, we examined linguistic connectors, such as "therefore" or "if…then", as well as temporal and logical order. For example, we identified two beliefs connected by an inference from the quote "When I heard about the revolution in Tunisia, my heart was overwhelmed with solidarity for the protestors." We identified the first belief from the sub-clause, B1 "revolution in Tunisia", and the second belief from the main clause, B2 "solidarity with protestors." We identified the inference connecting the two from the temporal connector ("when") and logical reasoning, B1 ⇒ B2.

Based on this procedure, we identified long narratives, represented by indirect connections between beliefs. For example, B2 could be connected to another belief B3 "Therefore, protest at home is also desirable", so that B1 => B2 => B3. Finally, connections between beliefs can end in decisions. For example, B3 could be connected to a decision D "I will join the protests on Tahrir Square", so that B1 => B2 => B3 => D.

Towards Rule Abstraction

The 121 narratives contained by the qualitative data consist of 145 beliefs that are connected to decisions by hundreds of inferences. Therefore, it is not immediately clear which narrative elements might apply in an agent-based model. In response, we applied a computational model [5], which had previously been developed by the qualitative researcher [6]. The model identifies key narrative elements by tracing the beliefs and inferences connected to decisions in each narrative contained by the data. Specifically, the model's output shows which of the 145 beliefs are connected to decisions, which beliefs are held by significantly more protestors than non-protestors, and how beliefs are connected to decisions by indirect inferences. Below, we explain how we apply this output to construct an agent-based model, focusing on (1) causal stories, (2) differences between agents, and (3) contexts. The qualitative analysis does not provide knowledge about scope, and we believe that when programming one does not code for the impossible.

Causal Stories

In past work [7], it was found that explicitly writing down the 'causal stories' we had in our minds was helpful. 'Causal stories' are simplified accounts of a single chain of events that typify the processes known to be occurring. They do not include how different processes may interact, nor the complex enabling or frustrating factors that may impact on the processes. These give an indication of the range of processes that would need to be included within the simulation. Making these explicit can help bring attention to their evidential support (or otherwise).

From our analysis of the qualitative data, we identified three causal stories (see Table 22.1):

Table 22.1 Key narrative elements identified from qualitative data (examples referring to stories 1–3)

Story 1
Safety + Violence abroad => Safety as priority => Decision against protest
Story 2
State attack on protestors => Feeling solidarity with protestors => Protest decision
Story 3
Successful protest abroad => Hope that protest at home will succeed => Protest decision

1. Some stay apart from protests by fear of consequences or worry about family
2. Some agents are initially motivated by conditions or seeing an attack
3. Others may join motivated by positive emotions of (optimism, solidarity…)

Furthermore, we added four stories that include spatial and temporal elements which are implied but not made explicit by our data, and which are important for the design of an agent-based model:

4. Emotion is most catching when sharing the same physical space
5. Emotion builds (and decays) over time
6. Knowledge is cumulative
7. When protesting people tend to gather in readily identifiable locations

The stories did not directly inform the simulation design in any simple manner, but as a constraint. The simulation has to display examples that would correspond to these.

How Agents May Differ

One of the key advantages of moving from a generic (e.g. statistical) to an agent-based account of events is that one can include some of the heterogeneity of individuals [8]. Thus, it is important to identify the ways in which individuals in the population can differ. This informs what variable characteristics agents are given.

In the qualitative analysis, we identified characteristics from the narrative elements (beliefs) expressed by the interviewees. The computational model identified beliefs that were addressed by significantly different proportions of protestors versus non-protestors, allowing us to identify key characteristics that differentiate these two groups. In the agent-based model, we included beliefs with significant differences (1 and 2 in the list below). We also included non-significant beliefs that have been considered important by previous studies of the Arab Spring and protest more generally (3–7):

1. Employed/unemployed
2. Susceptibility to emotion and their current level of emotional arousal

3. Whether on Facebook
4. What personal friends they have (others they would text/phone)
5. Where they are physically
6. Current knowledge of attacks, protests happening
7. Whether protesting and whether attacked

Some of these are unchanging characteristics determined by parameters (e.g. proportion of population that is employed), whilst others quickly vary with events and interactions within the simulation (knowledge, level of emotion).

Different Contexts

Context is a key factor affecting behaviour in the CSNE framework [3]. Thus, we tried to identify what the key differences in context were. This is slightly tricky since context is often implicit in qualitative evidence, and so might not appear directly within the data. Language presumes a common knowledge of things like context so their identification involves the background knowledge of the researchers. Here we determined upon two aspects: location and time of day.

Different *locations*:

- **Home**—away from active involvement, but still in contact via phone and Facebook
- **Street**—socialising area, vulnerable to attack, face-face emotional influence, start of protests
- **Square**—where critical mass is achieved, protests persist

Different *times of day*:

- **Waking**—calmer at start of day but with variation, clean slate as to knowledge of protests, attacks
- **Daytime**—unemployed socialise on street, might move to square
- **Evening**—all socialise in street, might move to square
- **Night**—employed go home, unemployed might go home

This does not mean that these are the only contextual aspects that might be used by individuals in determining the saliency of knowledge, but these are the accessible ones. It might well be that the identification of context requires further development in terms of some specific techniques or interventions during the interviews or some kind of feedback of these to subjects to check for their relevance.

Scope

Scope (in the CSNE framework—see 3.1) is the construction on action (reflected in narratives) due to what is (or is not) possible in any given situation. However this did not come up explicitly in the bridging process because simple programming styles (such as used here) do not bother to code for what is known to be impossible. The scope is thus implicit in the coding. This means that such a simulation will not capture any of the decision-making or frustration that agents might experience in trying things that do not work. This aspect probably needs more consideration.

The Simulation

The simulation was designed to be as directly informed by the qualitative analysis as possible. In other words, to include the elements, processes and decision making as revealed in the narrative data, but to add as little as possible otherwise. Thus the strategy roughly followed that of ‘KIDS’ (Keep it Descriptive Stupid)—aiming for a simulation that reflected the (qualitative) evidence as a starting point [9]. The purpose of the simulation was to explore the process of building a bridge between qualitative analysis and simulation specification, and thus understand it better. Thus, the simulation is just an illustration of what might result from such a process.

Outline Description

As described above, there is a daily cycle of possible events concerning a population of agents, representing citizens. All agents start the day at home, and attacks on them and protests (as well as knowledge of these) develop over the day depending on the phase of the day (morning, daytime, evening, night). Broadly, agents progress to the nearest street locations to socialise (unemployed during the day and additionally employed in the evening). Over night, the agents’ emotional arousal drops a bit, but unevenly. During a new day, agents may be emotionally influenced if they know of an attack then, subsequently, influence each other if on the same patch. If their level of emotional arousal goes above a personal critical level, they might start protesting and move to the square. Their critical level represents that individual’s propensity to an emotional (rather than safety-oriented reasoning) as described above so that this process resembles Granovetter’s threshold model [10].

Many aspects of agent behaviour are context-sensitive, depending on the agent’s location (home, street or square) and the phase of the day. At the moment, these kinds of restrictions on behaviour are simply hard-coded into clusters of if…then… rules for the different times of the day. For example:

```
if context = street [
      …
      if know-of-protest
         and positive-emotion > safety-prop
            [goto-square]
```

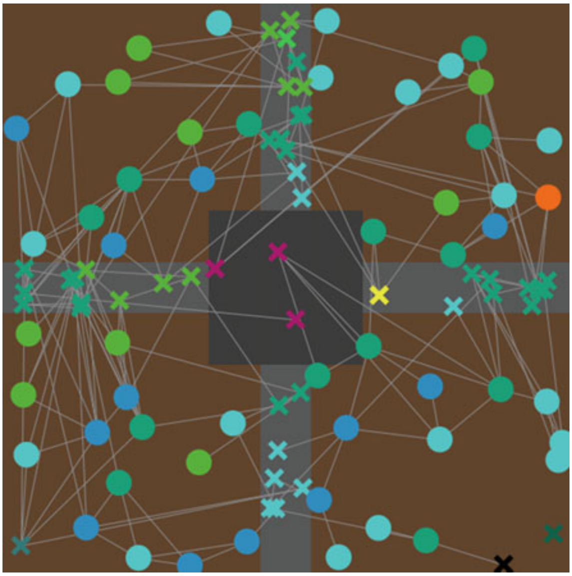

Fig. 22.1 The snapshot of the world from a run of the simulation. The brown patches are residential districts, the grey are streets where people might socialize, the dark grey patch is a gathering place for protest. Citizens are shown as crosses (unemployed) or circles (employed). Their phone-based social links are shown as lines. The colour of agents indicate: if attacked (black); if protesting (magenta); otherwise the more blue their colour the lower their emotional state, the more red the higher their arousal (also slightly greyed if they know of an attack)

A description of the simulation along with the program code can be found in [11] an illustration of what the world looks like is below in Fig. 22.1.

Illustrative Simulation Behaviour

Given that the point of the simulation is only as an illustration, we will not present a sensitivity analysis—that may become relevant after we have developed the simulation further into one that attempts to explain observed aspects of the protests. Here we just show some illustrative simulation behaviour, so the reader gets some idea of how the model that resulted from this bridge-building exercise can behave.

In the graphs and illustrations below, we show the results of one run as the outcomes develop over 40 simulation ticks (representing three and a half days). Figures 22.2 and 22.3, show the developing actions, and knowledge of these (respectively) over this period of time. One can see a strong daily cycle since each day starts

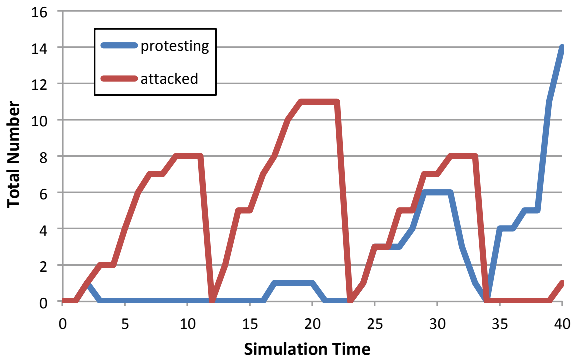

Fig. 22.2 Number of citizens protesting (blue) and attacked (red) over 3.5 days

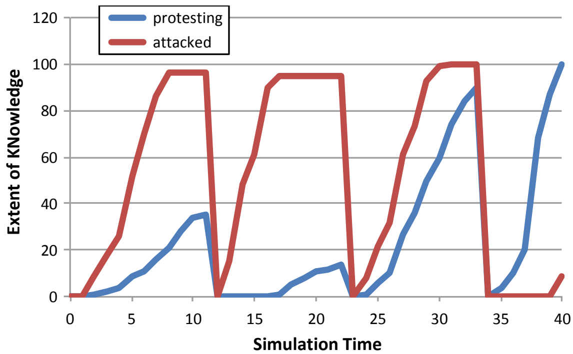

Fig. 22.3 Number of citizens with knowledge of protests (blue) and attacks (red)

afresh in terms of protests and attacks happening that day. What carries on from one day to the next is the level of emotional arousal shown in Fig. 22.4—although agents level of arousal decreases during the night phase, it does not enough (in this particular run) to offset the growing level of emotion in the population, resulting in increasing number of protesters each day (Fig. 22.2).

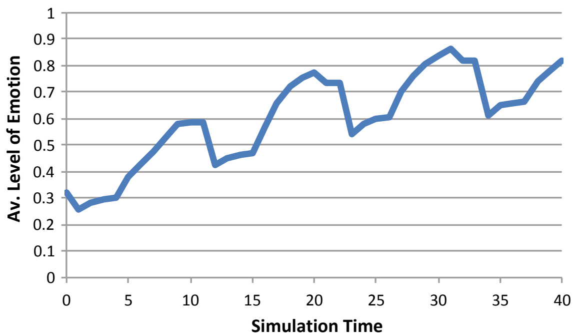

Fig. 22.4 Average level of emotion as simulation time progresses. Agents (on average) 'cool down' over night, but face-face meeting may increase levels of emotion by a contagion process

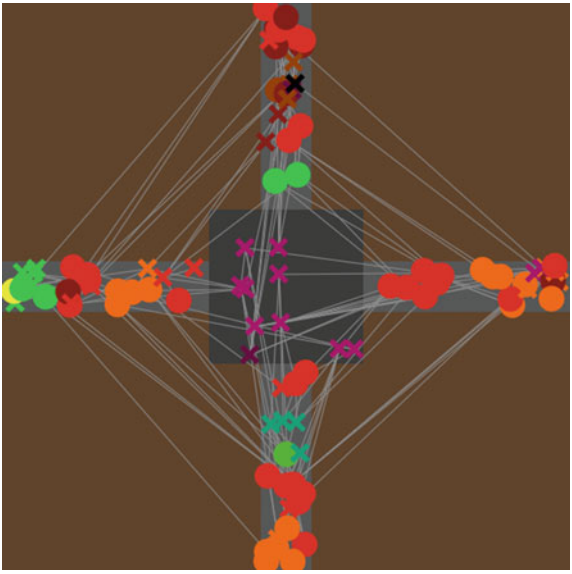

Fig. 22.5 Snapshot of the simulation at the end of the processes shown in Figs. 22.2, 22.3 and 22.4. Note some of the unemployed protesting in the square as well as others in the streets and that agents are clustered with similar levels of emotional arousal

The end result of these processes is shown in Fig. 22.5. Here one can see that, although the level of arousal is generally high (indicated by the red colouring of agents) this is highly clustered by location. In this case, an agent at the top has been attacked and many of those around it and a few elsewhere are aware of this fact (shown by a slight darkening of the agent colour), but none of those at the bottom.

The role of employed agents is interesting—although they do not protest (due to fear of losing their job if they do), they play an important role in terms of transmitting knowledge and emotion to others who might protest.

Reflections, Conclusions and Future Work

The result of this collaboration is an agent-based model of political protest that integrates qualitative evidence gathered from accounts of protestors during the Arab Spring. Both authors benefitted from this collaboration. The qualitative researcher discovered opportunities to explore the social interactions that can follow from the cognitive processes she identified in her analysis. The agent-based modeller was able to implement new qualitative evidence, and to explore this evidence in conversations with the qualitative researcher. Here are a few steps that facilitated the collaboration.

Reflections on the Process

Reflecting upon the process of bridging between qualitative analysis and simulation design, we identified a number of factors that helped. *Firstly*, it seemed important that the process of discussion between the two authors was iterative, that is we both increased our understanding each time we had a conversation that alternated with periods of analysis, design or reflection. *Secondly*, it helped that both had some knowledge of the other's point of view. *Thirdly*, it helped that the agent-based modeller asked the qualitative researcher specific questions about the rules to be implemented by the model, such as questions about branch points or the locations captured by the model. *Fourthly*, it helped that the agent-based modeller wrote a preliminary model based on early conversations. This allowed the qualitative researcher to explore what could happen in the ABM environment, and make further recommendations, based on her data. *Fifthly*, it helped that the authors presented their collaboration and were asked questions about their project by both qualitative and quantitative researchers (at the workshop in Leiden) (Fig. 22.6).

Future Work

There are many possible additions to the model that are suggested by the qualitative analysis and other sources. For example, the literature on protest suggests that negative emotions of anger or outrage can mobilize people to revolt against the government even when there is no visible resistance movement. We may therefore wish to add negative emotions of anger or outrage to early stages of protest, and investigate how these negative emotions contribute to mass uprisings together with the positive emotions we have already included in the model.

Another direction would be to explore the effects of different responses by the government, assuming it wished to dampen or suppress the protests. These could include: (1) Making it more difficult to travel (to streets or to the square), (2) Making access to Facebook impossible, (3) Changing how and when protesters are attacked.

We could also apply the model to explore the effects of governmental attacks in particular, which are known to vary between dampening or spurring resistance movements. Our model can contribute to the literature exploring these effects by allowing agents to respond to various levels of attacks by (1) developing positive emotions, such as courage or solidarity with victims, and subsequently joining the protest, or (2) considering their safety and going home instead.

At the moment, the qualitative analysis still informs the simulation design at a fairly generic level. One possible future development of the model could be to input all the decision trees identified in the computational analysis of the interview data and then initialise each of the agents of the simulation with a tree randomly selected from these. This would require a more sophisticated and generic inference method so that each agent could apply the indicated reasoning in terms of possible actions they could

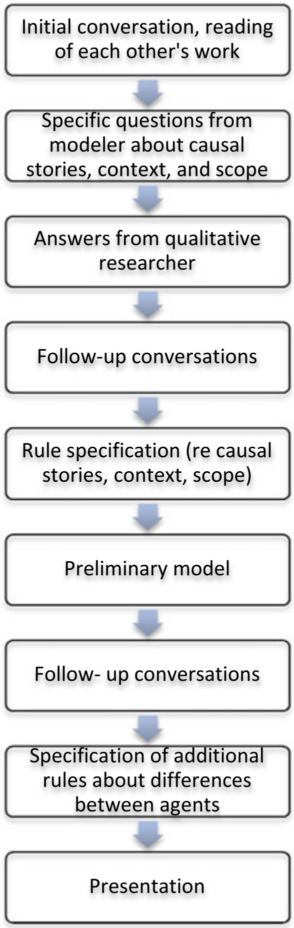

Fig. 22.6 Some of the steps in the collaboration in the bridging between qualitative analysis and the presentation of the simulation (at the workshop)

take. It would also necessitate some ‘grounding’ for each of the identified beliefs (the leaves of the trees) so that they could be triggered in different circumstances.

Another application of the model could be to investigate the level of detail that is needed from the qualitative research when building an agent-based model: By varying the number of narratives included by our model, it could be shown how many narratives and narrative elements are needed to match behaviour in the real world.

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Chapter 23
Un Drôle De Type: The Schelling Model, Calibration, Specification, Validation and Using Relevant Data

Edmund Chattoe-Brown

Abstract This paper identifies a potential blind spot in ABM, linking aspects of methodology and data use. The relative neglect of "specification" (empirical justification of model components like particular agent decision processes) combined with a relative paucity of qualitative data in ABM draws attention away from the possibility that agents may make decisions in heterogeneous ways with uncertain implications for macroscopic system properties. Using the Schelling model as a simple and well known example, this paper considers the role of specification as complementary to calibration and validation, the way that different kinds of data (qualitative and quantitative) map on to different aspects of ABM methodology to justify a model empirically and the possible implications of systematically heterogeneous decision making. Some preliminary simulation results are presented and discussed for mixtures of heterogeneous decision "types" grounded in existing secondary data. The paper also considers exactly what the Schelling model can (and cannot) be taken to show and how the legitimacy of various claims made for it relate to its empirical justification.

Introduction

Famously, according to Maslow [1], to the man [sic] who has only a hammer, everything begins to look like a nail (though it is less well known that the earliest citable statement of this definite idea originated with Abraham Kaplan in 1964). One of the general advantages of ABM is that it does *not* require assumptions to be made for "technical" (i.e. not empirically justified or perhaps even justifiable) reasons as some other formal methods do. However, as I hope to show in this paper, using variants of the well known Schelling model [2], it is still unfortunately possible for ABM to mistake something else for a nail, although rather through inadvertence and lack of

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methodological care than the technical limitations of the approach itself. The argument proceeds as follows. The next section considers the relative neglect of model *specification* (empirical justification for claims about how particular elements of a social process come to be represented as they do in an ABM) in contrast to the more widely recognised concepts of *calibration* and *validation*. The third section considers how various data types relate to particular aspects of specifying the Schelling model (chosen as an example), namely how it is assumed that agents take moving decisions. The fourth section presents and analyses some preliminary simulation results on heterogeneous decision making. The fifth and final section concludes and discusses the possibilities for further research on heterogeneity involving more effective use of qualitative data.

The Assumptions You Don't Realise You Are Making

The first problem with discussing this issue is clearly one one of concepts and associated terminology. Leaving aside the contentious issue of what the range of legitimate aims for ABM are (and how we establish whether they have been successfully realised in a particular piece of research)—see for example [3, 4], let us suppose that we are interested in building an empirical ABM, one that is constructed using (and assessed in terms of) data. Although their names sometimes vary, two concepts (which I shall call calibration and validation following widespread but not universal usage) involve assigning numerical values to parameters arising in the construction of an ABM (calibration) and comparing simulated output with corresponding real data (validation). The Schelling model has been chosen for the argument here because it is widely known in the ABM community and simple enough to demonstrate relevant issues clearly without "bogging down" in potentially divisive modelling detail. (Another disadvantage of non-empirical ABM is that arguments about the relative plausibility of variant assumptions are typically unproductive.) The argument presented here does not hinge on whether the Schelling model is "legitimate" or "valid" or exactly what it "proves" (though it does potentially cast additional light on such matters as I shall try to show shortly).

In this context, then, calibration involves assigning numerical values (a single value for all agents, different constant values for different agent types, different ranges for different agent types and so on) to the value of PP (the Preferred Proportion of one's own kind in the immediate neighbourhood) and validation involves choosing a measure of clustering according to which corresponding real and simulated data might be compared. This measure can be very qualitative ("there are some clusters") or rigorously quantitative (taking account of the advantages and pitfalls of different formal measures of clustering [5]) without affecting the core argument of this paper.

However, for my purposes, what is important here is the related concept which (while obvious *ex post* and probably "unavoidable" to effective empirical modelling) is *not* commonly given a name (and certainly not a standard name). Leaving any other assumptions of the Schelling model aside for a moment (although in fact we will rapidly return to them), we have to ask on what *grounds* Schelling decided that agents would make the decision in the way he assumes they do and, in particular, why they would all make that decision in the "same" way—leaving aside any variation in PP which has been added to subsequent variant models. (We could ask on what *empirical* grounds but that would be unfair to Schelling's stated intention—despite being a reasonable question generally—but even making the arguments Schelling wished to make, there may be more or less legitimate grounds for specifying a particular decision process. For example, it would not be ideal in scientific terms if he had discarded decision processes without acknowledgement until he found one that would serve the theoretical or policy point he wished to make! There seems to be a belief in the ABM community that if you decide not to build an empirical model you are not obliged to provide *any* objective grounds for saying that you have achieved your modelling goals. In extreme cases, modellers do not even make clear what these goals are which, of course, makes it very hard to fail in them!) Once this aspect of the model specification (what kind of decision process or processes agents should have) has been decided, the task of calibration is relatively banal in that it is obvious what parameters need to be assigned values and (broadly) how those parameters should be interpreted. (Other interesting matters can arise here however. If specification is not carefully considered in an ABM then calibration may fail because the parameters of an arbitrarily conceived decision process turn out to have no empirical referents.) Without some decision process involving movement, an ABM would really no longer be an example in the class of Schelling models at all. But the question legitimately remains even though there may be a range of appropriate responses (depending on the purposes of the model for example). Why *that* decision process? (And why that decision process *for everyone?*)

Here, however, we divert briefly into the "meaning" and "value" of the Schelling model to support arguments that follow. Clearly, regardless of the empirical correspondence of either assigned PP values or the decision process, the Schelling model *does* provide a simple and accessible introduction to concepts like *non-linearity* (the "collapse" of increasingly rigorous clustering above a certain PP value), *emergence* (the properties of clusters themselves which are not "reducible" to the properties of agents) and *complexity* (the non intuitive relationship between individual agents and their interactions and the macroscopic properties of clustering)—see [6] for more detail on these ideas in the context of the Schelling model. This outcome does not require the Schelling model to be "true" in any empirical sense, only that the social story told about the model is not *so* implausible that the reader cannot engage effectively with it at all. The "conceptual" value of the model can also be translated into legitimate advice about real styles of social science reasoning (though not without some additional cautions). Under the set of assumptions that Schelling makes (including the specification of a homogeneous agent decision process), the model shows that clustering should not "automatically" be assumed to arise from the "obvious" causes of individual "xenophobia" (or perhaps less morally disagreeable self-preference). There will still be clusters even if people are quite tolerant given Schelling's assumptions (and some but perhaps not all other sets of assumptions he might have chosen instead). There can also be an *absence* of clusters if people are very *intolerant* so that demonstrates that the naïve relationship assumed between levels of analysis is neither necessary *nor* sufficient. However, this finding probably has no bearing on what would happen in the real world if people made decisions differently (and in particular with more diversity) than Schelling asserts that they do. It also has no bearing on whether (in fact) intolerance or self preference *are* contributors to observed pattern of ethnic residential segregation (which we have solid empirical evidence to think that they may be—see, for example [7, 8]). Finally, we can be fairly clear that (except under a rather special and unlikely set of circumstances) the Schelling model does not "explain" the actual pattern of ethnic residential segregation in, say, a particular area of Chicago in 1965. The reason for this is that it is unlikely that, "from his armchair" as it were, Schelling has hit on the correct (or "processually dominant") decision process and been correct in his (implied) judgements that things like demography (specifically changes in family composition) or the housing market (for example) do not have a significant impact on real patterns of segregation. In fact, we have independent reasons [9] for thinking such things *do* matter. (It is an interesting question whether it would be "fair" to test the Schelling model empirically and how much it would really prove if it "failed" such a test. Schelling himself did not claim it was an empirical model, though he did use it to draw certain classes of conclusions which may or may not then be legitimate based on an abstract model of this kind. However, subsequently, data collection methods have been created to give at least a reasonable proxy for the PP parameter [10] thus making it testable at least "in principle". There have also been a fairly large number of ABM "extending" the Schelling model [11] without really addressing the issue of specification—and largely without validation either—thus implying that more complicated models are somehow more plausible—or perhaps just less implausible. This reminds me of the old joke about the farmer giving advice to the lost tourist: "If I were you I wouldn't start from here at all." If the problem is not the specific features of any variant model but their arbitrary nature, then simply having more arbitrary features is not likely to produce scientific progress but rather models that are increasingly difficult to interpret to no advantage).

Arguments about definitions can often bog down effective debate but it is clear that, whatever we choose to call it, the empirical justification for a particular specification of decision making in the Schelling model is an important matter, likely to affect both the behaviour of the model (and thus even its "abstract" conclusions about complexity and legitimate inference between micro and macro levels of analysis) and its ability to empirically "track" corresponding elements of the real world. This being so, I shall refer to the empirical justification of model elements (like the decision process) as *specification* to form a trinity with the better known and more widely recognised processes of calibration and validation. (I would be happy to change this term for a widely used pre-existing term but I can't find any evidence of one. Obviously, there is no particular reason for changing the arbitrary term I am using to an arbitrary term used by someone else unless it is already generally accepted.) Taken together, these three processes thus have the opportunity to offer empirical justification for all aspects of an ABM (barring one complication discussed in the next section).

But What About the Data?

On the whole, ABM seems far more interested in data in principle than in practice [12]. Given the general preponderance of non empirical models, there is a small but thriving community interested in the distinctive role of *qualitative* data (semi structured interviews, ethnography and so on) in ABM (see, for example, the set of articles discussed in [13]). From the more general social science perspective, however, the relations between different data types and ABM methodology actually seem relatively straightforward. The validation of the Schelling model involves large scale surveys of the ethnic composition of households in neighbourhoods that can be compared with the output of the model. (However, the lack of interest in data can still cause ABM to overlook important issues. Taking the Schelling model or some variant as potentially "true" for a moment, moving decisions would be determined by how neighbours *appear* in terms of the subjective ethnic categories of each decision maker. This is not the same—necessarily—as the self declared ethnicity that would be established by a large scale household survey.) By contrast, broadly speaking, how people *actually* make moving decisions (and how diverse these decisions are as a matter of fact) i.e. specification, seem likely to be established predominantly by *qualitative* methods [14]. This claim is clearly something of a simplification for the purposes of argument. Firstly, some motivations may be inaccessible to self report and/or extremely socially unacceptable (for example because they are illegal) and may thus require covert and unobtrusive methods [7, 8] or perhaps experiments (provided the broad shape of the decision process is already known so these can be designed effectively). Secondly, data about moving decisions is not *irreducibly* qualitative. Once one has a justified idea about *broadly* how people decide to move which has been established robustly from interviews, surveys can then be used to obtain more representative information about, for example, the relative importance of different aspects in the decision. (In fact, given the unsuitability of existing qualitative research on moving decisions, I am, in a manner of speaking, using this approach in reverse—suitable secondary survey data temporarily "standing in for" qualitative data—to justify the ABM presented here.) Finally, it should be noted that qualitative research for use in ABM may have particular requirements which pre-existing research on the same topic may not happen to satisfy [15]. For example, it may need to be more process based and more focused on the exact detail of decision mechanisms [14].

There simply seems to be very little qualitative research on house moving decisions generally and what there is does not seem very suitable to the specification of ABM (having been designed without reference to the strengths and requirements of the method). Pending the collection of more effective data in this area, however, it is possible to make the necessary arguments for this paper provisionally using secondary survey data. In a highly regarded study, which would have been available to Schelling, Rossi [9] asked people to report reasons for wanting to move. The answers given are not necessarily of direct help in formulating a well grounded ABM but they do give a more nuanced sense of what *might* matter in moving decisions and thus whether these might be systematically heterogeneous. For example, the largest single response category (33%) concerns amount of closet (cupboard) space. This is a property of a *dwelling*, not a "neighbourhood" or wider geographical context and several other large response categories fall into this broad class: Open space around the house (28%), amount of room (22%), heating equipment (16%), amount of air and sunlight (14%) and amount of privacy (12%). Other reported reasons deal with the *neighbourhood* but in a physical, rather than social sense: Street noise (23%). The economic dimension is also relevant but not, contra economics as an academic discipline, dominant: Rent (15%). Only two relatively small categories potentially address Schelling's interest in "neighbour preference" and even then we must be cautious in our exact interpretation. Kind of people around here (13%) could be interpreted in this way but need not be exclusively about ethnic composition. It could also be about a neighbourhood that is noisy, untidy, unfriendly, "snobby" and so on. Thus this 13% puts an *upper bound* on this kind of Schelling style motivation (assuming accurate reporting but if we do *not* assume this, at least in the first instance, we are dooming ourselves to a competition between entirely speculative models). The same applies to the category kind of schools round here (6%). This *could* be read as a coded reference to ethnic composition but might also refer to other issues such as school quality. (It is actually an element of good questionnaire design that questions should not be open to more than one interpretation by respondents.) Finally, there is a moderately large class of responses which refer to the *locations* of places and persons as part of the moving decision: nearness to friends or relatives (15%), nearness to church (9%), travel to work (8%), shopping facilities (6%). We can thus see that the self-reported motivations on which the Schelling model is based are quite a small proportion of the overall reasons given. (This data is not perfect and should not be treated as quantitatively definitive. In several cases, it could be argued that the data is open to more than one reasonable interpretation. For example should open space around the house be treated entirely as a property of a dwelling or could there also be an element of neighbourhood properties there? Fortunately, for the argument presented here, based on qualitative not quantitative properties of the data, this does not matter).

This analysis gives rise to the caveat about the exhaustiveness of calibration, validation and specification for empirical ABM raised in the last section. One relatively neglected implication of the Schelling model is that it needs no "real" geography. Because (by assumption) people only care about neighbouring types, there is no virtue in modelling school location, shopping centres and so on. But if people *do* report that they mind about such things (as in the Rossi data for example) then the model needs to include them and how schools come to be located where they are is not a fact that we can understand effectively just by talking to individual households. We may thus need to access other kinds of data to justify our model assumptions, creating the kind of simulated environment in which we would expect the empirically observed decision making processes to generate at least broadly the right kind of simulated segregation. (It is an interesting question whether, to do this, we just need a plausible *distributio*n of schools or their exact locations for example.) Thus, in order to be exhaustive, specification cannot be limited to agents but must also apply to the environment (and the properties of the environment cannot legitimately be simplified just by making arbitrary assumptions about how moving decisions are made.) In the next section I explore the patterns of segregation that arise under the assumption of heterogeneous decision making in the Schelling model based broadly on the Rossi data.

Some Preliminary Results

In the abstract I referred to this issue as a possible blind spot in ABM and it is interesting that existing research (as far as I have yet been able to determine) seems to interpret "heterogeneous decision making" in the Schelling model as meaning *not* that people make decisions in systematically different ways (for example based on different aspects of the environment following Rossi) but that they make decisions in the same way but based on different *preferences* [16, 17]. In fact, ABM with agents that are heterogeneous in decision *process* rather than parameters are still relatively rare. (One reason for this may be that, without specification data, such models could be argued to be avoidably complicated with no compensating virtues.) The same might be said to apply to any model which simply gave different weights to different features of the dwelling, the immediate environment and the wider city like churches and schools. (It is an interesting conceptual question whether permitting "zero weights" would allow these decision models to be considered systematically heterogeneous. It would partly depend on the distribution of weights to different reasons across the population. In such a case, one person could decide entirely on dwelling properties and another entirely on target locations but, arguably, they would still be choosing "in the same way" but based on different weights.) The apparent interpretation of "heterogeneous" in the literature conjecturally supports the view that lack of attention to qualitative data (how do people actually make decisions?) and to specification (why this decision rule rather than that?) has "shaped" the approach to modelling in an implicit way that (once made explicit) cannot really be justified in empirical terms. (This is fine, of course, if the modeller says they are not attempting to build an empirical model as long as they also clearly state what other objective contribution their model makes.) Once the problem has been set up this way, however, it is relatively easy to build a relevant model and investigate the results. The ABM (written in NetLogo version 6.0.4 and available from the author) starts with the standard "Schelling type" found in the relevant Models Library. However, it then adds the possibility of several other types (in proportions the modeller can specify) based on the broad classes of responses found in the Rossi data. For example, one type of agent is unhappy unless they are within a certain target distance (which can again be specified by the modeller) of a particular (arbitrary) location. This is a deliberate abstraction from the idea that various physical locations like schools, churches and offices may have some bearing on whether an agent wants to move. But how will this reason for moving "interact" with the standard Schelling motivation in various different proportions of the population? Can the presence of one type impact on the convergence of another to an equilibrium state? How and under what circumstances? Another type of agent (again deliberately abstracted) is one that becomes unhappy for "random"—which could actually mean non-modelled—reasons and becomes happy again once they have moved. (It should be noted that this is a moderately plausible way of introducing "noise" into the system—though it would be more plausible if every agent sometimes moved for non modelled reasons rather than one type *always* doing so. It is not really plausible that agents should do something as important as moving house genuinely "at random"—moving costs are another issue missing from the Schelling model quite apart from the housing market—so we might be claiming instead that they did it for reasons without a process yet explicitly specified in the model such as a death in the family.) Such agents are again fundamentally different from both the "location targeting" agents described above and the standard Schelling ones. This is how I use the term heterogeneous in this paper (which is not always how it is used in other research which claims to deal with heterogeneous decision making): That an agent makes decisions according to a different process/specification and not just based on different parameters for a homogenous process. Again, how will different combinations of these various types impact on the resulting patterns of ethnic segregation? The final type presented in this analysis is the "person targeting" type, who judges their happiness not in terms of a physical location but in terms of the position of a designated "significant other". Again, this is a deliberate abstraction from all the possible "person based" reasons (children, grown up parents, friends, partners in business) given by Rossi that might impact on the ranking of different locations. (I have only begun sketching out this approach and one detail still to be clarified is exactly when we should call two decision processes different. For example, the location seeking and person seeking types both make the decision based on distance between them and the target and aiming to reduce it by random movement but the kind of target differs in each case: A place or a person. Further, the person seeking agent may find that the person they "seek" moves while the location seeker will not. Thus, for example, the effect of random movers may be "amplified" to the extent that person seekers happen to nominate them as targets. Does it make more sense, then, to call these two decision processes homogenous or heterogeneous? I merely remark on this issue for now.) For reasons of space and simplicity, one broad type identifiable from the Rossi data has not yet been implemented (though it should be simple to do so). This is the "dwelling targeting" type that is happy if the property they live in meets various criteria of rent, adequate storage, privacy and so on. It is hoped that this type may be implemented by the time of the conference but it could be argued that in terms of the logic of the Schelling model, such types are, on their own, socially trivial. (More generally, however, types that have trivial behaviours in isolation may have non trivial ones in combination with other types. This is one motivation for exploring the behaviour of such systems).

The form of the simulation results is actually very simple to report. Using a population of standard Schelling types as a baseline, a number of runs (ten per experimental condition) were performed with various combinations of types (to be described in detail below). These runs were characterised (as with the standard Schelling model) using % of similar neighbours and % of agents "happy" at the end of the run.

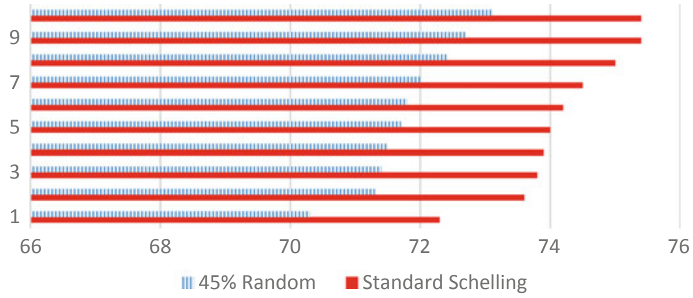

Fig. 23.1 Comparison of % similar neighbours for ten runs where all agents are standard Schelling types (dashed) and when 45% are random movement types (solid)

However, because with some combinations of types, complete satisfaction is impossible (random movers are potentially *never* satisfied), the simulation was run until complete satisfaction or for 100 ticks whichever was shorter. This time period was chosen because the standard Schelling model converges easily within this length of time for the parameters used and there was no sign that any run had failed to converge as far as it was going to within this time period. (The initial population density in all runs was 90% and the % of similar neighbours wanted—where relevant—was 30%.) Figure 23.1 shows a typical result from this comparison between sets of runs.

Several points should be noted from this Figure supporting the rest of the analysis. Firstly, by presenting each set of ten runs ordered by value, it is clear that there is an effect of a certain size between the different conditions. In all runs, the % similar is higher in the standard Schelling condition by about the same amount. Not all such results can be reported here (for reasons of space) but are available from the author. However, such an analysis justifies reporting average values of conditions (and differences between them) as meaningful (and demonstrates that ten runs per condition is "sufficient" for the results to be relied upon.) Secondly, there is the result itself. Clustering is higher when all agents are the standard Schelling type rather than 45% being random movers. (This % was chosen arbitrarily because it divided easily into the three other types being analysed but also because it was a large though not dominant proportion. The majority of agents in all runs—55%—are still standard Schelling types.) Thirdly, although the result is robust, it is small, with a difference between averages of only 2.39%. If we choose to think of the Schelling model in empirical terms, it might be quite hard to distinguish between these two possibilities assuming, for example, that there was noise (or non response) in the household survey data or if the modelled types were only an approximation to the whole population of behaviours discovered by qualitative interviews. This shows that the homogeneity assumption "matters" to the behavior of the model but that the size of the effects may make them quite hard to distinguish without careful attention to data and research design.

It would be wasteful to report all the bar charts for different combinations of types but all bar one (which shows a single anomalous pair of runs out of ten) display the

Table 23.1 % similar and % unhappy for different proportions of four decision making types (standard Schelling, random mover, ideal location seeker, ideal person seeker)

Proportions of non Schelling types (random, location seeking, person seeking)	% similar (average of 10 runs)	% unhappy (average of 10 runs)
0, 0, 0	74.21	0
45, 0, 0	71.82	2.46
0, 45, 0	73.99	7.21
0, 0, 45	64.21	0
15, 30, 0	73.6	5.61
15, 0, 30	69.05	0.84
0, 30, 15	71.58	5.15
15, 15, 15	71.56	3.11

same pattern of consistent effects sizes between pairs of conditions. Table 23.1 is a summary of results from a number of conditions which will form the basis for the rest of the analysis.

A number of points can be noted from this table. Firstly, only the person seeking type on its own is compatible with the complete satisfaction found in the pure Schelling case but leads to significantly lower % similarity. Apart from this, even when there are no random types (which are, by design, perennially unsatisfied), there is always residual dis-satisfaction but the differences between the % similarity in all these conditions are small relative to pure Schelling and are therefore likely to be difficult to detect in data. (It should be noted that this provides another example of the advantages of taking the Schelling model "seriously" in empirical terms. It would be very straightforward to collect data about levels of housing disaffection and "aims" for desired new dwellings as part of the household surveys potentially used to validate the Schelling model. To my knowledge this has not been done however).

Secondly, apart from the condition mixing Schelling types and person seekers, all levels of similarity are broadly comparable across conditions and below the value for the pure Schelling population. There is more proportionate variation in the % unhappy across conditions and we can consider whether this phenomenon can be decomposed into separate effects for each type. Table 23.2 shows the results of this analysis, which

Table 23.2 Calculated and actual % unhappy for different combinations of non Schelling types

Proportions of non schelling types (random, location seeking, person seeking)	Calculated % unhappy	Actual % unhappy
15, 30, 0	5.63	5.61
15, 0, 30	0.82	0.84
0, 30, 15	4.81	5.15
15, 15, 15	3.22	3.11

involves combining the effects of runs with only one other type in proportion to their fractions in the population for runs with more than one other type. For example, 45% random gives an unhappiness of 2.46 and 45% person seeking gives an unhappiness of 0%. This predicts that (assuming the type effects are separable), that a combination of 1/3 * 2.46 + 2/3 * 0 = 0.82%. The corresponding actual value with three types is 0.84% suggesting that these effects are very close to decomposable.

Finally, we can think about what these results might actually signify. Because of the way they are specified, random movers will never be permanently satisfied and thus, in principle, it is easy to distinguish populations containing them from those that do not. In practice, however, this is only true because of another arbitrary simplification in the standard Schelling model, namely that agents do not arrive from outside or leave the area. If they did this (which in reality they do of course), then it might be significantly harder to distinguish dis-satisfaction of this kind from that arising via random mover types. Because of the simplifying assumptions made to illustrate points about decision heterogeneity, there is a plausible explanation for the decomposability of different type effects observed here. Getting near to a single target person (who is statistically unlikely to be the target for many other people) is relatively unchallenging. The same is true of getting close to a particular location because, again, there is little "competition" for any particular spot. The same might not be true if, for example, some target locations were much more "in demand" than others (which we would actually expect, for good schools for example) and your target individual happened to be located close to one of these. Interestingly, the least convincingly decomposable combination involves a mixture of location seekers, person seekers and *no* random movers. Perhaps there is at least some "aggregate interference" by each type in the goal satisfaction of the other which random movers in some way meliorate. (It should be noted that, arbitrarily, agents have to be really rather close to their target to count as satisfied, no more than four "coordinate points"—sum of differences in x and y coordinates.)

However, it is important to draw the right conclusions from this analysis. What is important is that we can explore the effects of decision homogeneity in the Schelling model (and by extension in ABM more generally) but also, to avoid this being a purely abstract exercise introducing complication to no empirical purpose, we can ground this heterogeneity in data (in this case secondary survey data but ideally effective qualitative data) by being explicitly aware of the concept of specification. In the final section I turn to the wider implications of this approach.

Conclusions and Further Work

The argument can usefully be recapped at this point. There seems to be a tendency to minimise the importance of *specification* in ABM (empirical justification of, to take the Schelling model as an example, why agents are assumed to make decisions the way they do and why they are all assumed to make decisions in the same way).

Qualitative data allows us to think effectively about this issue by acting as a potential justification for decision processes *and* their observed diversity. (The standard method of systematic qualitative analysis—so called Grounded Theory—argues that one should focus on the most recurring patterns in data which could be for example, if the right questions were asked, the commonest ways of making decisions [18].) Since this is a work in progress and existing qualitative research on relocation has proved unhelpful regarding moving decisions, I have made the argument "provisionally" using secondary survey data.

Nonetheless, this analysis allows us to think more carefully about exactly what we mean by heterogeneous decision making, to explore the dynamic implications of such heterogeneity (and consider how challenging it might be to confirm or reject such diversity using real data) and to extend our thinking about exactly why (and when) different types of decision making might have (or fail to have) effects that are decomposable in a simplifying way. At this stage, the broad answer seems to be that effects are decomposable when type decision processes do not create "lumpiness" in the structure of residence which might distort the outcomes of other types of decision making. It so happens that the types specified here satisfy this requirement but others that can easily be envisaged need not.

This in turn suggests a number of obvious areas for further the research. The first is a much more detailed exploration of the parameter space with 45% of non Schelling types being pretty much arbitrary. Another obvious way to look at the decomposability of effects is to see whether these "scale". (Are 15% of location seekers 3 times as unhappy as 5%?) Do these results depend on the size of the Schelling type proportion (which has been left constant across all runs?) Are there other combinations of types behaving in unexpected ways? Are type effects less decomposable when satisfaction is more challenging to achieve? A second set of explorations involves contextualising the observed behaviour. Is it still so easy to distinguish between levels of unhappiness when agents arrive and leave in the simulation? What would happen if "random" (i.e. non-modelled) behaviour wasn't a type in itself but applied to other types with a low probability? (It is generally useful to think about what is means for the Schelling model to be non deterministic in empirically plausible ways.) Does it matter that these results abstracted out from agents seeking dwellings with particular attributes? Would such agents "break" the significant amount of decomposability observed here? (More generally, what can we learn from the fact that some type effects are plainly decomposable and others apparently less so?).

Finally, a combination of having a definite model in mind (albeit a stylised one) and seeing what is wrong with existing qualitative research on relocation from the perspective of ABM will make it much more feasible to collect qualitative data that can actually justify a specification for an ABM of ethnic residential segregation that is likely to "survive" validation.

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Chapter 24
First Steps Towards RAT: A Protocol for Documenting Data Use in the Agent-Based Modeling Process

Peer-Olaf Siebers, Sebastian Achter, Cristiane Palaretti Bernardo, Melania Borit, and Edmund Chattoe-Brown

Abstract While there is a number of frameworks and protocols in Agent-Based Modeling (ABM) that support the documentation of different aspects of a simulation study, it is surprising to find only a small number dealing with the handling of data. Here we present the results of discussions we had on the topic at the Lorentz Center workshop on Integrating Qualitative and Quantitative Evidence using Social Simulation (8-12 April 2019, Leiden, the Netherlands). We believe that important distinctions to be considered in the context of data use documentation are the differences of data use in relation to modeling approaches (theory driven etc.) and data documentation needs at the different stages in the modeling process (conceptualization, specification, calibration, and validation). What we hope to achieve by presenting this paper at this conference, with the help of the community, is to move forward the development of a generally acceptable protocol for documenting data use in the ABM process.

Keywords Agent-Based Modeling · Data · Documentation · Protocol · Rigor · Transparency

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Introduction

A big problem in Agent-Based Modeling (ABM) is rigorous and transparent use of data [1]. Often a model is broadly explained, but justification in terms of decisions about what data has been used, how it has been used, and why the modeler has decided to use it in this way, is most often missing. This can be very frustrating, making it difficult to understand and perhaps replicate the model. Looking at practices within the simulation domain, there are some rigorous procedures in place [2, 3], however, mostly referring to specific fields, stages of the modeling process or simulation paradigms.

There is a number of frameworks and protocols in ABM that support the documentation of different aspects of a simulation study, e.g. ODD (Overview, Design concepts, and Details), DOE (Design of Experiments), EABSS (Engineering Agent-Based Social Simulations). The ODD protocol aims to provide a standard format for describing individual-based and agent-based models [4]. Several additions to the original protocol have been proposed, in order to increase its functionality, i.e. ODD + D (ODD + Decision) [5], ODD + 2D (ODD + Decision + Data) [1], ODD + P (ODD + Provenance) [6]. The DOE framework focuses on increased transparency and effective communication through the systematic design of experiments [7]. The EABSS framework focuses on driving and documenting the model development process of mixed approach models [8]. However, it is relevant to consider that some frameworks emphasize certain steps of a simulation study more strongly, while others have a more holistic approach. Given the emphasis on promoting such standards in order to increase scientific rigor and transparency in ABM, it is surprising to find only a small number dealing with the handling of data, whether quantitative or qualitative, in ABMs. The most notable effort is made by Laatabi et al. [1] by proposing an extension of the ODD protocol to improve the description of data-model connections. However, our goal is to move forward with this discussion posing further questions:

- What can we learn from achievements regarding data documentation in other disciplines? That includes existing standards with the field of simulation research outside ABM but also from fields with similar challenges (e.g. the interdisciplinarity or diverse data types).
- Is there a need to distinguish a reporting protocol for different model approaches (data-driven vs. theory-driven vs. participatory)?
- What specific reporting requirements come with different stages in the modeling process (e.g. conceptualization, specification, calibration or validation)?

The initiative presented here arose from a Lorentz Center workshop on Integrating Qualitative and Quantitative Evidence using Social Simulation (8-12 April 2019, Leiden, the Netherlands). At this workshop, we came together as a multidisciplinary group of junior and senior modelers. Our aim was to create a framework for augmenting rigor and transparency (RAT) of data use in ABM when it comes to publication of these models. The RAT framework is still work in progress. What we present here is our strategy for developing this framework and some possible questions that we considered to include with corresponding fictive responses for demonstration purposes. What we hope to gain from presenting this extended abstract at the Social Simulation Conference 2019 is feedback on our initial work. We are aware that the creation process of an ABM is shaped by researchers' individual nuances. Hence, feedback from looking back at one's own research projects is of high value for us. Besides the presentation based on the extended abstract, we are also participating in the poster session and organize a round table. Thus, we are looking forward to meeting those of you who would like to contribute to developing the protocol with their feedback.

Methodology

In order to develop the framework, we used the following strategy. We looked at typical stages in the modeling process, within which we identified issues regarding data requirements. We summarized those requirements in form of questions in a protocol format. We recognized that there can be fundamental differences in the model approach that lead to different reporting issues for data used also within the different stages of the modeling process. Thus, we distinguished two generic modeling approaches: (1) theory-driven; (2) data-driven. For evaluation purposes and to uncover gaps in our protocol, during the development process we used the working example of a theory-driven model. The same procedure is pending for an example of a data-driven model. Lastly, we also recognized modeling approaches such as mixed approaches (i.e. partly theory-driven, partly data-driven) and participatory modeling not neatly fitting into one of the approaches, hence, probably representing a separate category we need to consider.

Our goal was to develop a framework that is easy to use and to only include the information required for rigorous and transparent documentation, i.e. to keep it as concise as possible in order to motivate people to use it. When working on it we asked ourselves two questions: "What should be in such a protocol when it comes to the use of data?" and "What is the data-related thing that is most frustrating when it is left out of an existing model documentation, making it difficult to replicate/understand the model?". What we were aiming to avoid was creating a protocol that, due to its complexity, would be counterproductive.

RAT Framework

RAT Roadmap

The RAT roadmap consist of several distinct steps to guide the modeling process. Currently they are labelled as START, SPECIFICATION, "DATARING" (i.e. the comprehensive consideration of the use of qualitative and quantitative data in an agent-based model), BUILDING MODEL PHYSICALLY, and OUTPUT. In the START step we clarify the research question and make a decision regarding model type (theory driven, data driven etc.). The decision about the latter will influence the specifics of the following steps. Assuming that we have a theory driven model, in the SPECIFICATION step we will focus on mapping theory elements to model elements. The "DATARING" step provides a systematic account of relationship between model elements and data (which is why we have created a new term subsuming calibration, validation, and specification). In the BUILDING MODEL PHYSICALLY step we will use a subset of the ODD protocol (possibly with its extensions) to formally describe the model. Finally, in the OUTPUT step we define the data that can be captured as output and which of these are used.

RAT Protocol

With the RAT protocol, we aim to document data use throughout the modeling process. We used the RAT roadmap to organize the protocol and followed a WHAT-WHY strategy, to combine the process of reporting and justification. We distinguish between the use of qualitative and quantitative data and we encourage the modeler to say why things that would be available have not been used. Furthermore, we encourage the modeler to unveil hidden aspects of the model (e.g. we ask for all potential outputs of the model, including unused ones) to support a "model reuse" culture.

Conclusions

In this study, we have presented a prototype of the RAT framework. This captures the considerations that should go into the decision making during the modeling process. This framework intends to integrate available practices (e.g. ODD + 2D, ODD + P, DOE) and fill in the gaps. As such, the framework can help with conceptual model validation as one has to be explicit about aspects of modeling, and could spot errors or lacunae, when one finds oneself stuck in completing later steps. Moreover, it could be used for communicating simulation models to those who are not experts in ABM.

We would appreciate suggestions for items that should be included in the literature reviews, "beta testers" and critical readers for the roadmap and protocol (from as many disciplines and modeling approaches as possible), reactions (whether positive or negative) to the initiative itself (including joining it!), and participation in the various activities we organize at the conference.

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Chapter 25
Participatory Agent-Based Modelling for Flood Risk Insurance

Sara Mehryar, Swenja Surminski, and Bruce Edmonds

Abstract In the context of climate change adaptation, there has been a recent research focus on the impact of flood insurance on flood risk reduction behaviour. ABM has been recently used in such researches to model the interaction of stakeholders. Building on this foundation, we propose the integration of participatory methods to capture the socio-cognitive and behavioral aspects of flood risk insurance, which have been missed in such models. The results of our suggested line of research on *Participatory ABM for Flood Risk Insurance* can support public and private sector considering their preferences and contextual requirements.

Keywords Flood risk insurance · Participatory methods · Agent-based modeling

Introduction

Policy makers and governments have recently showed growing interest in using insurance as an economic flood risk management tool [12]. However, the impact of insurance policies go beyond the financial recovery: it can directly or indirectly influence the behaviour of those at flood risk. While insurance can encourage more risky behavior (e.g., property development in high risk locations with reliance on the insurance support) but can also trigger desirable risk reduction behaviors, through incentive mechanisms like risk-base pricing, deductibles, and no-claims bonuses [11].

Recent studies have shown that actors' responses to flood insurance policies strongly rely on socio-cognitive and behavioural aspects of decision making such as

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risk perception, dynamic preferences, and social values [6]. To incorporate human behavioral aspects in flood risk analysis, Agent-Based Modeling (ABM) has been used in a few number of studies [5, 9]. Building on such an agent-based perspective, we see the need for integrating stakeholders' knowledge and perceptions using participatory techniques. In this study, we suggest the combination of *participatory modelling methods* and ABM as an approach to capture and present the contextualized human behavior in simulating impacts of flood insurance policies. Then, we explain applicability of three participatory methods i.e. narrative data analysis, fuzzy cognitive mapping and role-playing game in this approach.

Flood Risk Insurance and Human Behavior

Flood insurance policies and their implementation differ widely across countries. It can be provided by the private insurance market alone (e.g., flood insurance in Ireland), with government intervention (e.g., the National Flood Insurance Program in the Us), or a combination of both (e.g., Flood Re in the UK). It can be mandatory (e.g., in France and Spain) or voluntary (in most of countries). Flood insurance can also be subsidized (reinsurance under Flood Re in the UK), indemnity-based (e.g., in Ireland and Australia), or index-based (e.g., mostly in developing countries) [11]. People's acceptability and reactions to such insurance policies might be complicated. For example, [13] show that Hungarian government subsidy in insurance rates has caused high concentration of properties in high-risk areas and has also been ineffective to attract insurance buyers in this area.

ABM has recently been used to simulate human behaviour in response to flood risk using the social-psychological theories—e.g., protection motivation theory. In such theories, human risk adaptation behavior results from individual's (1) threat appraisal and (2) coping appraisal, both of which highly depend on human perceptions in terms of *perceived* vulnerability, *perceived* flood severity, and *perceived* effectiveness/feasibility of interventions [5]. However, how to capture such perceptions is still an open question. We suggest that a combination of *participatory methods* and ABM would be a robust modelling approach, providing supportive evidence for flood risk insurance analysis.

A Methodological Toolbox

Participatory methods are used to actively engage actors in co-design, co-analyze and co-implementation of policy option simulation [14] and involve their heterogeneous perceptions, preferences, and values in the process of modelling [7]. In this section, we introduce three methods that can be used in integrating human behaviour in the ABM of flood risk insurance.

Narrative Data Analysis (NDA) techniques provide formal structures for the process of using narrative data (collected via interviews) to develop decision making processes in ABM. NDA generally consists of four stages: (1) conducting interviews, (2) transcribing them into text, (3) analyzing text, and (4) coding decision rules for an ABM [3]. Using narrative data to develop ABM of flood risk insurance offer the possibility to gather additional valuable information—not achievable by questionnaires—and result in more empirically grounded and contextualized simulations of human flood adaptation behavior. However, developing a systematic process for translating flood-relevant narrative data into ABM program codes requires further investigations.

Fuzzy Cognitive Mapping (FCM) is a kind of mind mapping method in which stakeholders collaboratively develop a cognitive map (a weighted and directed graph). In an FCM, components of a system and their casual relationships are identified and semi-quantified via stakeholders' perception [10]. FCM can enable stakeholders to represent their decision making process. Moreover, FCM can capture the uncertainty of human perceptions by translating verbal causal weights (low, medium, high) into numerical values. To collect flood-related decision making process, for instance, actors can be asked to identify (1) the actions they take to reduce flood risk, (2) the conditions, drivers, barriers and timing of those actions, and (3) the impact of each action on the flood risk of properties. There have been limited number of studies on using this method to inform actors' decision rules in the ABM (e.g., [4, 7, 8]) which can be used as a basis for FCM-based ABM for flood insurance analysis.

Role-Playing Game (RPG) is a participatory method in which players are asked to behave as particular actors in a roughly defined setting [1]. Observing the decisions and actions made by game-players can reveal implicit social rules, norms, and values, which are not easy to grasp during survey questioners and interviews. To develop an RPG-based ABM for flood risk insurance, the players can participate in a game, specified by flood-related barriers/incentives and under different flood insurance policies. Gathering data on various rounds of game play can provide justifications for formulating ABM decision rules. In a two-sided relation, one can also use the output of ABM for updating insurance policies in RPG. There are some games developed to present, model, or train the flood risk reduction activities, which can be integrated with the ABM of flood risk insurance, e.g., *Extreme Event Game*, *FloodSim*, and *Stop Disaster*.

Challenges and Opportunities

Each participatory method has its own challenges and potentials. FCM-based ABM provides an easy-to-use software for non-modelers who want to capture and represent the perception of a large group of stakeholders. However, it weakly represents spatial and temporal aspects of the problem. RPG-based ABM, on the other hand, is effective for creating synergy among stakeholders and observing actors' behaviour in response to each other's actions and environmental changes. However, developing and playing games can be costly in terms of time and resources. Moreover, verifying whether game plays correspond to actions in real life is challenging. Knowing potentials/challenges of these methods, to identify the appropriate participatory ABM for flood risk insurance, we need to consider context-related specifications including (1) the spatial and social heterogeneity of decision makers, (2) the scope and specificity of decisions, and (3) inherent complexity and uncertainty of the human decisions. Moreover, the technical issues of each methodology relating to translating qualitative data into formal rules need to be further studied. This work is the first attempt to propose the application of participatory ABM for flood risk insurance. We plan to apply our participatory approach by collecting and formalizing human decision making processes for flood risk and integrating them into an existing ABM [2]. This model can be used to test the impact of the UK insurance policies on the uptake of flood risk reduction measures.

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Part VI
Methods

Chapter 26
A Plea for Modelling Geographical Spaces—Because They Do not Exist as Such

Andreas Koch

Abstract The aim of this paper is to explain the nature of geographical spaces as simultaneously material, relational and semantic. Given this functional characteristic, it is stated that such spaces do not exist—as such—materially or empirically. Instead, they are transformed and transferred as elements of communication in social systems. Models play a central role in the process of transformation and transfer as they are capable of creating geographical spaces in a comprehensive albeit non-holistic way.

Keywords Materiality · Topology · Semantics · System theory

Introduction

Social-geographical space in particular and geographical space in general does not exist as a materially empirical fact. Neither human beings nor communities or societies are determined in their activities by geographical space—just as they are not determined by historical time. Contemporary modern societies can be described adequately as functionally differentiated social systems working on different scales whose central operating mechanism is communication and which is the source of social phenomena.

The emergence of these social phenomena is—quite often—epistemologically explained and methodologically explored without any reference to geographical space or to simplified abstractions of it at best. Neumann [17], for example, approaches social norms by emphasising their individual (belief) and social (shared interaction) components. Neither the creation of norms nor the mechanisms of their compliance seem to need any contextualisation in space. Giardini et al. [6], in a similar vein, acknowledge the presence of actors in the creation, alteration, and loss of reputation. Issues of geographical space, however, play only an implicit role if at all (more examples are presented in the book *Simulating Social Complexity* by Edmonds and Meyer [4], and Edmonds et al. conclude the book with a couple of challenges

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modellers have to cope with; an explicit consideration of geographical spaces has not been mentioned, perhaps because of its less significant role in understanding social facts).

On the other hand, there is also well-known empirical knowledge that social interactions take part in space and time, and even that 'space matters!'. A lot of sophisticated approaches in geography and related sociology have been developed to analyse, represent, and understand geospatial characteristics in social contexts (see, for example, Kohler and Gumerman [10], Krzanowski and Raper [11], Lantuéjoul [12] or Stimson [19]). Sometimes a deliberate distinction between different forms of spatial connotation is carried out in socio-spatial analyses, as is the case by Torrens [20]: "Often simultaneously, these spaces can take a variety of forms, including mathematical, social, cognitive, physical, urban, architectural, visual, and spaces of the body".

More often, however, a fuzzy and confusing commingling of social and spatial properties prevails, such as the idea that social systems are regarded as equal with spatial systems, i.e., cities, or that spatial systems are anticipated as over-complex—"[…] everything within a city, region or country is connected to a place" [2]—in the belief or hope of comprehensively explaining the link between the social and the spatial (the book *Agent-Based Models of Geographical Systems* by Heppenstall et al. [8] provides further examples of how difficult it is to connect the two basic realms).

The proposal suggested here, to tie together the two antagonistic natures of geographical space, is—at the theoretical level—to conceptualise space as a system type which interrelates with social systems. The medium to realise the interrelation between the two system types (actually, there are more than two system types incorporated, which will be not discussed here, however) is given, alongside language in general, with models. This will be discussed briefly as the methodological part of the proposal. We start with a short description of the three core characteristics of geographical space.

The Material, Relational and Semantic Domains of Geographical Space

A large part of the problem with geographical spaces as dialectically existing and non-existing is due to a selective and imbalanced use of the three core domains. This quite often induces the equalisation of geographical space with one of the three domains without indicating it explicitly. This does not mean that all three domains have to be implemented equivalently. In fact, an implicit imbalance is given with the semantic domain regarded as prior compared with the material and topological domains.

The material domain of geographical spaces recognises the fact that any kind of sociality is, beyond social construction and emergence, grounded in its materiality.

Critical realism emphasises that social collectives are surrounded by material artefacts—houses, workplaces, tangible infrastructure, devices, etc.—that influence the ways in which we perceive and (inter-)act within our socio-material environment [16]. Marginalising material spatiality implies the risk of discounting socio-ecological requirements in order to preserve a liveable and healthy environment. Overvaluing material spatiality may lead to a geo-deterministic thinking that reduces social interaction to passive, fatalistic behaviour. Furthermore, it confuses material objects with geographical space, which results in a misleading reification.

The relational domain of geographical spaces considers the relationship among spatial-material objects, and between them and social units (from dyadic to large collective structures). Besides enabling structural visibility, relations also allow for an incorporation of socio-spatial mechanisms and processes, not to forget power relations embedded into these. The relational (topological) domain is prominently represented in Actor-Network-Theory [13] which connects human beings with material artefacts in order to detect traces of social relationships by relocating and redistributing the effects of social interactions mutually from the global to the local level and vice versa. Also, relational spatiality is a premise in the investigation of economic, social, cultural, and symbolic capital which is transferred between social members to gain trust, repetition, and solidarity, and herewith mechanisms of exclusion and inclusion [1].

The semantic domain of geographical spaces focuses on space as a theoretical social construct and thus as an abstraction in social communication. This domain is the closest to strong thinking in social systems as it refers space and spatiality exclusively to their meanings within social systems and denies any real-world existence. According to Hard [7], a social scientific enquiry about space has to ask (i) which functions spatial abstractions have in social reality, and (ii) which social systems produce what kind(s) of spatial abstraction with which purpose? The predominant justification for this perspective is that spatial indicators such as 'materiality' or 'distance' do not generate an explanatory power in the understanding of social phenomena since they are contingent in their effects. 'Materiality' can, but need not necessarily, exert an influence on social structuring or mechanisms.

Marginalising semantic spatiality contributes to a similar confusion as mentioned above as it confuses notions with material artefacts; 'homeland', for example, is just an expression for a feeling of belonging, but has no real geographical existence. Overvaluing semantic spatiality neglects the material rootedness of human beings as also biological beings and of social collectives as also socio-ecological collectives. Climate change adaptation is one striking example of this interdependency between the social and the biological/material world. Housing in its capitalistically materialised form (profit-oriented accumulation) may serve as another example.

To conclude: any reductionism towards one or two of the three domains is problematic and partly even impossible because without semantic representation (language and models) we are unable to communicate about the meanings of geographical space in social contexts. One approach to cope with all three domains is given with an extended system theoretical approach, taking social and spatial facts in two distinct system types into account.

Social and Spatial Systems

The theoretical argument of conceptualising geographical space in a system theoretical manner is justified by the problem that none of the three domains, on its own, is sufficient to adequately explain the multilevel and multidimensional composition of it [18]. In fact, geographical space is not identical with the material objects, a geometrical representation of a city, or an urban cartographic plan. Instead, all three components (and many more of these such as networks, territories or landscapes) interdependently refer to each other.

Social system theory rests upon the idea that communication is the core principle responsible for the emergence and maintenance of social collectives on all scales, ranging from small interaction systems to organisations and to large, functionally differentiated systems like the economy, politics or science [15]. Data, information and knowledge about geographical spaces are incorporated from the respective environment(s) of the respective social system(s). Companies as organisations, for example, establish programmes on how to organise their business, and one part of such programmes is dedicated to tailoring the business spatially (e.g., the allocation of branches). Likewise, all other social systems operate by implementing a kind of a communication structure, including its spatial component. One aim is to gain social control over potential disturbances.

In order to achieve successful communication with low levels of accident-sensitivity, the nature of spatial systems must have a minimum ability of translating properties from their system type to the social system type (and we should keep in mind that this ability has changed from the ancient world up to contemporary societies, and will continue to do so in the future). One way to organise information transfer is to address materiality with regard to the individual. Material objects (clothing, housing, transportation, shops, electronic devices, etc.) influence the behaviour of the individual. At the level of social systems, the many and manifold individually internalised engagements with the material world(s) are then connected to specifically selected (though only temporarily fixed) relationships within the spatial systems. These relationships create a subset of particular locations out of a population of potential places. Those spatial networks may endure as long as the social system under investigation exists. And the networks of material objects, together with their locations, will then be assigned to a notion or a phrase.

This brief and coarse delineation of structurally coupling social with spatial systems serves to help understand the introductory statement that geographical spaces do not exist purely as a materially empirical fact. However, they exist as language (semantics) in its widest meaning, including models. This, in turn, justifies the central meaning of models in approaching geographical spaces both scientifically and in our daily life.

The Meaning of Models

If geographical spaces cannot be reduced to their material domain but should be understood as linguistic elements used in social systems, and if geographical spaces cannot be fully comprehended without their material and relational domain, then models can be seen as a proper and well-established tool in social communication (models are important tools also for the individual in gaining knowledge of and orientation in our complex world; here, I refer to the communicative function only). Models have been mostly appreciated by their function of representing artefacts in a simplified and purpose-based manner. As such they are imaginations that social systems use to deal with their respective environment.

Besides this representational function, and more important with respect to the idea outlined here, is their constructivist function. Models have the capability to make geographical spaces visible and tractable. This capability is not necessarily given with all models that claim to make geographical spaces visible and tractable; in fact, most models restrict themselves, sometimes explicitly, mostly implicitly to certain parts of spatial systems. For example, a raster map is used to represent the spatial distribution of population.

The point I want to make here is: models are not then only simplified representations of what is more or less already known, but offer opportunities to create new insights. Closely related to Lenhard et al. [14], it is a "pragmatic construction of reality", whereby reality emerges inside the models. In a similar vein, Knuuttila [9] states: "Rather than being representations in themselves, models are often valued for the results they produce". In other words, it is not *the* reality or an absolute truth we refer to in the process of modelling, and the aim and claim of modelling is not to represent reality as best as possible, simply because reality is not given as a single world. Instead, there is collaboration and/or competition of models concerning their use, utility, power of persuasion, and aesthetics (of those models we are aware of; how many do we not know?). And the decision about the selection of models will be made in the social systems. Models, thus, influence our thinking at least as much as our empirical perception does.

It is, furthermore, important to take the self-referencing characteristic of models into account. The theory of social systems, for example, has in part been developed through models that had their origin in biology. In addition, the theory refers to models that emerged in the process of theory creation which refer to other models within the theory. In so doing, models try to capture the mechanisms and structures of the theory.

Conclusion

Because geographical spaces do not exist materially and empirically, it is important to create and use models that help approach the comprehensiveness of what is communicated in social systems as geographical spaces. Therefore, we are convinced that 'models do not behave badly', as Derman [3] believes. He claims that theories "are attempts to discover the principles that drive the world", while models are understood as "metaphors that compare the object of their attention to something else that it resembles" (ibid.: 6). Besides the problematic assumption that principles of the world have only to be discovered, it remains open how the principles will be discovered if not by models.

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Chapter 27
Peek Over the Fence—How to Introduce Students to Computational Social Sciences

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Abstract The aim of the paper is to present an idea on how to introduce students of social sciences to computational approach. We discuss why there is a need to develop computational education in the social sciences and why it is a challenge. We consider barriers related to students and to academic teachers. Then we present the idea on how to help overcome those barriers. Within the project Action for Computational Thinking in Social Sciences we plan to set up a MOOC program on social computation at an introductory level. The program is addressed to learners of social sciences (mostly bachelor level) who often experience high levels of anxiety when it comes to mathematics, computers and formal modeling and have no working knowledge of advanced algebra, mathematical analysis, programming etc., but it is open for larger audience. We aim at providing them with a series of short introductory courses that will give them an opportunity to peek over this fence built of fears, stereotypes and lack of practice. We want to show the learners that computational approach to social sciences is, first, worthwhile, as it provides a new angle to look at societal phenomena and, second, accessible, if only approached from the story side rather than from the mathematical formulas side. We hope this will encourage the learners to engage in more demanding courses or, at minimum, approach the computational social sciences with a better general understanding.

Keywords Computational social science · Education · Sociology of education · Massive open on-line courses

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Demand for Computational Social Scientists

In the current digital era, with an increasingly complex and turbulent society, demand is rising for social scientists capable of analysing behavioural dynamics[1]. Studying behavioural dynamics is a valuable lens, both in public policy making and community planning, as in scientific projects on how human (economical) behaviour affects ecosystems. Computational Social Science (CSS) offers a framework that connects a complex networked systems perspective with a suite of computational tools and methodologies. CSS covers collecting, processing and visualising large data sets and simulating the dynamics of behaviour, ranging from processes within the individual to society at large. It provides an interdisciplinary approach to the social sciences [3] and allows for a more precise testing of behavioural mechanisms in a dynamic setting [15]. Thus it offers tools to address the current problems in the social sciences regarding lack of replication, artificial and non-representative laboratory settings, and the fundamental limitations of statistical analysis [12]. Furthermore it allows linking to other formal models, such as ecological and economical models. This contributes to bringing social scientific knowledge into projects addressing multidisciplinary challenges, such as adaptation to climate change, opinion dynamics, transitions in energy use and food consumption, and the adaptive capacity of societies dealing with migration (see e.g. [7]). Computer simulations of artificial societies are increasingly being used as a tool to systematically explore the complex behavioural dynamics in social systems [6, 14].

Despite its potential and fast growth, CSS is still hardly found in programs at bachelor and master levels in Europe, be it social psychology, cognitive psychology or sociology. Hence most students are not aware of developments in modelling societal dynamics, automated information extraction (big data) and modelling the complexity of individual behaviour and cognition. It seems that in the current educational landscape there is still a lot to do in order to meet the increasing demand for computational social scientists. Integrating CSS tools into the curricula would help to enhance problem-solving capacities of social scientists, but also offer the necessary approaches in dealing with new kinds of data that are available and relevant for analysing behavioural dynamics (e.g.automatically extracted data that allow us to observe individual behaviour, as well as interactions on a large scale of extended periods of time [17]).

Barriers for CSS Education

Unfortunately, it seems that CSS teaching has not developed the muscle that we had hoped for. In a survey among 4026 teachers of methods and/or statistics in social sciences (31% of which cover big data analytics or data science methods in

[1]The first part of the paper is based on a conference paper: Jager et al."Looking into the educational mirror: why computation is hardly being taught in the social sciences, and what to do about it" [8].

their courses) the level of programming and statistical knowledge that the students possess was indicated as the biggest problem [9]. A key question we face is: why is CSS—despite its relevance—not being widely taught in social scientific educational programs, at least on an introductory level. Two main reasons we identify are: (1) students feeling uncomfortable with more computational approaches, and (2) teaching staff having only limited experience and resources to teach CSS, and limited support from managing boards.

Concerning the student perspective, many students of social sciences do not feel capable enough to study subjects which require competences in mathematics and/or ICT. In a typical social studies curriculum students attend obligatory courses in statistics and quantitative methods. These are usually perceived as difficult and computational social science is often associated with bad experiences with those courses. This problem is described in the literature as "mathematics and statistics anxiety" [1, 11, 18]. Several studies about social sciences students show a high prevalence of statistics anxiety among them (75–80%). This has an impact on students' subsequent educational and professional paths (e.g. [18]). Considering that CSS relies on programming skills, it is obvious that this anxiety for computing may constitute a first barrier to address.

This problem is related to gender composition of population of social sciences students. Girls are often conditioned from an early childhood to doubt their STEM-related abilities (Science, Technology, Engineering, and Math). As a consequence, perceived self-efficacy in advanced ICT and mathematical skills for girls is significantly lower than for boys [5]. At the same time in all the European countries a student of social sciences is typically a woman. Differences in gender shares of men and women in this group reach even 23 pp. [4]. It is a manifestation of disciplinary segregation, which creates an impression that STEM and Social Sciences, Humanities and Arts (SSHA) are mutually exclusive and contributes to underrepresentation of women in STEM disciplines [2]. At later stages of education this restricts educational options for young women.

A second barrier resides in the fact that within social sciences faculties only few—often junior—scientists are familiar with CSS, and if they are familiar, this does not always translate into CSS education. One reason is pretty simple and it is the division into two almost separate worlds of researchers: using qualitative and quantitative methods, which does not occur in case of STEM disciplines. Therefore, some researchers do not use quantitative methods and are not familiar with CSS methods. More importantly, traditional social science is relying very much on statistics, whereas CSS is focussing more on dynamics of behaviour. Because it is very difficult to translate for example regression equations into agent rules, discussion on a theoretical level is often avoided.

Summarising, to stimulate CSS teaching at social scientific faculties, we need to address computational anxiety in students, and support teaching staff with an easily available high quality material tailored to the needs of students of social sciences.

How to Change That—Action for Computational Thinking in Social Sciences

To help the social scientific community in absorbing the CSS approach, it would be good to offer educational material that supports students in getting an accessible introduction into CSS. This material could be studied independently, but preferably local learning communities emerge around this educational material, especially when exercises address programming issues. Especially here peer support is important, and universities could support such learning communities by allocating support staff.

It is worth noting that much material is already freely available on the web, facilitating the organisation of learning communities. For example, within Netlogo [16] a rich library of exemplary models is available, organised along different scientific disciplines, including the social sciences. Netlogo offers a number of standard models that are inviting to play with, which naturally raise an interest in the computations in the model and its dynamic outcomes. The CoMSES computational library (www.comses.net/codebases) offers a growing collection of executable models that have been used in published research. Many videos can be found on the web explaining computational methods and platforms. To connect with this material, Massive Open Online Course (MOOC) modules can be developed addressing different theoretical concepts, applied cases, methodology and tools. We aim at creating such a modular MOOC within the project "Action for Computational Thinking in Social Sciences" (ACTISS), co-funded by the Erasmus + Programme of the European Union.

For this endeavour to be successful several conditions should be met. As it was already stated it is crucial that the program is tailored to the needs of students of social sciences (mostly bachelor level) who often experience high levels of anxiety when it comes to mathematics, computers and formal modeling and have no working knowledge of advanced algebra, mathematical analysis, programming etc. We aim at providing them with a series of short introductory courses that will give them an opportunity to *peek over this fence* built of fears, stereotypes and lack of practice. The concept of peeking over the fence relies on two principles: the educational materials have to be accessible (to help get 'through the fence') and they have to be relevant (to make it worthwhile).

So, first, in order to help social sciences students beginning their education overcome the barriers all the educational materials should not require prior knowledge of advanced maths and programming. E.g. with NetLogo models learners can investigate interesting social mechanisms illustrated by Agent-Based Models in an almost "game-like" manner which will be engaging and informative both for students with and without prior knowledge of mathematics and programming (students with more advanced skills can engage in more advanced tasks and modify the code while those without them may experiment with a ready ABM). Secondly, educational materials should rely on examples that are relevant for social problems. We should give students the opportunity to get a better understanding of future applicability of computational models in different professional fields. By presenting them real-world cases from public policy, marketing, economy, finances or others, where computational models are being used to analyse or improve problem-solving capacities in general, a MOOC can inspire students to deepen their knowledge in CSS.

In addition, in order to make the learning experience more accessible and easier to combine with other educational activities, we propose that the program is structured in a modular way (one basic introductory course and 4 thematic courses independent of each other, meaning that a student should be able to choose any of them and skip others without any problems with following the material). Within each module the same principles as stated above should hold: we want to show the learners that computational approach to social sciences is, first, worthwhile, as it provides a new angle to look at societal phenomena and, second, accessible, if only approached from the story side rather than from the mathematical formulas side. In order to achieve those goals we want each module to have a similar structure:

- Start with a real-life example that is important to nowadays society and build an intuitive understanding of the dynamics of the phenomena
- Introduce very simple models, starting with those that can be done with pen and paper and slowly enriching them with details
- Show, without going too much into details, some advanced models that can be used to understand the real-life phenomena introduced in the beginning (in order to show how specific models or tools can be applied to study real-life problems and encourage learners to pursue the path of computational social sciences e.g. by taking more advanced courses).

Offering a basic introduction to CSS in a comprehensive MOOC for students could be the first step of a broader strategy leading to an increased use of computational thinking in social sciences. By gaining the first experience in CSS and realising the benefits for own research and studies, as well as by identifying the potential to provide enhanced problem-solving capacities and the connectivity to real-world problems, social science students might develop a greater interest in acquiring CSS skills in the future. In other words, we hope this will encourage the learners to engage in more demanding courses or, at minimum, approach the computational social sciences with a better general understanding.

As far as the format is concerned, MOOC seems promising for a couple of reasons: in a modular MOOC we can bring together videos with basic explanation of a phenomena, papers with the full details, models to exercise with, and a worked out learning paths to build up and test students' knowledge and experience. This opens up the possibility for students to follow more individual learning lines. At the same time, for teaching staff it becomes easier to organise various courses when such educational materials are available. MOOCs in particular fit well in new educational formats such as community learning and flipping the classroom. Working in small groups on exercises, watching and discussing the videos on social phenomena, and studying and reflecting on papers contributes to a vivid learning environment where students help each other in mastering the computational skills. This is also an educational format that is well defined and that can reach large audiences—e.g. on Futurelearn platform, dedicated for such courses, an average MOOC has appr. 5 thousand participants in one edition and it is possible to have multiple reruns of such courses. In future, we may see even more possibilities to make our work accessible for various types of learners. Perhaps we could develop exciting computational challenges for high school projects, or even primary education. And hopefully they may witness CSS reaching a scientific adulthood.

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Chapter 28
Are We Done Yet? or When is Our Model Perfect (Enough)?

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Introduction

When a simulation paper is under review (or being discussed at a conference), some objections are almost always raised: the authors could have calibrated some parameters; they could have validated the model by empirically testing its predictions; they could have added another variable or another process to their model; they could have explored some other areas of the parameter space, or tried out some other conditions. But they did not. These objections are very diverse: some question the limited use of empirical evidence, some the model's simplicity, lack of realism, or the limited robustness of its findings. However, they all have one important thing in common: they all target some *arbitrary choice* made by researchers. Researchers did not add further empirical data, model ingredients, or parameter configurations, because they thought that their model was already sufficiently complete. Despite some tentatives to establish standards (see e.g. [8]), scientific justifications for these arbitrary choices are often missing.In our work as simulation researchers, we constantly have to decide whether our model is sufficiently accurate and complete for the purpose at hand, or

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whether we need to pour in something more (data, realism, behavioural rules, etc.). The fact that our choice is questioned so often highlights how there are no generally followed guidelines, best practices, or rules of thumb to guide our arbitrary decision, and how different researchers end up making different choices.

In this paper we explore the impact that these arbitrary decisions have on the outcome model. We use a comparative analysis approach for measuring the differences between researchers on these arbitrary decisions. We designed (and set out to run) a pilot experiment with student participants, each tasked with the creation of an agent-based model of a given target social phenomenon. By studying how different researchers develop different solutions, and their motives behind their decisions, we can learn about the best practices on how to answer the question "Is my model perfect now?".

Premise and Theory

Many of the arbitrary choices faced by researchers can be boiled down to the decision of whether or not to add more detail to the simulation model (hereafter, the 'stopping question').

A typical example is the decision of whether to add more data for the empirical validation of a model. On the one hand, empirical testing of hypotheses is a cornerstone of science, and scholars have long been advocating for the empirical validation of simulation models [4]. On the other hand, validating a model is made difficult by incomplete data and by the challenges of integrating diverse data sources (see e.g. [3, 5]). There are simple heuristics for this stopping question: one could stop adding data once the model fits the data that was gathered thus far. However, upon closer inspection, a good fit may not be a valid reason to stop adding data, as further data may further improve the model (or, in some cases, lead to unexpected results). This heuristic taken to the extreme would lead to gathering very little data, because then it is easier to fit the model. At the limit, it is pretty easy to fit a model with one data point!

We propose three factors as possible determinants for answering the stopping question: the model's level of abstraction, its level of aggregation, and some pragmatic considerations

(1) Level of abstraction
Building on Lindenberg's theory of decreasing abstraction [6], Amblard and coauthors identify the level of abstraction as a key determinant of a model's level of detail [1]. Which level of abstraction to choose ultimately depends on the aim of the study the researcher is working on. Abstract research questions imply the need to easily communicate results, and tentative explorations of poorly understood phenomena typically lead to highly abstract models. These models are characterized by minimalistic agent choice models, simplistic environments, and reduced need for empirical calibration of the parameters. By

contrast, some research questions might require researchers to closely mimic social phenomena. In these circumstances, the model requires more details, be it spatial information, empirical calibration, or realistic agents.

(2) Level of aggregation
A model's level of aggregation (e.g. individuals, groups, cities, countries, etc.) is a second factor, related to (but distinct from) the level of abstraction. The appropriate level of aggregation can be deduced by the theories implemented in the model, or determined by the structure of the data that are used to calibrate or validate the model. A common aggregation level is to have one agent represent a household (instead of an individual person in the household). However, this agent can still have very concrete, micro-level decision rules. An example could be: "when the temperature rises, shower more often". But these agents can also be using more abstract models, where the decision to shower depends on the priority given to the environment value calibrated with cleanliness.

(3) Pragmatic considerations
Finally (and not unimportantly!), researchers' options on the stopping question are often limited by some pragmatic considerations. Typically, deadlines or budget constraints dictate how much more realism and data a researcher can afford to add to her study.

With our research, we explore the idea that there might be differences between researchers in how they cope with the three aforementioned factors. If different researchers are endowed with the same data and resources, and are told to model the same social phenomenon, to what degree will their final models differ?

A strong difference in approaches and/or final results (aka 'high researcher dependency') can be considered a problem, as it signals the lack of standardized and reproducible methods to craft a simulation model. Thus, the question arises: how consistent are researchers in choosing when to stop improving their model?

In the remainder of this contribution we elaborate on our approach to (1) gauge researchers' consistency, and (2) to identify some possible best practices to improve researchers' consistency and circulate them within the social simulation community.

Methodology

In order to start answering these two questions we are setting up a pilot experiment with students participating in a social simulation course (see https://www.cs.uu.nl/docs/vakken/msosi/ for an overview and project descriptions). Different groups of students (having similar backgrounds) will perform the same assignment, which is to devise a social simulation model for a specific phenomenon, but with a quite general research question that leaves room for multiple interpretations and design processes. We will follow the students during the course and compare the starting points, processes and final output of the groups. We hope to use this experiment as a starting point of a more thorough research in these fundamental questions. We aim to get some best practices and guidelines for developing social simulations that could eventually lead to a more standardised methodology. Note that the students will be taught about the ODD (Overview, Design, Details) protocol [2] as a starting point. This facilitates the final comparison between the models as is e.g. also shown in [7].

In total there are around 40 master students, almost all from the master AI (a multi-disciplinary master combining, computer science, linguistics, psychology and philosophy). They need to work in teams of 4 persons, resulting in 10 groups in total.

Earlier in the course, students get acquainted with social simulation and learning Netlogo. To do so, we ask them to re-write some procedures in the "segregation model" from the Netlogo library. Our experiment concerns the team project during the last 7 weeks of the course. Teams are free to choose among five given project topics (traffic simulation, drug trafficking, terrorism and radicalism, electric cars and sustainability, and interventions in criminal networks). The projects are different in the level of complexity, available implementation, and available data. For example, teams who want to work on traffic simulation need to design and implement a simulation model from scratch (or find one on the web); teams who choose to work on drug trafficking have access to a simple simulation that implements a supply chain based on both economic and trust factors.

In order to track their progress and their modeling choices, students are asked to prepare a weekly report that states what they did in the previous week, what they plan to do in the next week, and their main challenges. For each decision, they are asked to write a brief argumentation. In addition to the weekly reports, students need to hand in a document that contains a description of their simulation using ODD protocol.

At the beginning of the course, we will give a consent form to ask the students for permission of using their help for our study. In that form, we explain the purpose of our study, which data we need to collect, and which data does not have effect on their final grading. For our analysis, we will be using the following outputs: the weekly and final reports, the final version of the ODD protocol, and a short questionnaire that will be given to all teams at the end of the course. The questionnaire is anonymous and will not be shared with the teacher of the course. Generally, the data we collect and report is treated completely anonymously in this study.

Expected Results and Discussion

As the pilot study is running in May and June 2019, at this point in time, we are only able to make some hypotheses about its results. First, we expect that different student groups, even though they are working on the same project topic, will make different choices regarding the starting point of their model, the level of abstraction, the level of aggregation and the decision on when to stop, eventually leading to entirely different simulation models. Potentially, these different simulation models could also lead to different answers to the research questions. Furthermore, we expect that even within the same group, students will have different opinions on the different decision aspects.

The analysis of the weekly reports and the ODD protocol will allow us to confirm or reject these hypotheses. For future research, the confirmation or rejection of these hypotheses will allow us to assess whether more attention should be given to the researchers' consistency. This brings us to the second goal of our research, namely to identify some possible best practices to improve the researchers' consistency. We expect that when students are given and actually following "best practices" guidelines concerning the stopping problem, they will make more homogeneous decisions, leading to more homogeneous simulation results, and potentially similar answers to the research questions. The results of the pilot study will show whether the guidelines provided will be sufficiently clear and accurate to help the students make similar decisions on the stopping problem, or whether some adjustments will still need to be made.

The goal of our research is to (1) investigate whether and why different researchers make different decisions on the stopping question, i.e. the decision of whether or not to add more detail to the simulation model, when they are presented with the same initial research questions and have access to the same data, and hence whether we should be aware of the researchers' consistency when interpreting research results; and (2) to identify some possible best practices to improve the researchers' consistency which will help the social simulation community in answering the stopping question.

Social simulation models are often found to be too abstract or too far from reality and oversimplifying social processes [9], and criticised for their limited use of empirical evidence to validate the model's results, or the limited robustness of its findings. While this criticism might be valid, it should be kept in mind that the final model presented in articles or in presentations is often the result of many decisions made by the researchers themselves during the model development process, as the researchers should be constantly evaluating whether their model is sufficiently accurate to answer the research question or whether more detail should be added.

We expect the results of our pilot study to show that even with the same research question, available data and model description, different groups of students will develop different simulation results and potentially formulate different answers to the same research questions. Furthermore, we aim to gain more insight into why certain decisions were made, more particularly on the stopping question. Finally, we aim to assess students' understanding and perceived usefulness of guidelines about best practices on how to make decisions on the stopping question. These guidelines with best practices refer to the following three main items: (1) the level of abstraction (how much detail is necessary to answer the research question); (2) the level of aggregation (at what level do you define your agents); and (3) pragmatic considerations (e.g. timing).

With regard to further research, we expect our results to give a first indication on whether a more extensive research could be interesting and beneficial for the community. Furthermore, as we are working with students from similar backgrounds, there are particular researchers' characteristics we cannot take into account in our study, such as modeling experience or educational background. A larger study should aim to take also such characteristics into account.

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Chapter 29
An Online Implementation of a Virtual Agent-Based Experiment Tool—An Exploration

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Keywords Online experiments · Experimental method · Implementation

Introduction

Social simulation targets social science problems and challenges, of theoretical, empirical and applied nature, using simulation. This implies contributing to the development of theory/explanations of social phenomena or using existing theories and models to understand or predict outcomes of social processes. The different uses of social simulation and the different roles it can play in the research process make it the Swiss army knife of social research.

In this paper we will focus on advancing the understanding of group processes for sustainable management of a common pool resource (CPR) in dynamic social-ecological environments. More specifically, the causal relations underlying cooperative sustainable resource use, namely confidence, individual and shared knowledge and uncertainty about the environment and others in common pool resource (CPR) problems. This issue has been studied using behavioural experiments, such as used in behavioural economics and psychology. The use of the experimental method is adopted to be able to develop causal explanations, moving beyond correlational

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understanding of CPR problems, since an experiment is a randomised/controlled evaluation of human behaviour. This allows for collecting empirical data of actual behaviour to test the causality between factors (instead of correlations) and thus enables testing of underlying assumptions of theory and explore empirical patterns when there are no theories (yet). These are very strong reasons for using the experimental method, however there are like any method also some limitations.

1. Control: although having a high control over the situation, this does not extend to the participants themselves, i.e. one cannot look into their heads to see why they choose to do something.
2. Cost: It is costly to perform, both in time and money.
3. Reach: Also, the explanation is bound one (or two) variables simultaneously that can be tested.
4. External validity: is the experiment an actual representation of/corresponds to reality, or rather lack thereof is a frequent critique by opponents of the method and a major concern of experimentalists.

Triggered by the observations in the lab experiments done [1–3], the inability of theory to explain the phenomenon of cooperative overexploitation was identified. To be able to explain this it was important to develop an explanation of why and how individuals decide and are influences in such a setting (limitation 1 and 3). As a result, a social simulation version of the experiments was developed, with artificial subjects (called AgentEx) allowing for testing an explanation for this particular observation [4, 5]. The use of social simulation was meant to counteract the first three issues mentioned above in the following ways:

- High control over the artificial agents participating in the place of human participants, both in manipulation and data collection. Enables to develop and test explanations/hypotheses of individual decision making within a group (dynamic) context.
- After development of the agents and simulation platform the cost of running experiments is lower as no human participants were used. An online tool would lower costs even more as the need to be in a specific location disappears.
- Allows for exploring and testing many relations that may potentially be important, both in the environment/situation and in the agents. This could allow for a less costly way of exploring factors one can then test for in experiments.
- Although it is costly to develop a simulation, when the model is there, the addition or diversity in things one can explore is relatively cheap.

The process and actual availability of AgentEx triggered many relevant questions and knowledge needs. E.g. what is the role of scaling it up beyond the one group of four experiment participants, by having multiple groups or more participants? And, what does actually happen in the communication process? How are group knowledge and agreements formed? Addressing these issues partially resulted in developing adaptations/extension to the existing AgentEx model and adaptations to the post-experimental questionnaire of the lab and field experiments. However, the limitations to and interests in, require (large amount of) human participants or a combination of human and artificial participants. This led to the idea of an online AgentEx, allowing for both the mix of participants, collecting data on the communication stage, and reaching a higher and maybe more diverse or fitting population of participants.

In the remainder of the paper we will introduce AgentEx-Online, its components and the lessons learned during its development.

AgentEx Online

AgentEx-Online aims to be an online virtual experiment, where the experiment participants play a common pool resource game, bringing AgentEx [5] a social simulation mimicking a lab experiment, online. The experiment participants are part of a (virtual) group and have common access to a resource stock. Participants can harvest resource units and earn points for every unit of resource harvested. They play several rounds, but do not know when the game will end. Each round the participants can communicate using the chat, harvest anonymously and individually, and are presented with the new resource stock before a new round starts.

AgentEx-Online thus connects to the same experimental design in a lab, field and simulation, however due to the medium in which the experiment is performed different questions, manipulations and data can be collected. One can distinguish different experimental forms/methods, for example: conventional lab, framed lab, lab-in-the-field, framed-field and natural field experiments, for a taxonomy, see [6]. The main difference between them is what kind of *participants* they have: student (lab) versus resource user (framed-lab in the field) and the way setup/*situation* approximates or is reality. In Table 29.1 we compare these including with virtual experiments. There we can see that differences between the experimental forms vary not just in the type of participant (student, resource user, agents) and setup (abstract, contextualised or real) the ability to go online and reach a larger pool of participants, with lower cost and having high manipulation freedom is an unique asset of virtual experiments.

Implementation

To recapitulate, AgentEx currently runs with artificial participants, i.e. agents, and has a predefined number of participants. The design requirements for AgentEx-Online are to bring AgentEx online, to also allow for groups that are completely human or mixed, i.e. human and artificial participants, and allow for bigger group sizes. In terms of data collection, this includes the addition of logging functions for the communication among the participants. Although it sounds simple to transform a simulation tool running on a local machine to an online running simulation tool this did not prove that straightforward. In order to develop the online multi-agent

Table 29.1 Overview of different approaches within the experimental method

	Lab experiment (clean, framed)	Field experiments (lab-in, framed)	Natural experiments	Virtual experiments
Context	[Abstract—Contextualised]	[Abstract—Contextualised]	Real	[Abstract—Contextualised]
Participants	Human [Student]	Resource User	Human [Student, Resource user]	Artificial
Experiment	[1—Few] causal relations	[1—Few] causal relations	[1—Few] causal relations	[Few—Many] causal relations
Control	Situational: High Individual: Low	Situational: High Individual: Low	Situational: Low Individual: Low	Situational: High Individual: High
Time	Development: Costly Experiment: Costly	Development: Costly Experiment: Costly	Development: Costly/None Experiment: Costly/None	Development: Costly Experiment: Cheaper
Availability	Offline	Offline	Offline	[Online, Offline]
Challenge	External validity Gamification	External validity Gamification	Low control over manipulation & participants[a]	External validity Gamification

[a] Not randomised, manipulated and who is affected

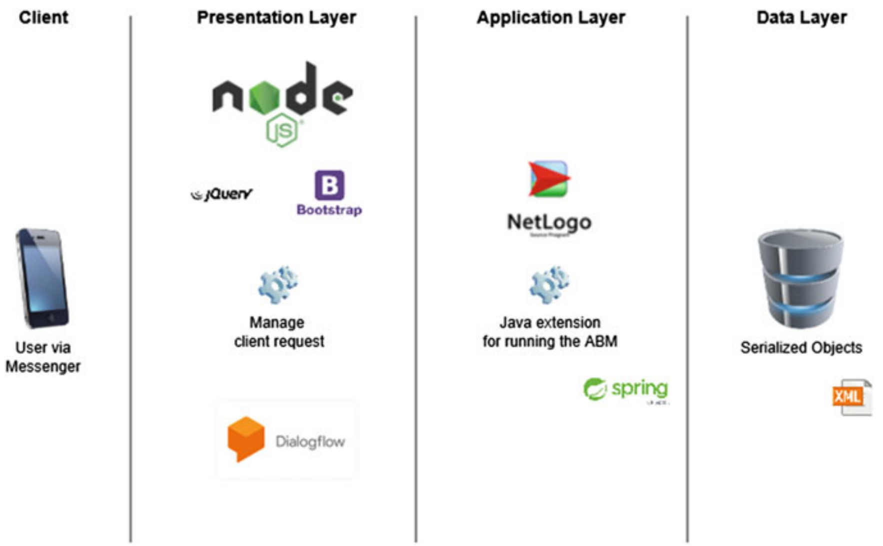

Fig. 29.1 Architecture of AgentEx-Online: system design and components

solution, AgentEx-Online thus needs to reflect (a) players that play the experiment, (b) an interface that connects players to the experiment, handling the game status and intermediate user interaction, (c) the experiment or AgentEx the simulation, and (d) data collection. This resulted in an architecture visualised in Fig. 29.1.

Tool selection. To connect the experiment (that runs on a server) with a participant (using a client) the choice was made to use a Java extension of NetLogo 6 to create a client–server solution. In such a scenario, each client can represent an artificial. (AgentEx) agent or a human participant. The client–server solution thus creates a separation between the application layer and the presentation layer (see Fig. 29.1). The implementation of the client uses Javascript (Node.JS in our case) for handling the game status and intermediation of user interaction. Since communication is a key aspect of the experiment, we aiming for interaction in natural language. For ease of implementation and to fit within the resource for a small-scale project we selected the free Google service for natural language processing DialogFlow,[1] which works very well with Node.js. For the interaction with the presentation layer, the interface towards the human users, we wanted to use a tool that we presume many human participants already use or are familiar with and which is available on many different platforms. To this end we selected Facebook Messenger which also has an easy to use api to connect to the presentation layer. Finally, to allow for a distributed environment in which each artificial agent can run on its own machine, we added a data layer for keeping all ongoing game data stored as well as create log files for each session and session participant.

[1] https://dialogflow.com/.

Reflections. A core implementation-reflection concerns the speed of the online experiment. NetLogo is the bottleneck of the architecture, and the slow start-up of new games had to be managed via pooled instances of AgentEx. This decision increased the memory use of the application, but were considered acceptable given to possibility to distribute the application layer to separate machines.

A design-implementation-conceptual challenge concerns the monetary incentive used for participants and necessary to be able to reproduce the same economic lab experiment that AgentEx originates from. The inclusion or exclusion of a monetary incentive is not just a disciplinary rule, it is a core manipulation that may affect the motivation and behaviour of human participant. This is difficult to include in the online setting, unless we involve international online payment systems such as PayPal, ApplePay, AliPay, etc., which would make running experiments online monetarily costlier. Another possible solution to this might be a gamified setting using points and e.g. leader boards for social competition and test the effect of different incentive manipulations (no, monetary, status).

Lastly, another reflection concerns the way the experiment is played. Whereas the artificial participants are well-behaved when it comes to retention and processing time for each decision. The same will not apply to its human participants. They might lose interest in the game and abandon it, especially if the game is experienced to be too slow and where there are little to no consequence from abandoning an ongoing session, in contrast to an experiment in which there is an experiment leader and other participants in the same room.

Conclusion

The project AgentEx-Online originates from the wish to scale up the existing experiment up (more participants and groups), manipulations that include certain type of participant (artificial participant), and collecting data on the communication stage that seems to be very important in shaping the short- and longer-term group dynamics. Implicitly, this tool also stimulates to think freely about what manipulations are relevant to do, regardless of the disciplinary ‘rules’ that may exist, e.g. economic experiments always needs to monetarily incentivise the participants, but may not be deceived. But also explore the role of groups size, what happens when groups get bigger, are there systematic differences in the way communication changes and how does this relate to the ability of groups to self-organise and sustain a resource?

For now, we continue with implementing this game and run a test AgentEx-Online experiment, which we will report on during the conference. We continue to think about how such an experiment can be taken to the field, where we want to be able to include participant that may not be able to read and write.

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Chapter 30
A NetLogo Extension to Secure Data Using GNUs Pretty Good Privacy Software Suite

Doug Salt and Gary Polhill

Abstract A description of a NetLogo extension and the reasoning behind its design and implementation. The extension makes use of Gnu's Pretty Good Privacy software suite to encrypt arbitrary data sources in Netlogo. This both secures the data to a reasonable degree and protects any sensitive data that might be in use for a publicly available model.

Keywords NetLogo · PGP · GnuPGP · Privacy · Security

Introduction

Cheap, publicly-accessible, distributed storage, colloquially known as the "cloud" is becoming increasingly prevalent: [1] and is increasingly used for the storing of experimental data [2]. Storing experimental data in this way has several advantages, such as any access to the internet allows instant access to this data [3, Chap. 1] [4]. This means the data is effectively accessible anywhere, while from the point of view of the consumer of the data, it all appears to originate at a single web-based location. Cloud storage is typically cloned and distributed in physical space for the purposes of fault-tolerance, meaning the chances of it being lost are remote (ibid).

It is reasonably easy to use such cloud-hosted data in NetLogo models. Some institutions provide their own cloud-based solutions, but most researchers will use (or have used) at least one of: Dropbox [5], Microsoft's OneDrive [6] and Google Drive [7]. Some, less technically-aware NetLogo users might make use of the cloud without being aware of the ramifications of doing so. Indeed, user-transparent mounting of

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cloud services on the local computer's hard drive means some users may not even be aware that the data they use is in the "cloud" already.

The advantages listed above are also the method's disadvantages. The globally accessible nature of such data could violate regional privacy laws. For instance, storing personally identifiable data of a sensitive nature without sufficient safe-guards now violates the European General Data Protection Regulation GDPR [8], and the resultant, regional legislation such as [9]. The multiplicity of the storage means the creator of the data has largely lost control over the destruction of the data. Most users of cloud data are unaware that even their "scratch" data (intermediate files and snapshots of works in progress) are stored in the cloud. This becomes problematic when regulations or ethics require that data is permanently and effectively deleted. Legislation, such as the GDPR, also stipulates that personally-identifiable data must be stored in particular geographical areas [8]. Similar constraints can also apply to the licences of proprietary data.

The *only* way to ensure effective deletion of data on the cloud is to encrypt the data sufficiently that when key for decrypting such data is withheld then the original data can no longer be retrieved [10]. This is reasonably easy to achieve given that, with current technology a brute-force attack on a 128 bit AES encoded data would take on average 1.02×10^{18} years to work [11]. Doubling the size of this key to 256 bits is thought to effectively protect such data from proposed attacks such as those theoretically available if quantum computing proves to be successful [12]. Destroying or withdrawing the encryption key therefore effectively deletes such data.

It should be noted that most "cloud" provision does not, as standard practice, encrypt users' data [3, p. 47]. The problem is that the provisioning entity controls the keys, and is is not entirely clear what jurisdictional laws to apply given the international nature of such providers. For example some doubt over data jurisdiction currently exists between the European Union and the US government [13]. Thus it is impossible for a user of such services to guarantee the correct jurisdictional standards are applied to their data, unless they take control of the encryption themselves.

Having established the need for encryption, the remainder of this paper will describe the installation and usage of a NetLogo extension that will allow the easy decryption of previously encrypted data sets. This extension will require the installation of GNU's Pretty Good Privacy suite of programs, or at the very least have the command `gpg` in the execution path currently invoking the NetLogo model. We will provide simple examples for each use case the extension has been designed for. This will be followed by the usual discussion of issues raised by the utility and use of this extension.

The NetLogo Extension

Firstly, and unfortunately we need to introduce some terminology. Every effort will be made to ensure that this is the bare minimum required. The terminology is show in Fig. 30.1.

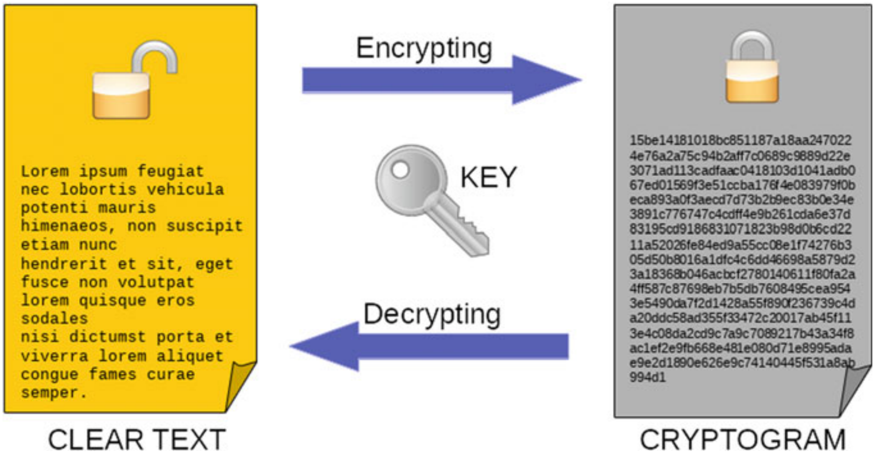

Fig. 30.1 Basic cryptographic terminology

The basic terminlogy consists of 5 terms, these being:

- *clear text*—the secret that is required to be hidden;
- a *key*—a thing this is used to unlock a secret (*decryption*) or conceal a secret (*encryption*), and
- a *cryptogram*—a piece of clear text or secret that is has been concealed by encryption.

Given that there is a need for such an encryption utility the problem becomes how can such user-controlled encryption be implemented in a user-friendly manner with minimal development. The last condition is important because coding encryption correctly is a hard problem [14]. Insufficient expertise can lead to attack opportunities due to weakness inherent in the developers' approaches. It therefore makes a great deal of sense to use existing and proven software. In addition there is a requirement that users be able to encrypt their data in the first place. This rules out the usual practice of utilising an existing, programmatic libraries, created for specifically for the purposes of encryption/decryption. Such libraries are indeed proven, but usually lack the user-friendly encryption tools required to do the initial encryption. Such tools although usually trivial to create, crucially, still have to be developed and moreover, documented. Such requirements contain the possibility of the introduction of bugs. Additionally the use of such libraries requires the constant updating of the extension software, each time the library is updated—say due to the discovery of a new attack or bug. Such constraints can be mitigated by the use of an external software suite. That is, a NetLogo extension can be designed in such a manner to make calls to an "external" program. An external program in this context is software that is independently installed on a computer, is independent of NetLogo, and does not require NetLogo to work. An example of this approach is the NetLogo R extension [15] which obviously requires the independent installation of the R programming suite for it to work with

NetLogo. Thus, if any problems are found with the external program, then just the external program needs updating. This does have the disadvantage of introducing an additional step in the utilization of NetLogo, but this is balanced not only by the additional utility and possible multiple uses of the external software suite, but by the huge reduction in complexity required to create the NetLogo extension. This has benefits in terms increasing stability and formal correctness for the extension.

The external tool chosen is GNU Privacy Guard, hereafter referred to as GPG. This is a well known suite of programs that at its heart uses OpenPGP standard as defined by RFC4880 (also known as PGP) [16]. Although designed primarily for the purposes of safe-guarding communications, GPG allows the encryption of data; it features a versatile key management system, along with access modules for all kinds of public key directories. GPG is a command line tool with features for easy integration with other applications. The software is mature in that it was created in 1996 [17] and is widely used [18, p. 10]. The presumption will be that GPG has been installed on the platform that is to run the NetLogo extension.

Because the extension uses GPG, the extension is very small and requires the installation of just one jar file. The extension is written in Scala [19] and built using, Scala Build Tool (SBT) [20, pp. 186–194] and consists of the following primitives:

- `gpg:cmd`
- `gpg:home`
- `gpg:open`
- `gpg:read-line`
- `gpg:at-end?`
- `gpg:close`

The normal flow would look like that shown in Fig. 30.2. We have tried to keep the operational semantics as natural and terse as we can make them.

The installation jar can be found at https://gitlab.com:doug.salt/gpg.git. The file
`target/scala-2.12/gpg.jar`
or equivalently:
`gpg-extension/target/scala/gpg-extension.jar`.
should be copied to a file named gpg.jar. This file should be placed in the extensions directory of the NetLogo installation. This is normally:

- On Mac OS X: `/Applications/NetLogo 6.0.4/extensions`
- On 64-bit Windows with 64-bit NetLogo or 32-bit Windows with 32-bit NetLogo: `C:\Program Files\NetLogo 6.0.4\app\extensions`
- On 64-bit Windows with 32-bit NetLogo: `C:\Program Files (x86)\NetLogo 6.0.4\app\extensions`
- On Linux, or other *nix: the app/extensions subdirectory of the NetLogo directory extracted from the compressed, installation tar ball (files ending in ".tgz", "tar.gz" or "tar.bz2").

Or, alternatively it can be placed in a sub-directory with the same name as the extension in the same directory as the source for the NetLogo model if the extension

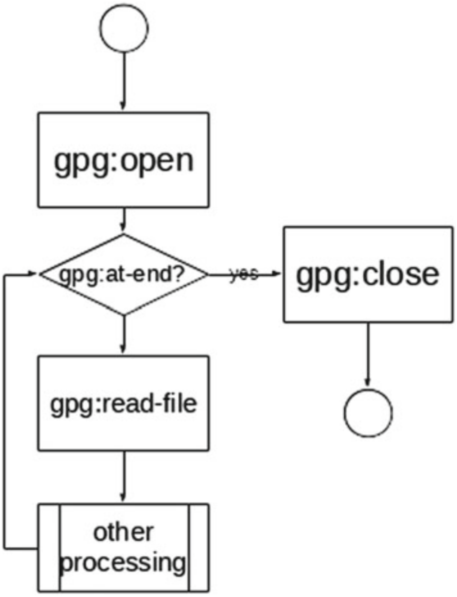

Fig. 30.2 Typical extension flow

is not to be used globally. So for instance, this extension is known as `gpg` so if the model `example.nlogo` was placed in the directory `/data/models` the extension would have the path `/data/models/gpg/gpg.jar`.

The extension is invoked in the NetLogo code by adding the keyword `gpg` to the extensions keyword beginning the NetLogo model code. For example in the code examples provided for the GPG implementation, the following appears at the top of the code section indicating that the `gpg` and `csv` extensions are to be used.

```
extensions [gpg csv]
```

The code has been converted to the latest version of NetLogo, which at the time of writing is 6.1.0. With the release of this version of the code, the addition of extensions to NetLogo has been simplified by the addition of the NetLogo extension manager. This is to be found under the tools menu in the main development interface and labelled extensions. This allows users to point and click to the extension or plugin that they want included in their code. Upon the completion of more testing for this extension, then this extension will undergo the submission process in order to decide whether this extension will be accepted for inclusion in the extensions and plugins manager.

A brief description of the available extension keywords now follows.

gpg:cmd

This sets the path of the gpg command if the gpg command is not in $PATH for *nix system or %PATH% for Windows based systems. It also allows the specification of additional parameters to gpg. The only parameters that should require changing are the home directory containing the keyring. However, this can also be done using gpg:home. This multiple way of achieving the same end is due to OS sensitivity over paths. gpg:home provides an operating system agnostic method of specifying the keyring directory. gpg:cmd also allows the GPG executable to be wrapped, or replaced with something else—which is a potential security vulnerability. However, the presence of the statement in the Code tab of the Netlogo model using the extension can be checked, and may in any case need to be edited when porting a model from one operating environment to another.

Some examples of the invocation of this command might be

```
gpg:cmd "/opt/gpg/bin/gpg"
```

or

```
gpg:cmd "gpg --homedir ~/some-directory"
```

Note, the state of execution string will persist, and not reset until the next invocation of gpg:cmd. The command can be cleared to default by using either
gpg:cmd "" or (gpg:cmd)

gpg:home

This sets the home directory relative to the directory in which the NetLogo model resides. If this command is not used then GPG assumes the that its key ring resides in the sub-directory .gnupg of the standard home directory for that system.

Examples of the usage of this command might be

```
gpg:home ".keyrings"
```

This would expect the key-rings to be found in a directory .keyrings immediately below the directory in which the NetLogo code for the model resides.

Note, the home-directory will persist, and not reset until the next invocation of gpg:home. The command can be cleared to default by using either
gpg:home "" or (gpg:home)

The home directory can also alternatively be set using:

```
gpg:cmd "gpg --homedir ~/some-directory"
```

gpg:open

This attaches and decrypts a given cryptogram.

If `cryptogram_path` is the filename of the cryptogram and `cryptogram_id` will be the variable holding the id of the attached and opened cryptogram, and in addition the cryptogram has not been encrypted symmetrically, nor has does the key that has encrypted it require a passphrase, then this command would be used in the following manner.

```
let cryptogram\_id gpg:open cryptogram\_path
```

If the cryptogram `cryptogram_path` has been symmetrically encoded, or the its decoding key requires a passphrase then this can be specified in the following manner, where "some-passphrase" is the required phrase (though in general it might be better to use `user-input` to get the passphrase rather than embed it in the code).

```
let cryptogram\_id  (gpg:open
    cryptogram\_path "some-passphrase")
```

The `gpg:open` command will raise an exception if the `cryptogram_path` does not exist, cannot be opened, or requires a passphrase when none has been supplied.

gpg:read-line

Reads a line of clear text, from a previously opened cryptogram. The file must have been successfully opened using `gpg:open`.

If `clear-text` is a previously declared NetLogo variable and `cryptogram_id` is the variable holding the id of the attached and opened cryptogram, then this command would be used in the following manner.

```
set clear-text gpg:read-line cryptogram\_id
```

This will exception if the `cryptogram_id` does not represent a cryptogram that is attached and opened.

gpg:at-end?

Tests whether there are additional lines of plain text available for `gpg:read-line` to obtain. The file must have been successfully opened using `gpg:open`.

If `cryptogram_id` is the variable holding the id of the attached and opened cryptogram, then this command would be used in the following manner.

```
if gpg:at-end? cryptogram\_id [
    ...
]
```

This will exception if the `cryptogram_id` does not represent a cryptogram that is attached and opened.

gpg:close

Closes and detaches the cryptogram. The file must have been successfully opened using `gpg:open`. This means the data is no longer sitting in memory encrypted.

If `cryptogram_id` is the variable holding the id of the attached and opened cryptogram, then this command would be used in the following manner.

```
gpg:close cryptogram\_id
```

This will exception if the `cryptogram_id` does not represent a cryptogram that is attached and opened.

Illustrations

Symmetric Encryption

This is the easier kind of encryption to understand. A secret is encrypted with a key to produce a cryptogram. That key and cryptogram are then passed to the person who wishes to decrypt it. This person then uses the key to decrypt the cryptogram in order to obtain the secret. Until the advent of asymmetric encryption, this was the most usual method of encryption. The weakness with this approach is that the key needs to be in possession of the decoder along with the cryptogram.

Say we have some clear text containing some sensitive data, and we wish to encrypt this a key, say the string, “some-string”, then the shell command using `gpg` would be the following:

```
gpg --symmetric \
  --passphrase "some-string" \
  --output cryptogram.gpg \
  clear.txt
```

The passphrase "some-password" and the cryptogram `cryptogram.gpg` can now be passed to the recipient (usually in separate messages). To decrypt and make use of the cryptogram in Netlogo, the code would be as follows:

```
let file (gpg:open cryptogram
  "some-string")
while [ not (gpg:at-end? file) ] [
  output-show gpg:read-line file
]
gpg:close file
```

This is not particularly secure as the key is embedded in the code. This insecurity could be reduced by requiring the pass-phrase to be supplied in an automatically clearing input field in the NetLogo interface or using `user-input`.

The primary advantage of this approach is its simplicity and its obvious semantics, which make it easier to follow than the asymmetric key approach in the next section.

Asymmetric Encryption

This is the most powerful facility of GPG. Asymmetric encryption offers the ability for any individual to encrypt a message, with only specific individuals being able to decrypt the file, *without having exchanged any (private) encryption keys*. This is achieved by encrypting the file with the public key of the recipient, so only the private key of the recipient can then unencrypt the cryptogram. This makes this form of encryption enormously secure, and hard to exploit, because the key is never exposed to other parties. This is the unique appeal of key asymmetry: the only people who can open the file must be in physical possession of the private key, and if a passphrase is used, then they must also know something as well.

Asymmetric key encryption tends to confuse people [21]. It may, however, be thought of in the following manner. Consider a chest which has two locks on it. The first lock is a deadlock and may only be locked permanently with a key, otherwise that lock is always open. If this lock is locked, then this triggers the latching of a second lock. The first key corresponds to the public key, the second to the private key. In this scenario, if a secret is locked in the box, by the public key, this causes the second lock to latch and lock. The box may only be opened if and only if we have both the public and private key. This is not quite how asymmetric encryption in GPG works, but is near enough to give a reasonable understanding of the principles and its implications. For instance using this box system we can pass a secret to a person who owns the private key, safe in the knowledge that once this box is locked only they can unlock it. GPG is effectively just a method of leaving many copies of such boxes and many copies of such locking, public keys just lying around, just waiting to be used.

The code below presumes a cryptogram with no passphrase on the private key. So if we have some user, denoted `aUser`, and this user has a public key `aUser.pub`, an email associated with this public key of `aUser@anInstitution.ac.uk`, a private key, `aUser.ppk` corresponding to the public key `aUser.pub` and the clear-text in `clear.txt` is available in the same directory containing the NetLogo model and code.

Firstly the public key would need to be imported into the keyring of the person performing the encryption:

```
gpg --import aUser.pub
```

This user would then encrypt the clear text in `clear.txt` using the following command:

```
gpg --encrypt \
  --output cryptogram.gpg \
  --recipient aUser@anInstitution.ac.uk \
  clear.txt
```

The cryptogram is now encoded in the file `cryptogram.gpg`, with the public key, `aUser.pub`. To be able to decrypt the cryptogram, `cryptogram.gpg`, then the user who wishes to do the decryption must have the private key, `aUser.ppk` in their keyring. This may have happened in only two ways. Firstly `aUser.pub` the public key was generated by the command:

```
gpg --gen-key
```

This generates a private key into a person's keyring and moreover associates that private key with a particular email address. To obtain the public key then the following must be run:

```
gpg --export  aUser@anInstitution.ac.uk \
  > aUser.pub
```

This is the public key and may be distributed to anybody. There are no privacy implications on the distribution of this key.

Alternatively the sender would have had to import the private key into the keyring, say something along the lines of

```
gpg --allow-secret-key-import aUser.ppk
```

Given all the above, if the file `cryptogram.gpg` is present in the same directory as the NetLogo code and model, the code to decrypt and show the clear text in Netlogo would be the following:

```
let file (gpg:open "cryptogram.gpg")
while [ not (gpg:at-end? file) ] [
  output-show gpg:read-line file
]
gpg:close file
```

This means that only a user in possession of `aUser.ppk` can decode the cryptogram `cryptogram.pgp`. Moreover if there is a passphrase associated with `aUser.ppk` then this must also be supplied by the user, further reducing the possibility of the cryptogram becoming compromised. The passphrase should really be supplied by `user-input`, or an automatically-clearing field provided in the interface. However we cannot enforce it, but only recommend this as the implementation.

The GPG tools also allow multiple public keys to be provided at the point of encryption, allowing a limited specific group of individuals with a matching private key to access the data, as opposed to just one person.

Reading an Asymmetrically Encoded CSV file

With a similar set-up as above; then imagine we have some user, denoted `aUser`, and this user has a public key `aUser.pub`, an email associated with this public key of `aUser@anInstitution.ac.uk`, and a private key, `aUser.ppk` corresponding to the public key `aUser.pub`. This time, a clear-text CSV file has been encrypted using `aUser.pub` to produce a file `cryptogram.gpg` in the directory that the NetLogo model and code resides. Then to read the encrypted CSV file we would use the following code.

```
let file gpg:open "cryptogram.gpg"
while [ not (gpg:at-end? file) ] [
  output-show (csv:from-row
      gpg:read-line file)
]
gpg:close file
```

This example is very similar to that of the previous section, and all it shows is that the extension can be used when coupled to other extensions available in NetLogo thus increasing its possible utility.

Discussion and Conclusion

We wish to encourage the use of asymmetric encryption for the purposes of securing potentially sensitive data. Asymmetric encryption allows secrets to be passed between sender and receiver based only on something publicly shared, something only the receiver has, and optionally something only the receiver knows (if there is a passphrase on their private key). What makes this method particularly secure is no exchange of private key information has to take place. With the ability to encrypt for multiple recipients using a single cryptogram containing data, then this effectively means that encrypted data can be personalised to the group of receivers only: each having their own particular private key. This restricts the use of the data to that group, and that group only, so long as their private keys remain uncompromised.

Asymmetric encryption has obviously been developed for other applications than encrypting data for use in models, most notably email. Consequently the infrastructure is in place to allow people to publish their public keys to the Internet, with some email clients having functionality to access them. Most notably there are a number of public key servers, where public keys may be retrieved on the basis of the supplied email address. To use this infrastructure to allow decryption and encryption of data in NetLogo, would have the extra dependency of users publishing their public keys on a public key server. Public key servers have the problem of becoming cluttered with keys that are no-longer used, or many duplicate keys for the same email. One way round that problem would be to make all keys time-limited, which can be done at the time of creation of the public key. Indeed, time-limited keys would effectively mean the data are deleted upon expiration of the private key.

Although the approach here is still vulnerable to code modification and memory sniffing (particularly memory freezing attacks crashing the application or entire machine such as those found in privilege-raising attacks[22]), it reduces the security requirement footprint to a level where it could be argued that "reasonable precautions" had been undertaken to secure the data. (Though obviously we are not in a position to offer any guarantees in this regard.)

We have developed a extension that uses the GNU PGP software to allow various types of encryption on the data only. A further security measure could be to obfuscate the code, but we believe that this not only violates the code of openness that surround the NetLogo community. Taking somebody's open code and concealing it legally violates the GNU General Public License, as this is precisely the reason the license was created in the first place [23]. It also violates the principle of open science as people should be able to inspect models to see the reasoning that underlies them. This is increasingly important where such models are intended to be used for policy decisions [24]

This code has been tested on Linux, Windows 7, Windows 10, and OSX so far the code could be ported in entirety into NetLogo. There are Java libraries available that mirror the functionality of PGP [25]. However this has the limitation of precluding the rapid release cycle of encryption software once vulnerabilities have been discovered. The code, as it stands is specifically designed for GPG, and the arguments expected by GPG. It would not be difficult to write wrapper scripts for other encryption suites, and therefore reuse this code. This, of course is a security weakness and does provide an additional attack surface, whereby the code could be replaced by compromised versions of the encryption suite, but as explained earlier, this provides a "reasonable" level of security.

The use of the shell command line to encrypt the data and to use keys may still be too complicated for non-technical users. However those users that deal with sensitive information have a duty to protect that data. If behoves them to understand the implications of not encrypting data, or making the effort to understand the basics of such encryption in order to use it safely and successfully.

In conclusion, we have developed a portable encryption solution for NetLogo that can be tailored to the various security requirements of either institutions or individuals. This has been done with the minimum coding required in order to reduce an possibility of mistake, and using pre-existing standard software that can utilise existing encryption infrastructure.

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Chapter 31
Archetypical Patterns in Agent-Based Models

Gert Jan Hofstede and Emile Chappin

Abstract Complex systems produce recognizable self-organized patterns across time. This conceptual paper consists of a systematic reflection on what kinds of archetypical patterns systems can show, and in what kinds of cases these patterns could occur. Agent-based models are used to exemplify each pattern. We present a classification of the breadth of typical patterns that agent-based models can show when one runs them. The patterns fall into three categories: resource use, contagion, and output patterns. These are pattern archetypes; most real-world systems, and also most models, could and will show combinations of the patterns. In real systems, the patterns will occur as phases and building blocks of developments. These are patterns frequently occurring in real-world systems. The classification is the first of its kind. It provides a way of thinking and a language to non-mathematicians. This classification should be beneficial to those researchers who are familiar with a real-world pattern in their discipline of interest, and try to get a grasp of pattern causation. It can also serve in education, for giving students from a variety of disciplines an idea of the possibilities of agent-based models.

Keywords Agent-based model · Pattern · Tragedy of the commons · Fixes that fail · Power law · Tipping point

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Introduction

In this age of interconnection of local social and economic systems, of human-induced climate change and of global pandemics, there is an increased need for recognizing, clustering and exploring (possible) patterns in complex systems. Science provides many methods to do so. Scientists in various disciplines and policy makers in many of today's socio-technical systems need to be able to recognize patterns and to know whether and how they could intervene to improve the systems they are part of and govern [1]. Some interventions could be crucial, others futile; and the difference can be clarified by studying underlying patterns in the behaviour of the systems that should be managed [2].

A pattern is a regularity in the world that can be observed by the senses or is inferred from collected data. A pattern can occur in many guises, for instance geometrical patterns representing mathematical principles, spatial-temporal patterns capturing developments of systems over time, and abstract patterns that describe conceptual ideas. This paper aims to identify and summarise archetypical patterns in complex systems including the mechanisms that form a possible cause for the pattern to come about. A key method in the complexity science that deals with patterns is agent-based modelling (ABM) [3]. ABM enables an explicit discussion on how patterns emerge on the system level out of lower level interactions. We use this key feature of ABM to define and describe a set of archetypical patterns. The actual patterns shown by real-world systems may be a combination of archetypical patterns, often containing recognizable elements of one or more of them. We use ABM for its conceptual closeness with real systems that consist of elements interacting across space and time. This will make our classification and examples accessible to practitioners of complex systems.

The article is structured as follows. Section "Materials and Methods" describes materials and methods. Section "Agent-Based Models and Patterns" discusses the elements of agent-based models that make them such prolific reproducers of patterns. Section "Mechanisms" lists a set of mechanisms by which patterns can be generated for ABMs. Section "Overview of Patterns" provides an overview of ten archetypical patterns with examples for all those patterns. We illustrate the patterns with simulation results from Netlogo [4] models from its online model library in more detail. These examples are accessible to anyone for closer scrutiny. The paper ends with a discussion and outlook in Sect. "Conclusions and Discussion".

Materials and Methods

This article derives from the experience of the authors with studying complex systems in various domains. In particular we have been modelling policy-relevant socio-technical and socio-ecological systems since many years. For this article, we deliberately use example models in the Netlogo models library [4]. This allows any reader access to the materials and methods to reproduce the figures and experiment with the models. We characterize each pattern with an appropriate model, in terms of a single run or of a set of runs with that model.

Agent-Based Models and Patterns

Agent-based modelling does not model the patterns we observe in complex systems directly. It models smaller building blocks: actions and interactions of agents and their environment that make up the system. If the growth of the anthill is the pattern, ABMs model the individual ants. They do so through agent capabilities such as observation and various kinds of action. These basic components and possible conceptualizations in agent-based modelling allow for a myriad of system-level patterns to occur during model runs. [3]. This is a strength, since systems in the real world also display these complex patterns [5]. Both in an ABM and in the real world, the patterns we observe are the result of what one would call in everyday language "a set of coincidences". One thing always leads to another. System elements act, react, and interact, and over time, self-organize into a pattern without necessarily having any intention of producing that pattern. In other words, patterns are emergent from the aggregated behaviour of agents. As a consequence, it is often difficult for developers of ABMs to understand why their models behave as they do—this is a serious limitation to be confident that models are actually useful [6].

The reasons why ABMs are so versatile are that:

- ABMs are primarily declared at the level of agent types. Any model run can be populated by many agents. The processes have a lot of freedom, e.g. in sequence, and in random differences across model runs.
- ABMs have agents of potentially many types and possible conceptualizations, and in potentially high numbers [7, 8]. Agents can be linked in a variety of ways. For instance, they could be neighbours, share characteristics, exchange information, beget one another, or serve as food to one another. ABM can be spatial and locations can be conceptualized in many ways.
- ABMs are temporal and model runs show path dependency. Agents can affect, or can be affected by, other agents, by aspects specific to their location and by system-wide developments. This latter possibility is often called 'second-order causation', or sometimes, with a term by Rosaria Conte, 'immergence', to reflect the fact that the system pattern that occurs during a run exerts a top-down influence on the agents [9].
- The consequence of the above points is that ABMs simulate patterns that are not directly coded, but instead emerge as a result of the aggregated actions of agents while a model runs. These patterns are often recognised by those who know the real-world systems on which models are based. The ABM thus helps these real-world system experts to investigate how these patterns are caused: 'abduction' is the methodological term for this.

Mimicking real-world systems, ABMs can show a huge variety of patterns. The same ABM can show several different patterns within a run, or across runs, depending on inputs and settings. Pattern-oriented modelling (POM) is one of the ways of establishing the validity of an ABM [10, 11]. If a model can be shown to replicate several patterns occurring in the corresponding real-world system, this increases confidence in its validity to make claims about real-world systems. These patterns are often spatio-temporal, by the nature of agent-based models as playing out over simulated time in a simulated two-dimensional space. In this case they can be visually observed in the simulated world while the simulation is running. They could also involve the fluctuation of one or more output variables over time. In that case one could show them by plotting the variable(s) over simulated time.

The variety of patterns occurring in real-world systems is staggering. A number of them that occur frequently and have recognizable 'Gestalt' have been named and are recognized in their occurrence, and sometimes in ways to deal with them. For instance, the 'tragedy of the commons' [12]. We can call such patterns 'archetypical'. How many of these archetypical patterns exist? It is a very relevant question for policy makers, researchers and anyone else that considers the possible dynamics of complex systems. Unfortunately, a systematic overview of the patterns that emerge from ABMs, in analogy to what has been developed for System Dynamics [13, 14], is still lacking. We build a systematic analysis for this purpose and provide a first reflection on what archetypical patterns can result from ABMs.

Mechanisms

Researchers and policy analysts are the architects and builders of ABMs: they conceptualize agents and decide what agents 'can do'. More precisely, they determine and code what agents perceive and deduce, whether agents and/or their environment are heterogeneous, how agents move, meet and interact, when they are born, and when they die. In other words, they build the mechanisms by which the agents—when the model runs over simulated time—collectively bring about system patterns.

Most of these patterns could be obtained in a variety of ways, employing a variety of mechanisms. Often, the modeller has some real-world knowledge or relevant theory about agents from which possible mechanisms can be deduced; in the absence of knowledge, Occam's Razor suggests that the simplest possible mechanism may be preferred on account of sparsity. Actually, one merit of ABM is that they often show that surprisingly simple agents and mechanisms can cause realistic, recognizable patterns. In other words, they show the multi-level nature of causation in systems: system-wide behaviours do not require system-wide causes. We give a rough categorization of mechanisms:

- **Direct interaction** between agents. Agents affect other agents' parameters through some form of direct interaction: killing, eating, taking or providing resources, communicating…

- **Indirect interaction** between agents. Agents may coordinate in a decentral fashion, not by directly interacting or even observing, but by responding to the same central entity/parameter that they shape together. Alternatively, agents shape the system developments together through 'stigmergy': a form of second-order causation in which agents do not directly interact, but change their environment and thus alter the decision-making of those that come after them. This occurs e.g. when agents form 'elephant paths' by being attracted to other agents' traces.
- **External drivers** may affect agents. These are exogenous to the model, so agents do not affect these values themselves. Exogenous changes may cause particular system patterns to emerge.
- **Memory**. Memory in the system can cause various effects, such as piling up, lack of responsiveness, or learning. Small effects repeated many times can lead to piling up, resulting in unanticipated system behaviour. This can happen when densities matter and are affected by these changes. Lack of responsiveness, also called myopia, can occur when obsolete information is kept and crowds out new information. Memory is then substituted for observation. More advanced forms of relying on memory could be called learning.

Overview of Patterns

This section briefly describes ten patterns, which are numbered below and grouped in the following classes: resource use (3.2), contagion (3.3), and output pattern (3.4). Table 31.1 provides an overview. Besides the category and name, it provides six emergent characteristics of each pattern. All of these occur as a result of the combined actions of agents.

Two emergent characteristics could occur at some place or time during a model run:

- *Positive feedback loop:* does it include self-reinforcing feedback behaviour;
- *Balancing loop with delay:* does it include self-limiting feedback behaviour.

Four emergent characteristics are properties of an entire model run

- *Finite:* Does it have a definite end;
- *Asymptotic:* if there is a central output variable, does it tend to a fixed value;
- *Repetitive:* does it repeat itself;
- *Ergodic:* does each run, if let go long enough, produce all the possible model states;

We see the patterns in Table 31.1 as archetypical: each of them is typical for ABMs, in the sense that they are frequently encountered, and they are also elementary, in the sense that they are basic and emerge from simple models. The patterns are not necessarily mutually exclusive and systems/models could show several of these patterns, or combinations of them, across simulated time.

Table 31.1 The overview of ten patterns. The table first gives an overview of possible mechanisms causing these patterns. ‘yes’ means a mechanism has to occur for producing a pattern, ‘no’ that it cannot occur. The table also gives the occurrence of four likely emergent characteristics of model runs

Pattern name	Mechanisms				Emergent characteristics					
	Direct interaction	Indirect interaction	External drivers	Memory	Positive loop	Balancing loop	Finite	Asymptotic	Repetitive	Ergodic
Resource use										
1. Tragedy of the commons	Maybe	Yes	Maybe	Maybe	Yes	No	Yes	Yes/No	No	No
2. Fixes that fail	Maybe	Yes	Maybe	Maybe	Yes	No	Yes	Yes/No	No	No
3. Sprawl	Maybe	Yes	Maybe	Maybe	Yes	Yes	No	No	Yes/No	No
4. Coexistence	Maybe	Yes	Maybe	Maybe	Yes	Yes	No	No	Yes/No	Yes
5. Ecosystem engineering	Maybe	Yes	Maybe	Maybe	Yes	Yes	No	No	Yes/No	No
Contagion										
6. Synchronization	Yes	Maybe	Maybe	Maybe	Yes	No	No	Yes	No	No
7. Spatial clustering	Yes	Maybe	Maybe	Maybe	Yes	Yes	No	Yes	No	No
8. Attribute patterns	Yes	Maybe	Maybe	Maybe	Yes	Yes	No	Yes	No	No
Output pattern										
9. Tipping point in output	Maybe	Maybe	Maybe	Yes	No	No	Yes	Yes/No	No	No
10. Power law distribution	Maybe	Maybe	Maybe	Maybe	No	No	Yes/No	No	No	No

Mechanisms are about what agents do to one another, while patterns are the emergent results. Any or all of the mechanisms can occur in a system. Some are indispensable for producing a certain pattern, but most are optional. Their precise nature and relative strength can vary. There could be mutual influences between mechanisms. Memory could lead to transition from one pattern into another, for instance through selective reproduction of agents with certain traits. Table 31.1 summarizes the complexity of pattern causation.

Agent-based models are intrinsically about more than one level of aggregation. In a running model, or in a real system for that matter, there can be more than two such levels of aggregation. A mechanism can lead to emergent results that themselves can serve as a mechanism for higher-level aggregated patterns. For instance, a plague organism can go through a phase of exponential growth before mechanisms start to occur that slow down this growth. We call such a phenomenon an ‘emergent mechanism’ to indicate that it operates not at the level of individual agents but at the level of collections of agents.

In fact, the distinction between ‘emergent characteristic’ and ‘pattern’ can be hard to make. ‘Pattern’ is intrinsically a recursive concept. For instance, positive or balanced loops can be considered patterns in their own right. However, they often occur for a time in a sequence of patterned elements that have a recognizable name of their own. Therefore, we consider them to be emergent mechanisms that can occur during a model run as part of its overall pattern. That is why we list them as columns in Table 31.1.

Section “Emergent Characteristics: Examples for Feedback Loops” describes emergent characteristics for feedbacks. Sections “Resource Use Patterns”, “Contagion Patterns”, and “Output Patterns” describes the ten patterns as listed in Table 31.1. We present these results in the following way:

- Title and brief description
- Iconic example(s) from the real world with a Netlogo example if available. To illustrate the ubiquity of each pattern, we give examples from four fields: society, biology, physics, and man-made technical constructions. We also present typical simulation results. Note that some patterns are apparent from observing one model run, e.g. patterns across simulated space/time. Others are apparent from graphs created based on a model run or even across runs. Making patterns apparent is one of the necessary skills of modellers.

Emergent Characteristics: Examples for Feedback Loops

We first give examples for feedback loops, which are two important emergent characteristics. All resource use or contagion patterns involve feedbacks. In resource use, agent behaviour feeds back into resource availability for the next time step. In contagion, agent behaviours directly feed back into one another. Mutual feedback loops are thus elements of all the first eight patterns of Table 31.1. These loops can occur as patterns in their own right, show repeating waves of changes. However, they

Fig. 31.1 Mechanisms, agent declarations, and patterns

tend to occur only locally or for a while, in the context of a wider-scale pattern. Both positive and balanced loops could result from the same model, depending on model settings as to delay, limits, mutual feedback, and number of variables. Because these are so simple, and occur as building blocks in the context of the eight other patterns, we treat them as emergent mechanisms in this overview.

Positive feedback loop. This is a loop the amplitude of which grows indefinitely. The resulting pattern has the shape of an exponential curve. It is obviously not sustainable for ever. The mechanism is that in each time step, the current quantity N of a variable (N > 1) gets multiplied by a factor that is proportional to N. This causes N to grow ever faster. Examples:

- Society: disease spread in the early phases of an epidemic or pandemic (Netlogo: epidemics). The start of hype cycles.
- Biology: population size in the absence of size-dependent mortality. In Netlogo, the sheep population in Netlogo sheep-wolves simulation in a run without grass, after all wolves have died out (see Fig. 31.1).
- Physics: objects falling to the ground without resistance.
- Engineering: two microphones circuiting by picking up and reinforcing one another's signal.

Balancing loop with delay. A wave pattern that continues indefinitely. A phenomenon of this category is sometimes called 'limits to growth': feedback loops that self-limit with resource availability, leading to more or less stable oscillations, whether desired or not.

Many positive feedback loops will balance at some point when other aspects of a simulation come in effect. As a result, positive feedback loops and balancing loops can result from the same model, depending on model settings as to delay, limits, mutual feedback, and number of variables.

Mechanism: a positive feedback is countered by a negative feedback, thereby providing balance, pushing the system towards a particular equilibrium or towards a kind of oscillation. Examples:

- Society: market cycles in which quantity produced and price fluctuate. The pork cycle is the archetype.

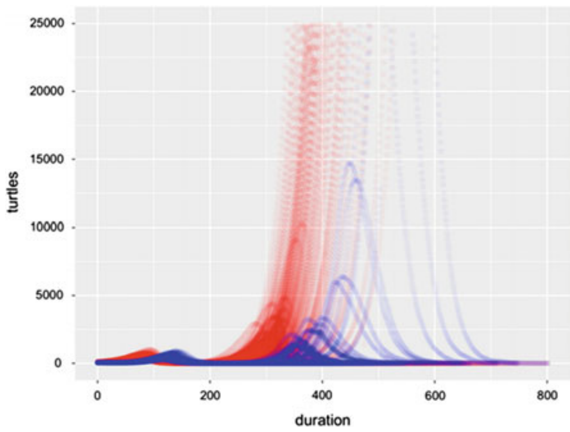

Fig. 31.2 Results from 1,000 runs with Wolf Sheep Predation model from the Netlogo 6.1 model library. Not all runs are similar, but the pattern is that either wolves (in blue) die out, which results in exponential growth of sheep (in red); or alternatively, if sheep die out first, the wolves die out afterwards

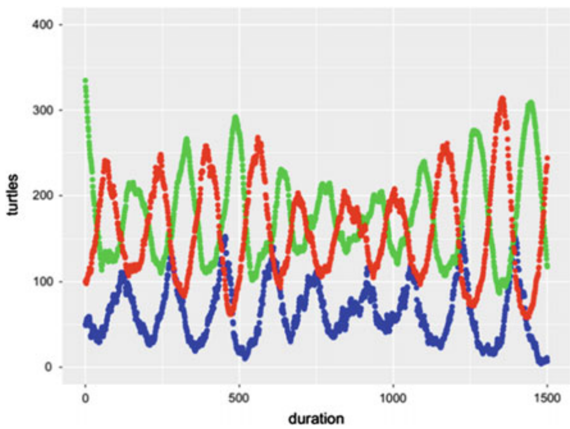

Fig. 31.3 Results from a single run with Wolf Sheep Predation model from the Netlogo model library with grass enabled. Not all runs are similar: this particular run show balancing loops with delay, which show as cyclical behaviour (or a dynamic equilibrium) of grass (green), sheep (red) and wolves (blue)

- Biology: populations that stabilize at similar birth/death rates and without net migration. In Netlogo: wolf-sheep-grass model, when population variations are buffered by the availability of grass for the sheep (see Figs. 31.2, 31.3).
- Physics: evapotranspiration—rainfall cycles.
- Engineering: thermostat of a shower.

Resource Use Patterns

Resources are quantities that agents need for survival, and may exhaust in doing so. Agents or grid cells ('patches') may also generate resources. Typically, agent motivations include behaviour directed at finding these resources. In the following patterns, which can contain elements of those mentioned above, an additional element is that the locations (grid cells, patches) in the model contain resources. Agents use

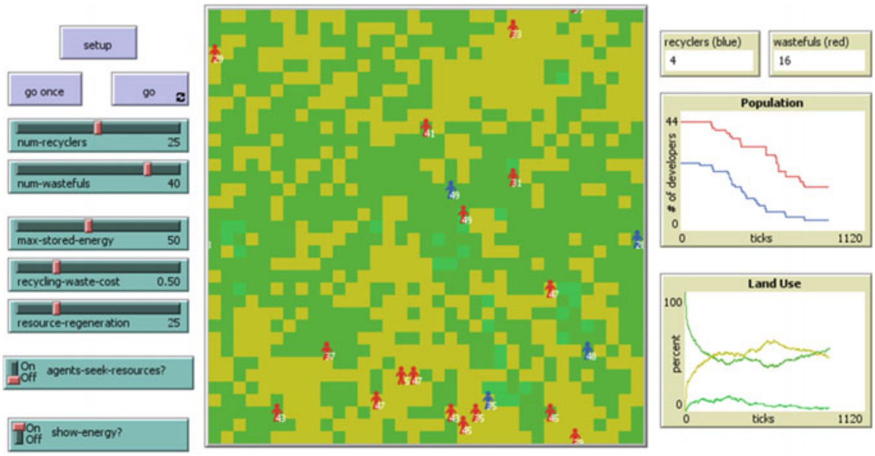

Fig. 31.4 Recycling model after a tragedy of the commons has occurred. Green patches are fertile; yellow ones are degraded; lime ones have been restored by the blue recycler agents. Bottom right graph: the environment quickly degraded in the first 100 ticks. Top right graph: 'Recyclers' first started to die, exhausted from clearing up; then 'wastefuls' followed, not finding any nourishment. After 100 ticks, the environment starts to recover, but with a much lower population

these, leading to various possible patterns with a spatial component. This means the agents do not interact with one another other than through shared resource use; the technical term for such indirect interaction is 'stigmergy'.

1. **Tragedy of the Commons**. This is a missing feedback loop between resource users and resources that leads to resource exhaustion and then death of all resource users. In the typical case, where resources are supposed to be shared and maintained by a commons, but free-riding occurs, it is frequently named 'Tragedy of the Commons'. Netlogo: recycling (Fig. 31.4). There are also other cases. A calamity such as a wildfire is also characterized by a lack of feedback and by exhaustion of resources, if not resource users. e.g. Netlogo: fire. Examples:
   - Society: tragedy of the commons. Climate change.
   - Biology: locust plague.
   - Physics: mineral exhaustion.
   - Engineering: the interventions needed to deal with strategies of software using internet bandwidth for non-crucial processes, while the internet may break down in times of a crisis.
2. **Fixes that fail**. Feedbacks are made by agents with an aim in mind that worsen the system-level predicament they were intended to solve. Examples:
   - Society: gun purchase to defend against violence.
   - Biology: lemmings taking to the sea. They sacrifice themselves for the good of the ecosystem, but that is unlikely to be their aim.

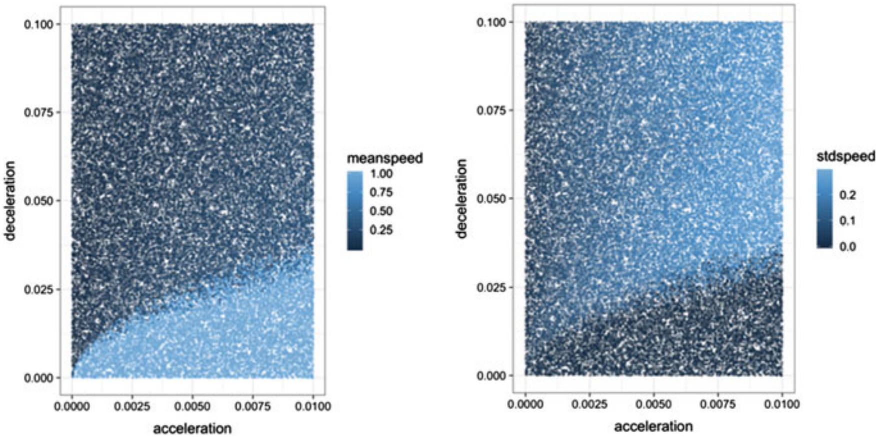

Fig. 31.5 Results from 50,000 runs with the Traffic Basic model from the NetLogo model library, varying deceleration and acceleration speeds, and varying the number of cars between 18 and 22. On the left, the average car speed and on the right the standard deviation of speeds between cars, both at time tick 20,000. Fast deceleration (late braking) is a fix that fails: it leads to traffic jams, in particular in combination with slow acceleration. The cross-over between jammed traffic and flowing traffic is surprisingly sharp

- Physics: unstable control of dynamical systems that are too slow or fast in their response to sensors
- Engineering: Netlogo: traffic basic, where abrupt braking can worsen the queueing time (Fig. 31.5).

3. **Sprawl**. A spatially bound process of resource depletion and renewal leads to spatial patterns. This occurs when positive feedbacks spread slowly. Examples:

    - Society: urban settlement Netlogo: urban sprawl (Fig. 31.6).
    - Biology: growth of lichens on stones and trees. Witch circles of mushrooms. Vegetation in arid landscapes, where roots can improve the capacity of the soil to retain water, leading to sprawling patches.
    - Physics: ripples.
    - Engineering: spread of technical innovations.

4. **Coexistence**. These are situations where populations coexist that compete for a resource, creating an ecosystem. Each population creates circumstances that facilitates the development of another type of agent. This could result in a feedback loop akin to sprawl mechanisms, but caused by several types of agents instead of one. The mutual influences need not be intentionally beneficial; the populations could be competing. This is for instance the case in Netlogo: cooperation (blue and red cows). One species may drive the other to extinction, but under some parameter settings, coexistence occurs (Fig. 31.7). Examples:

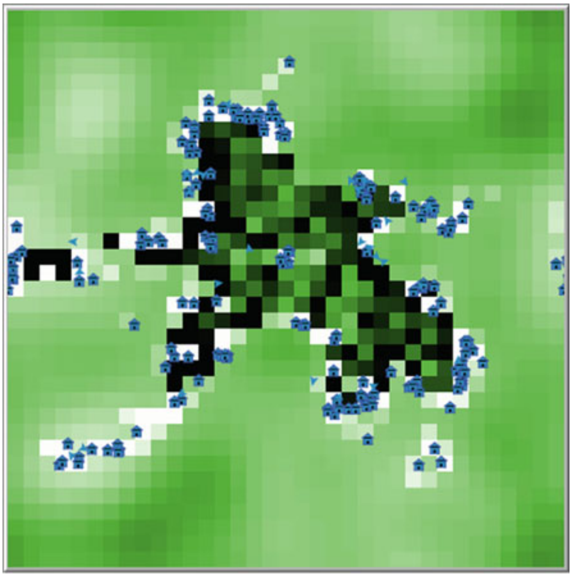

Fig. 31.6 Snapshot of a run with the Urban Sprawl model from the NetLogo model library. During the first phase of the simulation run, agents spread slowly from the centre, increasing the fitness of their environment (lighter patches). Later, the environment collapses (flips to black patches) and slowly recovers (patches become lighter and are re-colonized)

- Society: economy. Actors complement one another in creating and using resources.
- Biology: coexistence of different types of animals that use the same resource. Netlogo: cooperation (Fig. 31.7).
- Physics: the effects that gravity has on star systems, keeping planets in orbit.
- Engineering: various modes of transport. New ones typically did not supplant but complement the existing ones.

5. **Ecosystem engineering**. This is the more general case of which Sprawl is a special one. The joint activities of agents lead to differentiation of an environment that is at first undifferentiated. So here, the 'resource' is not necessarily in the patch itself, but in the emergent configuration of patches. Locations randomly picked thus become endowed with new roles. Social animals do this, e.g. humans or ants. Examples:

   - Society: paths. Netlogo: paths (Fig. 31.8). institutions. Institutions effectively constitute niches that allow certain actions and inhibit others. Informal institutions can be considered paths in symbolic space.
   - Biology: beavers, ants and termites. Netlogo: termites.
   - Physics: star and planet formation.
   - Engineering: centrifuges.

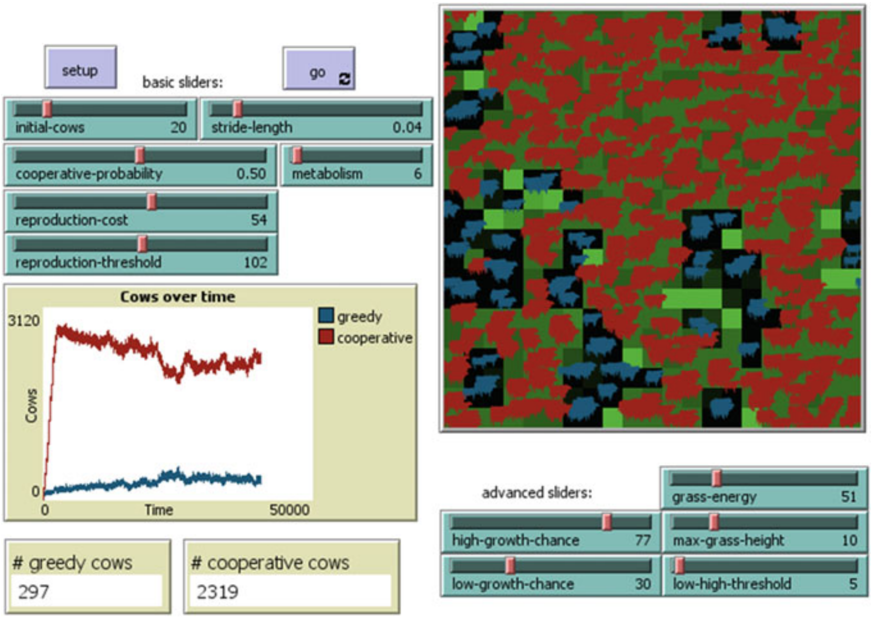

Fig. 31.7 'cooperative' (red) cows that leave some grass behind quickly colonize the empty world. 'Greedy' (blue) cows finish the food on their patch and then some migrate, the others die out, after which the patch recovers (light green). When the world is full, a dynamic equilibrium occurs between the cooperative and the greedy cows. If the cows were quicker (increased stride-length), the greedy ones would exterminate the cooperative ones with a hit-and-run strategy

Contagion Patterns

These patterns involve mutual observation and adjustment by agents, with an important role for space, time or other observable attributes.

6. **Synchronization**. Agents come to synchronize their behaviour in time, leading to temporal clustering, in other words to a system-level pulsing pattern. Synchronous collective actions are real-world cases. Netlogo: fireflies (Fig. 31.9). In human societies, the expectation of future events can lead to temporal clustering, or in crowd formation. Examples:

   - Society: pork cycles [15]. Crowd formation. Netlogo: El Farol bar.
   - Biology: pulsing by fireflies, leading to clearer attraction of potential mates. Netlogo: fireflies.
   - Physics: solar cycles.
   - Engineering: time steps in computer memory.

7. **Spatial clustering**. Agents orient themselves in space by observing and copying their neighbours, leading to spatial grouping and patterned movement. This is also a case of para-synchronization: agents copy one another's behaviour with

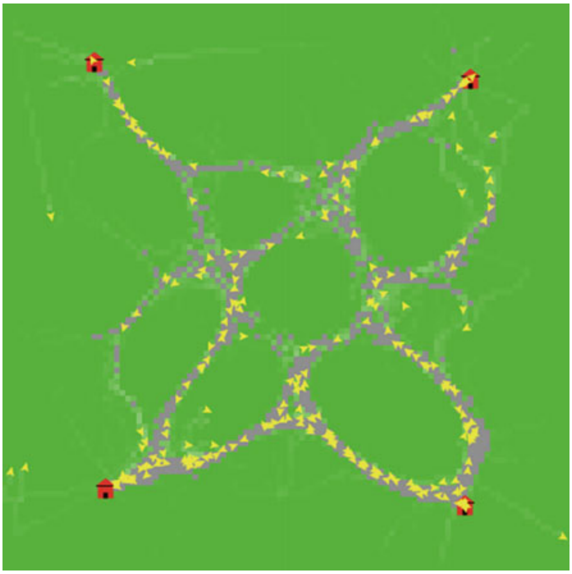

Fig. 31.8 Paths model. The agents flatten the grass (lighter shade) by walking. Repeated walking over a patch creates a path (grey). They have walked randomly, creating random paths because they prefer to walk where others have flattened the grass. Then they were given targets (four red houses). They keep using their existing paths. These decay only slowly

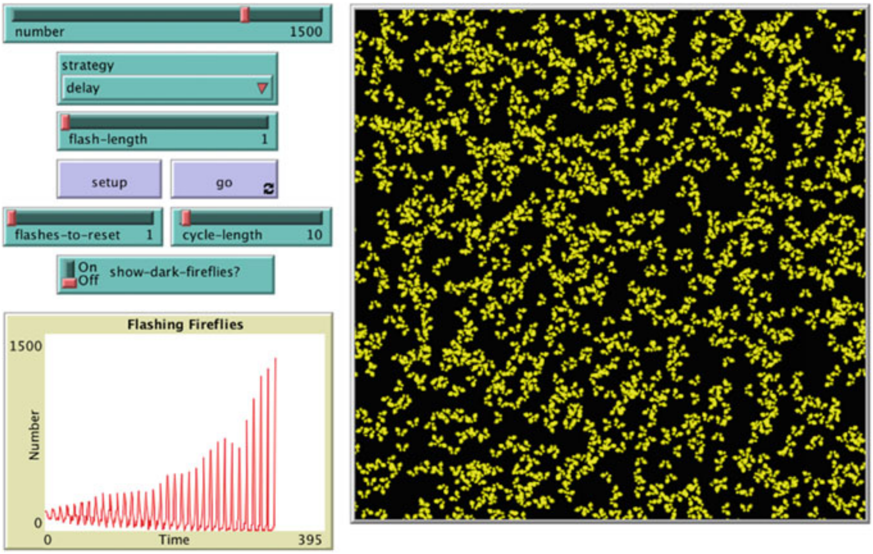

Fig. 31.9 Fireflies model. The agents synchronize flashing only on the basis of individual interactions, by the strategy to delay their next flash. Depending on the settings, the portion of the population that synchronizes grows during the simulation

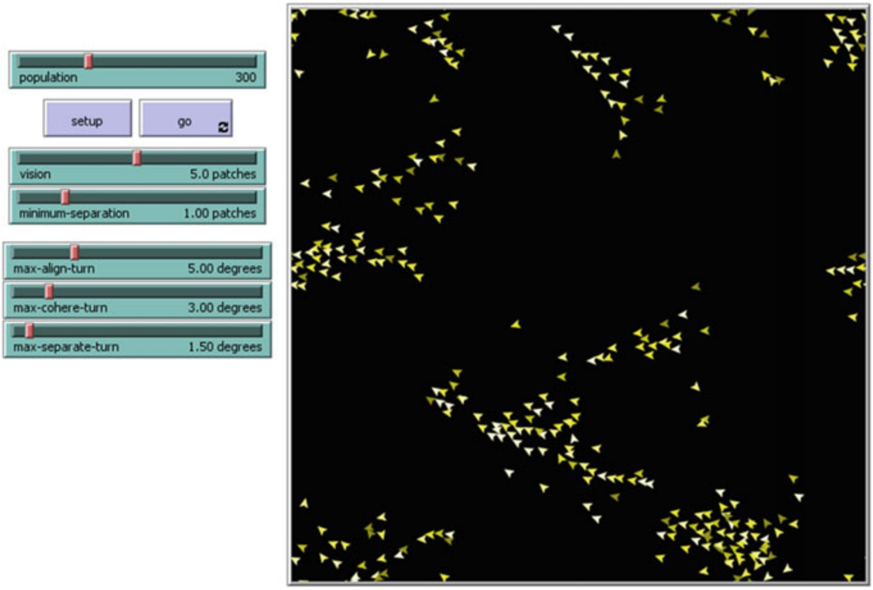

Fig. 31.10 Birds adapting their movement only to their close neighbours, distributed at random at the start of a run, end up in flocks

a delay. Where patches copy one another's attributes rather than agents, this is called diffusion. A useful property of agent-based models is that the spatial parameters can be used to symbolize something else. This allows to visualise abstract issues, e.g. position in some symbolic space. Examples:

- Society: creating and keeping walking lanes in busy places.
- Biology: path finding by ants. Netlogo: ants. Flocking by birds, herding by mammals, schooling by fish. Netlogo: flocking (Fig. 31.10).
- Physics: magnetism. Structure of crystals. density-dependent clustering of material around stars into planets.
- Engineering: nano-engineering of surfaces.

8. **Attribute patterns**. Agents adopt the same attributes, typically because deviants are weeded out. This leads to something one could call 'attribute value clustering'. If the attribute is opinion, it is called opinion dynamics. Agents copy values in binary or higher-order opinion space. This is a much-modelled phenomenon, for instance in the context of voting. Examples:

- Society: opinion dynamics. Netlogo: Rumor Mill (see Fig. 31.11).
- Biology: mimicry, where organisms evolved to look like others so that they can stay out of harm's way. E.g. cuckoo eggs. Netlogo: mimicry.
- Physics: in the physical world, this amounts to the same as clustering.
- Engineering: mimicry of artefacts such as bottles and car clutches, so that their usage or function becomes apparent.

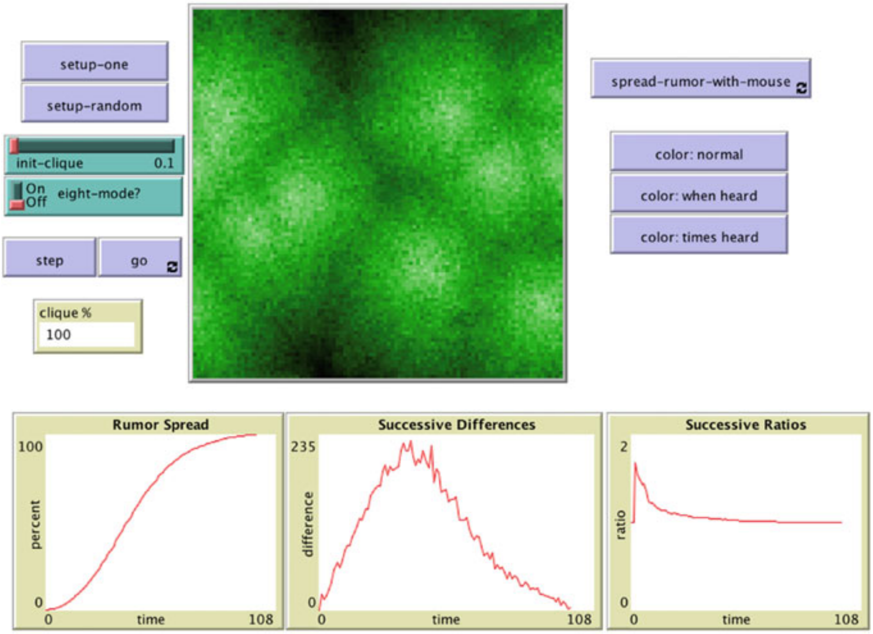

Fig. 31.11 Rumor Mill showing the spread of a rumor in a typical run. In the final system state, everyone has heard of the rumor, but not equally frequently, which is shown in the number of times a rumor was heard. The original sources for the rumor can be seen in the brightest areas

Output Patterns

9. **Tipping point in system output**. A positive feedback loop which leads to an irreversible termination condition after which a significantly different pattern takes over. This may involve processes such as dying or burning. In mathematical terms, this is a mechanism for bifurcation. In laymen's terms, a causal chain that was of little importance in the system now becomes dominant. It could be argued that a tipping point is not a pattern, but merely a transition from one pattern into another one. Small deviations in starting conditions may lead to changes in these effects, causing transitions in system patterns for which it is hard to predict whether, and at what moment in the simulation, they will occur. Examples:

   - Society: a behaviour dies out. Netlogo: altruism. Or a behaviour starts and supplants others, as e.g. in hypes or memes for greeting.
   - Biology: a population dies out, e.g. Cooperation (Fig. 31.7), or Wolf-sheep (see Fig. 31.1). Or a niche is created that allows a population to settle, as in ecosystem engineering.

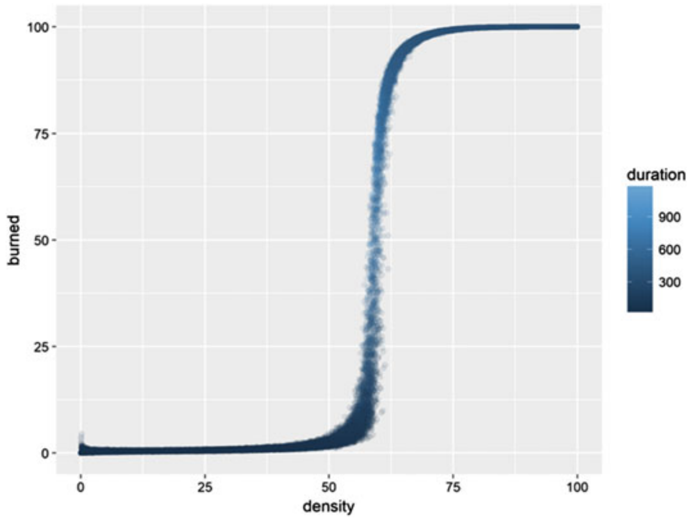

Fig. 31.12 Results from 50,000 runs with Fire model from the Netlogo model library. The fraction of the forest that burns shows a tipping point around 59% density. The results show stochasticity—the actual tipping point depends on the spatial distribution of trees. Below the tipping point the fire dies out. Above the tipping point the forest burns quickly. The fire moves slower, and hence the simulation runs take longer, around the tipping point

- Physics: a resource gets depleted. For instance, a forest could burn. In Netlogo, check the fire model. See also Fig. 31.12, which shows the tipping point for the fire model.
- Engineering: a buffer is depleted. See e.g. the Netlogo traffic models, that can be stable for a wide parameter space, until the road is full and one extra car pushes it into a traffic jam.

10. **Power law distribution**. A variable acquires a power law distribution of its frequency during the model run. Typically, this is not obvious during the model run, but clear from the distributions of output variables. Power law distributions are caused by the laws of chance affecting the probability of a variable acquiring certain values. Power laws across agents or patches are often observed. This means there is an inverse relationship between the value of some variable, and the frequency with which it occurs. This is relevant because it shows that nothing but chance is needed to account for inequality in a distribution. Power law distributions are found in innumerable phenomena. Examples:

- Society: wealth distribution in society. Netlogo: wealth distribution (Fig. 31.13).
- Biology: numerous frequency distribution in biology [16].
- Physics: earthquake frequency versus magnitude.
- Engineering: number of incoming Web links versus frequency of occurrence.

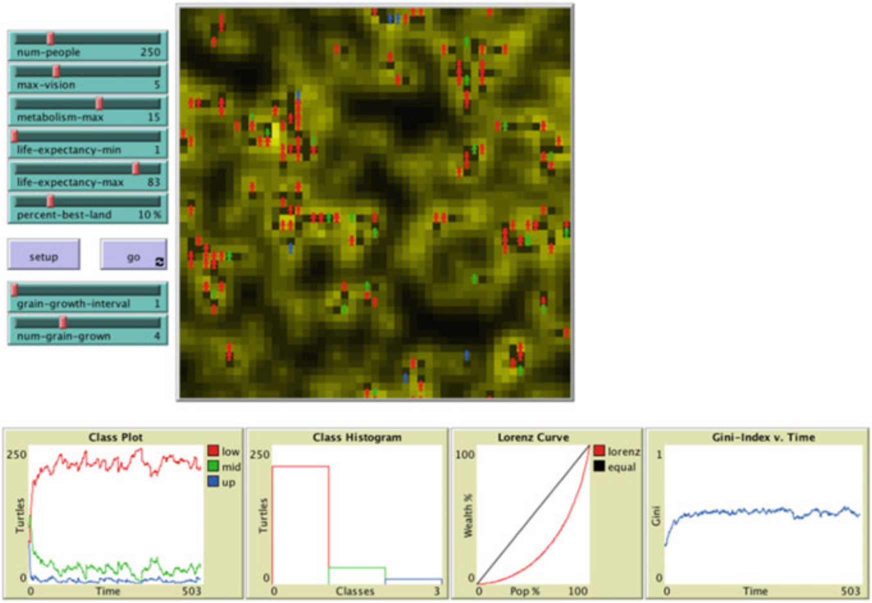

Fig. 31.13 Results from wealth distribution. Fire model from the Netlogo model library. Already with a very simple representation of the economy, a large lower class forms when turtles are assigned to the lower, middle or upper class based on their wealth in relation to the maximum wealth in the population

Conclusions and Discussion

The ability to recognize patterns in the behaviours of real-world systems is crucial in science and in policy. Yet a systematic understanding of archetypical patterns in complex systems is lacking. Agent-based modelling enable us to chart archetypical patterns and consider their causation by the mutual influences and interactions of agents such as people, politics, molecules or animals. This article presents ten archetypical patterns in three classes: resource use with unintended outcomes; contagion across time, space or symbolic space; output patterns.

Our aim in compiling these patterns is to help practitioners across various scientific fields. Humans are good at intuitively recognizing patterns, and the article builds on that strength: the ambition is to provide the concepts to describe typical patterns. This enables a discussion what simulation results one could expect, whether one already built a model or not. Scientists in many disciplines, as well as policy makers, can use them as a reference to ask themselves which of these archetypes occur in the systems they study. The typology also is an invitation to finding variants and other patterns. For instance, what about the causation of other fat-tailed distributions than power laws that are observed in reality? No doubt many other extensions are possible and indeed desirable.

This paper can be input to developments for further standardization and promoting good modelling practices [17]. It could be used when carrying out Pattern-Oriented Modelling, which measures the quality of an agent-based model by how many of the patterns from the corresponding real world system the model can produce [10].

The staggering universe of possibilities that agent-based models offer can use more structure. We envision that scholars new to computational modelling, students, policy makers, and first-time modellers are encouraged to start modelling equipped with the variety of examples of mechanisms causing patterns. The typology may train them as to what behaviour to expect, both in their own models and in those of others.

Acknowledgements The paper profited from comments by the participants of the Social Simulation Conference, September 2019 in Mainz, where an earlier version was presented. Thanks also to Tim Verwaart for clear-headed comments.

Data availability All models used to generate the simulation figures in this paper were taken from the library of Netlogo. https://ccl.northwestern.edu/netlogo/. The analysis code for the models with multiple runs is available on request.

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Part VII
Socio-Cognitive Aspects in Socio-Ecological Systems

Chapter 32
Externalities, Spillover Effects, and Implications for Payment-for-Performance Programs

Hongxing Liu and Christopher S. Ruebeck

Abstract To reduce the non-point source pollution generated by agricultural activities that leads to undesirable effects on downstream water resources, policymakers have instituted programs to incentivize farmers' mitigation adoption behavior. These programs, however, have proven to be costly and generate low participation rates. We investigate the interaction of two externalities in farmers' best management practices (BMP) adoption decisions under performance-based payment programs: knowledge spillovers and positive environmental outcomes. Our results illustrate that targeted programs can improve the cost-effectiveness of policies by focusing on those communities where the programs have more impact through the spillover mechanism. The results are driven by interactions between the distribution of farmers' willingness to adopt and the positive externalities generated by neighbors' decisions

Keywords Agricultural decision making · Agent-based modeling · Non-point source pollution · Externality

Introduction

Agricultural non-point source pollution has led to nutrient accumulation in receiving water bodies, which can create harmful algal blooms (HABs) and hypoxic zones that affect ecosystems, human health, and other economic activities. Attempts to change farmers' behavior in recent decades have included regulations (such as total maximum daily loads), incentive programs (e.g., EQIP from the USDA's NRCS), and market-based interventions.

Our investigation is in the context of pay-for-performance (PFP) programs where participating farmers are rewarded for their nutrient reduction performance [4, 11].

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These programs can thus increase cost-effectiveness by equating payments to the marginal environmental benefit, taking into account heterogeneity in fields' soil productivity. Participation decisions are influenced by farmers' attitude towards the environment [1, 3] and the social context, where knowledge spillover effects allow technology adoption to spread among neighbors through learning [2, 9, 12]. By incorporating farmer behavior heterogeneity and interactions, we help policymakers address the limited participation observed in these programs, attributed to high transaction costs and information asymmetry [6–8]. To the best of our knowledge, none of these previous studies have examined knowledge spillover effects under a PFP program, nor the dependence of these effects on the distribution of farmers' attitudes towards the environment.

Model

As [5] describes in detail, the features of our agent-based model are as follows. Farmers occupy uniformly-spaced patches on a grid of heterogeneous land productivity, with peer influence arising from their nearest neighbors. They can participate in the PFP by adopting a generic BMP, which has heterogeneous costs and returns depending on their land productivity and their neighbors' decisions. Following [10], our model's three farmer types are based on their attitudes towards the value of the program, in decreasing order of their willingness to bear participation costs: innovator, mainstream, and traditional. Two externalities mediate those costs; a knowledge spillover effect lowers participation cost, and an environmental outcome externality increases performance and economic returns. We set parameters in the model based on data collected [4] from 196 farms on the Eastern Shore of Maryland participating in Maryland water quality trading.

Results

The model's time increments by year, and results converge to a steady-state in a few years [5]. Our outcome of interest is the steady-state fraction of farmers who have adopted the BMP. Its final value in a simulation depends on the distribution of farmer types and their locations relative to each other; we find that taking the average value over 30 runs for each setup produces repeatable results. As we vary the fractions of the three farmer types, all possible communities are contained in a two-dimensional probability simplex. We thus display the participation number outcome as the height z above the triangle with corners $(0, 0)$, $(1, 0)$, and $(0, 1)$ in the x-y plane, where x and y are the fractions of traditional and mainstream types and the innovators make up the

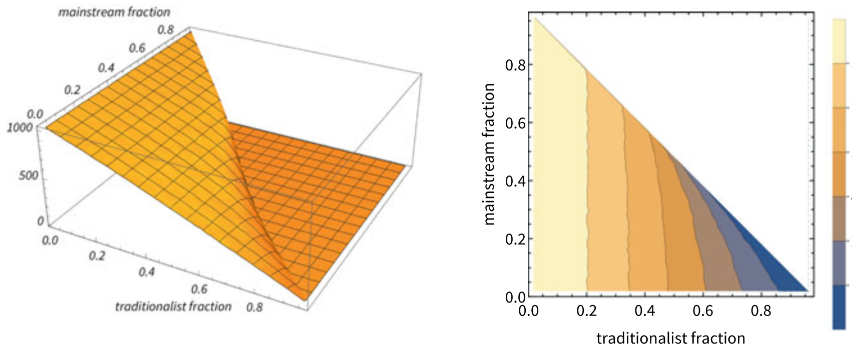

Fig. 32.1 Agents adopting BMP in steady-state as a surface (left) or contour lines (right)

remainder of the population. Note the non-linearities in the darker areas of Fig. 32.1's contour plot, near the diagonal edge with very few innovators and traditional types in the majority.

To further explore this non-linearity and its role in policy cost-effectiveness, we consider encouraging BMP adoption in communities with different farmer type distributions. Assuming in this stylized model that the differences between farmers are captured by their willingness to incur the adoption cost [5], incentivizing some farmers (effectively changing their type) can lead to increases in the steady-state participants. Our model's difference in willingness to bear participation costs between the traditionalist and innovator types is \$20. Inducing a change from 4% to 10% of the population behaving as innovators could thus be effected at a cost of \$20 paid to 6% of the population (all of whom are traditionalists in this case). With no feedback in the system this would be the end of the story, but—given that behaviors evolve in this model—we then divide that total cost by the increase in the number of steady-state adopters to derive the cost per increased participant. Figure 32.2 shows how these costs per adopter vary with the distribution of farmer types. We see that the most cost-effective policy scenarios occur when the percentage of innovators is low and traditionalists make up 50–60% of the population, corresponding to an area in Fig. 32.1 near the middle of the diagonal and somewhat towards the bottom-right corner. The results illustrate the non-linear feedback present in the system and the varying nature of that feedback's effect in different population distributions.

There are three forces determining the results in Fig. 32.2. First, there is a greater return to spending in a community with a smaller percentage of farmers who are innovators because innovators will always adopt. There is thus also more return to incentivizing traditional types to become mainstream types rather than mainstream types to become innovators. Because the knowledge spillover effect and the environmental externalities of others' decisions [5] can spread and reinforce each other, the cost to having one more steady-state participant can be lower than the willingness-

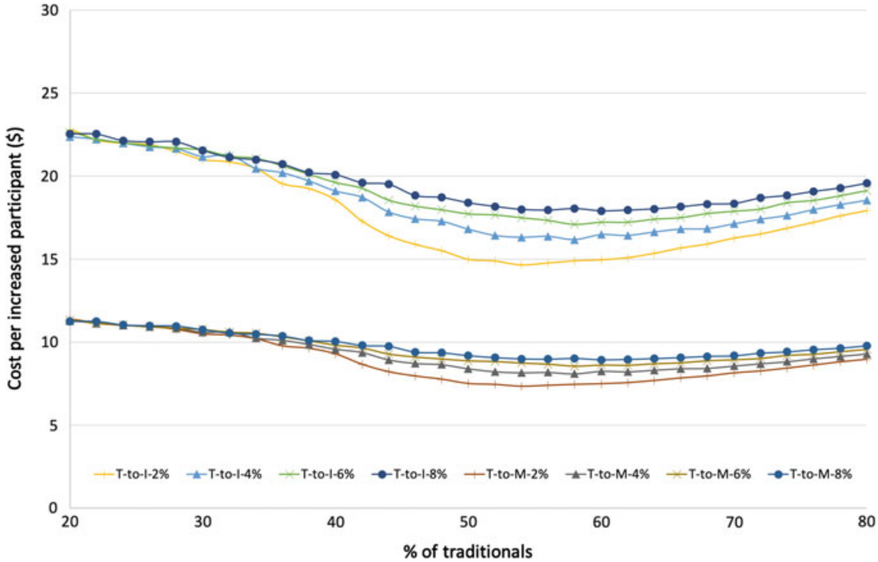

Fig. 32.2 The cost effects of various percentage point changes from traditional (T) to mainstream (M) or innovator (I) types given the current percentage (%) of innovators

to-pay difference between types. Finally, Fig. 32.2's U-shaped curves show that there is an optimally cost-effective type of community to target due to the these countervailing forces.

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Chapter 33
Coupling Agent-Based Models and Argumentation Framework to Simulate Opinion Dynamics: Application to Vegetarian Diet Diffusion

Patrick Taillandier, Nicolas Salliou, and Rallou Thomopoulos

Abstract Agent-based simulation has been extensively used to study opinion dynamics. However, the vast majority of the existing models have been limited to extremely abstract and simplified representations of the diffusion process, which impairs the realism of the simulations and disables the understanding of the reasons for the shift of an actor's opinion. This paper presents a generic framework implemented in the GAMA platform allowing to explicitly represent exchanges of arguments between actors in a context of an opinion dynamic model. More precisely, we propose to formalize the inner attitude towards an opinion of each agent as an argumentation graph and give them the possibility to share arguments with other agents. We present an application of the framework to study the evolution of the vegetarian diet at a city level.

Keywords Opinion dynamics · Agent-based simulation · Argumentation framework · GAMA platform · Vegetarian diets

Introduction

Agent-based modeling is a classical approach to study opinion dynamics, as it allows to take into account the heterogeneity of actors and the impact of local interactions between them. Among existing approaches, the most popular uses a numerical value

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to represent the opinion towards an option [8, 14]. The opinion of each agent is updated by averaging a set of agent opinions. These last fifteen years, many studies have proposed to enrich this generic model, for example by taking into account fixed uncertainties and by studying the model behaviour when adding extremists [17] or contrasting effects [15].

These models are very relevant to study social influence, however, most of them remain theoretical as very few of them have been applied to real case-studies using data and validated [12]. Another drawback is the difficulty to understand the inner motivation concerning the modification of opinion of an agent. Indeed, as the opinion is usually summarized by a single numerical value, it is not possible to know precisely why the agent has changed his/her opinion.

In order to better represent the inner deliberation of agents towards an opinion, we propose to follow an opposite approach by adopting a KIDS [10] approach rather than a KISS [1] one. Doing so, we assume that explicitly representing how people deal with arguments and diffuse them to other people to try to convince them to change their opinion (or reinforce their opinion) can lead to the development of more grounded opinion dynamic models.

Another relevant framework is the argumentation model [3]. Argumentation deals with situations where information contains contradictions because it comes from several sources or corresponds to several points of view that possibly have different priorities. It is a reasoning model based on the construction and evaluation of interacting arguments. It has been formalized both in philosophy and in computer science [23] and applied to various domains including non-monotonic reasoning [9], decision making [28] or negotiation [16]. The system introduced in [9] consists of a set of arguments and a binary relation on that set, expressing conflicts among arguments. An argument gives a reason for believing a claim, or for doing an action. Historically, the typical field of application of argumentation in computer science was the legal domain [22]. More recently, several studies proved its relevance in social-related concerns, medicine, food systems, chains, policies and controversies, especially for decision-making purposes [28].

We thus propose to integrate these studies, and in particular the system introduced by [9], in a generic framework implemented in the GAMA platform [27], dedicated to the development of opinion dynamic models. Doing so, the model presented adds an important innovation to the literature in social influence models [12, 30], by implementing interactions between arguments. Compared to [9], our argument descriptions are not abstract but detailed by a rich set of attributes, including criteria, the latter being in line with the conclusions of [30].

Section "Generic Framework Proposed" presents the generic framework that we propose. Section "Application to Vegetarian Diets Diffusion" presents an application of this framework in a model to study the evolution of the vegetarian diet at a city level. Finally, Sect. "Conclusion" concludes and presents some perspectives of this work.

Generic Framework Proposed

The main goal of this study is to enable modelers to easily define agent-based models using argumentation. Modelers, especially those who are not computer scientists, tend to use modeling platforms such as Netlogo [29], GAMA [27] or CORMAS [5] to develop their models. We made the choice to directly integrate an argumentation framework inside the GAMA platform.

GAMA, like Netlogo, provides modelers with a dedicated modeling language which is easy to use and learn. It also allows them to naturally integrate GIS data and includes an extension dedicated to generating a spatialized and structured synthetic population [7], which is particularly interesting for building KIDS models. Finally, GAMA integrates an optional BDI architecture, called BEN [4, 26], that provides agents with cognition, emotions, emotional contagion, social relations, personality and norms.

The framework proposed was implemented as a plug-in for the GAMA platform and was designed to be usable with the BEN architecture. The idea behind this framework is to explicitly represents agents' own mental deliberation process from arguments towards an opinion, through the use of the argumentation framework of [9].

Definition 1 *(Dung's argumentation graph).* An argumentation graph is a pair $(\mathcal{A}, \mathcal{R})$ where $\mathcal{A}$ is a set of arguments and $\mathcal{R} \subseteq \mathcal{A} \times \mathcal{A}$ is an attack relation. An argument a attacks an argument a' if and only if $(a, a') \in \mathcal{R}$.

The framework is built on the concept of argument that is defined as a new type of variable in GAMA.

Definition 2 *(argument in GAMA).* We describe an argument by a tuple $a = (I; O; T; S; R; C; A; Ts)$, with:

- I (mandatory): the identifier of the argument;
- O (mandatory): the option that is concerned by the argument;
- T (mandatory): the type of the argument (with values in favour of, denoted by '+', against, denoted by '-', or neutral, denoted by '0', towards the option);
- S (optional): the statement of the argument, i.e. its conclusion;
- R (optional): the rationale underlying the argument, i.e. its hypothesis;
- C (optional): the criteria which the argument relies on: defined as a map in GAMA, which associates a set of criteria with their corresponding numerical values that represent the importance of each criterion for the argument;
- A (optional): the agent who proposes the argument;
- Ts (optional): the type of source the argument comes from.

Example 1 An example of argument for the vegetarian diet context is ("1", "adoption of the vegetarian diet", "-", "Vegan diet is deficient in B12 vitamin", "Vegetable proteins do not contain B12 vitamin", "Nutritional::1.0", "journalist of'Canard Enchain', "Newspaper"). Except for the three first variables that are mandatory, the others are optional: according to the application context (and to the knowledge/data of the modeler), the modeler will not necessary have to fill all these variables.

The plug-in also defines a new skill for agents, called *argumenting*. A skill in GAMA is a built-in module that provides agents with a set of related built-in attributes and built-in actions. The *argumenting* skill provides agents with 2 new attributes and 7 new actions.

List of attributes:

– *criterion_importance*: for each criterion which arguments rely on, a score (numerical value between O and 1) representing the importance of this criterion for the agent;
– *argumentation_graph*: a directed graph that represents a Dung's argumentation system. Each node is an argument, and each edge represents an attack from an argument to another argument. The weight of an edge represents the strength of the attack for the agent.

List of actions:

– *add_ an_argument(new_argument, referenced_graph)*: add *new_argument* to the agent's argumentation graph and connect the argument to the other arguments according to the existing attacks in the *referenced_graph*. The interested reader can refer to [32] for different ways to define attacks.
– *evaluate_argument(an_argument)*: evaluate the strength of *an_argument* for the agent. More precisely, the strength of an argument arg for an agent ag is computed as follows:

$$strength(ag, arg) = \sum_{c \in CRIT} arg(c) \times ag(c) \quad (1)$$

with $CRIT$, the set of criteria, $arg(c)$ the value associated with the criterion c in the map C of the argument arg (see Definition 2), and $ag(c)$ the importance of c for the agent ag.
– *preferred_extensions(an_argumentation_graph)*: compute the set of preferred extensions from *an_argumentation_graph* using $JArgSemSAT$ library [6].

Definition 3 *(Preferred extension).* Let an argumentation system $(\mathcal{A}, \mathcal{R})$ and $B \subseteq \mathcal{A}$. Then:

- B is conflict-free if and only if $\nexists a_i, a_j \in B$ such that $(a_i, a_j) \in \mathcal{R}$;
- B defends an argument $a_i \in B$ if and only if for each argument $a_j \in \mathcal{A}$, if $(a_j, a_i) \in \mathcal{R}$, then $\exists a_k \in B$ such that $(a_k, a_j) \in \mathcal{R}$;
- a conflict-free set B of arguments is admissible if and only if B defends all its elements.

A preferred extension is a maximal (with respect to set inclusion) admissible set of arguments.

– *evaluate_conclusion(list_of_arguments)*: evaluate the conclusion that can be taken from *list_of_arguments*. More precisely, the value of a set of arguments $Args$ for an agent ag is computed as follows:

$$value(ag, Args) = \sum_{arg \in Args} strength(ag, arg) \times type(arg) \quad (2)$$

with: $type(arg) = \begin{cases} -1 & \text{if arg.T = -} \\ 0 & \text{if arg.T = 0} \\ 1 & \text{if arg.T = +} \end{cases}$

– *update_graph_weight*: update (recompute) the weights of the edges (attacks) of the argumentation graph according to the argument criteria and to the agent's criterion importance. We define the weight of an attack as the strength of the argument at the origin of the attack and evaluated by action *evaluate_argument*.
– *simplify_graph*: simplify the argumentation graph according to the weights of the edges. If an argument a attacks an argument a' and if a' attacks a, only the attack with the highest weight is kept in the simplified graph. If the attacks have the same weight, both attacks are kept. Formally:

Definition 4 *(Simplified argumentation graph).* Let $(\mathcal{A}, \mathcal{R})$ be an argumentation graph and $(a, a') \in \mathcal{R}$. The simplified argumentation graph $(\mathcal{A}, \mathcal{R}')$ obtained from $(\mathcal{A}, \mathcal{R})$ is defined by: $(a, a') \in \mathcal{R}'$ if and only if:

- $(a, a') \in \mathcal{R}$ and
- if $(a', a) \in \mathcal{R}$ then $strength(ag, a) \geq strength(ag, a')$.

– *deliberate*: make a decision concerning an option from the argumentation graph. The deliberation action is composed of 4 steps:

1. updating the weights of the attacks of the argumentation graph using the *update_graph_weight* action.
2. simplifying the argumentation graph using the *simplify_graph* action.
3. computing the set of preferred extensions from the simplified argumentation graph using the *preferred_extension* action.
4. computing the opinion from the preferred extensions: for each extension compute its value using the *evaluate_conclusion* action, then return the value of the extension with the maximal absolute value. If this value is higher than 0, it means that the agent is in favour of the option, if the value is lower than 0, it means that the agent is against the option, and if the value is 0, the agent is neutral towards the option.

The plugin was designed to be as modular as possible. Indeed, several actions depend on other actions (for example, the *deliberate* action depends on the *evaluate_argument*, *update_graph_weight*, *simplify_graph*, *preferred_extension* and *evaluate_conclusion* actions) that can be easily tuned by the modeler. For example, a modeler who wants to take into account the type of source in the computation of the strength of an argument can just override the *evaluate_argument* action using the modeling language of the GAMA platform. All the other actions that depend on this action (e.g.. *deliberate*) will take into account the action defined by the modeler instead of the built-in one.

The plug-in was developed under the GPL-3 licence, and is available on Github.[1] It can be directly downloaded and installed from GAMA 1.8 from the gama experimental p2 update site.[2]

Application to Vegetarian Diets Diffusion

Context

Vegetarian diets are gaining more attention as animal welfare concerns are raising and environmental impacts of animal productions are better assessed [13, 19]. While higher income per capita is historically correlated with higher consumption of animal products [20], recent data suggest that this tendency might reach a turning point in the near future, where higher income per capita would correlate with lower consumption of animal products [31]. One hypothesis to explain such trend shift would be the diffusion and wider adoption of diverse vegetarian diets, from semi-vegetarian (or flexitarian) to strict vegetarianism (or vegan diet) [2]. Reasons for such diet choice range from ethical, environmental and health concern [24]. Our assumption is that the diffusion of ethical, health and environmental arguments in favour of such diets probably fuels the vegetarian diets adoption process. The relation between argument acquisition at the individual level and behavior diffusion has never been explored for vegetarian diets.

In order to get insights on arguments as well as external events at stake when a citizen decide whether to follow a vegetarian diet, we conducted individual interviews, a survey, and built an argument database. We conducted 20 life story individual interviews about vegetarian diets transitions. We collected detailed qualitative data about the process of diet change. We also conducted a survey among a panel of 1714 French citizens. They were asked their willingness to change, the type of argument they are sensitive to (economic, health, ethical or environmental), as well as expressing on a lickert-scale their degree of agreement with 16 key arguments. These 16 arguments were extracted from the participatory online platform Kialo which allows users to co-construct argument hierarchies about any topic. We considered the first level of arguments of the hierarchical network about "humans should stop eating meat".[3] Finally, we also constructed a database of 114 arguments obtained from google search about vegetarian diets and established an argumentation network establishing attacks between them [25].

[1] https://github.com/gama-platform/gama.experimental.

[2] http://updates.gama-platform.org/experimental.

[3] https://www.kialo.com/the-ethics-of-eating-animals-is-eating-meat-wrong-1229?path=1229.01229.1.

Generic Model

To illustrate the use of the proposed framework to study opinion dynamic -and more specifically the diffusion of vegetarian diet- we built a simple model based on two types of entities:

- citizen: the main agent of the model, it owns the *argumenting* skill. In addition to the attributes provides by the *argumenting* skill, citizen agents have the following attributes:
  - social_attributes: all types of attributes that are necessary to characterize the agent.
  - social_network: list of other citizens they can exchange arguments with,
  - opinion: correspond to the opinion of the agent.
- event: an event will be the source of new arguments for a sub-set of citizens
  - new_arguments: new arguments brought to citizens,
  - citizen_aware: list of citizens that will directly receive the new arguments.

At each simulation step, three types of processes are activated:

1. an event can occur and bring new arguments to some of the citizen agents,
2. citizen agents can give one or several arguments to other citizen agents of its social_network,
3. based on their internal argument graph, citizen agents choose to keep their current opinion or to modify it.

The first process concerns the occurring of an event that will impact the base of arguments of some of the agents. For instance, for our application, a sanitary crisis can bring new arguments for some people to stop to eat animal products.

The second process deals with citizen agents who try to convince other citizen agents through the exchange of arguments. More precisely, each citizen agent can choose to give one or several arguments to one or several other citizen agents. The choice to exchange arguments and which arguments to exchange can depend on the personality of the citizen, but also on his/her opinion. Indeed, someone who is radicalized tends to be more proselyte than someone who is neutral.

The last process consists for the citizen agents who got new arguments to deliberate on their new argument graph and eventually change their opinion. To do so, we use the *deliberate* action provided by the *argumenting* skill.

Simulation of Vegetarian Diet Diffusion

The generic model was instanced in the context of the vegetarian diet diffusion in the city of Rouen. Rouen is a middle size city of France with an estimated population of 110,754.

Table 33.1 Proportion of omnivorous, flexitarian, vegetarian and vegan according to the survey and at the initialization of the model

Category	Model–Mean value (standard deviation)	Survey (%)
Omnivorous	74.25% (0.17%)	70.4
Flexitarian	22.48% (0.15%)	26.7
Vegetarian	2.82% (0.04%)	2.5
Vegan	0.45% (0.02%)	0.5

We use the data from the French National Institute of Statistics and Economic Studies (INSEE) and the Gen* plugin of GAMA [7] to generate and spatialize the population. Each citizen agent has 3 social attributes: age, occupational category and localization. These attributes were used to generated the social network: the closest are the agents (for these three attributes), the higher the the probability to be connected. For each citizen agents, we drew a number of citizen agents in its social network using a Gaussian distribution, with a mean of 10 and a standard deviation of 3.

Concerning the arguments, we use the 114 arguments collected. For the initial argumentation graph, for each citizen agent, we drew a number of initial arguments using a Gaussian distribution, with a mean of 20 and a standard deviation of 5. The arguments were selected randomly among the 114 arguments.

For the criterion importance values, we used the survey to determine the relative importance of the different criteria. More precisely, we use the data collected to define for each criterion a mean value, then we drew the importance of criteria by using a Gaussian distribution. In the future, we plan to use the survey to make a link between these values and the social attributes of the people (in particular, the occupational category and the age).

Finally, we used the survey to define 4 possible categories that correspond to possible diet choices: omnivorous, flexitarian, vegetarian and vegan. The choice of a category depends of the value returned by the *deliberate* action. We defined for each category an interval of values:

- omnivorous: $[-\infty, 2.0]$
- flexitarian: $[2.0, 3.5]$
- vegetarian: $[3.5, 4.5]$
- vegan: $[4.5, \infty]$

The intervals were defined in order to approximately get the same proportion of people in each category than in the survey. Table 33.1 shows the proportion obtained at the initialization of the simulation (mean of 10 simulations) in comparison to the one of the survey.

Figure 33.1 shows a snapshot of the simulation after the initialization and a deliberation stage from their initial argumentation graph.

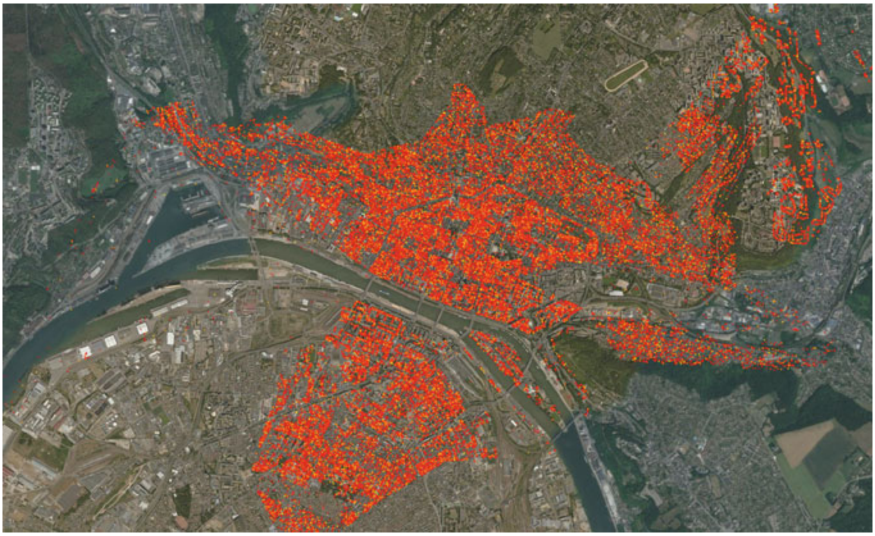

Fig. 33.1 Snapshot at the initialization of the simulation. red circle: omnivorous; orange circle: flexitarian; yellow: vegetarian; green: vegan

In the simulation, a simulation step corresponds to 1 year. The number of arguments and the choice of argument exchanged each step depend on the agent opinion. Indeed, someone who is very convinced by his/her opinion and whose opinion is not standard for society, like a vegan, will be more proselyte than someone rather neutral. In addition, a vegan will try to give arguments that are in favour of not eating animal product, while an omnivorous will tend to give arguments against it. So we define the following rules according to the value returned by the *deliberate* action:

- $[-\infty, -2.0]$: gives 1 argument against veg. diets to 10% of its social_network
- $[-2.0, 2.0]$: gives 1 argument against veg. diets to 5% of its social_network
- $[2.0, 3.5]$: gives 1 argument in favour of veg. diets to 10% of its social_network
- $[3.5, 4.5]$: gives 1 argument in favour of veg. diets to 20% of its social_network
- $[4.5, \infty]$: gives 2 arguments in favour of veg.diets to 30% of its social_network

We use the model to test two scenarios. The first one is the business as usual scenario in which no specific event occurs during 20 years. In the second scenario, we integrate a sanitary crisis (like the mad cow disease crisis in the nineties in Europe) that occurs after 5 years. This event adds a new argument about the danger of eating meat (health criterion) to 2O% of the population.

Figure 33.2 shows the yearly evolution of the proportions of the different categories for the business as usual and the sanitary crisis scenarios (mean of 10 simulations). For both scenarios, the number of omnivorous tends to decrease over time with a constant speed as more people become convinced by vegetarian diets. We can see in the sanitary crisis scenario the impact of the integration of a new argument:

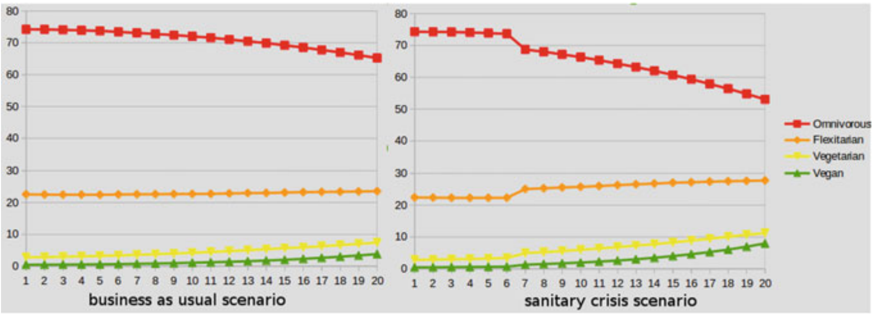

Fig. 33.2 Result for the two scenarios (mean of 10 simulations); x-axis: number of years; y-axis: percentage of the population

when the event occurs, a significant part of the omnivorous population change their diet for a vegetarian one.

A last result to mention is the computation time: with an i7 computer (only 1 core used), the total time for the simulation of the 110,754 agents for 20 simulations step was less than 8 min (less than 25 s per simulation step), which is rather good considering the number of agents and the fact that there is a lot of room for optimization (first of all, the possibility to distribute the computation on several cores).

To conclude on this application, our generic framework, and its application for opinion dynamic simulation offers numerous possibilities. If the purpose of the simple model presented was above all to illustrate the type of use that could be made, we plan in the future, by using the collected data, to build a more credible and grounded model. The source code of the model is available on OpenABM.[4]

Conclusion

The paper presented a generic framework integrated in the GAMA platform allowing to use formal argumentation in agent-based models, in particular in the context of opinion dynamics. The use of the framework was illustrated through an application concerning the diffusion of vegetarian diet. The experiment carried out shows the possibilities offered by our framework.

This study is a first step towards the coupling between argumentation and agent-based modeling and its use for opinion dynamic models. In particular, we plan to enrich the generic framework implemented in the GAMA platform in order to offer complementary tools to the modelers in terms of management and analysis of an argumentation graph, such as computing various types of extensions (complete, stable, semi-stable, etc.).

[4] https://www.comses.net/codebases/23ab03f4-4c8f-42f5-b5e8-351558b5aa33/releases/1.0.0/.

We also plan to enrich the way arguments are evaluated. In the current version, the evaluation of arguments depends on the criteria concerned by the argument and on the importance for the agent of these criteria. Other factors can impact the perception of an argument, and among them, the source of the argument [21]. Indeed, for example, the profusion of fake news from dubious source can impact people differently. Our framework should soon be able to take this difference of perception into account.

A last perspective related to the generic framework concerns the link between this framework and the BEN architecture. Indeed, in addition to the BDI reasoning engine, the BEN architecture introduces numerous concepts that could be interesting for our work such as the personality of agents based on the classic OCEAN model [18] and the social relation between agents evaluated according to 5 dimensions (liking, dominance, solidarity, familiarity and trust).

Concerning the generic model, we plan to add new types of agents, in particular influencers (lobby, government, company, etc.), which will diffuse new arguments to citizen agents. We are considering as well to add a mechanism to enable en evolution of the criterion importance for the agents. Indeed, these values are not fixed for life but can evolve after a particular event and from the influence of other people. Finally, we plan to enrich the argument exchange protocol (which arguments citizen agents choose to exchange). In this regard, [11] describes how social norms are mainly questioned when individuals holding different views interact. Indeed, one of the utilities of social norms is that they save time and energy in decision making. As Josh Epstein puts it in [11] : "When I'd had my coffee this morning and went upstairs to get dressed for work, I never considered being a nudist for the day". In that sense, we could first improve the argument exchange procedure by limiting it to interactions between agents holding differing norms, or else, by limiting such exchange in case they have in their social network another agent holding a differing perspective. Secondly, we could adapt the type of arguments exchanged depending on norms hold by both parties. For ', a flexitarian would exchange a pro-vegetarian argument to an omnivore, but would exchange a pro-omnivore argument to a vegetarian.

For the application case of the diffusion of the vegetarian diet, we plan to better take profit from the data collected to generate a more credible population of agents (criterion importance, social networks, initial arguments, etc.), validate the model, take profit of the model to test a wide range of scenarios.

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Chapter 34
Analysing Water Quality Management Through a Social-Ecological Model Using the Theory of Planned Behaviour

Amélie Bourceret, Laurence Amblard, and Jean-Denis Mathias

Abstract In this chapter, we present an agent-based model using the Theory of Planned Behaviour to understand the participation of farmers to water quality protection programmes.

Introduction

In the modelling of social-ecological systems (SES), human behaviour is often represented by the rational actor model. Yet, it is recognised that it is important to represent a more complex human behaviour to increase the usefulness of formal models and the effectiveness of management of SES [1].

Concerns about water systems are increasing. In France and Europe, the water used for drinking water production is often polluted. Diffuse pollution from agriculture constitutes the main cause of water quality degradation. Policy measures targeting farmers promote farming practices in favor of water quality. In France, the

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implementation of the various protection measures is based on farmers' voluntary commitment. Therefore, farmers' participation is important in terms of water quality outcomes. Understanding the social, economic and institutional factors that influence the involvement of farmers is crucial for defining public policies leading to an effective improvement of water quality. The objective of this research is to analyse the impact of different policy measures on the evolution of agricultural practices in drinking water catchment areas. To answer this question, we build up an agent-based model representing a SES of a water catchment area in which farmers choose a farming practice.

Farmers' decision-making process has been broadly studied [2, 3]. One of the most frequently used approach to understand farmers' decision-making with regard to agri-environmental policies is the theory of reasoned action of Ajzen and Fishbein [4] which was later extended to the theory of planned behaviour (TPB) [5]. In this frame, the intention towards a behaviour, considered as a trustworthy predictor as whether or not the behaviour will be performed, is influenced by three global variables: the judgment about the desirability of the behaviour and its consequences (attitude towards behaviour); considerations about the influence and opinions of others on that behaviour (subjective norm); and beliefs about the individual's ability to succeed in the behaviour (perceived behavioural control). The implementation of TPB in agent-based models still reveals some issues although this theory has been already implemented a few times in different fields [6–8]. Scalco et al. [9] describe these issues: integration of real data, working with a static model, links between intention and behaviour, feedback mechanisms. We use the TPB to model farmers' behaviour, i.e., their choice of farming practice. Agricultural practices affect water quality. Policy measures are offered to farmers to promote water quality. This first step model will allow us to qualitatively explore how the choice by farmers of different practices and their consequences in terms of drinking water quality are influenced by, first, different behavioural specifications and, second, different characteristics of the policy measures implemented.

Model

The modelling is based on the social-ecological framework developed by Ostrom [10]. Actors, here farmers, are randomly spatially distributed in the environment. They all have the same farm area and the same type of production but they can choose between different farming practices. Each year (the time step of the model), they can change their practice. Their choice modifies the quantity of inputs used as well as the profit. Beyond a given level, the use of inputs has the undesirable effect of polluting the watershed, the ressource system. Among the farming practices, one of them is more favourable to water quality, named low-input practice, than the other, named high-input practice. A program aiming at protecting the drinking water catchment is implemented. The farmer may or may not choose to participate in the

Table 34.1 Description of measures

Measure	Description	Model dynamics
Agri-environmental measure (AEM)	Instrument of the Common Agricultural Policy (CAP). Aim at promoting the adoption of agricultural practices that are favourable to the preservation of the environment. Undertaken voluntarily by farmers in exchange for a monetary compensation	Influence the economic profits associated with a farming practice, hence economic aspect of the attitude. The compensation is given annually
Training measure	Actions aiming at raising farmers' awareness regarding the impact of their practices and improving their knowledge about practices in favor of the environment, such as individual and collective technical support and advice, tests and experiments, etc.	Affect perceived control by increasing farmers' knowledge about a farming practice. One shot training. Knowledge persist in time

program. If the farmer enters the process, he must change his farming practice to the low-input practice.

Ressource system description It is assumed that the water used for drinking water production is abstracted from a groundwater body. A natural flow feeding the groundwater and a flow exiting the groundwater, are constant.

Actors description Farmers' intention to participate to the protection program and therefore to change their farming practice is calculated. It is composed of the three attributes of TPB: attitude, subjective norm and perceived behavioural control, weighted by their relative contribution to the intention. Following Kaufmann et al. [7], if the farmer's intention exceeds a threshold, he will choose to change the practice.

Following Mettepenningen et al. [3], we divide the attitude in two weighted parts: attitude towards the environment and attitude towards the policy program. Attitude towards the program reflects economic considerations, considering that the level of the financial compensation is an important factor. In the model, agents can exchange with neighboring agents and agents members of the agent's influence group about their farming practices to build the subjective norm. The last variable that influences intention, the perception of the ease and difficulty of adopting the behaviour, is represented by the knowledge about the farming practice. We define two types of agents, "economicus" and "eco-friendly". "Economicus" places more emphasis to the economic profit, hence the weight of attitude towards the protection program is higher than for "eco-friendly" who attaches more importance to the environment.

Governance system A protection program may include one or more measures (see Table 34.1).

Results

In the following, we present our first qualitative results. We explore the dynamics of the model to examine the effect of different weights of the variables affecting the intention of behaviour and the effect of different characteristics of protection programs. We initialize the parameters of the model (reference scenario) with, among other things, the equalisation of the TPB variables weights and an arbitration between financial compensation and training intensity, which leads to a conversion rate to low-input farming equal to the average conversion rate to organic farming in France, used as a proxy.

Actors behaviour We test different weights of the variables influencing the intention of behaviour with a given measure. We find that, depending of these weights, the results in terms of water quality and number of farmers changing their practices are different. Initially, there is no farmer using the low-input practice. Because of this setup, the initial subjective norm negatively influences farmers' intention to change their practice. Thus, the higher is the weight of the subjective norm, the lesser is the share of farmers participating to the protection program. Further, the importance of the attitude influences agents types differently.

Influence of the characteristics of the protection programs Secondly, we test different combinations of the two measures included in protection programs. The amount of financial compensation is tested from 0 to twice the difference between farming profits. The intensity of training measure represents the level of knowledge gained by formation from 0 to 0.5. The higher is the level of financial compensation or the level of training proposed, the higher is the percentage of farmers participating to the program. There is a combination of minimum levels of financial compensation and training intensity needed to trigger participation.

The relative importance of the three attributes in the prediction of intention of a behaviour is expected to vary across situations [5], e.g., different watershed areas. This implies a management, e.g., a water protection program, adapted to the situation and these behavioural characteristics.

Perspectives This model is a first step and deserves further development. On the one hand, we will consider that agents could have a perception of ecological system. Also, we could implement the possiblity of returning to the high-input farming practice. This could make it possible to better analyse difference between AEM which have annual costs for public policies and are fixed-term, and training which are one-time investments with potential ongoing effects. Then, a possible development could be to focus on social interactions and learning, which can lead agents to change their thinking, including their attitudes towards farming practices. Finally, a further development will be to implement real data.

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Chapter 35
Do Habits Fade Out? Discerning Between Two Theories Using Agent-Based Simulation

Rijk Mercuur, Virginia Dignum, and Catholijn M. Jonker

Abstract Inducing behavioural change requires a good understanding of how habits break. We identified two theories in the psychological literature on this process: the decrease theory and persist theory. Both theories are used to explain behavioural change, but one states the original habit fades out, while the other theory states the habit persists. We use agent-based simulation to show that the two theories lead to different behaviour when the agents are motivated to do *multiple* alternative actions (e.g., take the bike or take the train), instead of *one* alternative action (e.g., take the bike). This finding is relevant for the social scientific field, because (1) it shows a scenario where it matters if habits persist and (2) it enables an empirical experiment to discern the two theories.

Introduction

There is an increasing interest in considering the influence of habits on behaviour [8–10, 18]. Habitability refers to the principle that behaviour persists because it has become an automatic response to a particular, regularly encountered, context [10]. Habits have been shown to be an important driver of behaviour (e.g., in transport choices [8], food choices [18] or recycling [9]). To change behaviour it is thus important to understand how habits break [10].

Breaking habits is studied on a behaviouristic level and a cognitive level [5]. On a behaviouristic level, a habit breaks if an agent portrays different behaviour given the same context. On a cognitive level, a habit breaks if the mental connection between

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the context and an action is gone. On a cognitive level, a habits can thus persist even when the observable behaviour changes [21]. We will refer to a habit breaking on the behaviouristic level as ‘the suspension of habitual behaviour’ and to a habit breaking on the cognitive level as ‘the decrease of the habitual connection’.

This paper aims to compare two theories on breaking habits focusing only on their long-term dynamics. We study a scenario where an agent is first motivated to do one action (e.g., take the car) and then motivated to do another action (e.g., to take the bike). In case of a successful intervention (e.g., [1]), most agents will change their behaviour (i.e., suspend their habitual behaviour). We identify two theories in the psychological literature that can explain this dynamic on a cognitive level: the decrease theory and persist theory [1, 4, 12, 13]. The decrease theory states that a new habitual connection (i.e., the bike-habit) emerges and the original habitual connection (i.e., the car-habit) *fades out* [12, 13]. The behaviour change is a consequence of the agent enacting the new habit. The persist theory states that a new habitual connection emerges, but the original habitual connection *persists* [1, 4]. The behaviour change is a consequence of the agent intentionally choosing the new action between two (now equally strong) habits. We construct two models to compare the theories and verify these models accurately represent these theories by using simulation.

This paper shows that the two theories lead to different behaviour when the agents are motivated to do *multiple* alternative actions (e.g., take the bike or take the train), instead of *one* alternative action (e.g., take the bike). In the decrease model, the alternative action is taken up and replaces the old habit. In the persist model, the original action persists and no new habit emerges. We explain this difference using the simulation: if the original habit does not decrease, then doing multiple alternatives does not lead to the development of a strong enough habit to replace the original one. This finding is relevant for the social scientific field, because (1) it shows a scenario where it matters if habits persist (i.e., the persistence influences behaviour change) (2) it enables an empirical experiment to discern the two theories.

The remainder of the paper is structured as follows. Section “Psychological Literature on Habits” summarizes literature on habits (in particular the decrease theory and the persist theory) into properties. Section “Model” uses these properties to construct two models: a persist model and a decrease model. Section “Verifying the Models Represent the Theories” verifies that the models accurately describe the theories by using simulation. Section “Finding a Scenario to Discern the Theories” describes the simulation experiment that shows the two theories are discernible when the agents are motivated to do multiple alternatives.

Psychological Literature on Habits

Habitual decisions are fast automatic decision that contrast with a slow intentional decisions [6, 20, 21]. Habits moderate the intention-behaviour relationship [6, 20]: the stronger the habit, the weaker the intention-behaviour relationship. For example, a strong ‘car habit’ weakens the influence of a ‘bike intention’ on behaviour. Habits predict behaviour without mediation by intentions [21]. Thus even in the absence of intention a habit continues to predict behaviour. For example, even when one does not intend to use the car anymore one can be 'stuck' in the habit of using a car. We require our habit models to separate between habits and intentions, include the moderating effect of habits on the intention-behaviour relationship and that intentions do not mediate the habit-behaviour relationship.

When a habitual decision is triggered depends on the strength of the habit and the current performance context (i.e., the context in which the agent acts) [21]. Habitual decisions are triggered by specific context-elements [21]. For example, the context-element 'home' can trigger the habit of taking the car (whereas the context-element 'work' might not). Furthermore, context-elements trigger a habitual decision only when they are nearby (i.e., part of same context as the agent). Thus, it is not so much of the habit *in general* that triggers the habitual decision, but the strength of multiple mental habitual connections specific to an activity, agent and nearby context-elements. We require our models to take into account which context-elements are part of the performance-context and with which habitual connections they are related to the deciding agent and the activity under consideration.

The amount of attention attributed to the action influences the decision to act out of habit [16]. The more attention attributed to the decision the lower the chance the action is done out of habit. The literature on the regulation of attention is extensive [2, 19]. Furthermore, to model attention one needs to take into account how different activities interact. When different activities run in parallel, conflicting or cooperating actions can influence which actions gain attention and therefore to what extent an action is done habitually [16]. Given the focus on this paper on the persist theory and decrease theory, we simplify attention and interaction with other activities to a normally distributed variable that lowers the chance the action is done out of habit.

This paper identifies two theories that can both explain the suspension of habitual behaviour, but differ in how a habitual connection updates over time: the decrease theory and the persist theory.

Decrease Theory The decrease theory states a new habitual connection (i.e., the bike-habit) emerges and the original habitual connection *fades out* [12, 13]. The suspension of habitual behaviour is thus a consequence of the agent enacting the new habit. [12] showed that the automaticity individuals report decreased by an average of 0.29 (on a 7-point scale) after missing an opportunity to enact the action. This decrease is small and had no long-term effect. However, this implies habits might lose strength over time. On the individual level, the Machado's model of conditioning [13] studies how mental connection between context-elements and actions update. In the model, an association loses strength when the context-element is presented, but the action is not. The context-element activates a corresponding mental node, which in turn starts a period of 'extinction' where the association at first loses strength quickly, but then decelerates until the strength loss comes to a halt. These authors thus theorize that a habitual connection loses strength when a context-element is presented, but the activity is not enacted.

Persist Theory The persist theory states a new habitual connection emerges, but the original habitual connection *persists* [1, 4]. The suspension of habitual behaviour is a consequence of the agent intentionally choosing the new action between two (now equally strong) habits. [4] argued for this theory when he advised that automatic elicitation of an unwanted habitual response will likely require that the associated cue is linked with a new alternative response, rather than a non-response. [1] showed that, at least in the short-term, performing an alternative action does not immediately replace the automatic activation of the original action with the alternative. However, once again, this leaves open the effect in the long-term. These authors thus theorize that a habitual connection does *not* lose strength when a context-element is presented, but the activity not enacted.

Both theories agree that a habitual connection gains strength when an agent performs an action in the setting of a context-element [21]. [11] empirically studied this strength gain in an experiment where subjects were asked to do the same action daily in the same context and report on automaticity. The subjects reported a gain in habit strength that followed an asymptotic curve and converged at a different maximum habit strength per subject. Similar results have been found when strength gain is studied on the individual level. For example, [3] uses Hebbian learning to capture the strength gain of habits. Hebbian learning is based on neurology and states if two or more neurons are co-activated, the connection between these neurons strengthen [7]. In our case, this implies the habitual connection strengthens each time the action is done in presence of the context-element. The habitual connection thus gains strength when an action is done in presence of the context-element and this strength gain follows a different asymptotic curve per human.

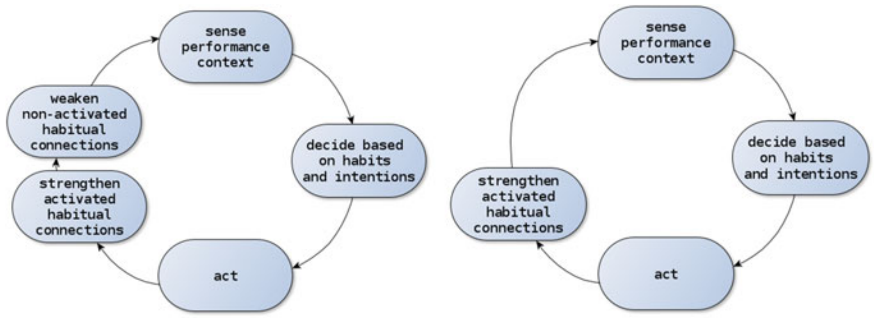
The following properties summarize the literature on habits and will be used to construct two models to compare the theories:

1. Habits and intentions are both predictors of behaviour and interact:
   (a) habits moderate the intention-behaviour relationship
   (b) intentions do not mediate the habit-behaviour relationship
2. The decision to act out of habit is influenced by strength of a habitual connection and the current performance context.
3. Agents increase the chance to break out of a habit when they focus their attention on the decision.
4. Habits gain strength:
   (a) when an action is done in presence of a context-element
   (b) following a different asymptotic curve per agent
5. When an alternative action is performed in the same context, the original habit of the agent:
   (a) **decrease theory:** decreases
   (b) **persist theory:** does not decrease.

Model

This section uses the properties from the last section to construct models that represent the persist theory and the decrease theory. Figure 35.1 presents a decision-making cycle for both the decrease model and the persist model. Both models follow a traditional agent cycle by sensing, deciding, acting and updating. The models differ only in one aspect: the decrease model weakens non-activated habitual connections while the persist model does not. The remainder of this section describes the models in more detail: the concepts necessary for both models and the different modules that form the decision-making cycle.

Concepts To model the dynamics of habits we need to have a conceptual static model the agent uses to decide, act, learn and update. We construct a simplified version of the SoPrA model [14, 15] that focuses on habits (SoPrA-habits) in



(a) The Decrease Model (b) The Persist Model

Fig. 35.1 The decision-making cycle of both the decrease model as well as the persist model

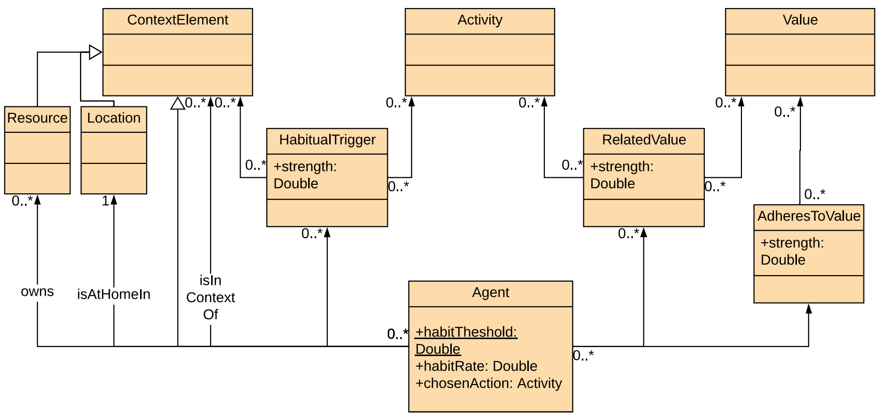


Fig. 35.2 A UML Class Diagram that provides the basic concepts to model habits

UML (Fig. 35.2). We first describe the main classes in the model (i.e., `Activity`, `ContextElement`, `Resource`, `Location` and `Agent`) and then classes with a strength attribute that connect the main classes (i.e., `HabitualTrigger`, `RelatedValue`, `AdheredToValue`).

The `Activity` class models represent things an agent can do. For example, taking the bike, taking the train, taking the car or walking. The `ContextElement` class represents different entities in the environment. There are three different classes that specify (denoted with the white arrowhead) the `ContextElement` class: the `Location` class (e.g., work), the `Resource` class (e.g., a car) and the `Agent` class (e.g., a colleague). The `Value` class represents what one finds important in life. For example, environmentalism or efficiency. Lastly, the `Agent` class represents a decision-maker that chooses between the activities based on how strong it associates these activities with other classes.

The agent associates the `Activity` class with context-elements and values. First, it associates activities with context-elements by keeping track of `HabitualTriggers`. The `HabitualTrigger` represents to what extent a context-element can habitually trigger an activity. For example, it can capture that there is a strong habitual connection between being at home and taking the car. (Thus from now one we will use the SoPrA term `HabitualTrigger` instead of habitual connection to refer to the habitual connection between an action and a context-element.) Second, an agent associates activities with values by keeping track of `RelatedValue` instances. The `RelatedValue` class represents to what extent values are promoted or demoted by the activity. For example, it can capture that taking the car strongly promotes efficiency. The `AdheresToValue` class keeps track of which values the agent finds important. The agent uses these associations to habitually (based on triggers) or intentionally (based on values) choose between activities. The remaining association will be explained in the relevant decision-making modules.

Sense Performance Context To sense the current performance context an agents retrieves a list of context-elements (e.g., locations, resources, other agents) with which it shares the `isInContextOf`-association. When the model initializes the agent uses the `owns` association to determine resources it initially shares a context with and the `atHomeIn` association to determines the other agents it originally shares a context with.

Decide Based On Habits And Intentions We separate between habitual decisions and intentional decisions (see Algorithm 1). First, the agent retrieves for each activity how strongly it is habitually attached to the current context. Second, the agent compares this habit strength of these candidate activities against a threshold (the `habitThreshold` attribute in Fig. 35.2). If the habit strength is lower then the threshold the agent filters the activity out. Third, based on how many activities remain the agent uses one of the following three options to make a decision. If zero candidates remain, habits have no influence and intention is used to make a decision. If one candidate remains, this decision is chosen habitually. If more than one candidates remain, intention is used to choose between these options. Note that the more attention attributed to the action the lower the chance the action is done out of habit. We model this by multiplying an attention variable with the threshold variable. Thus when attention is high (above 1) a higher habit-strength is needed to habitually trigger the action, lowering the chance an action is done out of habit. Recall, attention regulation is postponed to future work and in this model captured by the normal distribution N(1,0.25). Algorithm 1 summarizes this decision process based on habits, intention and attention. Two methods in the algorithm are explained in more detail:

calculateHabitStrength() To calculate the habit strength of each activity given the performance context and an agent we retrieve the `HabitualTrigger.strength` double for each context-element, in that performance context. We have a choice in how we combine these individual strengths into a total. For example, we can average or sum. In contrast to averaging, when summing a habit is triggered even if there are other context cue's distracting you from the triggering ones. Based on the intuition that—even in an abundance of context cue's—relevant context cue's will capture your attention and trigger habits, we choose a summation model.

intentionalDecision() Although we do not have detailed properties regarding the intentional decision, we do need an intentional model to contrast with the habitual model. To make an intentional choice we compare the activities based on a rating. To rate the activities we use the variables related to the `Value` class that SoPrA-habits provides. We calculate a `candidateRating` for each candidate activity based on how strongly an agent adheres to a value (`AdheredValue.strength`) and how strongly an agent relates an activity to the same value (`RelatedValue.strength`). The higher these two variables the higher the rating. The chance an agent chooses an action is based on this rating. For example, if the rating for walking and taking the car have a 5:1 ratio there is a 5:1 chance the agent will walk. Instead of deterministicly choosing the highest rated candidate, we choose a chance model based on the intuition that a human intentionally varies in its actions to satisfy multiple values.

Algorithm 1: The decision influenced by habits and intentions

```
Data: Candidates - a list of activities, Agent - the agent making the decision, attention -
      random variable drawn from N(1,0.25)
List possibleCandidates;
foreach Activity AC in Candidates do
    habitStrength = calculateHabitStrength(Ac);
    if habitStrength > attention * threshold then
        possibleCandidates.add(A)
if possibleCandidates.length == 0 then
    chosenAction = intentionalDecision(Candidates)
if possibleCandidates.length == 1 then
    agent.chosenAction = candidate
if possibleCandidates.length > 1 then
    chosenAction = intentionalDecision(possibleCandidates)
```

Act Given the focus of the paper the agent does not need to effect the environment with its actions. Acting thus retains to updating the `chosenAction` variable as described in Algorithm 1.

Strengthen Activated Habit Associations The strength of a `Habitual Trigger` class increases when an agent performs the related action in the presence of the related context-element. We use the `habitRate` variable in the `Agent` class to decide the speed with which the strength updates. The model uses a Hebbian learning-rule to increase the strength [7]:

$$newHabitStrength = (1 - habitRate) * oldHabitStrength + habitRate * 1.$$

Weaken Non-Activated Habit Associations (Decrease Model Only) In the decrease model, the strength of a `HabitualTrigger` class decreases when an agent performs the relevant action, but the relevant context-element is not present. We use a similar Hebbian learning-rule to decrease the strength [7]:

$$newHabitStrength = (1 - habitRate) * oldHabitStrength + habitRate * 0.$$

Verifying the Models Represent the Theories

This section verifies that the models portray the properties described in section "Psychological Literature on Habits" and thus reflect the persist theory and decrease theory. Property 1–3 are verified analytically (i.e., without simulation). Property 4 and 5 are verified in a simulation experiment performed on a use case model presented in Table 35.1.[1] In this experiment, the agents are initially motivated to take the car, but after tick 100 are motivated to take the train ($|alt| = 1$). We model 'motivating the agent' as doubling the rating of activities based on intentions. In addition, the amount of attention an agent focuses on the decision is temporarily increased by att_{extra} and discounted each timestep by att_{disc} until it returns to normal. We used Repast Simphony [17] to run the experiment and averaged over 50 individual runs.

Property 1a Habits moderate the intention-behaviour relationship as (1) strong habits prevent intention from influencing behaviour (see line 8–9 of Algorithm 1) and (2) weaker habits influence the intention-behaviour relation. The latter is shown by Algorithm 1 (line 10–11): weak habits will act as an initial filter on actions, but intentions still influence the final decision.

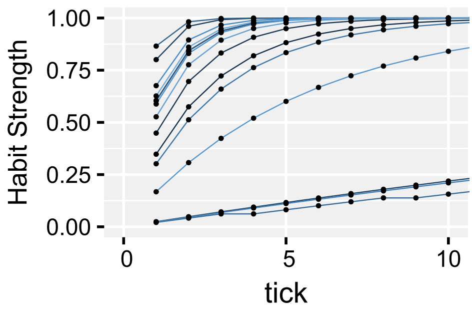
Property 1b Intentions do not mediate the habit-behaviour relationship as strong habits independently trigger action (see line 8–9 of Algorithm 1).

[1] A full description of the computational model and initialization is available on https://github.com/rmercuur/HabitsTraffic.

Table 35.1 The classes and attributes of the use case model used in the verification and simulation experiment. The underlined attributes are parameters that are varied in the simulation experiment

Class/Attribute	Instances	Class/Attribute	Instances
Resource	Car, Bike	Agent.habitRate	N(hr_μ,0.25hr_μ)
Location	Home, Work	Mean Habit Rate	hr_μ
Activity	takeCar, rideBike, etc.	AdheresToValue.Strength	N(v_μ,0.25v_μ)
Value	efficiency, environment	Mean of Value Adherence	v_μ
Agent	1–15	Attention Discount Rate	att_{disc}
RelatedValue.Strength	N(1,0.25)	Amount Of Alternatives	$\|alt\|$
HabitualTrigger. Strength (initiation)	0.0	Temporary Extra Attention	att_{extra}

Fig. 35.3 The habit-strength of 15 agents for taking the car at the onset of the simulation (tick 0–10). Each line depicts one agent



Property 2 As explained in the paragraph Sense Performance Context, the performance context influences the decision by triggering only relevant habitual connections (`HabitualTrigger` classes) and the strength of these habitual connections influences the decision.

Property 3 As explained in the paragraph Decide Based On Habits and Intentions, attention influences the habit threshold and consequently can increase the chance the agent break out of a habit.

Property 4 Fig. 35.3 depicts the habit strength to take the car for each agent between tick 0 and 10. This shows that the habit strength of the agents follows a different asymptotic curve per agent.

Property 5 Fig. 35.4 depicts the habit strength to take the car for each agent between tick 100 and 110; right after the agents are motivated to take the train instead of the car. This shows that in the persist model the strength of the habit persists and in the decrease model the strength of the habit decreases.

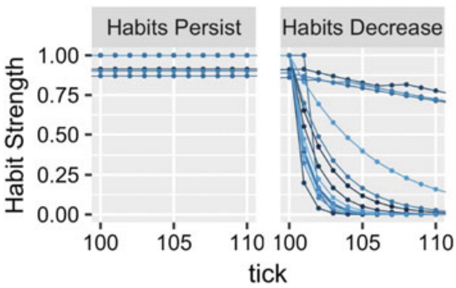


Fig. 35.4 The habit-strength of 15 agents for taking the car after an intervention (tick 100–110) in the persist model and the decrease model. Each line depicts one agent.

Finding a Scenario to Discern the Theories

By simulation a range of scenarios, we aim to find a case where the two theories show a different result. Based on a more course-grained initial exploration study we explore the following parameter settings: $|alt| \in [1, 5]$, $att_{extra} \in [2, 5]$, $att_{disc} \in [0.95, 0.99]$, $hr_\mu \in [0.01, 0.16]$ and $v_\mu \in [0.1, 0.5]$. We used Repast Simphony [17] to simulate these experiments and averaged over 50 individual runs. For each run, we calculate the difference between the number of agents that use a transport mode in the persist model and in the decrease model (e.g., 12 agents use a car in the persist model but only 3 agents use a car in the decrease model). Next, to obtain the total difference ($\Delta_{d,p}$) between the decrease model d and the persist model p we sum over the different transport modes. This results in a performance measure $\Delta_{d,p}$ that represents the difference between the two theories for each parameter setting.

We found that for $|alt| = 2, att_{extra} = 4, att_{disc} = 0.95, hr_\mu = 0.01$ and $v_\mu = 0.4$ the distance between the two models ($\Delta_{d,p}$) is maximal. This represents a scenario where agents are at first motivated to take the car, but after tick 100 are motivated to do multiple alternatives: take the train or take the bike. The results are depicted in Fig. 35.5. The figure shows that in the persist model agents predominantly take the car and in the decrease model the agents switch their behaviour to taking the bike or train. We explain this result by obtaining the mean habit strengths for the different transport modes from the simulation run. In the persist model, the car habit does not decline and the newly motivated behaviours (i.e., taking the train or taking the bike) do not lead to a strong enough habit to surpass the car habit. Therefore the agent habitually decides to go by car. In the decrease model, the car habit declines and the new bike or train habit surpasses the car habit. Therefore the agents adopt the new behaviour and go by car or bike. In short, in a scenario where agents are motivated to do multiple alternatives the two models show a different result: the agents adopt the new behaviour or not. We interpret this as that the decrease theory and persist theory can be discerned in an empirical experiment where humans are motivated to do *multiple* alternatives.

Using sensitivity analysis we fond that the difference between the two theories in this scenario ($\Delta_{d,p}$) is depended on the mean of the habit rate (corr(hr_μ,$\Delta_{d,p}$ = -0.69) and the amount of attention given to the decision after the intervention

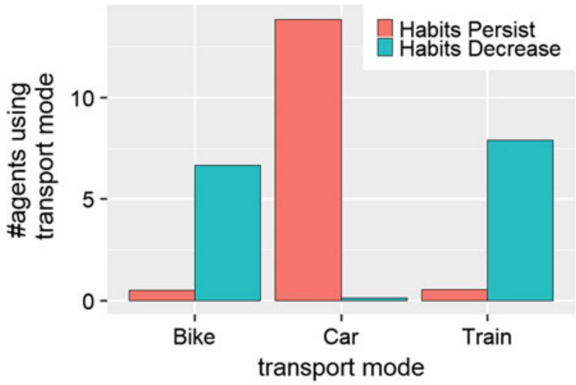


Fig. 35.5 The amount of agents choosing a transport mode in the scenario where the difference between the two models is maximal

(corr(att_{extra},$\Delta_{d,p}$) = −0.17). The mean habit rate and the amount of intervention given to the decision are variables of a different character than the number of alternatives that are motivated. The $|alt|$ is a factor that is easy to manipulate in an experiment: one treatment group is motivated to take the train whereas the other treatment group is motivated to take the train or bike. The hr_μ and att_{extra} are factors that are hard or impossible to manipulate in an experiment. Although the sensitivity to these variables cannot be used as a treatment factor it gives insights relevant so selecting the sample (e.g., selecting people that learn habits fast). The sensitivity analysis thus shows that a sample is needed with subjects that learn habits fast and pay extra attention to a decision after an intervention.

Conclusion

This paper aimed to compare two theories on habits focusing only on the implications of the long-term dynamics of updating habits. We showed that the two theories lead to different behaviour when the agents are motivated to do *multiple* alternative actions (e.g., take the bike or take the train), instead of *one* alternative action (e.g., take the bike). Our finding is relevant for the social scientific field, because (1) it shows a scenario where it matters if habits persist and (2) it enables an empirical experiment to discern the two theories.

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Chapter 36
The Role of Wealth Inequality on Collective Action for Management of Common Pool Resource

Molood Ale Ebrahim Dehkordi, Amineh Ghorbani, Paulien Herder, Mike Farjam, Anders Forsman, René van Weeren, Tine De Moor, and Giangiacomo Bravo

Introduction

Common-pool resources (CPR) are shared resources that can be at the risk of depletion as a result of over-use [1]. To avoid the *Tragedy of the commons*, users can build institutions for collective action, i.e., systems of rules and enforcement mechanisms that allow for collective management and use of those resources [2]. In other words,

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such institutions are the collection of rules-in-use that emerge as a result of collective decision making of entitled users [3]. The cooperation among the members of an institution for collective action can enable the sustainable governance of resources. However, these members are heterogeneous in different way, possibly affecting their level of cooperation. In commons literature, heterogeneity is defined as diversity in wealth, power, cast, preferences, income among commoners [4, 5].

While theoretical research suggests that inequality can have a positive influence on collective action [6], some empirical studies have highlighted the negative effect of heterogeneity on collective action [4, 7]. Agent-based modeling is a suitable method to deal with complexity and ambiguity of these social systems [8] where modeling multiple factors and parameters under different conditions is needed. Yet little work on this topic has been done using agent-based modelling. In this paper we propose a model that investigates how heterogeneity (here defined in terms of wealth inequality) shapes individuals' behavior with regards to participation in collective action.

Model Description

We extend an existing, empirically validated model of the emergence of institutions for the management and use of CPRs, when agents collectively exploit a resource using both individual strategies and an endogenously-generated institutional rules [9]. Resource grows according to $\Delta R = rR\left(1 - \frac{R}{K}\right)$ formula, where K is the carrying capacity and r is the reproduction rate. At the beginning agents randomly select an action-condition as a strategy when no institution exists and follow that strategy to extract "energy" from the resource, where energy represents their wealth. If agents are not satisfied with their energy level, they change their strategy. Later on in the time, the agents vote on an institutional rule, which is basically the most popular individual strategy and everyone must comply with the selected institution. If a number of people (above a threshold) are not satisfied with the institution, a new one is selected.

Our goal is to analyze the relation between overall wealth inequality among the members and cooperation. We hence modified the original model to allow for different levels of wealth inequality at the setup and defined cooperation in two different ways: (1) participation in voting to establish the institutional rules [10] and (2) cheating, i.e., not complying with the collectively chosen institutional rule. Following previous findings [11], cooperation is linked to the local visible wealth gap. More specifically, agents are linked in a social network and tend to decrease their cooperation when they see a significant wealth gap between themselves and their neighbors, i.e., their probability of cheating is increased and the probability of participating in voting is decreased. Note that this effect only depends on the local level of inequality (i.e., between neighboring agents), while it is independent of the global inequality.

To define institutional rules and individual strategies, we use ADICO grammar [12]. In the ADICO grammar A denotes Attributes: specifies subject, to whom a strategy or rule applies; D refers to Deontic: determines how an action is done (prohibition, obligation, and permission); I represents Aims: identifies the actions toward which Deontic applies; C indicates Conditions: under which conditions or, when, where, and how a strategy or rule applies; and O denotes Or Else: determines specific punishments to be applied when an agent acts in violation of the institutional rules.

The resulting model was implemented in Python using the Mesa library. The model includes the following components.

- **Agents**. An initial random energy between 1000 to 2000 units is assigned to each agent. Each agent records his current and best strategies (coded using the ADICO grammar), along with its location, neighbors, and energy level.
- Best strategy: the agents always save the strategy that has led them to a greater consumed resource. This parameter is updated during the simulation (based on new institutions or strategies). This depicts a simple learning behaviour based on history.
- Strategy change: happens when the agent's energy is less than a threshold. The change can follow three different procedures: copy from a neighbour, randomly select another strategy (innovation), or choose the best strategy of the agent (learning).
- Each agent has a confidence level and innovativeness level. The former increases the chance of using the best strategy in the next round, and the latter increases the chance of coming up with completely new strategy.
- **Institutional rules**. Also coded following the ADICO framework.
- Cheating: if the agent finds a significant gap between its energy and the average energy of his neighbours, it may cheat (i.e. not comply with the established institution and act based on his own current strategy).
- Voting: agents who observe a gap between their energy and the average energy of their neighbours have a lower probably for participating in voting.

Results

As mentioned before, we define cooperation as voting and cheating tendency which take place when there is an institution in place. Therefore, we only look at the runs which have emerging institution (151 out of 200 total independent runs). To measure the level of cooperation value, we count the number of agents who have participated in voting AND complied with the established institution, then divide that with the total number of agents.

We used the Gini-coefficient to evaluate the final wealth inequality (i.e. energy) distribution of agents. The Gini-coefficient is distributed between 0 and 1, with larger values meaning greater inequality. As shown in Fig. 36.1, when $0.2 < \; =$ Gini, in almost all the simulation runs, inequality leads to lower cooperation. This means the collaboration is lower when we have wealth inequality. But as we move to zero on x dimension, Gini < 0.2, we have less density and we cannot see a stable relationship

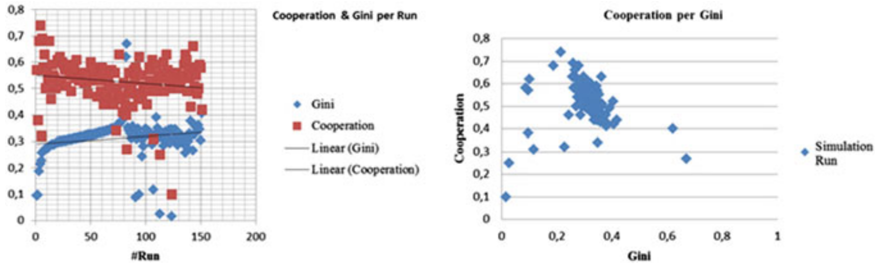

Fig. 36.1 Cooperation-Gini

between cooperation and the Gini. It seems when we have agents with similar levels of energy (Gini < 0.2), the cooperation behavior of agents do not follow the same trend.

We analyze the correlation between Gini (as inequality factor) and cooperation in 200 simulation runs. Although we cannot see significant correlation when we consider all instances with emerging institution ($r = -0.0298$), significant correlation is shown when we analyze the results with significant final inequality (i.e., $0.2 \leq$ Gini in 143 runs). We have density of instances where the Gini is between 0.2 and 1, the result is significant at $p < 0.05$ and there is a tendency for high Gini scores (more inequality) to go with low cooperation scores and vice versa ($r = -0.555$).

Conclusion

The goal of this research was to study the relation between inequality and cooperation in CPR settings. While it seems trivial that there is a negative correlation between the two, some research suggests the opposite. Yet, our model suggested the negative correlation. The model shows that inequality has a negative correlation with cooperation in the management and use of CPRs. Cooperation was defined through participation in setting up the institution for the management of the CPR, and compliance with the institution once it is in place. Our next step is to highlight the interplay between these two paths, and identify mechanisms that could be empirically tested. We aim to step up our analysis from cooperation to collective action in general.

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Part VIII
Policy Modelling

Chapter 37
A Closer Look at Dutch Policy Development

A. Melchior, Frank Dignum, and M. Ruiz

Abstract In the world of Agent-Based Modelling we claim that models and simulations are well suited to aid policy development. Yet it proves difficult to find the right connection with policy developers. In this paper we provide various insights in the policy development world in the context of the Dutch national government. We discuss relevant literature, report on conducted interviews with policy developers and reflect on participatory observations while working in Dutch ministries. This provides us with a set of needs and goals of (Dutch) policy developers. It also thought us that *the* policy process and *the* policy developer do not exist. A policy is only one element in the policy process. We found different elements in the policy process for which ABM's can be used, like consensus building or communication of problem understanding. We pose that ABM is currently not fit to predict policy outcomes in our context. After discussing these elements we have summarized them in requirements that can be operationalized by us and others to find a better connection with policy developers. The requirements are a starting point for a framework that supports policy developers in their work with ABM.

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Keywords Policy development · Agent-based modelling · Process dynamics · Goals of models · Policy developers · Policy theory · Policy practice · ABM for policy · Participatory Observations

Introduction

Agent-Based modelling (ABM) is seen as a promising technique to gain good insights in complex problems [1]. These problems are often not well defined, dynamic, can be seen from different perspectives, have many stakeholders and contexts. One domain that deals with these complex problems is the world of policy development. Policy developers, usually within governments, are tasked to develop policies that solve these complex problems and make the world a better place. Thus it stands to reason that policy developers will benefit from using ABM in their work. This idea is voiced by many: [2–6]. Edmonds and Gershenson [4] put it the following way:

> For policy and decision-making, models can be an essential component, as models allow the description of a situation, the exploration of future scenarios, the valuation of different outcomes and the establishment of possible explanations for what is observed.

Gilbert et al. [6] put it even stronger:

> [...], it is not only common sense to use policy modelling to inform decision making, but it would be unethical not to.

Yet we don't see a lot of ABM in policy development. Despite all the claims that ABM is very well suited for the issues that policy developers face. This poses the question; "how come they don't use ABM's?". Rosewell voices some reasons in [3] (e.g., people stick to their old habits). In [6] Gilbert et al. reflect on their experiences with modelling policies. Many lessons are learned and made explicit for modellers to take into account. But they also state:

> [...] culture [in the policy world] may have to change to permit and even encourage a more collaborative, Agile modelling approach.

To answer the posed questions we want to construct a framework that enables policy developers to use ABM in a way that suits their needs. In this paper we give an insight in the needs of Dutch policy developers from the Agent-Based Modelling perspective. These insights serve as starting point for our framework for policy developers.

What are the needs of policy developers? What challenges do they face? What does their world and work look like? What do they perceive as added value? And how would ABM fit in all of this?

These are the main questions that we answer in this paper. We focus on the Dutch policy development process at the Dutch national level (Het Rijk). Within this domain we are interested in the aspects of ABM that are useful for policy development. For the construction of the framework we use Wieringa's Design Science [7]. The questions stated earlier are part of the *Problem Investigation* phase which provides insights for the framework to support policy development.

To find these requirements we discuss literature on the policy process in Sect. "Literature". We use this literature to set up and conduct interviews with policy developers regarding policy development, which are discussed in Sect. "Interviews". During this period we have also done Participatory Observations while interacting with policy developers. We discuss this, and more of the Dutch policy context, in Sect. "Participatory Observations". In Sect. "Discussion: ABM and Policy Development" we combine all three sources of information, discuss our findings and put forward a number of requirements for the framework. We conclude with our aims for future research in Sect. "Conclusions and FutureWork".

Literature

Why would you model at all? The importance of this question is put forward by Edmonds and Gershenson [4] and Gilbert et al. [6]. The possible answers are numerous, as is illustrated by Epstein in [8] by listing 17 reasons. These reasons are more than "final goals" of a model. Chattoe-brown et al. [9] show that the process of making an ABM can be more useful than the result. Maybe the same can be said for the policy process? For this question we look at the different literature regarding the policy *process* from the theoretical and practical perspective.

Policy Process Theory

Klein uses various policy process theories in his interesting thesis[10] to model the policy process using ABM. The most relevant are: 1. The Multi Stream Theory, 2. The Feedback Theory, 3. The Advocacy Coalition Framework and 4. The Diffusion Theory.

The *Multi Streams Theory* (MST) uses multiple different "worlds". The Problem stream indicates a certain public problem and how it is perceived by its surrounding. The Policy stream consists of possible solutions (policies) for this problem. The Politics stream represents the political will concerning the problem and policy. The flow of a stream can be influenced by external events like crisis's, accidents or "policy entrepreneurs". A policy change can occur when all the streams come together, as seen in Fig. 37.1, and a policy window opens. The MST model shows us that policy development is something of opportunities, but the model seems to be rather simplistic. Of note is that it is created by focusing on the USA context exclusively [13]. It lacks a great deal of formalization, as neither the problem, policy and politics are well defined.

The *Diffusion Theory* focuses on the effects of other governments on the policy decisions of a government, a seen in Fig. 37.1. The basic mechanic is that a govern-

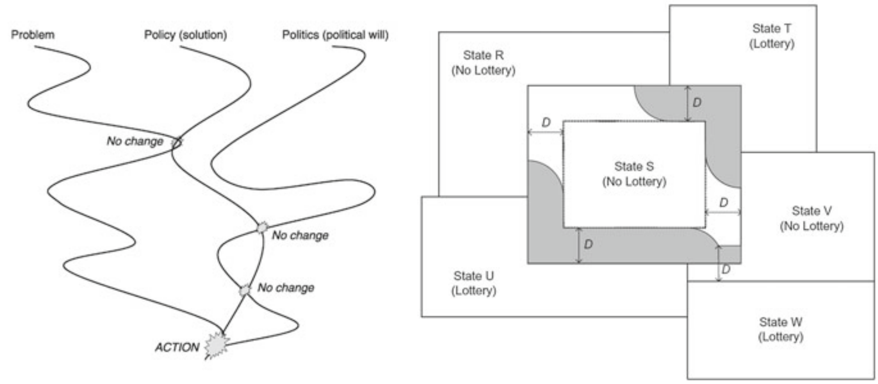

Fig. 37.1 Diagram of multi streams theory from Kingdon found in Buse et al. [11] on the left and an example of Diffusion Theory with state lotteries from Baybeck et al. [12] on the right

ment is able to adopt a policy from an other government. In [14] Braun and Gilardi list, on which Klein based his model, reasons for this adoption: Learning, Competitive, Coercion, Common norm and Symbolic Imitation. The theory seems to only address a single dimension in the policy process: how do neighbouring governments influence each other?

The *Feedback Theory* looks at the feedback effect a policy has with respect to "mass politics" and the political system [15]. Just like MST this theory lacks formalization. If we translate the idea of this theory to ABM it deals with one aspect: policies influence agents and causes them to change their behaviour, a feedback effect. Thus it focuses on only one aspect of policy development.

The *Advocacy Coalition Framework* (ACF) depicts different coalitions that want to change policies in a subsystem. A subsystem can be seen as a particular context, such as health care. ACF is a structured theory with many elements that influence the policy process [16], as illustrated in Fig. 37.2. It focuses on coalition forming and shows a policy broker interacting with these coalitions. ACF gives us many steps, relationships and actors that are relevant to understand the policy process.

Policy Process Practices

Literature on Dutch Policy Practices seems to be limited. Works like [17] on public administration give us basic understanding of our Dutch context. The "Integrated impact assessment framework for policy and legislation" (IAK) [18] is a framework presented by the Dutch ministry of Justice and Security. This is a framework to guide the policy process. The IAK [18] poses 7 central questions, in three phases, regarding the proposed policy. In Phase 1 (Problem analysis) most questions are stated: What is the "starting point"? Which parties to involve? What is the problem?

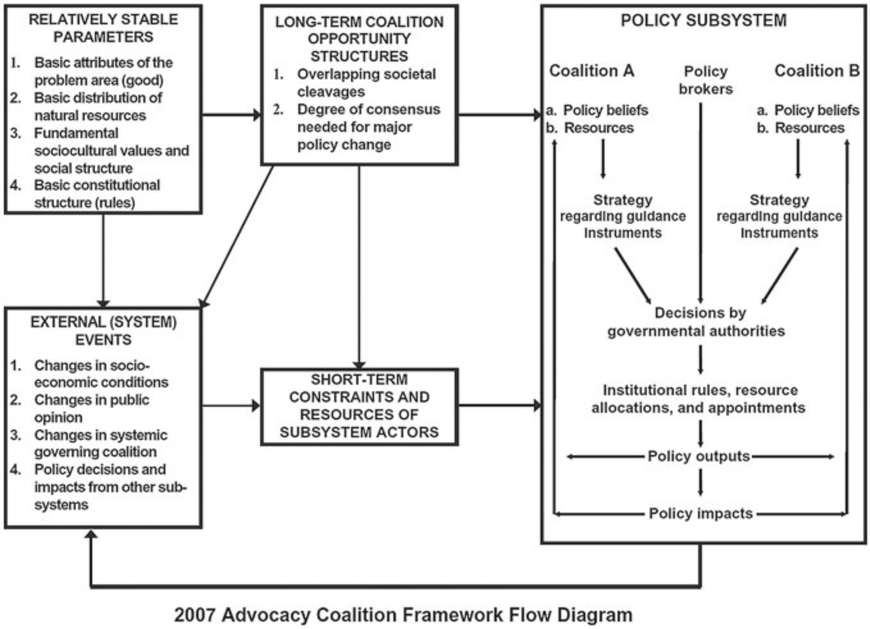

Fig. 37.2 2007 advocacy Coalition framework flow diagram from Weible et al. [16]

What is the goal? What justifies government intervention? In Phase 2 (Choice of intervention) it discusses: interventions, legality, effectiveness, feasibility and the introduction of the policy. Phase 3 (Impact assessment) concludes with discussing the impact, evaluation and monitoring of the policy. If one wants to submit the policy proposals to the Cabinet the use of the IAK needs to be indicated.

Another (inter)nation standard is the Policy Cycle. In Fig. 37.3 a theoretical policy cycle is depicted. A policy cycle has 5–7 stages, depending on the version used. The five stages used here are: Agenda Setting, Policy Formulation, Policy Adoption, Policy Implementation, Policy Evaluation. The policy cycle is used in governmental communication regarding the policy process. It is used in introductions to public administration like [17] and guides [19] on how to write bills or other documents. [19] also gives an insight in other things that policy developers do, like a force-field analysis and suggests using SMART[1] formulations.

Herold [20] looks at *wicked problems* and the relevance of policy culture. As wicked problems are complex they require an early and open approach for policy modelling with a diversity of stakeholders, such as citizens, companies and representative groups. Yet the 4 unwritten rules in policy development that Herold found make this difficult. Translated from Dutch they are:

[1] Specific, Measurable, Achievable, Relevant and Time-bound.

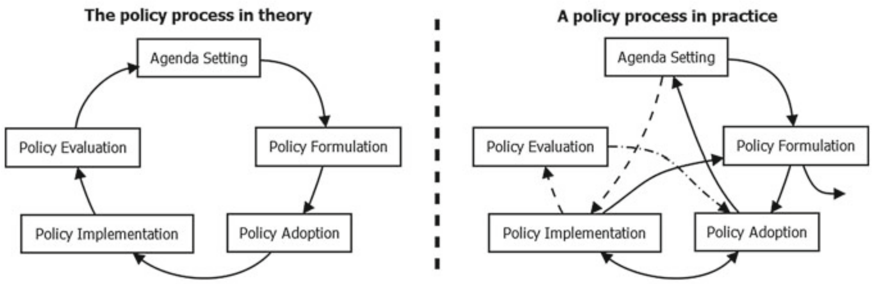

Fig. 37.3 Theoretical policy cycle on the left and a policy "cycle" in practice on the right

1. *Always remember that you serve your minister and the hierarchy.*
   Attention is mainly focused upwards within the organization. The policy developer is loyal to this organization and hierarchy.
2. *Be visible for the hierarchy.*
   If you're not visible for the people in the hierarchy your added value as policy developer will be called into doubt.
3. *Meet your schedule.*
   If you fail to meet your schedule you will miss the right momentum and your chance to be visible in the hierarchy. It could even lead to political problems for your minster.
4. *Your network is crucial, especially the usual suspects.*
   Your network, especially the usual suspects, have political influence. If you include your network correctly in the policy development process it will progress much faster.

These rules reflect the political view on policy development which contrasts the analytical view as explained in Chap. 4 of [17] (in Dutch).

Interviews

In the literature overview we have shown multiple ways to look at the policy process. We want to know how well this reflects reality. To answer this we have conducted interviews with policy developers.

The interviews have been conducted using the discussed literature and are based on the Observational Case Study methodology as described by Wieringa [7]. We have discussed the four policy process theories used by Klein [10] first. The IAK [18] and policy cycle were discussed next. Lastly we talked about the different reasons why one would want to use a model using the 17 reasons of Epstein [8].

During the interviews, which were planned to last 2 h, all audio was recorded. Nvivo was used to encode the recordings. The participants were all policy developers within the Ministry of Economic Affairs and Climate Policy and the Ministry of Agriculture, Nature and Food Quality. All interviews have been held in Dutch. English material was translated. Quotes used in this paper are translated from Dutch to English for the comfort of the reader.

The Policy Theories are seen as “not wrong” by the policy developers. The *Feedback* and *Diffusion* theories are said to only treat a single aspect of the policy process. They are also not operationalizable and thus not fit to be used in the policy process. The *Multi Streams* theory is found too simplified to reflect their work. One participant remarked that “it should have multiple lines in a single stream” to indicate that reality is more complex. It is remarked that a Dutch policy developer “tries to get the streams together” and isn’t part of a stream.

Most recognition was found in the *Advocacy Coalition Framework*. ACF uses subsystems (like contexts or domains), many different influencing factors and coalitions (of stakeholders) with certain beliefs. The context dependency, complexity, time horizon and stakeholders were mentioned often during the interviews as important aspects. Stakeholder management and coalition forming is relevant for every part of the policy process. Be it from politics to single citizens. One example is the following question regarding the energy transition: “How can we form a coalition of all owners of windmills? If we can unite windmill owners in a coalition they can develop policies for themselves and the policy developer has less stakeholders to deal with”.

In contrast to the four policy theories, the IAK and the policy cycle were known by the participants. The IAK was perceived differently by participants. It is seen as a helpful guideline on “what to do” or serve as a minimum effort check-list when finalizing the policy. How its usefulness is perceived seems related to the seniority and personality of the policy developer. People who are new to the policy process and those who like to have a structured way of working like to use it.

The same can be said for the use of the policy cycle. It can help with figuring out what to do if you are in a certain phase, but the structure the cycle suggests is an utopian view: “I have never seen a good administrative process [model] of the core activities of policy developers”. The policy process in practice is perceived as chaotic and unpredictable, as depicted in Fig. 37.3.

During the interviews the discussions led to the insight that role of a policy developer might be more ambiguous than initially thought. A policy developer usually doesn’t follow a well structured process. He or she has a certain set of skills that enables him or her to guide the process of policy development. Usually a policy developer has limited knowledge of the problem domain and leaves most decisions to be made regarding the content of a policy to the stakeholders. The policy developer makes process decisions, like “which stakeholders to involve?”, “what is the next step?” and “how do we organize support for this policy?”. A policy developer is expected to able to fulfil different roles in this process. What these roles are is influenced by the type of policy.

It is interesting to see the (lack off a) relationship between policies and politics One illustration of this is the following quote: “roughly 95% of policy problems are technical, only 5% are political”. Here “political” classifies policies in which members of parliament and/or the media have an interest, thus having potential political consequences. The vast majority is of the "technical" and just business as usual.

The Reasons to Model proved a difficult topic to discuss. The first issue is found in the concept of a model. Depending on the background of the participant their understanding of models differs. Some regard models purely as predictive objects, like techno-economic models, that institutions such as the PBL Netherlands Environmental Assessment Agency[2] (PBL) use. A distinction between scenario's and models was made as well, but in a different way than we are used to in ABM. The distinction made here was between "mathematical models" and "conceptual scenarios".

We discussed the relevance of the different modelling goals for their work. The reasons *Predict*, *Illuminate core dynamics*, *Demonstrate trade-offs/suggest efficiencies* and *Explain* were regarded as most relevant by the participants. The reasons related to a better understanding of the problem felt all as the same thing. *Discipline the policy dialogue* was seen as very relevant for stakeholder management and collaborative policy modelling. The focus was put on communication: with models you could create a common language and understanding. It also serves as a way to create good stories, possibly in a visual way, and find proper framing for a policy.

Regarded semi-relevant: *Illuminate core uncertainties*, *Challenge the robustness of prevailing theory through perturbations*, *Expose prevailing wisdom as incompatible with available data* and *Reveal the apparently simple (complex) to be complex (simple)*. Not regarded relevant: *Guide data collection*, *Suggest dynamical analogies*, *Promote a scientific habit of mind*, *Offer crisis options in near-real time*, *Train practitioners* and *Educate the general public*. *Discover new questions* was also not regarded as relevant, but at the same time it was said that "[...] I don't want to discover more questions, I want to discover the *right* question!".

Participatory Observations

> [...], it is clear that engaging with real research problems, even in the early stages, generates insights that unlikely to be developed by cogitation alone.

This quote taken from Chattoe-brown et al. [9] expresses a core element of this paper. The main author works part-time as a civil servant at the Dutch Ministry of Economic Affairs and Climate Policy and the Ministry of Agriculture, Nature and Food Quality. This way we can do participatory observations within the problem context. Here we report our findings based on many (informal) interactions with civil servants.

Firstly, being "part of the system" the four rules of Herold [20] can be felt in our work. One interviewee remarked that serving the same minister had more value than the signed informed consent and non-disclosure form. This loyalty is part of "being

[2] English PBL website: https://www.pbl.nl/en/.

sensitive for political and organizational aspects".[3] In a nutshell this means that you need to have a feeling for what you can do, both formal and informal, within the context of your problem domain and organization. This can be done by building a good network, both internal and external, and maintaining it (rule #4 of Herold). This sensitivity is also reflected in internal governmental language; direct statements are often avoided.

Secondly, and closely related, is knowing what to do when. One example of this are the general elections. In the Netherlands these are usually held every four years. After an election the biggest parties negotiate to form a coalition and a cabinet. One of the results of this negotiation is a set of goals and plans (Dutch: regeerakkoord) for the cabinet's time in office. As a policy developer you can try to navigate a proposal to the negotiation table and hope it gets adopted. An other option is to adjust your proposal after the negotiations such that it is aligned with the goals of the new cabinet. Do note that others around you are trying to do the same thing and might compete with you.

Thirdly, framing and story telling. You need to have the support from many different stakeholders with many different views. Having a good story really helps convincing them. Two basic questions a story must answer are: "What is in it for me?" and "What do I have to do?". This holds for any audience, be it a politician, company, other civil servant or the general public.

Fourthly, a policy developer is only one of many people involved in developing a policy. As confirmed by the interviews, policy developers mainly manage the process of policy development. We see this during our own interactions with policy developers as well. One reason for this is that policy developers change positions quite often. Consequently policy developers are often not experts in the field they are developing policies for. They need others to supply the right expertise. One example of these experts are the PBL and Statistics Netherlands (CBS). Expert backing is needed to give legitimacy to decisions, something that can be done using the PBL and CBS and their expert authority. If there would be a "national institute for simulation based modelling" it would be easier to involve simulations in the policy making process. Policy developers focus on bringing the process and the right expertise together.

Lastly, time constraints. Policy development is heavily time-boxed, partly due to the political relevance (such as elections). The political process requires that certain progress has been made at a certain time, without knowing the complexity beforehand. It can happen than a policy needs to be finished in 4 months, while all experts say you need at least 2 years to develop a good policy. Here all the previous elements come into play: if the policy developer plays the game well he or she might be able to extend the deadline. This aligns with the idea that policy development is both a science and a craft.

[3]See for example the (Dutch) job descriptions: Coördinerend Beleidsmedewerker, Senior wetenschappelijk medewerker.

Discussion: ABM and Policy Development

"*The* policy process and *the* policy developer don't exist", a remark that is often made by policy developers. This is a testament to how diverse, delicate, social, complex and context dependent their work and role is. Looking at the different policy theories the ACF seems to be the best representation of the policy process from an outside perspective as it reflects some of the complexity. From the inside perspective the policy cycle is a way to find the *current process goals* of a policy developer. This inside-outside relationship is also indicated in Fig. 37.3 by the dashed line. A policy process is planned according to the theory, when executed it is usually more dynamic than planned, but when reported on the process the taken actions are rationalized to fit the initial plan. The rationalization makes it harder for outsiders to grasp the complexity of the policy development process. An analogy to this can be found in software development with the (in)famous Waterfall Model.

If we take a closer look at the policy cycle we can map the goals of most public policy ABM's to the adoption, implementation or evaluation phases. The questions posed here are mostly regarding the prediction or evaluation of the efficiency and effectivity of a policy. In the Netherlands renowned governmental institutes, like the PBL, answer these types of questions. They hold commanding positions and out-pace the individual modeller. Competing with them would be a tall order. Our Dutch nation context is important here: while discussing this situation with a Flemish civil servant we learned that this situation didn't exist in Flanders.

When focusing on the ministerial context we see that quite some work by policy developers is done in the other phases: agenda setting and policy formalization. Here it is important to talk about the strategic implications of process decisions and path dependency issues. An example of this is the choice of fundamental economic model used for reasoning. Do we use classical approaches based on economic growth or do we use different theories, like Doughnut economics [21], as our ground truth? Such strategic choices reflect core beliefs (recall ACF) and impose different paths of policy options. It would be most valuable to have a better insight in these path dependencies.

The work of policy developers involves a lot of communicating and structuring the process. We see this reflected in the reasons to model that are regarded as relevant for the policy development process. Closely related is stakeholder management, which comes up in ACF, our interviews and the participatory observations. One also needs to communicate in an apt way with the hierarchy and stakeholders from different contexts and perspectives. For this a basic understanding and insight in the core dynamics of the context and problem domain is needed. An ABM example of this is found in [22] where system dynamics regarding refugee well-being are made explicit.

People like images and visuals, which is a strong point of ABM. But the same thing should be done with models themselves. Here we can look at ontologies. This are models of entities, e.g., agents, with their relationships. They offer a visual way to create domain and context knowledge in a structured way. This structure can be hierarchical, offering a way to find the right aggregation and the best problem or question.

During the interviews good discussions formed. One of the reasons these sparked was, interestingly, misunderstanding of the open questions by the participants. This misunderstanding shows that we need to create the framework in a language that is understood.

The policy process is time boxed, be it 3–4 years, 3–4 months or even weeks. At the same time most modellers are limited to their own time and ability, or have a small team to do the modelling. Thus it is often infeasible to create detailed models for a policy within the available time. For this issue standardized building blocks of ABM's would offer a solution. Some questions are asked more often than others, e.g., "What is the impact on the economic market?". One way of approach is to create rich building blocks of which elements can be selected to be used for the model at hand.

As the policy process can be highly dynamic an agile and interactive way of working can be beneficial. During the creation of a model new ideas and insights can come up. A participatory modelling approaches and a flexible architecture for the framework can support this. Participatory modelling can also be used by policy developers to interact with their stakeholders to get more buy-in and support. It also enables the framework to be used to think about storytelling and frames: the flexible architecture needs to support multiple contexts and perspectives. Each ministry, and even a division within one, has its own culture and perception of what the *right* way of developing a policy is. This influences the process in which a policy is developed and how this process is seen in the hierarchy. This means that there is no silver bullet approach for our framework, it needs to be flexible for different uses.

With all this complexity good insight in the organizational politics and a strong political awareness is preferred. ABM focuses on agents or actors and helps the modeller to clearly define the problem at hand. This way ABM can help with the a SMART formulation and the creation of a force-field analysis.

As a final point of our discussion we want to address the thorny issue of *predictions*. What policy developers expect of a prediction is wholly different from the predictions offered by modellers. Modellers usually predict things given a certain context, making various assumptions, make generalizations and with a certain degree of correctness, among many others. Policy developers need predictions that take almost all real life complexity into account, has assumptions that laymen do not consider weird and has at least 100% correctness. These requirements of policy developers on predictions are the results of the demands of their environment. This discrepancy, *in our context*, makes us believe that ABM's are better suited to be used for other things than prediction in policy development.

Table 37.1 Overview of identified requirements when using ABM for other reasons than prediction in policy development. *Lit* is Literature, *Int* are Interviews and *PO* are Participatory Observations

Requirements for ABM in policy development			
#	Description	Potential solution	Source
1	Path in-dependency, Context switching	Modular architecture	PO (#1, #2, #3, #4, #5)
2	Interact with stakeholders	Participatory modelling	Int (Stakeholder engagement), PO(#3, #4, #5)
3	Visual representation of models	Diagrams, ontologies	Lit [20], Int, PO (#3)
4	An easy to understand modelling process	ABM modelling principles in the right language	Lit (Hierarchy [20]), Int (Model misunderstandings), PO(#4, #5)
5	Time box	Pre-build model blocks	Lit(Meet your schedule [20]), PO(#5))
6	Flexibility for process dynamics	Iterative, agile methodologies	Lit [16, 17], PO (#1, #2, #4)
7	"Right" aggregation level of problems	Ontologies, differentiate between types of problems	Int(Finding the best question), PO (#1, #2, #3, #4, #5)

Conclusions and Future Work

In this paper we have given an unique insight in Dutch policy development on the national level. The world of policy developers is complex, but complex in a different way than we anticipated. We expected that most complexity and attention would concern the content of a policy, not the process of its development.

While predicting policy outcomes is something every policy developer values highly it doesn't help them with their everyday work. We found a need for consensus building, the understanding of system dynamics and organizing support for a *good* policy, usually with tight time constraints. An ABM that focuses on predicting the outcome of a policy has a high chance of not being informative, proposing infeasible changes or not meeting the requirements. Thus focusing on other modelling goals should be more fruitful when aiding policy development.

By combining all our findings and discussing them we have compiled a list (Table 37.1) of requirements that can be used to create and use ABM in a policy development context. We realize that our overview of the policy development complexity is far from complete, but also realize that it will never be complete. The posed solutions are educated guesses based our experiences and are in now way tested or implemented in our problem context. We are well aware that the solutions are far from simple and can each be problematic in their own right. Yet they serve as a starting point for our future work in the Ph.D. project on the ABM policy development framework.

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Chapter 38
A Policy-Oriented Agent-Based Model of Recruitment into Organized Crime

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Abstract Criminal organizations exploit their presence on territories and local communities to recruit new workforce in order to carry out their criminal activities and business. The ability to attract individuals is crucial for maintaining power and control over the territories in which these groups are settled. This study proposes the formalization, development and analysis of an agent-based model (ABM) that simulates a neighborhood of Palermo (Sicily) with the aim to understand the pathways that lead individuals to recruitment into organized crime groups (OCGs). Using empirical data on social, economic and criminal conditions of the area under analysis, we use a multi-layer network approach to simulate this scenario. As the final goal, we test different policies to counter recruitment into OCGs. These scenarios are based on two different dimensions of prevention and intervention: (i) primary and secondary socialization and (ii) law enforcement targeting strategies.

Keywords Criminal organizations · Disruption strategies · Public Policy · Criminal involvement · Law enforcement

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Introduction

Organized crime (OC hereinafter) is present in a wide number of countries all over the world [1, 3, 7, 20] posing social, economic and security challenges to societies, institutions and legal economies. OCGs are capable to attract people and strengthen their presence on a territory. Human workforce is a crucial asset for OCGs: a higher number of affiliates and members is an indicator of the actual resources at their disposal and a measure of the potential strength of the groups itself. Understanding how recruitment works, then, becomes a relevant issue both from the research and the policy standpoints. However, investigating recruitment dynamics at scale is extremely costly in a real-world setting, involving first and foremost feasibility constraints. Additionally, it also poses ethical questions that are often present when dealing with social experiments. Computer simulations, conversely, can overcome these issues. With this regard, their potential has also started to be investigated in criminology [11, 13, 18].

In light of these considerations, this paper presents the rationale and structure of an agent-based model of recruitment into OC. To best of our knowledge, this is the first simulation model that specifically integrates computational science and criminology to address the problem of recruitment into OC, and this paper presents its overall structure and rationale. The ABM will resemble a neighbourhood of Palermo, the main city of Sicily: our artificial society will comprise 10,000 agents with socio-economic, demographic and criminal characteristics derived from empirical data. The investigation of recruitment dynamics will be coupled with the final goal of the simulation, which is the testing of potential policies to prevent or reduce recruitment into OCGs, especially for youth.

The rest of the paper is organised as follows: the theoretical framework part will briefly cover the main theories that constitute the criminological backbone of the model. The Data section will describe the empirical information used in the ABM and the sources from which data have been extracted. The Main Structure section will thoroughly explain the rationale of the multiplex approach and the two main components of the model. Finally, in the Policy Scenarios section, the two proposed families of counter-policies that respectively deal with socialisation and network disruption will be presented.

Theoretical Framework

The rationale of our simulated society is rooted in the outcomes of a recent systematic review on the factors leading to recruitment into OC [14]. Furthermore, it also takes into account several theoretical perspectives. Some of these suggest that organised crime is embedded in the social environment and that social relations are crucial for the recruitment into organised crime. With this regard, differential association theory and social learning theory [5, 17] posit that crime in its various aspects is learned in a social environment by relating with other criminal agents. Empirical studies have also highlighted that OC is socially and criminally embedded in the surrounding environment [9, 12]. The position agents occupy within a criminal network determines their possibilities to commit crimes. In this sense, an agent's valuable criminal ties determine his social opportunity structure [10]. Conversely, other theories such as the general theory of crime [8] argue that an individual's low self-control levels determine an inability to compute the negative consequences of one's criminal behaviour, thereby determining persisting patterns of criminality throughout his life. The general theory of crime contends that group crime does not have specific characteristics and that the formation of criminal groups is mostly driven by self-selection processes. The social relations (i.e., social learning and differential association) and self-control (i.e., general theory of crime) perspectives may generate opposing views about the recruitment into organised crime: however, a more comprehensive explanation of criminal activity could be reached via the combination of elements of both frameworks. With this regard, the development of an agent-based model is a convenient way to do so, since its flexibility can allow to integrate both personal and inter-personal components. In light of this, the present model operationalizes criminal involvement both as the result of interaction with others and as emerging from agents' individual characteristics pushing towards crime.

The Model

Data

Using empirical data to feed the simulations is fundamental when aiming at setting up a reasonable and grounded model and ex-post validation, besides theoretical and formal mechanisms (e.g., the mechanism of crime commission). To develop the model and validate the results, we have retrieved and processed several data from different sources regarding specific demographic, economic, social and criminal aspects. We have chosen the city of Palermo as the specific setting to be resembled by the simulation model, as Palermo is one of the cities with the highest mafia presence in Italy [6] (Table 38.1).

A Multiplex-Network Approach

Simulating the dynamics and processes that lead to the recruitment into OC requires to take into account a wide variety of factors. While certain elements are inherently linked to the individual sphere (e.g., age, gender), others span over the personal characteristics of an agent: making new friends, for instance, is dependent upon the social environment in which an agent is set.

Table 38.1 Data Employed to Inform and Validate the Simulation

Data	Variable type	Source, time Span
Distribution of female fertility according to age	Demographic	Istat, 2017
Mortality probability by age and gender	Demographic	Istat, 2016
Wealth level distribution by a person's level of education	Economic	Bank of Italy Survey, 2016 Istat, 2011
Distribution of employer sizes in Palermo	Economic	Istat, 2011
Household size distribution by the household head's age in Palermo	Demographic	Census data, Istat 2011, Municipality of Palermo
Distribution of household sizes in Palermo	Demographic	Census data, Istat 2011, Municipality of Palermo
Distributionof household type by age of household head	Demographic	Census data, Istat 2011, Municipality of Palermo
Distribution of people's age by gender in Palermo	Demographic	Istat, 2018
Number of schools in the city of Palermo by level of education	Social	Ministry of Education and Research, 2016
Distribution of Mafia families in Palermo	Criminal	Corte d'Appello di Reggio Calabria, 2012; Criminal Investigations "Aemilia", "Crimine", "Infinito", "Minotauro"
Co-offending prevalence	Criminal	Istat, 2012–2016
Crime rates (corrected for dark number)	Criminal	Istat, 2012–2016
Punishment distribution	Criminal	Istat, 2012–2016
Imprisonment length distribution	Criminal	Istat, 2012–2016

In real life, every person engages in different types of relations, e.g., as part of a family, in friendships, at work, and—if criminals—in co-offending. A member of an OCG is also part of a wider social environment as embedded in multiple social worlds. The literature proves that relations of different types may drive the involvement and recruitment into organised crime [2, 4]. To adequately address the dynamics of individual and social drivers, we opted for an ABM based on a multiplex rationale. A multiplex network includes several networks, each mapping specific social relations. Five relational layers are modelled in the simulations: families, friendship networks, professional and school ties, criminal relations and organised crime groups.

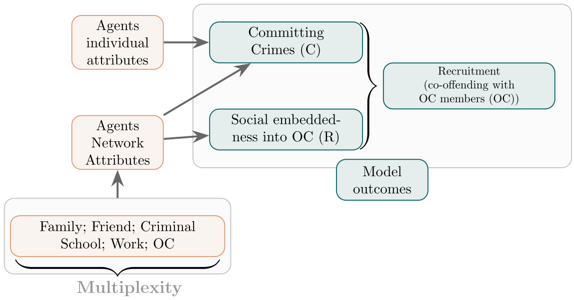

Fig. 38.1 Synthetic description of the general structure of the model

Considering the need for creating a society that synthetically mirrors the real-world, we have decided to include all the main dimensions through which an individual can realistically act and behave. The structure, topology and characteristics of the networks are empirically grounded using official statistics or replicating mechanics found in existing scientific works. The multiplex network framework also allows for considering individual-level characteristics as agents' attributes, thus making possible to analyse individual and social factors to simulate realistic recruitment dynamics. Agents in the simulation, regardless of being or not part of an OC groups, can be born, get engaged/married, make children, die, create and break relations, and commit crimes. Specifically focusing on the organised crime dimension, the model considers one single OCG existing in the simulation. Its internal structure, composition (in terms of gender distribution and generation/age distribution) reflects the ones found through analyses of several police investigations on Italian OC groups.

Recruitment into Organised Crime

For the purpose of this simulation, recruitment occurs when an agent commits a crime with at least another agent who is already a member of the OCG.[1] This option was driven by different considerations. First, it is observable and easily operationalizable. Requiring the commission of a crime with OCG members models in a straightforward way the process of recruitment, avoiding subjective evaluations. Second, it is broadly consistent with the criminal law approaches criminalising organised crime across countries. Two different complementary dimensions contribute to the determination of the recruitment processes in the model, namely the probability of committing a crime (called C) and the embeddedness into organised crime (called R) (Fig. 38.1).

[1]It has to be noted that the model is initialised with a certain number of agents estimated based on data retrieved from criminal investigations, as showed in Table 38.1.

Table 38.2 Gender and age class probabilities ($(C|\theta(g, a))$ of committing a crime in Palermo

(Sex, Age class)	Probability
(Female, ≤13 yrs)	0.0004
(Female, 14–17)	0.0223
(Female, 18–24)	0.0511
(Female, 25–34)	0.0634
(Female, 35–44)	0.0643
(Female, 45–54)	0.0489
(Female, 55–64)	0.0308
(Female, ≥ 65)	0.0111
(Male, ≤13 yrs)	0.0022
(Male, 14–17)	0.1502
(Male, 18–24)	0.3019
(Male, 25–34)	0.3036
(Male, 35–44)	0.2751
(Male, 45–54)	0.1996
(Male, 55–64)	0.1268
(Male, ≥ 65)	0.0537

Modelling Crime Commission: The "*C*" Function

The C function models the probability that agent i will commit a crime at time t. Its structure revolves around two components: the probability of committing a crime given gender and age class and the risk of committing a crime associated with several social and criminal factors. The first component has been derived estimating baseline probabilities of committing a crime in Sicily using official statistics. The probabilities are computed using both the figures on reported crimes and data gathered from victimisation surveys. This complementary computation allows to eliminate the problem of crime dark figure [15]. In the model, we have thus reliably estimated the actual real number of crimes occurred in Palermo in the period 2012–2016. Baseline probabilities are reported in Table 38.2. The second component originates from empirical findings in the existing literature. Specifically, several systematic reviews providing information on the impact of certain factors on the general probability of committing a crime. These sources provide effect sizes (in different forms, e.g., odds ratios) allowing to determine the different probabilities of coming a crime given an agent's network and individual characteristics Table 38.3.

Given the data at our disposal, we model the probability of committing a crime $p(\bar{C})$ for an individual i at time t as:

$$p(\bar{C})_{i,t} = \left[(C|\theta(g, a)_{i,t}) \left(\sum_{j=1}^{m} \gamma_{j_{i,t}} \right) \right] + \varepsilon \quad (1)$$

Table 38.3 Individual-level factors (γ) driving the crime Commission process—odds ratios

Risk factor	OR	Definition
Unemployment	1.30	Having/not having a job
Education	0.94	Having/not having an high school diploma
Natural propensity	1.97	Having a crime propensity higher than a certain value x (log-normally distributed in the population)
Criminal history	1.62	Having/not having committed a crime in the past
Criminal family	1.45	Having a share of criminal family ties which is higher or equal to 0.5.*
Criminal friends and co-workers	1.81	Having a share of criminal friends ties which is higher or equal to 0.5.**
OC Membership	4.5	Being part of an OC group

* A criminal family tie is a direct link with a family member which has committed at least one crime in the last 2 years.
** A criminal friendship/professional tie is a direct link with a family member which has committed at least one crime in the last 2 years

where $(C|\theta(g,a)_{i,t})$ is the baseline probability for the individual given its gender and age class, and $(\sum_{j=1}^{m} \gamma_{j_{i,t}})$ is the summation of the risk factors γ and ε is an error term stochastically distributed in order to bound the individual probabilities of committing a crime to the population average. Specifically, given the odds ratio of a risk factor, we increase/decrease the baseline risk by the percentage provided by the Odds Ratio (OR) itself (e.g.,: if the OR is equal to 1.41, and an individual has it among their characteristics, and their baseline is 0.15, it means that the final value has to be the product between the baseline and 0.41, namely the increase of the risk in percentage given that risk factor). Therefore, at each time of reference $\bar{t}$ and for each subset of the population (g,a) of given gender and age class, the following equation shall hold:

$$C(g,a)_{\bar{t}} \approx \frac{1}{n(g,a)} \sum_{i=1}^{n(g,a)} p(\bar{C}) \tag{2}$$

The equation means that at each time of reference, the average probability of committing a crime for all individuals belonging to the same (gender,age) class shall be approximately similar to the fixed average values presented in Table 38.1, where approximately means that we can allow the model to float in a ± 0.1 range in order not to set overly deterministic mechanics to the model. In other words, we model the distribution of C as a strictly stationary and ergodic random process:

$$F_C\left[C(g,a)_{t_1},\ldots,C(g,a)_{t_k}\right]=F_C\left[C(g,a)_{t_{1+\tau}},\ldots,C(g,a)_{t_{k+\tau}}\right] \text{ for } \forall\ \tau,t_1,\ldots,t_k \quad (3)$$

C has been computed to provide realistic figures on committed offences within the model, in the form of rates by 100,000 inhabitants, using official statistics for different years (2012–2016, specifically). The calculation relied on the correction of crime figures by the dark number of each crime category. This allowed to take into account and include also those offences that have not been discovered or prosecuted in the original data at our disposal, thus giving more solid and reliable estimates.

Most crimes are committed by single offenders [16, 19]. Based on the literature on co-offending, a few crimes will require more than one offender. These works also help in shaping the mechanisms that lead two or more individuals to commit a crime together. Peer and more in general social influence play a relevant role in driving this criminal cooperation [21]. The model thus matches co-offenders based on mechanisms of social proximity: the closer two agents are in terms of social relations across network layers and the higher is the value of C of both individuals, the higher the probability of becoming co-offenders.

Once agents commit crimes they can be incarcerated. Incarceration is estimated using empirical data retrieved from official statistics. Apart from family links, an agent in prison loses all the ties that he/she has created during his/her life (including during his/her job). The mechanism for incarceration is based on a countdown that allows to establish when the agent leaves prison and returns to be "free" in the society, recovering part of its ties.

Modelling Organized Crime Embeddedness: Defining "*R*" R defines the embeddedness into OC and allows to adequately model the probability of an artificial agent to be recruited into a criminal organisation. The theoretically-driven assumption is that individuals that are embedded in communities (across all types of networks considered by our simulation) that are highly populated by OC members face higher risks of being recruited. R affects the selection of new OC members in the simulation. For example, among two equally suitable co-offenders, OC members are likely to co-offend with the agent who is more embedded in OC. In a simple form - but coherently with the differential association and social learning theories as well as the social embeddedness of OC—R is then operationalised as the proportion of OC members among the social relations of each individual. In mathematical notation, a multiplex network $\mathcal{G}=\left\{G^1,\ldots,G^l,\ldots,G^M\right\}$ which resembles our simulated society is a set of M single-layer networks that get dynamically updated at each time unit t. Each single-layer network is denoted as $G^l=(V,E)$, that takes the form of a $N\times N$ matrix. Given this notation, for each G^l, we define an h-hop neighbourhood graph for each node i. The node set of the h-hop neighbourhood graph is defined as the set $N_i^h=\left\{j|k\in N_i^{h-1}, j\in V,(k,j)\in E\right\}\cup N_i^{h-1}$ with $h\geq 1$. The set of edges is then formalised as $E_i^h=\left\{(j,k)|j\in N_i^{h-1},k\in N_i^h,(j,k)\in E)\right\}$. The local neighbourhood of agent i in the single layer network $G^l=(V,E)$ becomes then a vector $\mathbf{w}_i^{G^l}=\left[\mathrm{w}_{i,l}^{G^l}\cdots\mathrm{w}_{i,j}^{G^l}\right]$ where each element represents the weight of the edges included in the h-hop local neighbourhood of the agent. Each value of the vector follows the relation $\mathrm{w}\propto h^{-1}$, meaning that the weights are inversely proportional to the distance between the ego i and an agent j included in the h-hop network. At this point, to compute the embeddedness R of an agent i in his local community, we sum over the vectors of each single-layer network:

$$\mathbf{w}^{\mathcal{G}} = \left[\mathrm{w}_{i,l}^{G^1} \cdots \mathrm{w}_{i,j}^{G^1}\right] + \cdots + \left[\mathrm{w}_{i,l}^{G^l} \cdots \mathrm{w}_{i,j}^{G^l}\right] = \left[\mathrm{w}_{i,l}^{\mathcal{G}} \cdots \mathrm{w}_{i,j}^{\mathcal{G}}\right] \quad (4)$$

This equation yields the resultant vector of weights deriving from the complete agent's h-hop network. To calculate the actual OC embeddedness, we derive the resultant vector of weights obtained from the agent's h-hop OC network $\Theta_i^{\mathcal{G}} = \left[\theta_{i,l}^{\mathcal{G}} \cdots \theta_{i,j}^{\mathcal{G}}\right]$, such that the node set is called $N_{i\,OC}^h$ and the set of edges is $E_{i\,OC}^h$, where $N_{i\,OC}^h \subseteq N_i^h$ and $E_{i\,OC}^h \subseteq E_i^h$. R is finally mathematically defined as:

$$R_i = \frac{\sum_{i=1}^{N_{OC}^h} \theta_{i,j}^{\mathcal{G}}}{\sum_{i=1}^{N^h} \mathrm{w}_{i,j}^{\mathcal{G}}} \in [0, 1] \quad (5)$$

which is the ratio between the total number of weights in the OC h-hop network and the general h-hop network of agent i. The values of R fall in the range [0, 1], with 1 indicating complete overlapping between the general h-hop networks and 0 highlighting total absence of OC members in the local community of the agent. The proposed method implicitly weights the OC embeddedness such that (i) the importance of OC ties is inversely proportional to the distance and (ii) the importance of OC ties (but also of other non-OC ties) is proportional to the number of different ties between any two individuals. R enables to clearly distinguish between active OC members and pro-OC agents. For example, this could be the case of women who are certainly living in OC-prone contexts (e.g., wives and daughters of OC members) but are rarely charged and convicted as OC members since they generally refrain from committing offences. Similarly, a juvenile son of an OC member who is just two years old cannot be considered an active member, but would still have a very high value of R, making it very likely that he will be recruited in the future. Furthermore, R may contribute to the simulation of prevention policies, especially those on the primary and secondary socialisation. The simulation will need to identify the target population and R could contribute in identifying the population at risk better than merely relying on other indicators e.g., the number of crimes committed by the parents or the involvement of a parent into OC.

Policy Scenarios

The policy scenarios that have been selected constitute the final goal of the ABM and they have followed suggestions and remarks given by policymakers belonging to several European institutions (e.g., Europol, Dutch Ministry of Justice, Italian

Ministry of Interior). They are specifically divided into two distinct types: (i) primary and secondary socialisation and (ii) law enforcement.

Primary and Secondary Socialisation

This policy scenario aims at protecting juveniles from socialisation processes leading them to recruitment into OC. Among the possible solutions, policies aiming at decreasing or countering the influence of OC-prone social relations may offer an effective strategy to prevent the recruitment into OC. These policies will be modelled through different solutions. They include (a) reducing the influence of parents (normally the father), (b) addition of pro-social ties such as non-criminal friends, (c) provision of educational and job opportunities (increasing education achievement, wealth and work ties). This scenario will put to the test and compare the effectiveness of these strategies both as separate and combined treatments. The primary socialisation policy targets young people aged 12–18 living in OC families, intended as OC families, families where at least one parent is an OC member. It will be possible to select the share of the target young people based on a risk score reflecting the family embeddedness (R) in OC and/or based on the OC members convicted in the simulation. This group of juveniles at risk will then be subjected to interventions measures aimed at reducing OC parental ties. For instance, the simulation will be able to model cases in which court orders limit the contacts between people involved in OC and their families or cases of OC members' conviction and imprisonment. In such cases, the ABM will temporarily decrease the relation that OC members have with their families and children while also providing juveniles at risk and their mothers with social and welfare support (e.g., school support, employment support). The secondary socialisation policy aims at children and young people aged 6–18 who are in school. Crime-prone children, i.e. those with higher criminal propensity C, will be targeted with increased social support and/or increased welfare support. Increased social support may include: (a) better educational support (in the ABM, the agent will complete high school and/or achieve a higher level of education), (b) support of psychologists and social workers (promotion of pro-social relations and inhibition of anti-social relations, randomly creating friendship ties with non-deviant peers and adults), (c) increased social activities between children (children will randomly create new friendship ties), and/or (d) move child to new school classes. Increased welfare support instead may include providing a job to the child's mother (resulting in diversification of mother's networks) and/or providing the child with a job when they turn 16 (resulting in diversification of the child's social networks and lower risk of crime commission).

Law Enforcement Targeting Policies

This scenario aims at analysing the impact on the recruitment into OC of different law enforcement strategies in tackling OCGs. In particular, the possible targets will consist of (a) OC group bosses/lieutenants (in the model, potentially OC agents with high scores in measures such as betweenness) and (b) workers in "facilitator" positions. "Facilitators" include logistic workers, such as long-distance truck drivers and airport workers, and legal and financial advisors. These agents have increased opportunities for crime due to their work position (e.g., drug smuggling, money laundering). This scenario will put to the test and compare the effectiveness of LEAs targeting OC bosses/leaders and facilitators toward reducing crime rates and OC recruitment, both as separate and combined policies. Regarding highly central OC members, two policies are proposed: (a.1) Higher scrutiny of OC members (it will decrease their ability to commit crimes and consequently create OC ties) and (a.2) Higher repression of OC members (it will lead to higher imprisonment rates for OC members). For what concerns facilitator workers, policies are related to: (b.1) Higher scrutiny of facilitator positions (will decrease facilitators' probability of crime commission and OC tie creation) and (b.2) Higher repression of criminal facilitators (will lead to higher imprisonment rates for criminal facilitators).

Conclusions

This paper has presented the rationale, input data and structure of an ABM designed to model recruitment into OC and to test different types of policies to contrast the strength of criminal groups in attracting new individuals. The model relies on empirical data gathered from official statistics when possible, and on information gathered from scientific literature otherwise. It is highly dependent on two dimensions, namely C and R. C formalises the individual probability of committing a crime of each agent, given its social, economic and criminal characteristics. R, conversely, quantifies the extent to which an agent is embedded into an highly OC-prone local community. This two-fold structure is a flexible and convenient solution that also permits to model and monitor non-criminal social processes, avoiding an overly narrow landscape of the simulation. This ABM originates in the context of PROTON, a three-year Horizon 2020-funded project and ultimately led to the development of a user-friendly interactive tool at the disposal of policy-makers, practitioners and analysts interested in running virtual experiments to assess the potential consequences of a given policies (http://193.142.112.125:8012/). Users are able to test alternative societies via the possibility to modify sensitive hyper-parameters such as unemployment rate, criminal presence and law enforcement repression in order to resemble other European contexts.

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Chapter 39
A Multi-purpose Agent-Based Model of the Healthcare System

Florian Chávez-Juárez, Lucy Hackett, Georgina Trujillo, and Alejandro Blasco

Abstract This article presents the main characteristics of the first version of *HealthSim*, a general purpose agent-based model of the health care system. We present the core elements which are likely to be common across health care systems and briefly discuss how the model can and must be adapted to be used for a specific context.

Keywords Health care system · Agent-based model · Public policy

Introduction

Countries around the globe are confronted with increasing costs of their respective health care systems, while trying to provide the best possible care to their population. Different policy measures to slow down the cost increase have been proposed, but due to the complexity of the health care system and the importance of not putting at risk the quality of care, it is extremely difficult to predict the widespread consequences of such policy measures. The goal of this short article is to present some core elements of the first version of *HealthSim*, an agent-based model to analyse the complex health care system.

The health care system is a highly complex system with a variety of actors such as health care providers, insurance companies, patients, pharmaceutical industries and the legislator. Different countries have different systems, but most of them face similar challenges: how to provide the best possible care at a reasonable cost and in a fair manner consistent with a country's values. Though health care systems around the world are very diverse, all of these systems are built around the dynamics that operate between the core actors of patients, providers, insurance companies and governments.

We would like to thank Paola Plata for her contributions during the development phase of the model.

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Recognising this common base to drastically different health systems, we have developed a flexible model of the interactions between the core agents of a health system. Through parameters and input data the model can be adapted to the rules and regulations of a specific national context. Thus, the model can be contextualised to a wide range of health systems. With the creation of a flexible model of a health system, we aim to study ex-ante the effects of policy change in the area of health, which can impact outcomes in surprising ways due to the complexity of the system.

The Model

The common challenge that the health systems of many countries face despite their differences points to shared mechanisms at the micro-level that lead to potential inefficiencies. All health systems must deal with problems of moral hazard, provider incentives and the dynamics of insurance schemes, be it through markets or public provision. While the way that countries confront these issues and respond to the health needs of their population certainly vary, these complex dynamics between patients, providers, insurance companies and regulators lie at the heart of all health systems. It is the complexity of the interactions between diverse agents with different and often opposing objectives that generates inefficiencies, misalignment of incentives, and failed markets.

In the first version of our model we include patients, providers and insurance companies with endogenous and adaptive behaviours, while the government is included through a vector of policy parameters. Figure 39.1 depicts the system as we understand it. The black boxes refer to actors we have fully implemented with endogenous decision making. Our model is built on discrete time, where each period corresponds to one week. In every period patients get sick according to calibrated data where we have a series of possible illnesses. Each medical condition has specific characteristics such as the initial severity and the progression if untreated. Based on the perceived medical need, patients compute their willingness to pay and if it exceeds the expected cost of seeking care, they go to a doctor. The expected cost will depend on previous health care expenditure and can be high if the individual did not yet reach the deductible or does not have health insurance coverage. Once the patient decides to visit a general practitioner (GP), the GP invests in diagnostics and correctly identifies the medical condition with a given endogenous probability. This endogenous probability is based on the number of simultaneous medical condition, the inherent difficulty of detecting a given medical condition and the ability of the provider. The inherent difficulty of detecting a medical condition was calibrated through expert advice.

If a treatment is available, it is prescribed, otherwise the patient is referred to a specialist. Insurance companies pay the medical treatments and the appointments according to the health insurance plans.

On an annual basis, patients might be able or required to purchase a new health insurance. The selection of the best plan depends on their own medical history and

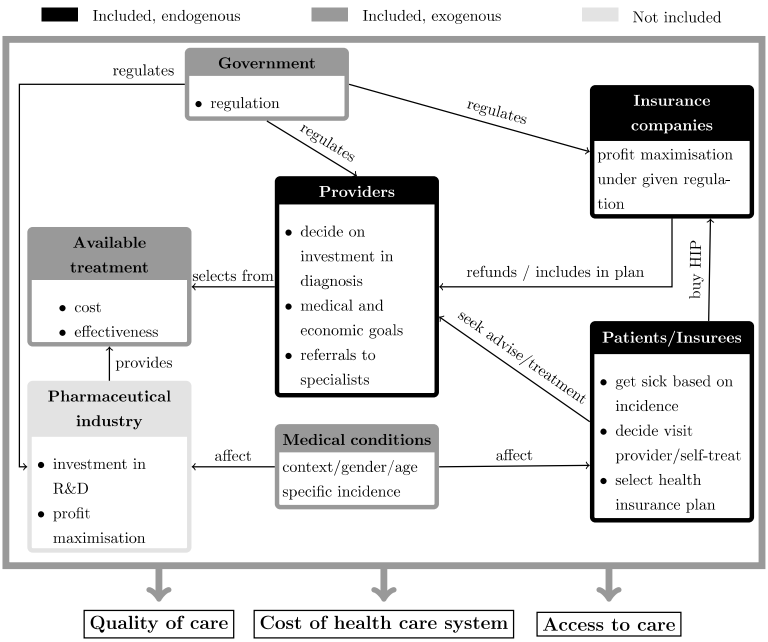

Fig. 39.1 Scheme of the model

common information on average costs by age and gender. The actual decision-making process is combining ideas of rational expectations with insights from behavioural economics related to this topic [6]. The model allows for multiple insurance companies and for both mandatory and non-mandatory insurance. Insurance companies aim at maximising their profits within the legal restrictions imposed by the model parameters. Finally, the behaviour of health care providers is modelled through a PID controller [1] to allow the model to adjust to substantial policy changes.

A much more detailed description of all these processes and decisions are reported in the ODD protocol presented in [2].

A critical characteristic of *HealthSim* is its flexibility regarding different health care systems. We include a relatively large set of policy parameters allowing us to easily adapt the model to a specific context. This can include different health insurance systems (single payer, multi-payer with or without mandatory insurance, single provider or multiple provider, etc.).

Furthermore, the model is adapted to a specific context through the inclusion of data describing the epidemiological profile of a society.[1]

[1]In [4] we provide a full exercise of adapting the model to the Swiss context to simulate the effects of a proposed public policy measure.

Results and Concluding Remarks

In this section we focus on a single chart that is the result of all the interactions and processes taking place in the model. Figure 39.2 stems from an analysis of the Swiss Health Care system and displays the average severity[2] of medical conditions by age and split into different disease categories.

These severities are the endogenous result of all processes taking place in the model. While disease incidence by age and gender is exogenous, medical attention and treatment is not, resulting in endogenous cumulative severity. The model correctly generates an increased morbidity for individuals above 50 years old and also the distribution of types of diseases follows the generally observed trends. In [4] we compare these figures in greater detail to the available data and discuss the quality of adjustment.

The use of *HealthSim*in [3, 4] has shown that the general model is adaptable to a specific context. These exercises use parameters to compare outcomes under mandatory and non-mandatory insurance schemes [3], as well as different policy interventions such as raising the minimum deductible in Switzerland [4]. Even though the calibration exercise requires a lot of data and medical knowledge, overall, we concluded from the exercises that the idea of having a general purpose model that can be adapted to specific research questions and contexts is a promising approach as it reduces the modelling cost by having a flexible core model.

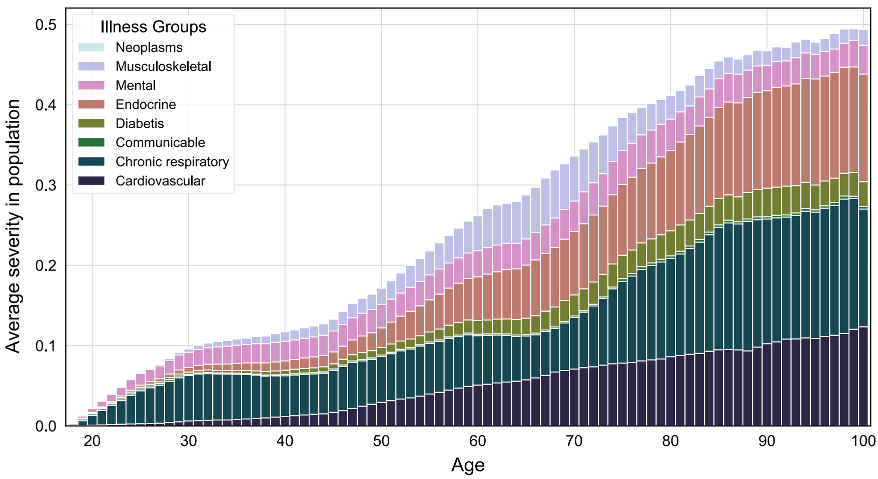

Fig. 39.2 Average severity of illnesses by age and illness group

[2]We use a scale from 0 to 1, where a combined severity of 1 refers to death [5].

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Chapter 40
On Three Ethical Aspects Involved in Using Agent-Based Social Simulation for Policy-Making

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Abstract The use of agent-based social simulation for policy-making involves ethical considerations of three different kinds: (i) in the agent-based policy model itself: the choice of values that are to be imbued in the simulated agents and in the policies; (ii) in the functionality of the system that is designed to support a policy-making process; and (iii) in the use of the system to design, negotiate, deploy and monitor an actual policy. In this paper we propose a value-driven framework to elucidate the corresponding ethical concerns of these kinds and then outline some guidelines to address them. We use the water policy domain to motivate and illustrate the proposal.

Keywords Agent-based simulation · Policy-making · Values · Socio-cognitive technical systems · Water policy

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Introduction

Agent-based Social Simulation (ABSS) has been acknowledged as a useful tool to support policy-making [7], although not without misgivings, as any other type of model whose purpose is to inform policy decisions [3]. Besides, agent-based modelling (ABM) may be based, unconsciously, on errors and artifices if modelling processes are not appropriate [6]. Hence, decision-makers and modellers should be aware of the limitations, since these tools may have substantial influence in policy processes. For instance, models can become "black box" tools [24], informing decisions despite ignoring the underlying assumptions, or they can contribute to crystallise the way to address social phenomena, inhibiting the exploration of alternative models and explanations. In the worst case, such tools may lead decision-makers to the abdication of their responsibility. Consequently, the design of agent-based models should take into consideration the uses that are meant for the system, so that users are properly informed of the limitations and concerns. Thus, designers are responsible not only for eliciting the user requirements, but also for reflecting design issues that are specific to policy modelling.

We suggest to work with value-driven models. Values are useful for clarifying whether a policy, besides effective, is good (see [18]). And they allow to shed light on how to contend with the aforementioned inconveniences that lead to ethical concerns when using ABSS for policy-making.

In this paper, we focus on how can values be imbued in a model using a concrete case of urban water management. We also suggest how this process is related to the design values of agent-based models for policy-making and the values associated with their use. Given these purposes, we characterise agent-based social simulation for policy-making as type of socio-cognitive technical system, which has values as a first-class entity (i.e. *value-driven policy-making support systems* [17]). In particular, values are imbued (i) in the social space through a policy-schema (that is, the set of means and ends that define a public policy); and in (ii) artificial agents by providing them with value-driven reasoning models.

The paper is structured as follows. First, we distinguish three perspectives to contextualise the ethical concerns involved in ABSS for policy-making in Sect. "Background". Second, we abstract features that characterise *value-driven policy-making support systems* in Sect. "ABSS with Value-Driven Policy-Making Support Systems". We then illustrate how these considerations may be addressed in modelling a policy for urban use of water in Sect. "Example: Values in Water Policy" and build on that example to suggest how to contend with those ethical concerns (Sect. "Approaching Ethical ConcernsWhen Modelling Public Policies"). Finally, we sum up our proposal in Sect. "Closing Remarks".

Background

Conceptually speaking, policy-making is an ethical space. Policy-makers intend to improve a fragment of the world (the policy domain) and device policy means to achieve the improvement. When policy-makers decide to support their task with agent-based models, they face ethical considerations in three levels. First, in the *policy enactment level*, where policy-makers must decide how to use agent-based simulation to back their policy decisions. Second, in the *policy support level*, when policy-makers decide to build a model of a relevant part of a policy domain and intend to use that model to design, negotiate and perhaps monitor their policy proposals. Third, in the *modelling level*, where policy-makers build an agent-based model to simulate policies for a given policy domain.

The class of ethical considerations involved in the three levels are different but they all essentially amount to moral judgements (decide whether something is "good") and ethical dilemmas (choosing the "right" thing to do). Values are involved in such judgements, as they serve to evaluate the "goodness" of states and outcomes, and to decide whether one action is preferable to another [9, 21]. Accordingly, "values are concepts or beliefs, about desirable end states or behaviours, that transcend specific situations, guide selection or evaluation of behaviour and events, and are ordered by relative importance" [21]. Noteworthy, values are involved in individual decisions in everyday life [16, 20], and in organisational settings and public affairs [11, 25].

Values in Policy Models

In general, in policy-making values are involved in two types of uses: (i) in assessing the worthiness of a state of the world, and (ii) in determining whether some policy means lead to a good state. Moreover, since in principle several combinations of policy means may bring about the desired ends, policy-makers face ethical dilemmas in choosing the particular set of means that will be part of the proposed policy. Furthermore, those target groups that are affected by the policy also behave according to their own values, and choose actions that best serve their interests.

In the case of *policy modelling*, we need to make these ethical aspects operational. For this reason, we take a *consequentalist* view of values where the value itself is defined through its consequences [23]; in other words, we assume that there are some observable facts of the world that can reflect that value. In practice, this means that one defines a value with indicators or indexes (i.e a combination of indicators) that can be observed in the world at any time. The consequentalist understanding of moral judgement allows one to say that one state of the world is better than another—with respect to a value—when it has a better scoring for the indicator of that value. This fact also allows one to decide when an action is better than another—with respect to a value—by comparing the effects each one would have in the state of the world. Moreover, when more than one value is involved in these ethical behaviours, one can make these values *commensurable* by assuming that stakeholders have *value aggregation models*. It does not mean that they are, necessarily, functions that aggregate multiple values to return a score that represents the overall *utility* [1], but rather that individuals are afforded to consider multiple values and solve value conflicts. Thus, in a particular situation, *value aggregation models* enable stakeholders to aggregate multiple relevant values and eventually make a decision or perform an action. Besides aggregation functions (see [2, 19]), these can be, among other options, satisficing combinations [22].

Values in Policy Support Systems

One can see agent-based modelling as part of a wider process of policy-making. In this context, the model itself is just one component of a larger socio-technical system that supports the policy-making process: *value-driven policy-making support systems* (VDPSS) [17]. For this purpose we adopt the value-sensitive design (VSD) approach [5, 19]. In particular, we adopt the *conscientious design* framework [15], that organises design values in three categories: (i) *thoroughness*, that includes classical technical values (like robustness, correctness, reliability, efficiency); (ii) *mindfulness*, that reflects the personal values of the users (like privacy, reciprocity, generosity); and (iii) *responsibility*, that includes those values related to the interaction of the system with the wider socio-technological environment where it is situated (like data ownership, liabilities, legal status and institutional effects).

Which Values?

The ethical questions, in this context, are partly associated with the *epistemic* aspects of the agent-based model. Thus, they refer to the abstract representation of the relevant part of the world and the type of insights the model may support. Other ethical questions involve the *rhetorical* uses of the model. These are, for instance, the awareness of the limitations of the model, the characterisation of scenarios and the ergonomics of the system. While these ethical questions may apply to all model-based decision-making, we postulate that the critical point in VDPMSS is how *values* are handled in the representation and the usability of the model.

In the case of individual agents one may choose different value systems and value aggregation models. For instance, *value aggregation models* may be based on the Schwartz universal values [21] (i.e. value systems) and “satisficing” combinations [22] (i.e. aggregation model). The way these two elements are modelled in the agents’ decision processes may follow different strategies [8, 12]. Both matters are outside the scope of this paper.

For policy-makers (and policy-making) we propose to use “public values” to guide public decisions of policy-makers and imbue public policies and public services. Public values apply to complex phenomena in political and socio-economic spheres. For instance, citizens may prefer public services that are ostensibly managed according values like fairness or justice, rather than being treated as consumers in a service market regulated by the "invisible hand" [13]. As we shall see in Sect. "Example: Values in Water Policy", we rely on Witesman and Walters' Public Service Values (PSV) [25] to account for values that are more likely to be invoked to justify decisions in public affairs.

ABSS with Value-Driven Policy-Making Support Systems

We propose to support agent-based social simulation for policy-making with socio-cognitive technical systems that are value-driven (VDPMSS) [17].

Socio-cognitive technical systems (SCTS) are situated, on-line, hybrid, open regulated multi-agent systems [14]. They consist of two first-class entities: a *social space* and participating *agents* who have opaque decision models that guide their actions. This distinction makes modelling policies quite natural: first, *values are imbued in simulated agents* by providing them with value-driven reasoning models; second, *values are imbued in the instrumentation of a policy* within a social space (by making values observable in the state of the system and instrumenting them as means to drive agent behaviour towards some ends). Such modelling is facilitated by a metamodel for VDPMSS [17].

The point of a metamodel is to facilitate the expression of the affordances that need to be modelled in a system [14]. The distinctive affordances for VDPMSS are: (i) the inclusion of *values*; (ii) the possibility of *subcontexts* that correspond to the phases of the policy cycle; (iii) a set of *stakeholder roles*; and more significant for modelling, (iv) the definition of a *policy-schema* and (v) the availability of *value aggregation models*. In particular, a *policy-schema* is an explicit expression of the use of values and how they are made operational and assessed with two main constructs (Fig. 40.1).

(i) *Policy means* aim to produce a behavioural change on policy-subjects so as to drive the system towards a desirable world-state, and are implemented with *instruments* (like norms, messages, etc.) that guide the social activity towards the policy objectives.
(ii) *Policy ends* define desirable world-states intended to be achieved, and are expressed through *indicators* and *indexes*, which are computed from variables that are observable and whose actual scores are used to assess whether policy goals are achieved or not.

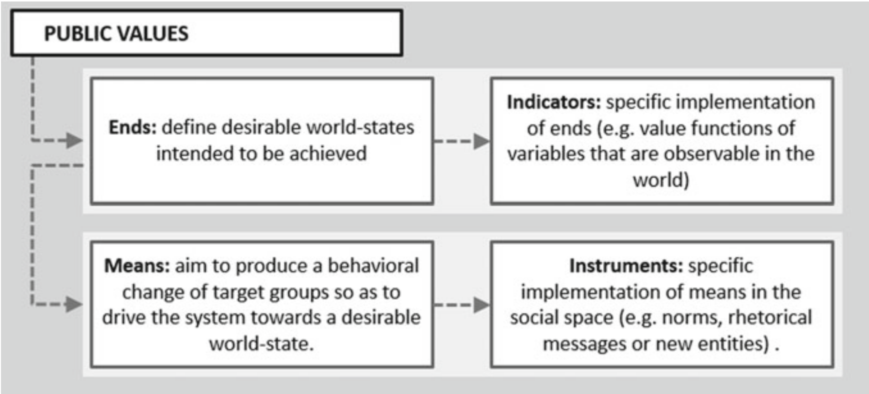

Fig. 40.1 Instantiation of values into a policy-schema [17]

Example: Values in Water Policy

In this section we illustrate how to bring values in the modelling of water public services in an urban environment. For this purpose we assume that: (i) a *water utility* is in charge of providing the public water services for a city (and managing their infrastructure); (ii) the (traditional) mission of the utility is to supply good quality water, with adequate pressure and without interruptions, and ensure good sanitation, while taking into account ecological, social, and economic concerns; and (iii) the water utility is responsible for the implementation of the corresponding policies.

The point of the example is to illustrate how to answer two questions: *"what are the relevant values in a given policy domain?"* and *"how to make these values operational?"*.

In order to address these questions we have proposed to adopt a list of values that are *relevant for the domain* and instantiate these values in a *policy schema* as a set of *ends* and the corresponding *means* to achieve those ends. A policy schema is made operational—in the ABM—by choosing some specific *indicators* that interpret those ends and some specific *instruments* that implement the means (Fig. 40.1).

1. **Policy domain values**. In line with the standard understanding of personal (motivational) values, policy-makers would hold some context-dependent values that are projected onto the policy design. Assuming these are instances of more general values, Jørgensen and Bozeman (e.g., [10]), for example, proposed a list of *public values*. Witesman and Walters [25] focused on public servants that make decisions, which reflect their own values, on behalf of many citizens. The authors compared public and motivational values (e.g., [10, 20]) and elicited an updated list of *Public Service Values* for decisions in the public sphere. Then, based on that work, Witesman [26] provided the descriptive list of values reproduced in Table 40.1. Each of these twelve values is, in turn, expanded into more specific value items [26] (pp. 32–33).

Table 40.1 Witesman's public service values [26]

1. Equity: Support of systems and actions that promote fairness and equality for individuals and groups	**2. Benevolence**: Preservation and enhancement of the welfare of people	**3. Social justice**: Preservation and protection of those who are at a disadvantage in society
4. Transparency: Providing visible, accurate and accessible information on all aspects of government	**5. Self-direction**: Independent thought and action choosing, creating, exploring	**6. Stimulation**: Excitement, novelty, and challenge in life
7. Citizen influence: Support of the right of individuals and groups to be heard by government and to work together to influence the institutions and policies that affect them	**8. Achievement**: Personal success through demonstrating competence according to social standards	**9. Power**: Social status and prestige, control or dominance over people and resources
10. Security: Safety, harmony, and stability of society, of relationships, and of self	**11. Tradition**: Respect, commitment, and acceptance of the customs and ideas that traditional culture or religion provide	**12. Conformity**: Restraint of actions, inclinations, and impulses likely to upset or harm others and violate social expectations or norms

2. **Making values operational**. We reformulate the expanded values to fit the water policy domain. For example, *Achievement* (value 8) is decomposed in three value items: *efficiency*, *economic responsibility* and *ecological sustainability*. In particular, we contextualise *achievement* to take the mission of water utilities into account: "water managers and water users should make a rational and prudent use of natural resources, considering also the financial sustainability of the water management cycle, and the status of water ecosystems". Once the contextualisation is made, one needs to define the end objectives of the policy—that need to be expressed in terms of factual indicators—and choose appropriate means to achieve them. With regards to the water cycle, one can draw from ideas of circular economy and use indicators like the ratio of reused water, and means that are not only technological (efficient water-treatment plants) but also social like encouraging citizens to not waste water or to accept reclaimed water.
3. **Instantiating abstract values**. This contextualisation process is more subtle when dealing with less technical values. For instance, *social justice* (value 3) is defined by Witesman [26] as "preservation and protection of those who are at disadvantage in society" and expanded into *advocacy* ("people who work for government should promote the interests of society's least advantaged"); *social justice* ("government workers should seek justice for everyone, even people they do not know"); and *protection of minorities* ("government should consider and protect the rights of those who do not have the greatest voice in society").

One may form a crisper interpretation of these value items: *redistribution of wealth* and *equal opportunities*, and contextualise them as “treat people differently in line with their (water use) needs in order for them to live a decent life, distributing costs and benefits accordingly” and “ensure that the right of water users to access water supply and sanitation is protected”. This contextualisation is reflected in some

Table 40.2 Making public values operational for policy models

Value	Ends	Means	Instruments	Indicators
Social Justice	Redistribution of wealth	Financial instruments for social aid	– Subsidies for vulnerable households (lower water cost) – [...]	– Relative utilities cost on household income (%) – Vulnerable households due to low income (%) – Households with poor home water systems (%) – [...]
		Economic instruments to ensure proportionate water service funding	– Specific tariffs for large and industrial users (higher water cost) – [...]	
	Equal opportunities	Financial instruments to empower households	– Scholarships for training in water sector funded by water companies (lower cost of education) – [...]	– Population without basic access (%) – Households whose water use is under 100 L/p·d (%) – Population exposed to harmful water pollutants (%) – [...]
		Technological solutionism	– Digital water meters will notify when anomalous low use is detected (new action for an artificial agent) – [...]	
	[...]	[...]	[...]	[...]

means and ends that are made precise in the form of instruments and indicators of the policy-schema as illustrated in Table 40.2.

The choice of such indicators is key for agent-based models for policy-making. First, because they determine the *ontology* of the model. Second, because they establish the *meaning* of the values embedded in a policy-schema by identifying and modelling those instruments that are involved or involve those indicators, and by using those indicators to specify value aggregation models.

One may follow a recursive approach to this selection process starting with a list of (expanded and contextualised) relevant values: from values to ends, from ends to a list of indicators, that is build in a circular way (start with performance metrics for the ends, for each indicator, find instruments that involve it—stakeholder actions, norms, agent reasoning knowledge and resources—; identify missing indicators in these instruments; and update list of indicators until no new indicators are found), and then from indicators back to a set of instruments that are implemented in the ABM.

Approaching Ethical Concerns When Modelling Public Policies

As we suggested before, a focus on values may be useful to throw light on sensitive ethical aspects in three levels of ABM for policy-making. The previous section illustrated how to make values operational in the model-building level; we now discuss how to approach them more systematically.

Model-building level. Modelling processes imply choices that have ethical implications with respect to the domain of interest. On the one hand, they are present in the *representation* of the policy domain. Indeed, the designer commits to a specific notion of what is the *state of the world*: an ontology for the policy domain that defines a set of observable facts, a set of functions that may modify the state of the world (i.e. agent actions and external events), a set of roles that agents may play, and the institutional framework that regulates roles and determines the feasibility and consequences of events and actions. On the other hand, they are present when characterising agents that populate the model, which are provided with (value sensitive) decision-making models, including their value aggregation models.

The key ethical issue is to choose the relevant values in the policy domain and to make them operational by identifying those variables that are pertinent for each of those values. Then, following the recursive procedure at the end of Sect. "Example: Values in Water Policy", there are two more choices. The fist one corresponds to the need to choose some of these variables to be used as indicators of the values or to be combine into indexes that reflect the values. The second one is to identify those actions and events that involve those variables and may change them, since they are key when modelling policy means and the decision-making models of simulated agents. Finally, the combination of the indicators and indexes of the relevant values are articulated as aggregation models for each simulated agent and to evaluate to what degree the policy is *effective* (i.e. its outcome is consistent with the policy declarations) and *good* (i.e. its outcome improves the state of the world in line with the values of stakeholders) (see [18]).

Model as artifact. It has to do with ensuring that the model supports an ethically responsible use for policy-making. The designers of the VDPMSS should refine the model to back the three types of *conscientious values* [15] proposed in Sect. "Background":

1. *Thoroughness*: classical technical values like appropriate level of abstraction, crisp delimitation of simulated phenomena, reliability, robustness, resiliency of the actual model.
2. *Mindfulness*: expressiveness of the model to adequately represent the needs of the policy-maker and the interests of all relevant stakeholders. Are disclaimers explicit? Are all relevant public domain values properly expressed in the model? Are relevant assumptions well justified? Are all stakeholders taken into consideration?
3. *Responsibility*: functionality that supports the (responsible) use of the system: Does the system support the relevant questions that its intended uses may pose? Does the system contribute to uphold all the relevant public policy values? Is the system accessible? Does it enable auditing? Are system liabilities known and addressed? Is the model robust enough to defend its outcomes in a public hearing?

Model use for policy-making. Policy-makers will use the ABM bound to the ethical responsibility of their role. The values involved may be subsumed in the notion of responsibility that should imbue the ethical choices that policy-makers face while using the model during the policy cycle. We find it convenient to separate the concerns that are implicit in their choices:

1. Awareness of the *limitations* of the system (scope, assumptions, validation, etc.).
2. Awareness of the *impact* of the model (cost/benefit analysis—opportunity, misalignment—, public values compliance, etc.)
3. Awareness of the *purpose of the use* of the model (and hence of the relevance of the other two concerns associated with these uses): the *epistemic* faithfulness of the model (mostly during agenda setting, negotiation and monitoring phases); the *predictive* accuracy of the system (mostly in the negotiation and monitoring phases); the *rhetorical* appeal of the model (mostly for policy negotiation and enactment).

Uses of Value-Driven Public Policy Agent-Based Models

Value-driven ABSS for public policy may be a useful tool for policy-assessment exercises by having the specific assessment concerns explicitly represented in terms of values in the ABM. Hence, this can clarify the pertinence and extent of the model results. Noteworthy, the European Commission considers necessary to conduct an Impact Assessment (IA) for those policies that are expected to have significant economic, environmental or social impacts (see [4]); which requires, among other topics, to set the policy ends and the policy means according to how the policy problem has been defined, and to establish indicators to compare, evaluate, and monitor the effects of alternative options.

Value-focus requires to make explicit what values are deemed relevant, how they are interpreted and what is the fragment of reality involved in the simulation. This clarifies the scope of the model and should also reduce the "black-box effect" for the use by policy-makers.

The ABM may be used (in different ways) in different stages of the policy cycle: the design of the model can be part of the agenda-setting phase; refinement and calibration could be part of the policy definition phase; a working model may be used to negotiate a policy and a working model may also provide the basis for monitoring (and value-feedback) of a running policy.

Finally, another use of value-based modelling is to provide a metamodel for sociological research of different sorts (empirical detection and interpretation of values; value-based reasoning; policy acceptance; etc.).

Closing Remarks

In this paper we propose to use values as a salient modelling construct. The purpose of this focus is twofold: (i) to elucidate the moral commitment implicit in ABSS for policy-making; and (ii) to make more explicit those values that are involved in the formulation of the problem in the specific policy domain and in the policy-making exercise.

In this last respect, we believe that our proposal is conducive to a crisp characterisation of the extent to which a policy may be effective and good—in line with the values of stakeholders. Moreover, a value-driven ABSS for policy-making may be a useful tool for policy-assessment exercises by having explicit representations of the assessment concerns.

We illustrated how to elucidate ethical choices in three levels of responsibilities, taking into account the expected uses of ABSS in the policy process (*epistemic*, *rhetorical* and *predictive*). Our driving concern is the fact that agents in the ABM stand for "real people" and that their simulated behaviour will inform decision-makers. Given that ABM for policy-making are designed to transcend the virtual world, *engineers* (e.g., modellers, developers, designers) have an ethical responsibility.

Furthermore, we think that a value-driven approach can stimulate contributions in policy understanding. A type of intelligence that agents must exhibit is ethical reasoning, as it is unavoidable in some political domains. This would make more explainable their individual and collective decisions in such contexts, and therefore it would contribute to understand the social outcomes.

Finally, we believe that the design of value-driven ABM for policy-making is a worthwhile effort from a conventional AI perspective, as it may constitute a very pertinent sandbox for the value-alignment problem. The problem of imbuing values in autonomous entities is decomposed in ABM for policy-making as two design problems:

(i) imbuing values in the system as a whole: it regulates the behaviour of the autonomous entities that it contains, and its own behaviour as a whole, in order to foster value-aligned problems; and
(ii) developing agent models whose decision-making models are aligned with intended values.

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Chapter 41
Healthy Snacks from Mom? An Agent-Based Model of Snackification in Three Countries

Gert Jan Hofstede, Eduardo Franco, Femke Damen, and Vincenzo Fogliano

Abstract An agent-based model SNACKMOMS was created to understand the implications and consequences of interventions that may change the dietary habits of children. It targets the giving of snacks to children aged 2–7 by their mother and how the snacking pattern is modified by the examples set at children parties. The model acknowledges individual-level, group-level and cultural-level variables. Dynamics of conformity at parties depending on social status are taken into account in Dutch, Indonesian and Italian culture, backed up by survey and interview data. The main model output is healthy versus unhealthy snacking, and it shows how this might change as a function of the mothers' characteristics and of external intervention. Results suggest differences in the effectiveness of the intervention across countries whether interventions target children's preferences versus mothers' health orientation. This indicates that the same approach might not be equally effective across societies.

Keywords Healthy food · Snackification · Mothers · Pre-school children · Agent-based model · National culture · Marketing · Intervention

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Introduction

Childhood obesity is a major problem worldwide. Rates increased over the last decades [12]. One factor contributing to childhood obesity is 'snackification'. The intake of calories outside meals is increasing all around the world, and among children the intake of energy-dense snacks is highly prevalent [7, 10]. Childhood unhealthy dietary behaviour, as well as the prevalence of overweight, could track into adulthood [15] which results in a higher risk for health problems, also later in life [13].

Parents are mainly responsible for the development of their young child's dietary behaviour [17] These are in most cases the mothers [14]. Therefore, mothers play an important role in the development of children's dietary behaviour [9]. Mothers from different countries experience different value conflicts between healthy and desired snacks. [1, 3, 11].

Child obesity development differs across countries and is on the decrease in some countries [16]. Nutrition policies and educational campaigns are clearly having some effects; results differ in across countries. This raises questions about cross-cultural differences in the mechanisms involved in mothers' snack choice.

Cultural values have a deep influence on all possible behaviours in society, especially ones around relationally important and/or taboo issues [4, 8]. The causes and mechanisms of snack-giving, as well as the ways to influence it in a desirable direction, thus also likely differ across cultures.

Snack choices of mothers with young children were investigated in a recent study [2]. Frequent snacks were fruits, cookies, and candy. Considerations most used were snack healthiness and child's preference. Higher educated mothers, as well as first-child mothers, showed more health-conscious behaviour.

Another study investigated which considerations play a role in the snack providing across countries [1]. Countries included in this study were the Netherlands (NL), Indonesia (ID) and Italy (IT); these three were chosen based on their differences on Hofstede's dimensions of national culture. Mothers from different countries revealed different considerations when choosing snacks for their young children, as presented in Table 41.1.

The dietary pattern of the children is subject to many influences that can be towards healthier or unhealthier habits. For example, many public campaigns have been launched in the last years to make mothers conscious about the benefits of healthier habits with their children; at the same time, companies are introducing new unhealthy snacks, launched with big mass advertisement campaigns targeting young children. Regulatory agencies ask food companies to improve the nutritional quality of their products. When they do this, they often face a decrease in sales because a consistent part of consumers is not ready to accept the reformulated healthier products.

In this framework, it would be useful to understand which are the interventions which might induce (or not) a shift in the dietary habits of a specific group of consumers. For this, we carried out a bottom-up modelling study in which we hypothesize mechanism of snack-giving that are compatible with the data presented

Table 41.1 Values arising during snack selection of mothers per country, adapted from [1]. Values mentioned by > half of the mothers in a country are in boldface

Key themes	Values	NL (n = 17)	ID (n = 17)	IT (n = 17)
Health-related	Healthiness	17	15	14
	Balance/Moderation	15	4	7
	Natural/Fresh/Organic	4	5	8
	Portion size	10	9	8
	Variety	9	4	9
Child-related	Child's preference	12	16	17
	Freedom for child/Not forcing to eat	3	2	6
	Health status of child	6	8	6
	Development of taste	2	2	1
	Prevent hunger	4	5	1
Time-related	Convenience	14	10	7
	Making own food	0	6	4
Product-related	Religion	0	10	0
	Price	9	6	5
	Brand	1	0	8
	Sustainability	6	0	1
	Packaging	4	3	5

above, and with the cross-cultural differences found in the studies by Hofstede et al. [8]. In our model we take a bottom-up approach of modelling children's parties and social influence by neighbours. We also take a cross-cultural perspective, using society-level cultural parameters, to parameterise our model. Using these elements, we 'grow' the system in which snack types are being selected and snacks are being provided.

We decided to model an issue that we deemed of central importance: the providing of snacks to young children (aged 2–7) by their mothers. From the empirical study in [1], we gather that both individual-level factors, shared cultural factors, and social contagion play a role. We therefore chose the technique of agent-based modelling, since it allows to 'grow' a real-world system in its context while staying close to that context [6]. Specifically, it allows to include individual variables, model-wide parameters, social status and everyday proximity. The result is the SNACKMOMS model presented here.

The main hypothesis of the proposed model is that the complex psychological and social factors highlighted above can be grouped in two main factors. An individual parameter named "mother health orientation" and a cultural parameter named

Table 41.2 Model's parameters related to national characteristics

Parameter name	Range	Default value			Function
		NL	ID	IT	
Mother-average-leniency	0–1	0.15	0.4	0.25	Mean value for random normal distribution used to setup mother's leniency. Mean value for random normal distribution used to setup mother's leniency
Mother-average-health-orientation	0–1	0.75	0.50	0.60	Mean for random normal distribution of mother's health orientation
Mother-average-social-status	0–1	0.70	0.30	0.50	Mean value for random normal distribu-tion of mother's social status
Value-conflict-decay-time	1–500	75	40	5	Time span that the value conflict de-creases to zero. High values cause moth-ers to dissipate value conflict fast
Health-orientation-stability	1–500	200	400	70	Period in which mothers change their health orientation trying to minimize future value conflict

"mother leniency" are assigned. The former is attitudinal. It differs between individual mothers based on a population average. The latter is a group-level characteristic of a certain mother group based on literature evidence and the findings of our previous studies.

The mother health orientation can be modified by the interaction with their children and with the other mothers. To allow for social pressure, SNACKMOMS simulates interaction by the attendance of kids and mothers at children's parties where a certain type of snacks is offered in a very public context.

Agent-based models such as the one created here can have many possible aims [5]. The aim of this paper is to better explain and understand the dynamics of snack

Table 41.3 Model's parameters related to the external interventions

Parameter name	Range	Default value			Function
		NL	ID	IT	
Intervention-type	N/A	N/A			Defines what will be influenced (mother leniency, mother health orientation, or child healthy preference)
Intervention-efficacy	– 1–1	−0.50			Impact value in attribute chosen for the *intervention-type*. Will temporarily change the agent's selected attribute
External-stimulus-decay	0–100	35			Decay time for the effect of *intervention-effect* on the agents. Higher values mean the stimulus will last for longer
Intervention-coverage	0–1	0.10			Percentage of the agents' population affected by the external intervention

providing by mothers to their young children across cultures, and its effects on the child's dietary pattern. The purpose is not to predict these effects; merely to understand them better, as well as offering a boundary object for discussing system structure with stakeholders such as marketers and health professionals. In addition, we aim to understand the potential effect of outside interventions such as media campaigns, specific policy enforcement or nutritional labelling. The current paper presents the model, model analysis, and preliminary results.

The Model: SNACKMOMS

Description

For reasons of space, the following description is incomplete; more details can be obtained from the authors. SNACKMOMS was built with NetLogo [18], and it will be placed on OpenABM. The model user interface is shown in Fig. 41.1.

The model "world" is represented as a square with 20 × 20 patches, and it contains three types of agents: child, mother, and the environment (i.e., patches). On each patch, there is a household composed of a mother and a set of children (ranging from 1 to 3). The mother is represented as a face, which illustrates some of her characteristics: leniency (happy—high leniency, straight—average leniency, and sad—low leniency), social status (the bigger the icon, the higher the social status), health experience (colour gradient between green and red, representing healthy and unhealthy snacks giving habit respectively), and number of children (small white number on the bottom right of the mother's icon).

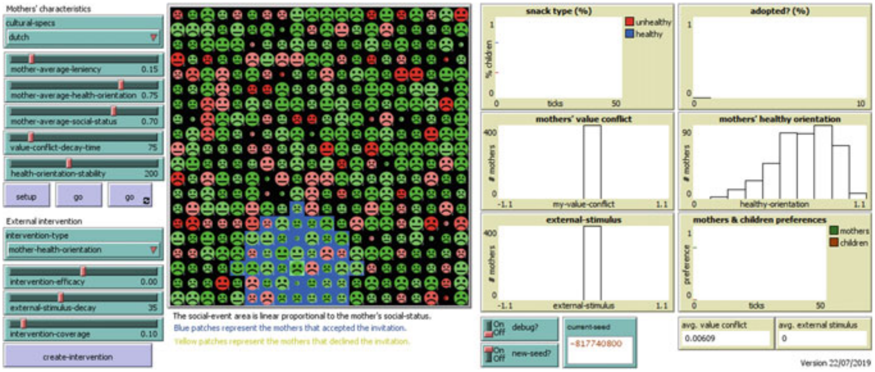

Fig. 41.1 The model interface at t = 0

Further, the model contains nine parameters that are located on the left side of Fig. 41.1 and listed in Tables 41.2 and 41.3. These parameters are mainly used to setup the model's initial conditions. The parameters in Table 41.2 show the default values which were defined based on the national specific characteristics.

These defaults are based on our interpretation, in terms of national culture dimensions proposed by Hofstede et al. [8], of the mother's snack giving behaviour, and on Table 41.1. The salient dimensions of culture concepts that were used in the model design are: Individualism, can be defined as a preference for a loosely-knit social framework in which individuals are expected to take care of only themselves and their immediate families (scores in Hofstede et al. [8]: Ind: 14,Ita: 76; Nl: 79); Power Distance, expresses the degree to which the less powerful members of a society accept and expect that power is distributed unequally (Ind: 78, Ita: 50, Nl: 38); and

Table 41.4 Model main state variables and their descriptions

Variable name	Description
My-value-conflict	Can change depending on whether the mothers give snacks that everyone around them give, or not (a floating number between 1 and 0)
Adopted?	Indicates whether the mother or child was influenced by the external intervention or not
Adoption-length	Indicates for how long the mother or child is being stimulated
External-stimulus	Stores the stimulus accrued by the mother or child from an external intervention
Behaviour	Randomly defined variable that represents how the child is behaving (higher numbers indicate "good" behaviour)
Memory	A list of child's pasts five snack experiences
Current-desire	Child desired snack orientation represented by a float number between "1" and "0" (a higher number indicates healthy snack)

Table 41.5 Model plots and their descriptions

Plot	Description
Snack type (%)	The relative number of healthy and unhealthy snack giving decisions taken over time
Adopted? (%)	The relative number of mothers or children that adopted the 'advertisement campaign' over time
Mothers' value conflict	A histogram of the mothers experienced value conflict
Mothers' healthy orientation	A histogram of the mothers' healthy orientation
External-stimulus	Shows the distribution of the external stimulus suffered by each agent (mothers or children) where it is possible to see how it decays over time
Mothers & children preferences	Shows the mothers' intentions and children's desires toward healthy snack. This is not the final decision, which is shown throw the *snack type (%)* plot

Uncertainty Avoidance, expresses the degree to which the members of a society feel uncomfortable with uncertainty and ambiguity (Ind: 48; Ita: 75; Nl: 53).

Note that in the model 'leniency' means the mother's tendency to follow the child's wish. We assume *mother-average-leniency* to be higher when complementarity, not independence is the essence of the mother–child relation; this is the case in Indonesia, the only collectivistic country in our set. We assume the reverse for *mother-average-health-orientation*; this is supported by Table 41.1. We assume *mother-average-social-status*, the capacity of an individual to exert social influence, to be inversely related to Power Distance. *Value-conflict-decay-time*, as a measure of independence, we assume to be proportional with Individualism. We finally assume *health-orientation-stability*, as a measure of tolerance of potential value conflict, to be inversely related with Uncertainty Avoidance.

Still on the user interface, there is a set of plots where it is possible to check the dynamics involved during the snack giving context. The plots are shown on the right side of the interface and a brief description of each of them is provided on Table 41.5.

Decision-making Process

Every time step ("*tick*"), each mother interacts with her children and other mothers (the number of mothers interacting depends on the current social dynamics occurring in tick *t*) to make her decisions on which snack type to give (healthy or unhealthy).

The decision-making process is illustrated in Fig. 41.2. First, the mother checks whether she is attending a social event or not. Next, each child formulates his/her snack type desire (healthy or unhealthy). Finally, mothers decide considering their intention and their children's desires, weighted by their leniency and children's behaviour. When a child misbehaves (i.e., has a low value for the variable *behaviour*

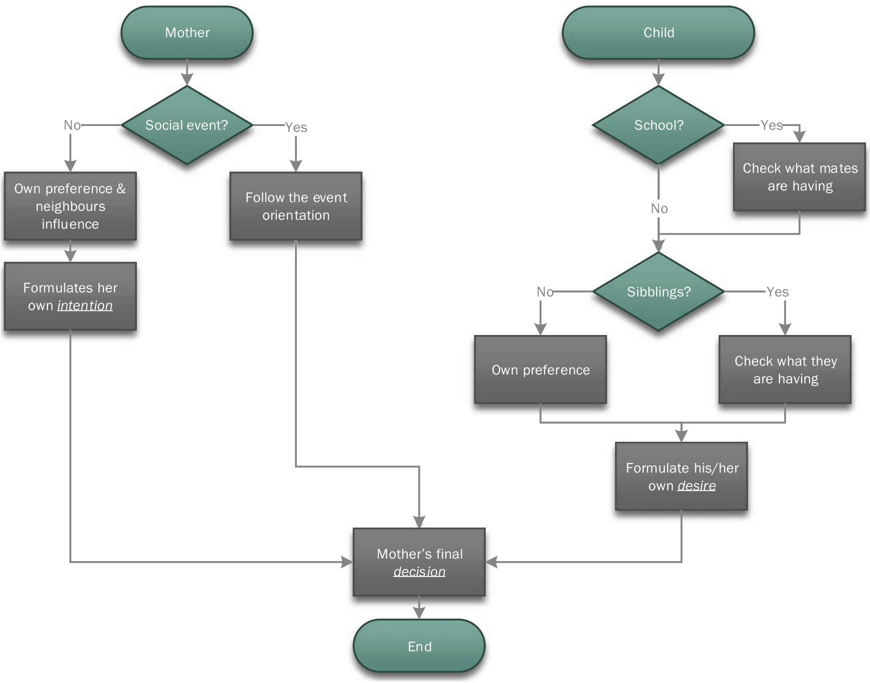

Fig. 41.2 Mother's and child's decision-making process

at tick *t*) and his/her mother is indulgent, the mother tends to follow the child's desire. On the other hand, if the mother is not indulgent, she tends to follow her intention despite the child's behaviour. Mothers can change their health orientation and leniency by interacting during social events.

Social Dynamics

In the model, every tick stands for one week. Within each tick, children and mothers formulate their snack desires and intention based on their intrinsic characteristics and the influences received from the environment (children are influenced by schoolmates and siblings, and mothers are influenced by their children and other mothers).

Every tick, a randomly chosen mother (at centre in Fig. 41.4) hosts a party and invites her neighbours for celebrating. The higher the social status of the inviting mother, the more neighbours will be invited.

Every party has a unique snack orientation, which is based on the past snacking experience (*memory*) of the host mother (green means healthy, red unhealthy). During a social event, each mother can experience a value conflict. This occurs when a snack offered by the host mother during a party is against her natural health orientation.

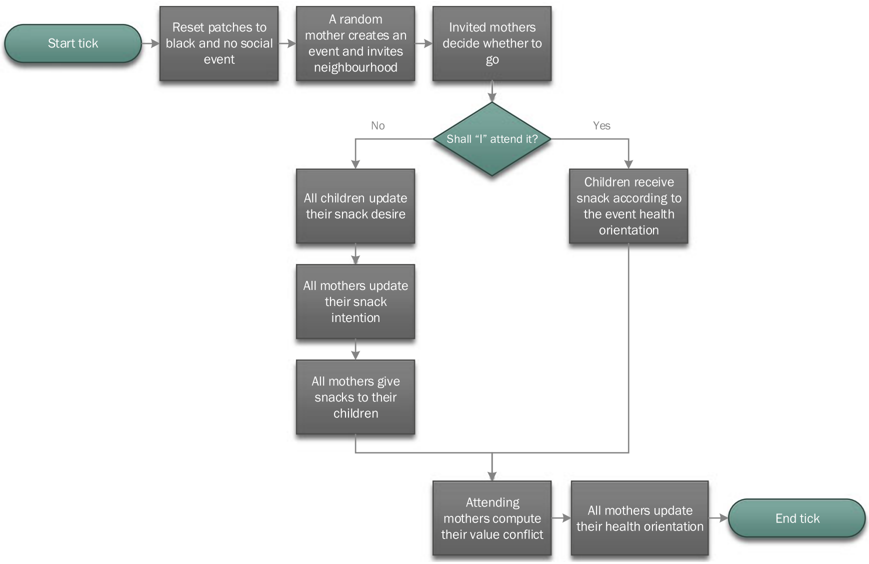

Fig. 41.3 Flowchart of actions performed during one time step ("*tick*")

After being invited, a mother chooses to accept (blue patches in Fig. 41.4) or decline (yellow patches in Fig. 41.4). The invited decides based on the difference in social status with the host, the host's health orientation, and the invited mother's value conflict.

After experiencing a value conflict, the mother will try to minimize her conflict applying two mechanisms: declining invitations for parties hosted by mothers with different health orientation, or accepting but adapting her health orientation.

Figure 41.3 shows a flowchart detailing how the social dynamics was implemented.

When an external intervention is created, a randomly set of mothers are impacted (according to the intervention-coverage parameter), and they are represented by purple background (Fig. 41.4). During a social event, mothers interact, and the ones that adopted the intervention and are under the influence defined by the intervention-efficacy parameter spread the message of the external intervention to the other susceptible mothers according to their social status (i.e., purple background).

Model Analysis

A one-at-a-time sensitivity analysis was conducted with a different seed for each run. To save space, the results are omitted. They can be obtained from the authors.

Fig. 41.4 Graphical representation of the model's social dynamics

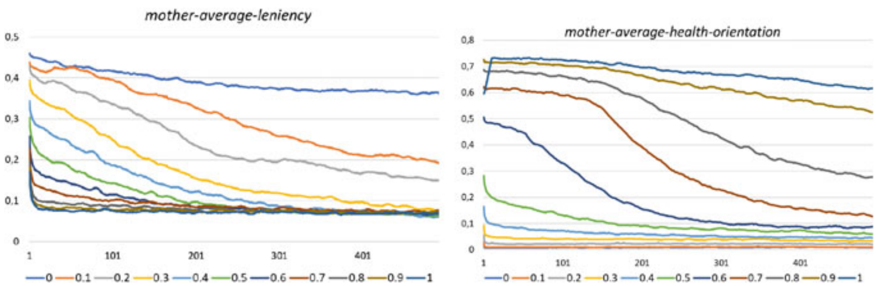

Fig. 41.5 Average values of snack giving patterns over time

Figure 41.5 shows that indulgent mothers (left-hand plot) tend to be less strict to their health orientation and provide their children with an unhealthy snack, and higher values of health-orientation lead to healthier habits (right-hand plot).

Model Results

Based on the output obtained from the sensitivity analysis and the mothers' characteristics gathered from [1], default values for the model for the three countries were defined (see Table 41.2). Then, we ran experiments to evaluate how mothers from the three countries would respond to external interventions.

The experiment was set to introduce an exogenous intervention at $t = 100$ ticks, using the default values presented in Table 41.2. Each country setting ran for two

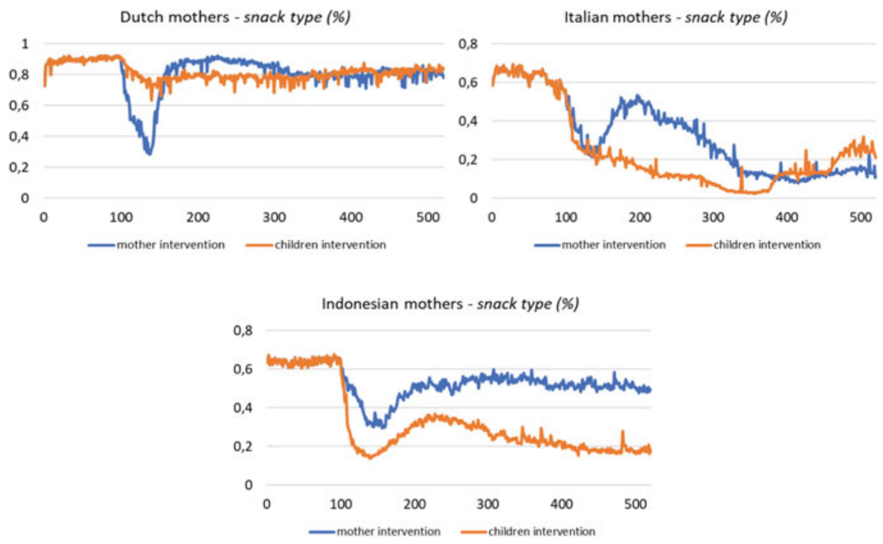

Fig. 41.6 Mothers reactions due to external intervention

runs to explore the effects of the two interventions type *child-healthy-preference* and *mother-health-orientation*, and the results are shown in Fig. 41.6.

The model shows Dutch mothers to be more resilient to external influence. Due to their parameters (Table 41.2), mothers tend to dissipate the external influence faster than changing their mindset. This behaviour can be explained by the mothers not being indulgent, and thus they are less influenced by their children.

Italian mothers change their mindset quickly (low value for *health-orientation-stability*), so when they are stimulated with negative influence, they tend to become unhealthy. Conversely, Indonesian mothers are tight in their health orientation, so they change their mindset slowly. They return to their natural health orientation after the effect of the intervention is gone. However, targeting children can bring an emergent unhealthy pattern, as Indonesian mothers are prone to give in to their children.

Discussion and Conclusion

Snacking dynamics. The sensitivity analysis shows huge variability of the output, snack healthiness percentage, for many values of the input variables leniency and health-orientation. This means that this is a system that has parts of its parameter space for which the outcome variable, healthiness of snacks provided, is highly unpredictable. That, in turn, makes it potentially possible to nudge that healthiness in the desired direction through interventions. Leniency, as a society-wide cultural parameter, is not directly susceptible to interventions. Health-orientation, an individual-level parameter, could be easier to influence. Our results show that whether it is more effective to target children or mothers would depend on local culture.

Options for interventions. The simulation includes three sets of parameter values that represent Italy, Netherlands, and Indonesia. Their current values are educated guesses. We claim plausibility for these values, but not realism. The exercise does show that the same approach might not be equally effective across societies.

Further research. Validation in country-specific studies would give more confidence. Sociological studies, questionnaire and market surveys can all contribute. Through its variables and parameters, the model suggests what kind of data could be used. The approach taken here can extend to other systems in society that are of public interest, can be affected by policy, and of which the micro-dynamics are reasonably well understood. One can think of snacking at secondary schools, school breakfast, but also sport- and leisure-related behaviours involving children.

Conclusion. SNACKMOMS can provide handles to institutional actors and private companies about interventions, depending on social propensities of the population. An example is the "School fruits" an EU program rolled out in all European countries distributing fruit in the school to encourage healthy snacking. The effectiveness of this intervention targeting millions of children can be very different depending of the societal context. Our simulation shows that a country-tailored approach matching the fruit distribution with educative measures toward children and their families could be more effective.

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Part IX
Tackling Climate Change and the Challenges of the Energy Transition

Chapter 42
Social Norms and the Threat of Climate Change: An Agent-Based Model to Investigate Pro-Environmental Behaviour

Marie L. Kapeller, Georg Jäger, and Manfred Füllsack

Abstract How people react towards threatening information such as climate change is a non-trivial matter. While people with a high environmental self-identity tend to react approach-motivated by engaging in pro-environmental behaviour, people of low environmental self-identity may exhibit proximal defence behaviour, by avoiding and distracting themselves from potentially threatening stimuli caused by identified anxious thoughts and circumstances. This psychological theory has recently been tested in experimental studies in which results suggest that the promotion of climate change information can also backfire. Based on these findings, we propose an agent-based model to address influences on anxiety and correlated pro-environmental actions in relation to societal norms of climate change scepticism and environmental self-identity.

Keywords Climate change · Social contagion · Networks · Agent-based · Threat and defence

Introduction

At a time when the worrying consequences of climate change can no longer be ignored, climate change has become a widely discussed issue. In response to the causal link between current global warming and human CO_2 emissions, environmental organisations, governments and involved stakeholders are trying to motivate citizens to adopt more environmentally friendly lifestyles by presenting information about the consequences of climate change. The realisation of a greener lifestyle, however, confronts us with a persistent stagnation, while there is currently no clear answer to how to accelerate the pace of this vital transition in order to avoid immediate threats to societies.

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Despite the constant flow of information on climate change, the public and media discussion is often distorted and shifted towards a discussion about whether scientifically solid facts are valid at all. While this shift in the discussion bias is criticised by climate scientists, it is often unintentionally supported by failing to take sufficient account of the social psychological background that can cause climate change denial. Calling for social transformation towards a climate-friendly lifestyle by spreading threatening information seems to be an intuitively correct assumption that more awareness about the problem of climate change also leads to more climate-friendly actions. However, the findings of threat and defence research indicate that this approach can create unplanned effects and may also backfire [23].

Here we present an agent-based simulation approach that models the correlation between climate communication and the resulting increase in environmentally friendly behavioural intentions from the perspective of socio-psychological threat and defence research. This model is a starting point which is intended to spur discussion on societal responses towards threatening information about global warming. Since in the field of agent-based modelling (ABM) there are only a few models that use socio-psychological theories as a basis, we would like to use this example to demonstrate the possibilities of combining socio-psychological research and ABM.

Threat and Defence Model: Theoretical Background

The social psychological literature on threat deals with reactions towards problems such as personal uncertainty, loss of control, goal conflicts or perceptual surprises. Recently, an 'integrative general model of threat and defence processes' has been developed by Jonas et al. [14], which provides a conceptual framework to understand such different phenomena. Based on societal psychological and neural perspectives on defensive reactions to threat, the model proposes the simple hypothesis that discrepancies arouse anxiety and thereby motivate diverse phenomena that activate approach-related states that can relieve anxiety.

Following this perspective, threats result from some experience of discrepancy between an expectation or desire and the current circumstances. This discrepancy is followed by feelings of anxiety which lead to a variety of proximal defence reactions such as avoidance of the problem. The threat-related processing is mediated by the Behavioural Inhibition System (BIS), known to responds with symptoms such as anxiety and avoidance. In case of potentially threatening information, individuals increase efforts to suppress or distract and distance themselves from identified anxious thoughts or circumstances.

A second way of countering anxiety is an approach-motivated behaviour, produced by the Behavioural Approach System (BAS). If activated, reactions involve striving for an effective solution to the problem at hand, if the discrepancy appears manageable. Since approach-motivated states are able to dampen anxiety and conflict, the anxious BIS stage is successively supplanted or shortened. In case of no available solutions to the threat (e.g., impending death due to ongoing sickness) individuals may still turn to approach-motivated states by indirectly solving the threat by soothing or mellowing reactive patterns.

In summary, the research of Jonas et al. [14] suggests that people tend to evade threats which they feel that they have no control over, and try to relieve anxiety in a symbolic way by turning to more rewarding aspects of life, even if this aspects are unrelated to the actual threat at hand or its solution.

Climate Change Information

How individuals process negative information about climate change is strongly influenced by their individual beliefs. Visiting several research efforts from environmental psychology investigating responses to environmental threats, we identify two significant characteristics being reported as important drivers: (i) climate change scepticism (CCS) and (ii) biospheric values and environmental self-identity (ESI).[1] Scepticism about climate change correlates with the belief in a just, orderly and stable world. As a consequence, people with high CCS show a low intention to reduce their CO_2 footprint when confronted with threatening messages [9] and, moreover, these information appears less convincing [5]. On the contrary, people who are less sceptical are positively influenced regarding their environmental attitude when confronted with the same information. High environmental self-identity (i.e. the extent to which you see yourself as a type of person who acts environmentally-friendly) has been shown to increase pro-environmental behaviour (PEB) of individuals, who are presented negative environmental information [4].

A recent study investigated the responses to a climate change threat exposure [23, 24] in accordance to the threat and defence model [14]. Their findings indicate that strong environmental values can not only increase approach-motivated behaviour but also foster symbolic responses and can backfire by lowering the donation willingness. Here, high ESI individuals resolve the threat directly by exhibiting higher PEB intentions, but, the same individuals show symbolic defensive behaviour by considering several groups, including criminals, overweight, or unattractive people more negatively. One possible explanation is that a higher ESI leads to a greater threat to these participants, who will then not be able to fully resolve the threat by only engaging in direct behaviour.

[1] Values are general and abstract principles that one strives for in life, while self-identity reflects how one sees oneself. We will limit further discussion to the latter terminology. See [26] for a conceptual differentiation between environmental preferences, intentions and behaviour.

Agent-Based Model

Several studies apply agent-based models to the study of climate change related issues, with a strong focus on socio-economic and socio-ecologic perspectives [20, 25], agricultural modelling [21, 22] and adaptation processes correlated to climate policy [1, 6, 11] and migration [13, 15]. Only a few socio-psychological models have been done, for example, [19] analyses an individual's perceived resilience to changing climatic conditions, [22] implemented risk, coping, and social appraisal in agricultural adaptation processes in Sri-Lanka. The process of individual adaptation capacity via human cognition has been explored in [12].

We like to contribute to this line of research with a social-psychological norm-based model on climate communication, where individuals have internal attitudes that shape the response and correlated probability for environmental behaviour when confronted with information about climate change. The agent architecture rests on the aforementioned threat and defence model [14] and is backed by findings in [23, 24]. In addition to negative information, a second influencing factor are social contagion processes, for which we use scale-free networks of agent-to-agent communication. The model dynamics describe the time evolution of internal states of the agents and correlating environmental-motivated actions.

Agent Architecture

Agents have several interal parameters, which are interconnected and build up the agent architecture. We use an agent architecture (see Table 42.1) of a composition of an anxiety state (anx) induced by threatening information (e.g., on climate change)

Table 42.1 Agent internal state and social norms: parameter, ranges and explanations

Parameter	Name	Range	Explanation
anx	Individual anxiety	$\in [0, 1]$	Agent's internal state towards negative information on climate change
esi	Individual environmental self-identity	$\in [0, 1]$	Agent's individual environmental orientation
ccs	Individual climate change scepticism	$\in [0, 1]$	Agent's individual belief in climate change
peb	Individual pro-environ. behaviour	$\in [0, 1]$	Agent's approach-motivated action

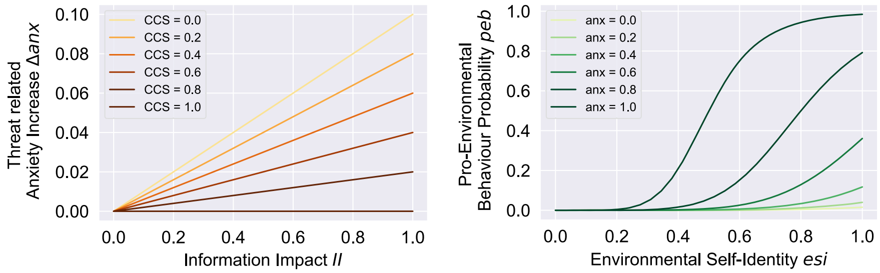

Fig. 42.1 Agent responses: (left) Anxiety response Δanx in relation to the information impact shown for six climate scepticism ccs values; (right) agents pro-environmental behaviour peb probability/intention in dependence of the environmental self-identity esi shown for different six anxiety states anx

and internal orientations of climate change scepticism (ccs) and environmental self-identity (esi). When an agent receives information, an anxiety response Δanx is triggered depending on the individual's ccs value the information impact (i.e. how severe or negative the information is) (Fig. 42.1(left)). Without detailed knowledge on the correlation of stimuli and reaction, we assume linearity. This linear response is added to the anxiety state anx of the individual, which increases the most for low ccs and high information impact. If no information is received, the anxiety state follows a small natural decay rate.

With regard to behavioural decision making, we implement a probability to engage in pro-environmental actions (peb). According to the psychological model of threat and defence, the likelihood for pro-environmental behaviour peb can increase or decrease in relation to an individual's environmental self-identity esi and its anxiety anx. The higher these parameters, the more probable it is that an agent engages in peb as it intentions to perform peb increases. We model this relation with a Hill function given by the equation

$$Hill = \frac{x^{\lambda}}{h^{\lambda} + x^{\lambda}} \tag{1}$$

with the hill parameter h and the hill exponent λ. Figure 42.1 (right) shows the relation of the pro-environmental behaviour probability peb with the anxiety and environmental self-identity for six different anxiety levels ($h = (1 - anx) * 1.5 + 0.5, x = esi, \lambda = 6$).

Our main interest is on the collective level of population behaviour. To facilitate notation, we use lower-case letters when referring to parameter of single agents (esi, ccs, anx, peb) and upper-case letters when referring to collective means of the population (ESI, CCS, ANX, PEB). While reactive values (anxiety and pro-environmental behaviour) only develop during the simulation, the internal orientations (environmental self-identity and climate change scepticism) require an initial distribution in the population. These initial distributions are trend-setting for the orientation of the entire population. We can thus compare the behaviour of populations with differences in the general mind setting, for example a population of mainly climate change deniers with mainly climate change believers. Initially, climate change scepticism environmental self-identity are randomly distributed with $mCCS \pm 0.2, mESI \pm 0.2$. Depending on these initial means $mCCS, mESI$ we can generate software populations of four types: (i) more sceptical and less environment-oriented, (ii) more sceptical and more environment-oriented, (iii) less sceptical and less environment-oriented, and (iv) less sceptical and more environment-oriented. The balanced population of no bias is at $mCCS = 0.5$ and $mESI = 0.5$.

External Information

Campaigns, documentaries, journalistic articles, mouth-to-mouth or online discussion are all considered powerful tools for shaping norms and leading to behaviour change in societies. We implement possible information streams unified as 'external information' with a certain possibility to be received by an agent. The information rate IR gives the probability of an agent to receive information in one time step. In the light of climate change information, only negative information is received, which can range from strong to light influence regulated by the information impact II. These two information parameters IR, II regulate the information density such that we can build scenarios ranging from 'mild but frequent' to 'intensive but sparse' distributions.

Social Norm Contagion

The interplay between the mental and the social dynamics allows norms to emerge, spread, and change as shown in different social norm-based ABMs [2, 3, 7, 8, 17]. We identify ESI, CCS and PEB as social norms, using the definition of 'an average like a standard, typical pattern, widespread practice or rule in a group' by the Merriam-Webster Dictionary. With the agent-based modelling approach being particularly suited for the study of dynamics that integrate mental and social aspects, we use an underlying network topology of a population N to account for social contagion dynamics of climate change scepticism. The higher the internal anxiety the more probable it is that an agent communicates and influences one of its link-neighbours climate change scepticism. If an agent is more likely to believe in climate change $CCS < 0.5$, it can decrease the scepticism of one of its link-neighbours up to a maximal learning-rate. On the other hand, if an agent denies climate change to a certain degree $CCS > 0.5$, this agent can increase the scepticism of a link-neighbour.

Implementing social norm contagion of CCS serves as a simple way to capture crucial dynamics without adding other direct network based processes of ESI

or PEB. We believe that climate change scepticism is the most contagious norm, compared to the others, due to several reasons. First, in relation to the non-fading movement of climate change denial, the contagious effect of CCS has been shown to be strongly influential among (some) members of the society. Second, we believe that climate change denial is closely linked to received information, and lesser linked to a real and scientific understanding of the situation, which makes this dynamic even faster. Third, environmental self-identity, which involves the process of the formation of one's own identity, has a stronger need for experience. Therefore, we consider that social contagion processes of ESI are negligible to a certain point for our modelling requirements so far.

Simulations

We now use the presented model in order to investigate different aspects of climate communication under ongoing information flow and social contagion processes over successive rounds. We do the following simulations using parameters presented in Table 42.2.

Results

For a prompt insight into the effects of external climate change information, we present most simulation results for the case of low information density ($II = 0.1$, $IR = 0.1$) and high information density ($II = 0.9$, $IR = 0.9$). We present the time evolution and equilibrium states of agents' internal norms and resulting collective pro-environmental behaviour. The results represent a small investigation on the model capacities to highlight some of the most important findings on anxiety, climate scepticism and pro-environmental behaviour in response to negative climate messaging.

Anxiety and PEB Evolution

The evolution of the collective anxiety level and correlating PEB actions are shown in Fig. 42.2 for low (top) and high (bottom) information density. Results are given for 100 simulations via mean (line) and standard deviations (shaded areas) (which are minor and only visible for PEB distributions). The initial ESI and CCS are chosen unbiased, such that $mESI = mCCS = 0.5$. Comparing the two information densities, the anxiety level is twice as high under high density of negative information. The correlated approach-motivated behaviour is increased by about 20% in the

Table 42.2 Model parameters, ranges and explanations of the full set of simulation parameters

	Name	Value	Explanation
N	Population	1000, 10000	Number of agents on the network
T	Time	$\in [0, 3000]$	Simulation time steps
IR	Information rate	$\in [0, 1]$	Probability of an agent to receive external information for each time step
II	Information impact	$\in [0, 1]$	Significance of external information
$mESI$	Initial mean Environmental Self-Identity	$\in [0, 1]$	Initial ESI distribution given by $mESI \pm 0.2$
$mCCS$	Initial mean Climate Change Scepticism	$\in [0, 1]$	Initial CCS distribution given by $mCCS \pm 0.2$
ΔA	Anxiety Increase	$\in [0, 0.1]$	Agent's anxiety response towards external information
–	Natural Anxiety Decrease	0.01	Agent's continuous anxiety decay without external information
–	PEB Anxiety Release	0.25	Agent's anxiety drop induced by PEB action
–	CCS Learn-rate	0.01	Agent's maximal learn-rate for social contagion of CCS

high density scenario while for low density almost no approach-motivated behaviour occurs.

Dependence on ESI and CCS

To test the dependence of the PEB actions on the agent's internal parameters ESI and CCS, a full parameter variation was done as shown in Fig. 42.3. Here, the initial distributions of both parameters are varied with $mESI \in [0.01, 1]$ and $mCCS \in [0.01, 1]$. The results are given for the collective anxiety A (left column, Fig. 42.3) and the performed collective PEB actions (right column, Fig. 42.3). The initial mean parameters $mESI, mCCS$ are reflected by the x, y-axis. Results are shown for the mean of 20 simulation runs for each set of parameters. Note, that the two scenarios (low information density (top) and high information density (bottom)) use

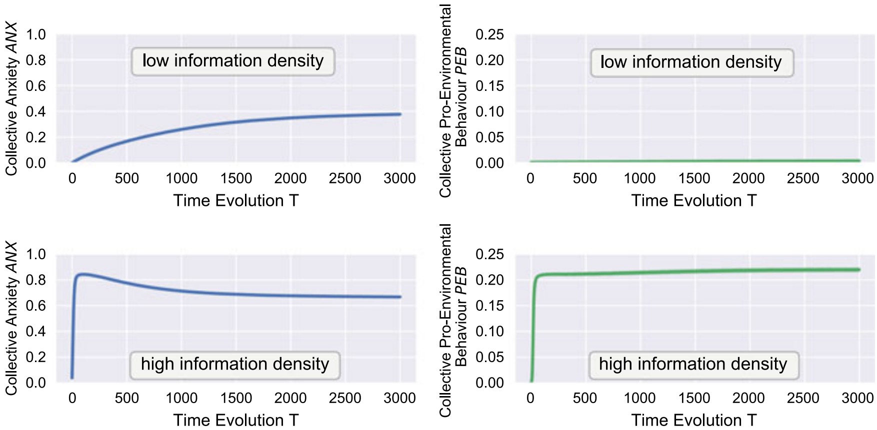

Fig. 42.2 Time evolution of collective anxiety A (left) and pro-environmental behaviour PEB (right) for two different information densities: (top) low ($II = 0.1$, $IR = 0.1$), and (bottom) high ($II = 0.9$, $IR = 0.9$). Results show mean values (blue or green line) and standard deviations (blue or green shaded area) of 100 simulation runs. Parameter: $N = 10000$, $mESI = 0.5$, $mCCS = 0.5$

a different scale for the colour maps in order to see the relative dependence on initial ESI, CCS within each scenario in high resolution. Anxiety is relatively decreased for a rise for both parameters, moreover, the overall anxiety level is significantly higher for more frequent and more negative information confrontation, especially pronounced in populations of high ESI.

In the low information density case, the overall number of PEB actions is low for all initial configurations with a minor increase in PEB for populations of very high environmental self-identity $ESI > 0.9$. In the high information density case, the collective anxious state shows a tendency towards more than 50% for $CCS < 0.5$. This correlates to a critical increase of PEB actions for populations with high $ESI > 0.5$, while populations of $ESI < 0.5$ show no significant change in performed PEB actions even though anxiety is rather high.

CCS Development

To picture the social contagion processes on CCS, we investigate the relative changes of initial CCS in a population to the equilibrium state, shown in Fig. 42.4(left). CCS values below the dashed line show a general decrease in respect to the initial configuration given by $mCCS$, while values above indicate an increase of the collective CCS. We show the results for three cases of information density: low ($II = 0.1$, $IR = 0.1$), medium ($II = 0.5$, $IR = 0.5$), and high ($II = 0.9$, $IR = 0.9$). In general, high initial CCS are provoking an increase in resulting CCS and low initial CCS support

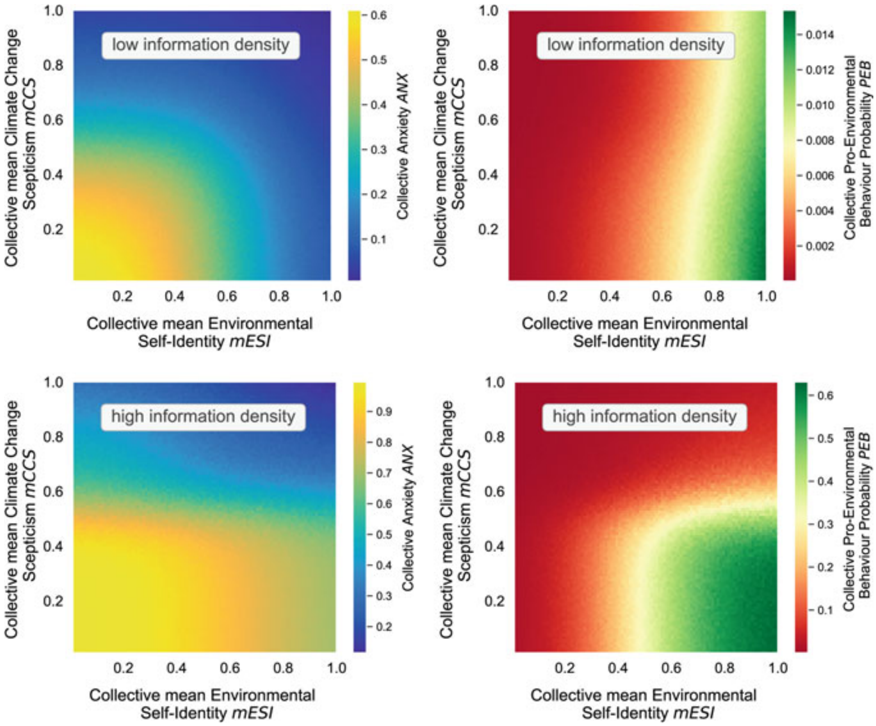

Fig. 42.3 Dependence on norm bias: Variation of initial ESI and CCS for (top) low ($II = 0.1$, $IR = 0.1$), and (bottom) high ($II = 0.9$, $IR = 0.9$) information density shown for collective anxiety A (left) and pro-environmental behaviour PEB actions (right) of 20 simulation runs. Colour code varies for all plots (shown in colour bar). Parameter $N = 1000$, $T = 3000$

a decrease in CCS under the influence of climate change information. Interestingly, the higher the information density, the stronger the CCS increase for same initial configurations. Moreover, in the unbiased scenario of $mCCS = 0.5$, only the case of high information density results in a relative increase of CCS. To highlight the correlating PEB actions to this three scenarios, Fig. 42.4(right) shows the effect of the information density on the collective PEB actions. Here, the highest action rates are given for high information density. Thus, if collective CCS levels are below 50%, the overall positive effect of information density on PEB exceeds the negative effect of higher collective CCS.

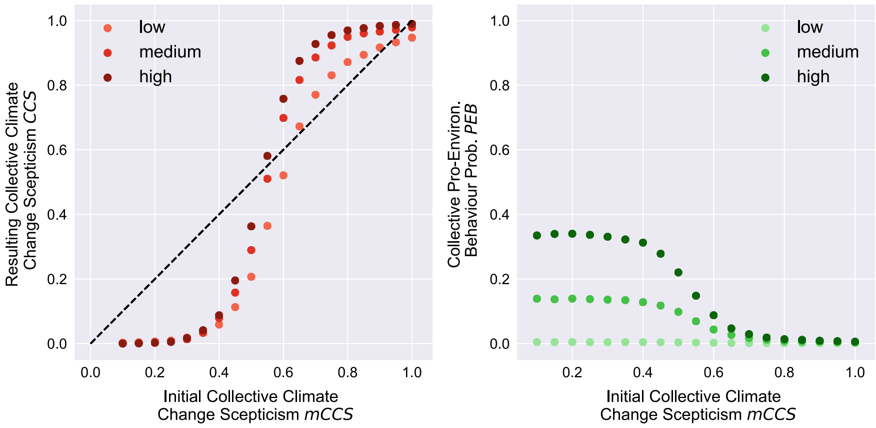

Fig. 42.4 Dependence on initial climate change scepticism: variation of initial $mCCS$ and resulting (left) climate change scepticism CCS and (right) pro-environmental behaviour PEB after $T = 3000$ time steps. Results shown for three different information densities (low, medium, high) as shown in the legend. Parameter: $N = 1000$, $mESI = 0.5$

Conclusion

Engaging in the study of the complex normative dynamics of climate change communication, we explored the effects of internal orientations, such as environmental self-identity and scepticism towards climate change, on pro-environmental behaviour. Visiting the problem from the angle of threat and defence reactions, anxiety caused by negative information about climate change can be released by approach-motivated behaviour in relation to the solution of the respective problem.

In general, the confrontation with the consequences of climate change does not increase the pro-environmental intent unless several conditions are met. First, the amount of information has to be large enough to encourage approach-motivated action, otherwise the anxiety increases but does not sufficiently promote such behaviour.

Second, a side effect of high levels of threatening information is an increase in public scepticism about climate change. This reflects an alternative way of dealing with anxiety by avoiding restless thoughts and moving away from them. More specifically, an initially sceptical society showed trends towards even more scepticism, while this trend was intensified as more information was distributed. On the other hand, if the initial scepticism showed a preference for believing in climate change, this believe was increased for all amounts of negative information. While promoting more threatening information has a negative effect on the collective scepticism about climate change, encouragingly the resulting environmentally friendly actions are positively correlated. If the initial belief in climate change is strong enough, the more information provided, the higher the increase in pro-environmental behaviour. This positive effect more than compensates for the negative effects of increasing scepticism about climate change. Moreover, while high initial CCS are provoking an increase in resulting CCS, low initial CCS are supporting a decrease in CCS under the influence of climate change information.

In summary, a combination of strong environmental values and sufficient information disseminated among the population can outweigh the negative impact of scepticism about climate, but only if a population is not biased towards denying climate change.

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Chapter 43
Creating a Model of the Earth System (MOTES): Some Experiences with Parallel ABM

M. Bithell

Abstract It is argued that certain kinds of problem in modern society impose a requirement on ABM to represent all human agents on the planet. Eleven reason are given, including the need for realism in social models, the importance of boundary conditions and scale, the need for global social justice, the existence of global scale dynamics created by and impacting directly on individuals, and the need to interface with other global models in order to address pressing problems such as climate change and ecosystem destruction. An indication of the difficulties involved in creating such models is given, drawing on experience of creating models with RepastHPC. The paper concludes by suggesting that rather than creating ever more model platforms and frameworks, what we need is a series of shared and collectively developed models, in a similar way to existing traffic models or, models of the physical parts of the earth system.

Keywords Climate change · Global models · Parallel processing · RepastHPC

Introduction

From a certain point of view, one might regard society as a massively parallel asynchronous processor of materials and information. Whether reasonable or not, it is perhaps a good description of the way ABM represent social systems, except that the majority of ABM at the present time are probably not working in parallel. For many models, particularly those testing concepts and ideas, or where the number of agents is quite small (less than about 1000 for Netlogo) and any spatial domain is not particularly highly resolved (so that the number of model grid patches is quite small), this is clearly fine. However, in this paper I argue that for certain classes of model, not only do we need models that work at large-scale (that is, with very large numbers of agents, acting in large highly resolved spatial domains), but we need them to work

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on the planet as a whole. In the next section suggestions are given as to why these global models are required. This is followed by a fairly high-level overview of the issues involved in making parallel models, and a description of using RepastHPC to model at scale. The conclusion reflects on how this could help, at least in part, to deal with the continual re-invention of ABM that currently hinders progress in the field.

Why We Need Global Models

In short, global problems need global solutions.

Increasing Realism

Recently [1] analysed 30 years of global satellite data in order to try to understand the degrees of deforestation imposed over the whole planet by the human population. The potential exists within the same dataset to look at the evolution of cities, the growth of road networks and similar phenomena. As this kind of data becomes more common, more realistic ABM, using real-world geographies and representing steadily larger scales will become possible, and the demand to be able to embed models in such realistic environments is likely to increase (see e.g. [2]). For policy purposes this kind of realism is likely to be necessary for ABM to make useful strides into actual decision making. The inter-connectedness of current society implies that such realism will ultimately demand a global approach, at least for some issues.

De Facto Dynamics is Already Global

The effects of human populations on the earth now dominates much of the global system ([3, 4]), to the extent that multiple planetary boundaries (in terms of exceeding available capacity) seem to have been overstepped [5]. The pressing problems of our time, such as anthropogenic climate change, deforestation, over-fishing, habitat loss, over-extraction of resources, poverty and inequality, economic fragility, food security, warfare and geo-political manoeuvering are global in scope, and cannot be effectively addressed using models that only cover small fractions of the global system. Economies are globally coupled through international trade and banking, populations through air transport and migration, societies through electronic communication. Potential threats from global pandemics [6] or large-scale societal collapse [7] cannot be meaningfully examined using only local case studies.

Integration is Needed with Other Existing Global Models

Current "Earth System Models" do not include humans. The typical such model is based largely on comprehensive physical models of the atmosphere and ocean, land surface and terrestrial vegetation [8, 9]. Recently models that include animals have become available, but not closely coupled to the other physical models [10]. Associated calls to "model all life on earth" distinctly lacked a human component [11]. "Integrated Assessment" models for looking at climate change effects are typically classical equilibrium models that look only at one way impacts from climate change to economics: Feedbacks between humans and their environmental impacts are entirely absent [12]. This is a significant hindrance to effective policy making for global scale phenomena e.g. [13] as the full complexity of social systems is not represented.

More is Different

This phrase comes from a well-known paper in the physical sciences [14], but applies with at least as much force in the case of societal phenomena. Dynamical phenomena change qualitatively with change in scale. The possibilities represented by a group of people in a small room differ from those within a building, a building differs from a street, a street from a city, a city from a country and a country from a region. At each level we encounter different dynamics, and different types of structure, with coupling both to levels above and below. Attempting to model the behaviour of people in a room depends for example on their perception of the transport system (will they get home in time given the city scale traffic jams?), where they will go for lunch (what has global trade provided by way of food?) and the ability to speak freely (what is the local political situation?). The background context is thus dependent on the embedding of people not just within social networks, but at the same time with infrastructural and economic ones, in a way that is inextricably bound up with global phenomena.

Boundary Conditions Are Problematic (Especially for Validation)

Most current ABM that attempt to make a more-or-less realistic connection to observed social situations (rather than abstract representations of mechanism, for example) focus on case-studies, often backed up by social surveys. In some cases this will be supplemented by census data or other larger-scale snapshots of the people under study. When trying to make dynamical representations of such cases, the situation is hampered not just by limited abilities to gather all information that might be relevant, but by the necessary lack of embedding in the surrounding social and spatial structures. When trying to model a farming community, for example, a key issue is usually not only the price of agricultural inputs, but also sale prices for outputs. Depending on the location and the type of crop, these are typically determined by much larger scales than that of the case study, including regional-scale climate variability and global scale economic markets for agricultural commodities, such as fuel for machinery, fertilizer for fields, and international demand for food. The possibilities for validating the dynamics within a small community are thus depend on assumptions about the situation beyond the model boundary. Future projections are likely to be invalidated by a lack of representation of out-of-boundary dynamical evolution. On the other hand, were there a global-scale dynamical model within which to embed the case study, the possibilities for more realistic presentation of dynamics would be enhanced.

Space and Timescales Are not Independent

Consider the case of modelling a city the scale of London. To know about traffic patterns a few hours ahead, we probably only need to model the city itself, plus a region outside to allow for traffic movements and interactions that can propagate on that timescale. However, consider instead trying to project energy needs in the same city for the next 30 years, something that is relevant to setting policy now, as infrastructure tends to have long lifetimes: just considering the city and a small region outside its boundary will be woefully inadequate. London is a globally coupled city, and the changes over 30 years bound to be connected not just to the whole UK but to Europe and beyond. It is not uncommon, however, to see case study ABM extrapolated for this kind of timescale (or possibly even longer). While projecting more than a few years into the future may be uncertain, the likely inaccuracies will become severe if long timescales are coupled with small spatial scales.

Social Justice Goes Global

While [5] emphasised the overstepping of physical and ecological boundaries, [15] pointed out that there are social justice boundaries that simultaneously need to be considered. Whilst some of these may be purely local, the social issues that arise as a result of climate change, international finance, ecosystem pressures and inequality need global social, political and governance (not just economic) models. Otherwise the current tendency to reduce all global issues to economic ones is likely to continue.

Models that Are not Materially Closed Are Under-Constrained

In attempting to understand whether current societies are sustainable, one of the key factors is to be able to trace the flows of material goods through international trade and their processing and re-processing by international industrial systems, on their way to the consumer. The implied inputs of energy, raw materials, human labour, and pre-existing capital infrastructure impose strong constraints both on the timescales that are needed and on the amount that can ultimately be consumed. Data on these flows is currently very sparse, and most complete for financial transactions reported at country scale (rather than actual material flows). Models of the global system would potentially be able to help in assessing how accurate and complete these accounts are in practice. Perhaps more crucially, in many current models, inputs needed for change over time are often assumed to exist without either time or physical cost being accounted for. This allows models to have more degrees of freedom than exist in reality, and leads to under-constrained models that are harder to validate. As a simple example, the typical Sakoda/Schelling model assumes that movement is both costless and instantaneous: in practice people face multiple constraints, not least the time and material cost of getting from place to place along with transport of all associated material goods. Once one begins to make more detailed simulations that include, for example, construction of new houses or tower blocks, the requirement to make such construction both materially and energetically closed leads to coupling to the international trade system, which again becomes a key factor in the possibilities for social change.

Global Datasets Provide Many Constraints

Pattern oriented modelling [16] seeks to use multiple different observational measures to constrain models, or exclude those that are insufficiently realistic for a given purpose. Making comparisons of models to measurement in only a few or even a single dimension (e.g. population size, or area of land-use change) can lead to under-constrained models that are hard to generalise. For [16] the point is that with multiple criteria available, even weak constraints (such as the sign of a change) when combined with others, can lead to strong constraints on models. Global satellite data, for example, is spatially extended, rich in detail, but generally coarse in resolution. Trade transaction data is sectorally detailed but often incomplete, whereas census data is typically detailed in some regions but not in others. With a global model where dynamics is fully coupled, multiple and partial weak or incomplete datasets could become powerful tools to exclude models with unrealistic mechanistic under-pinnings.

"Rumsfeldian" Reasons (We don't Know What to Leave Out)

The degree to which local dynamics are independent or otherwise of larger-scale factors is currently unclear. It is possible that some small-scale phenomena are dynamically de-coupled from larger scale, but which these might be is not necessarily obvious a priori. For example, the factors that lead to global price spikes for fuel and food might trigger events such as the Arab Spring, but the extent to which this might be true is hard to evaluate for lack of sufficiently detailed global models. At the moment we have no real idea whether a global ABM would be better (or worse) than the current approach (i.e. guesswork).

Attempting to Construct Such Models Will Lead to Learning

Simply making the attempt to build models at global scale will be sufficiently demanding that, even if not successful in addressing the issues mentioned above, new concepts, techniques, datasets, analyses and computational methods will almost certainly be required. A project to create a plausible and meaningful global model (or better, multiple different global models created by different research teams) of all society should also help to point out our areas of ignorance and stimulate future pathways for appropriate-scale case studies. Furthermore, linking to other communities of global modellers should help to raise the profile of ABM and break the stifling stranglehold of equilibrium economics on the thinking of decision makers.

Objections

The typical reaction to the idea of such large scale models is "because < insert reason here > this cannot be done" often (but not always) followed by an implication of "and therefore *it should not be tried*"; The classic example is the infamous paper by Lee [17]. This is much like the reaction of some social scientists to the idea of computational modelling of society, and thus to ABM in general. I give here a few samples and some possible counter arguments.

(a) You can't create a model of everything.
This, however, is not the objective. The idea is that anything less than global is *insufficient* to the task for certain issues of relevance to society. What is *necessary* (i.e. how much of "everything" do we need to model) then becomes a question for experimentation; to do the experiments we need to build the models.

(b) We are all doomed so why bother?
The doomsday dialogue has become all too common, particularly when talking about climate change. Warnings need to be given, but the mantra needs to change from "everything is hopeless" to "can we change things?", to which the answer

is hopefully, “yes, we can”. However, blindly changing at random may do as much harm as good—we need guidance in complex systems, and models may be able to help. If there are things that cannot be changed, then models may show how to cope. Either way global issues will remain hard to study without appropriate scale models.

(c) If we have to model every person, then why not every cell in every person? Or every molecule in every cell?
Again this is a question of sufficiency versus necessity. Model boundaries should be extended as far as needed, but no further. The standard assumption for ABM is that people can be treated as indivisible discrete entities, as we do in most of our social lives. It could be, though, that in order to model, say, global disease propagation, we find we need to include a dynamical immune system in each person—perhaps for influenza, where mutation of the virus within the organism matters—and that models that do not do this make important errors. However, if this process is largely decoupled from disease spread between people, then perhaps not. Again, finding this out requires testing, and we should model as much of the system as is required to answer the questions of interest. As a result of building a detailed global model we might also find phenomena where social structures decouple from the larger scale, or can be treated in isolation, but we need the large scale models to find this out. On the other hand some issues, for example those associated with gender, cannot be adequately treated with aggregate entities like households—one needs to represent individuals.

(d) Social systems are too complicated
Again an objection sometimes levelled at ABM in general, but here the implication is that on going global the number of social phenomena and the range of scales is so large that our lack of understanding will prove overwhelming. If on the other hand we try to cope by using some kinds of aggregates (e.g. modelling cities or regions as agents) then we again have the problem that we don’t know what the appropriate dynamics for such agents might be. The way to deal with this is, as with any model project, to start simple and then build in structure as needed. Here I suggest that “simple” implies modelling individual people, as this does not, intially, require assumptions about how to model aggregates—we hope, as usual, that these can be made to emerge, in later developments, from agent interactions. On the other hand [10] makes some progress with cohorts of agents, at least for the purposes of modelling necessities such as food, metabolism and breeding. The useful level of approximation depends on whether the model can match datasets that are of interest for model output.

(e) The model will be too complicated
The underlying complicatedness of a model is not necessarily related to the scale of the system it represents. The global scale ecosystem model of [10] is mechanistically quite simple, but the emergent spatial patterns have structure all the way from the grid scale out to half of the globe, driven by patterns in rainfall or ocean temperature, as well as by local dynamics. How complicated a global model needs to be will depend upon the purpose for which it is to be used, just as with a smaller scale model.

(f) The output will be too hard to analyse
Large models already exist that produce tera-bytes of output. As data sizes and complexities have increased, the methods needed for their analysis have been developed. Machine learning may help, both in terms of processing inputs and understanding outputs. Although a model may be highly dis-aggregated, its outputs need not be—sanity checks can be made on highly aggregate variables (e.g. global total biomass, global GDP), and then one can examine output in increasing levels of granularity.

(g) Just building a big model has no purpose
In the first instance the purpose is technical exploration. Can global models be constructed at all ([18] demonstrates "yes, at least at some level")? How long will they take to run? What input data is needed? How can we structure the output? These technical questions are the first port of call, and the beginnings are tackled in the next section. Beyond that there are multiple research questions that can be built around a model structure that has a global scope—e.g. Can we model the relation between global trade and water consumption? How are global ecosystems impacted by human activity? What policies might usefully limit global CO_2 emissions? Each of these is likely to need model (or sub-model) specialisation for a particular purpose, but the global model system needs to exist as a background, and to provide code to progressively build upon. Where questions overlap (e.g. land-use change and climate change) then we have the global technical frame ready to build the dynamics into a single model (rather than creating an "integronster" out of separate models with different reference scales, different levels of aggregation and so on).

None of these points, it is argued here, are reasons for *not trying* to build global models. As mentioned above, at the very least the process will lead to learning: Without the attempt we have no demonstration of the ways in which such models might fail. The key will, as always, not to be tempted to use models for policy advice too early, before model capabilities have been sufficiently tested.

The computing power exists to make models at such scales. The GSAM of [18] included one agent for every member of the global population: Since that time, however, little seems to have been published building on or extending this approach, although [2] implies that USA-scale models are now in routine use for decision making. More recently the Episimdemics model [19] has been run on a large high performance computing (HPC) machine using 655,360 cores (!). The focus of these very large models remains with disease however. The next largest scale is currently that of traffic modelling (on which the disease models tend to be based), one example being "virtual Belgium" [20], incorporating 10,000,000 agents. However, in order to make such large models it is necessary to use parallel programming techniques.

A Parallel Primer

Unfortunately the issue of creating parallel programs is a rather complex one. This is perhaps one of the reasons why few ABM to date have taken up the challenge to work at scale. Coupled to this are the difficulties of using the available platforms with which most modellers are familiar; only a few really support making models that are efficient when working with large numbers of agents and/or large spatial domains. Partly this is because there are multiple issues to do with hardware, software libraries and algorithms that do not arise in the case of standard serial (i.e. non-parallel) code.

Where the aim is to run a single large program and gain an improvement in speed of a single model run, the idea is to split the code in such a way that parts of the single model run concurrently on separate threads. Since we are thinking of single model in which interactions between different model parts are likely to be important (e.g. communication between different agents), exchange of data between threads becomes crucially important, and the speed of the code depends strongly on how efficiently this communication takes place. Parallel models of this type (as opposed to parameter space exploration, for example) for this reason rarely achieve anything close to the maximum possible speed-up for a given number of threads: in many cases the communication overhead can become so high that speed-up saturates beyond some rather small number of threads, or performance even decreases.

Approaches to parallelisation differ depending both on the nature of the application and the programming language and parallel framework to be used. For example, while Java runs efficiently using its own built-in threading system on a single machine, it tends to suffer from high latency in communication between machines, and historically this has led to poor performance relative to other languages on HPC. In GSAM Parker and Epstein managed to circumvent this problem, but at some cost in designing their system, and newer libraries such as AKKA have promise in making Java applications scale (for example used in conjunction with the Matsim traffic modelling platform—see e.g. the BEAM platform https://beam.lbl.gov/). The "extreme scale" systems that allow for very large scale models, as given in the review of ABM platforms by [21] are RepastHPC [22], PDES-MAS, Matsim and Swarm (Objective -C). The first two of these are based on C++. This also applies to the CHARM++ system used for the Episimdemics model, which is clearly "extreme scale" although not mentioned by [21]. [23] also include FLAME, D-Mason and Pandora. However, for direct comparison they only present results from FLAME and RepastHPC, of which the latter comes out with better performance overall. D-Mason they feel is currently rather at an early stage of development, and therefore perhaps not ready for such comparative evaluation. The virtual Belgium model combines Matsim with RepastHPC, and thus would appear to depend on C++. Systems such as FLAME and CHARM++ concentrate on message passing between agents and treat the simulation largely as task parallel. RepastHPC and D-Mason by comparison are more set up to use domain-decomposition—a model grid (or network in RepastHPC) is used as a container for agents, and sections are cut out and handed to individual threads. Agents may move between the various parts of the subdivided domain as required. Given the apparent performance advantages, and the spatial flavour of the application, the following reports some experience in global modelling using C++ and RepastHPC.

Making MOTES

The starting point for the current model development was a C++ version [24] of [10]. The original code was written in C#, translated in order to run it on a linux-based HPC. In the process model run-time improved somewhat, since C++ has a more efficient memory management model than C#. The code was first parallelised using the OpenMP library. This allows one to use “loop-level” or “block-level” parallelism to speed particular sub-sections of the code. This consists of “decorating” selected loops or regions of code with short directives to indicate that they should be run over multiple concurrent threads. Good speed up can then often be achieved with minimal modification to the code, although the degree of speedup then also depends on the relative proportions of time spent on the parallel and serial sections (as given by Amdahl’s law), and complexities ensue if there needs to be any cross-thread exchange of data.

However, OpenMP is only useful on a single machine and thus limited in the ability to scale: In the current study this limited exploration to just 24 threads (although machines exist that support 256). RepastHPC uses the MPI library, which allows code to be distributed over arbitrarily large numbers of machines. Usually though, more code modification is required, and this proved to be so for the current case.

This model used RepastHPC 2.2.0. This comes in two flavours—a Relogo version (which tries to look somewhat like Netlogo) and plain RepastHPC without logo-like syntax. In either case some understanding of C++ templates is needed to make progress. Reasonably good documentation is supplied and a set of example models can be downloaded, built around a set of online tutorials. In both cases the RepastHPC library hides details of the MPI library, so that in principle the programmer does not need to be concerned about this detail. Model stepping is carried out using the Repast scheduler as for a standard Repast model. Multiple agent-types can be used, with a user-defined type identifier. Agents are place in a container (called a “context”) and then can be subdivided automatically across threads using “projections”, the latter being either a grid or a network (or both). Grids can be hard edged or toroidal (cf Netlogo), and agents can be located either at grid-cell centres (more efficient) or have arbitrary positions, or again, both. Since the domain is subdivided, when there can be interaction between agents in different grid cells, some cells within a neighbourhood may end up on different threads. RepastHPC allows for agents in a remote grid cell from a given thread to be copied onto that thread, and distinguished as remote agents, as opposed to thread-local. A user-defined parameter allows for the programmer to specify how many rows and columns of “buffer” zone are shared in this way. A core part of the library is the provision of synchronization; this provides for synchronizing data to remote copies, but also for movement of agents across threads in their entirety. Multiple synchronization methods can be specified, so that, for example, just a sub-set of the agent information is sent to remote copies, as needed. Value-layers are also provided for representation of more continuous fields such as temperature, for example. A limited level of I/O is provided, in ascii or NetCDF (a binary format best suited to gridded time series, and much used in the atmospheric modelling community).

While the above set of facilities is quite useful, in practice there were difficulties in setting up the global model. In the first place, a globe needs to be wrapped differently at the poles compared to wrapping in longitude. Because the agent-copying mechanism for representing those remote to a given thread assumes toroidal geometry, it is not immediately possible to set up a globe without the risk of agents at the South pole encountering those at the North (and a hard edged grid would exclude wrapping in longitude). In the current case this issue can be worked around by having a distance measure between agents that depends on latitude and using this to detect when agents are actually at polar extremes. However, a proper fix requires an additional grid-type to be added to the library so as to deal with spheres. Secondly, distances on a plane or toroidal grid do not vary in the same way as on a sphere, so agents needed to keep their own local co-ordinates so as to be able to use the correct spherical distance. Again this could be added to an updated RepastHPC core.

A further difficulty arose with erratic crashes of a Relogo model version, and subsequently with agents disappearing from the model on movement between threads. This proved to be a result of assumptions about the range of movement likely to be undertaken by an agent in a given timestep. RepastHPC uses MPI cartesian grids to subdivide the domain, and then assumes that agents will not move beyond the range of a Moore neighbourhood of this larger grid (where each MPI grid box contains a potentially large number of model grid cells). In practice, in the case of the current model, movements were capable of taking agents beyond the limits of the neighbourhood in this larger grid, with the result that they became lost from the model, or else gave rise to pointers aimed at memory that had been de-allocated. This required a code edit in the RepastHPC core to make sure that grid cell searches could find agents anywhere in the model grid, rather than just the local MPI-cartesian neighbourhood.

As a final issue, (apart from some small bugfixes to do with mapping ranges of co-ordinates to grid cells, and some edits needed enhance the I/O) it became necessary both to move to the standard RepastHPC version (rather than Relogo) and to introduce some explicit MPI calls in order to deal with algorithmic details in the implementation of the application. The model of [10] is an agent-based eco-system model based on functional types (in a similar way to the suggestion of [25] for human agents). Since the numbers of animals and numbers of species on the planet is much larger than can be represented as individuals, the agents are cohorts representing many individuals across multiple species (similar to the super-individuals described in [26]), but the number of cohorts can easily be in the hundreds of millions. Predator cohorts eat based on the size distribution of prey: this is the expensive part of the algorithm, as it scales as the square of the number of cohorts within the range of any given predator. Nominally these cohorts include "wild" humans that behave exactly as other animals in their equivalent functional group. Migration of cohorts between

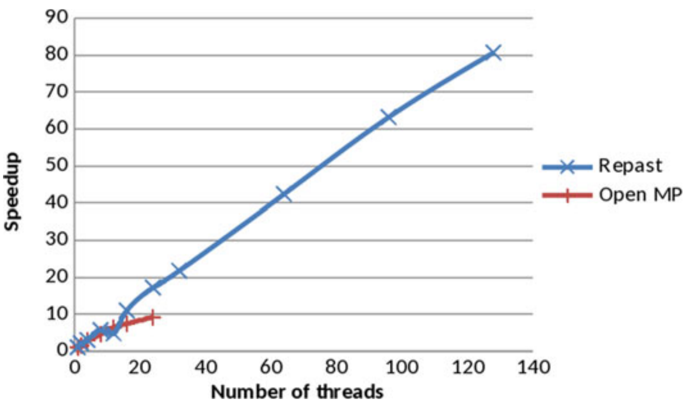

Fig. 43.1 Red line: Open MP version of the model running on a single workstation with up to 24 threads available. For comparison repastHPC was run on the Cambridge CSD3 Intel skylake cluster. For small numbers of core the two are somewhat comparable, but RepastHPC clearly scales better above 10 threads and continues to scale well out to 128 threads and beyond

cells is relatively less expensive, but once predation is parallelised, a significant extra gain in performance is obtained by also ensuring migration takes place in parallel. Figure 43.1 shows the kind of scaling that can be obtained from these various parallel methods on two different types of hardware.

Conclusion

Abar et al. [21] indicate that using extreme-scale libraries for modelling with agents is difficult. Experience with RepastHPC certainly bears this out if the requirement is to implement a model essentially from scratch. Detailed knowledge of C++ and of MPI is required. RepastHPC comes with demonstration models, but no tests, and the reasons for model failures can be hard to diagnose. The way in which cross-cell synchronization works is not transparent, particularly if you have never encountered the Boost serialization library before. Understanding how to reliably adapt a working serial algorithm to this particular parallel environment can also be non-trivial. Any developer must either have a high level of programming skill, or know someone who does. Part of the problem here may be starting from the wrong place: It may be that newer languages designed with parallelism in mind, such as Julia, Rust or Chapel, are the way to go in the future. Even so these are not easy for the naive programmer in the way that Netlogo can be. On the other hand more sophisticated ways of representing agents, such as discrete event systems, functional programming or declarative methods are also typically hard for the beginner to grasp: each of these may also have different implications for scaling up onto large machines.

On the other hand, the scaling offered by RepastHPC is excellent, showing no sign of saturating beyond 320 cores (the current tested limit), and promising to continue well beyond. Having created a working model and tested the fundamentals of its operation, further model additions now become straightforward: the current model has all the parallel machinery operational. The requirement for extensions to represent sophisticated human behaviour is one of defining agent rules and behaviours in a fairly standard way, using standard syntax accessible by those with reasonably elementary programming skills in C++ or any of its close cousins such as Java or C#.

The current proliferation of toolkits and platforms for creation of ABM is perhaps not helping the development of the field. I suggest that what is actually required to make significant advances is focussed models that are sufficiently complex to represent a wide range of behaviours and circumstances, are realistic in their representation of the world (rather than highly abstract) and to which programmers can add modules of their own whilst taking advantage of previous programmers' effort in developing well tested and robust code. This is the situation for the current generation of earth system models: writing such a model from scratch (in excess, typically of 500,000 lines of code, albeit still typically in FORTRAN) for every new application would not be sensible. Traffic models form one such kind of development, with open-source examples such as TRANSIMS, Matsim and SUMO allowing newcomers to the field to access sophisticated models to which they can contribute. One possible application to encourage such model development in the current social and political situation might be to concentrate some efforts on global ABM for dealing with the social issues of disease, climate change and environmental destruction: this would have automatic policy relevance, whilst presenting many challenges to the field of social systems modelling. Such models must by definition, however, be global in scale and scope.

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Chapter 44
The Role of Economic, Behavioral, and Social Factors in Technology Adoption

Giulia Chersoni, Nives Della Valle, and Magda Fontana

Abstract The paper models the choice of adopting a technology as a combination of economic, behavioral, and social factors and discusses their relative role in the diffusion of the technology. The model encompasses the cost of the technology, the propensity to adopt and the imitative behavior. Results show that the traditional adoption curve only emerges when the decision to adopt a technology is driven uniquely by imitation. It also appears that the rate and level of diffusion depend on the structure of interaction—i.e. network topology. Interestingly, if agents interact in preferential attachment environments, the adoption is higher than in small world topologies when we take into account economic, behavioral, and social factors. Overall, the paper suggests that none of the considered elements taken in isolation can explain the adoption decision.

Keywords Innovation diffusion · Agent-based model · Decision-making process

Introduction

Understanding the drivers of technology adoption is a key topic in economics. Research follows three main lines: traditional models depict technological choices

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as based on the comparison between monetary costs and benefits [14, 19]. However, the behavioral economic literature suggests that the decision to adopt a technology can also be influenced by behavioral factors [4, 15, 17]. Finally, epidemic models stress the role of imitation in technology adoption [5, 12].

In this paper, we show that the three approaches are not mutually exclusive and we highlight the marginal effect of each of them on the level and pace of adoption. Conventional bottom-up models characterize technological choices in terms of capital and operational costs, and their profitability in the long-run based on their discounted value [19]. However, part of the relevant literature (e.g. [14]) emphasizes that such models only account for purely economic motives. At the same time, they oversimplify decision-making by assuming complete information, homogeneity of agents, and no interaction among them. Conversely, the field of behavioral economics enables to account for the cognitive limitations that bias the decision-making process and to acknowledge individual heterogeneity not only in terms of what individuals prefer, but also in terms of how much they differ in their degree of self-interest and motivations. Finally, epidemic models consider diffusion as a social contagion process based on imitation but, in most cases, do not thoroughly assess economic motives and cognitive biases [10].

We claim that adoption is affected by all these three elements and that their relative role has not been examined so far. To investigate this issue, we join the three parts in an agent-based model (ABM) that accounts for heterogeneity (in a behavioral perspective) and decentralized interaction (as in epidemic models). We start from the framework devised by Bénabou and Tirole [3] in which individual decisions concerning public goods are influenced by economic and behavioral factors, and by peer pressure, and we reframe the model in order to make it applicable to private goods. In their model, decisions are made by balancing inner motivations (i.e. the degree of other-regarding concerns) and social influence (i.e. reputational costs and benefits). We translate the former into a general agent's propensity to adopt—that intuitively varies across individuals—and the latter into neighbors' influence. It is worth noting that peer pressure *ála Bénabou and Tirole* [3] assigns the same weight to all the signals, whereas in epidemic models and in our ABM, agents weight the information on the basis of their individual characteristics, i.e. their propensity to adopt. Agents with weak inner motivations (i.e. low propensity to adopt) are more likely to conform to the behavior of others (i.e. have a high propensity to imitate) [2].

It is widely acknowledged [5, 22, 23] that the structure of the neighborhood affects the level and the pace of innovation diffusion. In our ABM agents with heterogeneous propensity to adopt interact in different network topologies (small world and preferential attachment) and make decisions on the basis of the information gathered in their neighborhood as in traditional epidemic models [12]. Overall, the decision has three drivers: the economic factors (income and investment cost), the behavioral component (propensity to adopt), and the sensitivity to neighbors' influence (propensity to imitate) meidated by the network topology.

Results show that the traditional adoption curve only emerges when the decision is driven uniquely by neighbor's influence. Whereas, when we consider economic and behavioral elements we obtain diverse interesting adoption paths. This implies that studying adoption from a single perspective neglects relevant aspects of both the decision-making and the diffusion process.

The paper is organized as follows: section "Theoretical Background" illustrates the literature that is relevant for the analysis, section "The Model" illustrates the model and the research questions, section "Analysis and Results" presents the results, and section " Discussion and Conclusions" discusses and concludes.

Theoretical Background

According to the literature, the decision to adopt a technology can be affected by three main elements: economic, behavioral and social factors. Economic factors consist in the cost and benefits associated to the technology and in the potential adopter's income constraints. Behavioral economics, while highlighting that individuals are often incapable of performing optimal decisions, suggests that the outcome of the comparison of cost and benefits is distorted by the presence of systematic cognitive biases. Individuals might assign to the benefits delayed in the future a weight that is lower than that assigned to the present purchasing cost (*present bias*) [15] and can be loss averse (*framing effect*) [25]. Also, individuals care not only about their own well-being, but also about that of others [9]: *other-regarding concerns* might enter the decision to adopt a technology if it also entails public benefits [16]. Finally, social factors such as peer pressure are investigated in the literature on innovation through the so- called epidemic models [10] where a technology spreads as a social contagion fostered by imitation [20].

In this study, we propose a model that can account for all the three factors by amending the model by Bénabou and Tirole [3]. As it will be illustrated in the following section, we change their original model to include the propensity to adopt (instead of other-regarding behavior) and we apply it to a private good (instead of a public good).

The model is not analytically solved but, in order to encompass individual heterogeneity, is simulated via an agent-based model [13, 18]. We relax the homogeneity and perfect mixing assumptions [12] of epidemic models and we introduce local network effects [26]. In our model, the increase in the proportion of adopters affects individual decision depending on the structure of the individual's network. Namely, ceteris paribus, the decision of adopting a technology is made when a certain threshold of adopters is reached within the individual neighborhood.[1]

[1] Differently from Valente [26], in our model the threshold variable is an individual feature, rather than of the network.

The Model

The model describes the adoption decision made by a heterogeneous population of agents interacting on a network.

The decision rule of agent i is the following:

$$Adoption(i,t) = \begin{cases} 1, \ if \ \ Z < ((1-\beta)/2)EB + \beta N \\ 0, \ otherwise \end{cases} \tag{1}$$

where EB represents economic and behavioral factors, N is the neighborhood (i.e. social) influence, and β $(0 \leq \beta \leq 1)$ is their respective weight. If $EB = 0$ the net effect of economic and behavioral factors cancels out and the investment choice depends only on N, while when the cost of the investment is too high relative to the agent's income, the economic factor takes over the positive effects of propensity to adopt ($EB < 0$). Finally, when $EB > 0$ and $\beta < 1$, adoption is positively affected by economic, behavioral, and neighbors' decisions.

In particular,

$$EB = (v_i - c_i) \tag{2}$$

where the agent propensity to adopt is measured by the parameter v_i $(0 \leq v \leq 1)$ and the financial burden associated to the investment is measured by the parameter c_i $(0 \leq c \leq 1)$. The latter is the normalized ratio between the cost of purchasing the technology and the agent's income. If y_i is the agent's income and $m_i = 1/y_i$ is the relative cost of the investment, $c_i = (m_i - m_{min})/(m_{max} - m_{min})$, with $0 \leq c_i \leq 1$, is the normalized relative cost. Therefore, higher y_i corresponds to lower m_i and, consequently, to a lower financial burden: agents with high income level and low financial burden have c_i that approximates 0. Similarly, $EB < 0$ when the propensity to adopt is low or the cost of investment is high with respect to the agent's income.

Finally, N is formalized as follows:

$$N = \frac{n_{adopt,i} + \left(n_{adopt,j} * q_i\right)}{n_{i,j}} \tag{3}$$

where n_i is the number of neighbors with a similar level of propensity to adopt, n_j is the sum of the remaining neighbors,[2] and q_i $(0 \leq q \leq 1)$ is the propensity to imitate, which is inversely proportional to v_i. The idea underlying this assumption is that individuals with weak inner motivations (i.e. low propensity to adopt) are more likely to conform to the behavior of others, in comparison with those who have high prior on their inner motivations [2]. The likelihood to adopt increases as N increases, i.e. as the number of adopters in the agent neighborhood network increases (i.e. the numerator of Eq. 3). This effect is stronger for those agents with a high propensity to imitate (higher q_i).

[2]Two agents are considered similar if their propensity to adopt differs less than ±0.2. For a similar approach see Beretta et al. [5].

The structure of the neighborhood is modelled by resorting to three typical network topologies: a small-world network with high and low clustering [28], and preferential attachment [1]. Small world networks reflect the propensity to create tighter and more numerous relationships with individuals that are close in terms of a given dimension.[3] The high number of cliques assures that if a links drops out, the relationship between the remaining individuals does not suffer from fragmentation, and the nucleus remains intact [11]. Preferential attachment networks,[4] on the other hand, approximate social interactions mediated by a leader (i.e. node with higher degree). In social environments with preferential attachment structure, the diffusion process is mediated by a subset of central nodes, while diffusion in small world societies results from more decentralized interactions. As for the pace of adoption, the literature [5] agrees that small world networks accelerate diffusion with respect to preferential attachment networks.

Finally, Z is a stochastic process that encompasses all the elements that are assumed to affect adoption but are not explicitly included in the model. It assumes a uniformly distributed random value between 0 and 1. The population is heterogeneous since the value of v_i, c_i, and q_i are randomly drawn from a normal distribution.

We analyse the level and pace of adoption at the population level by focusing on the following questions:

Question I (QI): Assuming that the adoption is influenced both by EB and N, we ask which is their respective weight (β) in the adoption process.

Question II (QII): We also ask, for each level of β, how the population income drives the adoption process.

Question III (QIII): Similarly, we inquire on the effect of the propensity to adopt.

Analysis and Results

In order to answer the above mentioned questions, we simulate a population of 100 agents that are nodes of a network.[5] We observe the decision over a period of 100 steps after which the model stabilizes. For each scenario, we run 100 repetitions to account for stochasticity. In addition, we also control for the effect of the position of the first adopter on the network (e.g. its social relevance). We consider a marginal adopter chosen with a function that minimizes closeness centrality, and central adopters chosen with a function the maximise betweenness and eigenvector centrality.[6] The simulated scenarios are summarized in Table 44.1.

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[3]The network has been generated with the Kleinberg algorithm.

[4]The network has been generated with the Barabasi-Albert algorithm.

[5] We choose the number of agents in the population based on the theory [27] and evidence [8] that network size does not affect diffusion processes due to the fractal properties of networks.

[6]If there exists more than one agent with the same centrality values, then we randomize among them. We also simulated an adopter chosen randomly. Results, for each scenario, broadly correspond to the average output obtained from the marginal, betweenness and eigenvector adopters.

Table 44.1 Simulation scenarios

Variable	Range of values
β	0.0–1.0
c_i	0.0–1.0
v_i	0.0–1.0
Share of agents with low income ($y_i < \tilde{y}*$)	0, 25, 50, 75
Share of agents with low propensity ($v_i < \tilde{v}*$)	0, 25, 50, 75
Networks	Preferential attachment, Small world
First adopter	Marginal, Betweenness, Eigenvector
QI	$\beta(0, 1)$, $v_i(0, 1)$, $c_i(0, 1)$
QII	$\beta(0, 1)$, $v_i = 1$, $c_i(0, 1)$
QIII	$\beta(0, 1)$, $v_i(0, 1)$, $c_i = 0$

$*\tilde{y} = 0.33$, $*\tilde{v} = 0.4$

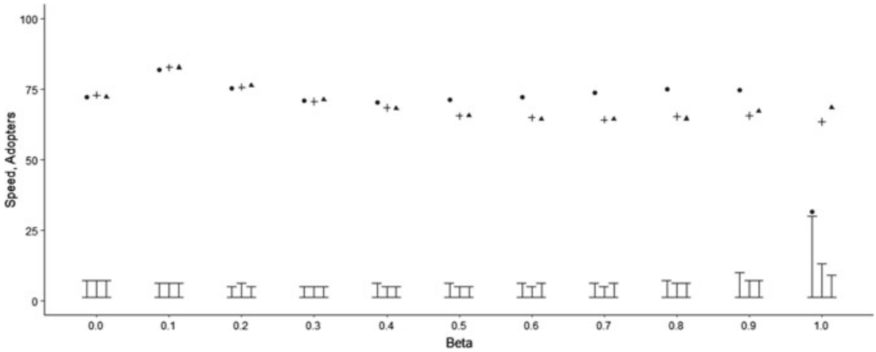

Fig. 44.1 Simulation results for $\beta(0, 1)$ split by network type. Bars represents the diffusion speed by network topology: first bar preferential attachment, second bar small-world-high-cluster, third bar small-world-low-cluster. Points represent the mean number of adopters by network topology: circle preferential-attachment, plus small-world-high-cluster, triangle small-world-low-cluster. Simulation results with 10 % of agent with $c_i \leq \tilde{c}$ and $v_i \leq \tilde{v}$, and one first adopter

QI: Balancing Economic, Behavioral and Social Motives

According to Eq. 1, increasing the value of β results in an increasing weight of neighbors influence over economics and behavioral factors. Figure 44.1 [7] shows that the total level of adoption is almost unaffected for $0.0 \leq \beta \leq 0.9$ for all the networks. It also shows that, when $\beta = 1$, the adoption level is lower and the pace of diffusion is slower in preferential attachment topology. This depends on the hierarchical structure of the networks that limits redundancy of connections, therefore reducing the probability of having neighbors that have adopted.

[7] Figure 44.1 shows the diffusion speed defined as the number of iterations necessary to reach the inflection point of the adoption curve.

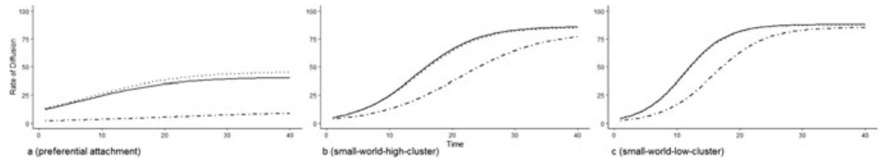

Fig. 44.2 Simulation results for $\beta = 1$ split by type of network. Coloured lines represent the diffusion curves by the position of the first adopter in the network: dotted and solid line central first adopter (betweennes and eigenvector), dotdash line marginal position

For β equals to 1 we find a strong effect of the network type and of the position of the first adopter in the preferential attachment topology (see Fig. 44.2). Unsurprisingly, when the first adopter is marginal, the level of adoption remains below the 25% of the population against the 50% of the central adopters. In the small world topology, the increase in β has a considerably less marked effect. The pace of adoption slightly slows down, but remains very similar to the results from lower values of β, (see Fig. 44.1) while the difference across seeding method is not as sharp as in the the preferential attachment case (see Fig. 44.2). The different clustering in the small world networks does not heavily affect the results. In line with the literature, the high clustering generates a slightly lower level of adoption.

QII: Merging Economic Factors and Neighbor Pressure

To investigate the role of income, we simulate the adoption process with the maximum propensity to adopt ($v_i = 1$) and an increasing share of agents that cannot afford the technology. As expected, Figs. 44.3 and 44.4 show that income positively affects the level of adoption. They also emphasize that, when the role of neighbors' influence is also accounted for, non-trivial results emerge.

Figure 44.3 reports the results of the simulation with $\beta = 1$. When all agents can afford and are willing to adopt, the diffusion is complete only for the small world topologies. While in the preferential attachment case, the role of N is stronger than the importance of EB. In addition, Fig. 44.3 also confirms that the position of the first adopter in the network matters to the final level of adoption especially when the agent is marginal. On the contrary, there are no relevant differences between central first adopters. Furthermore, in the scenario where the 75% of agents have an income lower than the investment cost, all the network topologies slow down the diffusion process that remains below the potential 25%. This suggests the presence of a threshold of $c_i \leq \tilde{c}$, above which the dispersion of adopting agents on the network is too high to trigger the neighboring pressure.

Overall, Fig. 44.4 highlights that the role of networks is not linearly increasing in the value of β. The process of adoption is almost unfettered by the presence of the network until $\beta = 1$. It shows that the neighboring effect prevails only at the extreme

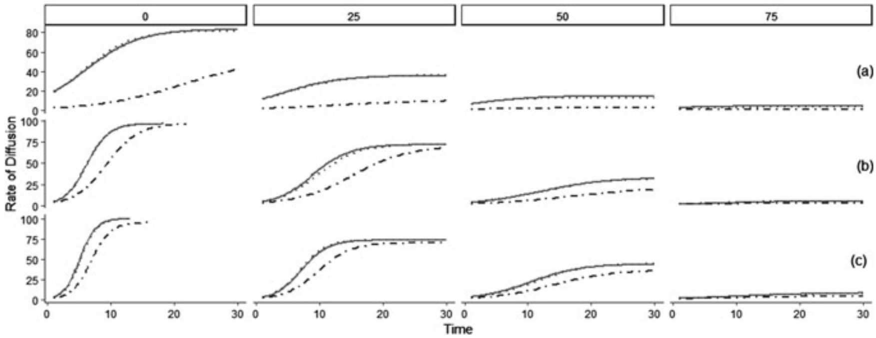

Fig. 44.3 Simulation results for $\beta = 1$ split by type of network and share of agents with $c_i \leq \tilde{c}$. Coloured lines represent the diffusion curves by the position of the first adopter in the network: dotted and solid line central first adopter (betweennes and eigenvector), dotdash line marginal position. (**a**) preferential attachment topology with increasing share of agents that cannot afford the technology. (**b**) small-world-high-cluster topology with increasing share of agents that cannot afford the technology. (**c**) small-world-low-cluster topology with increasing share of agents that cannot afford the technology

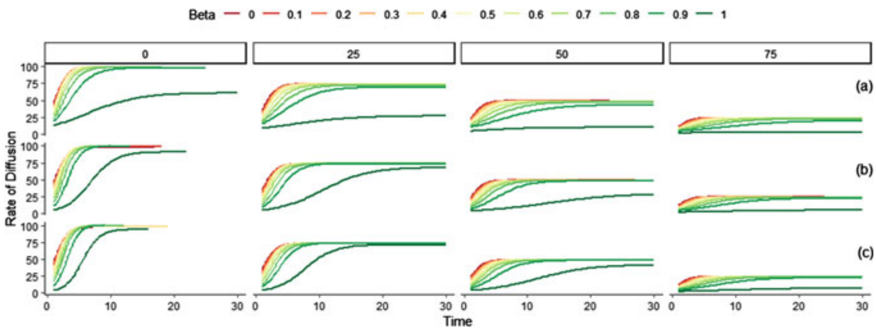

Fig. 44.4 Simulation results split by type of network and share of agents with $c_i \leq \tilde{c}$. Coloured lines represent the diffusion curves by values of β. (**a**) Preferential attachment topology with increasing share of agents that cannot afford the technology. (**b**) Small-world-high-cluster topology with increasing share of agents that cannot afford the technology. (**c**) Small-world-low-cluster topology with increasing share of agents that cannot afford the technology

of the parameter value. We can stress that epidemic models ($\beta = 1$) produce results that are very different from the more traditional EB perspective. This encourages further investigations, possibly empirical, on this matter.

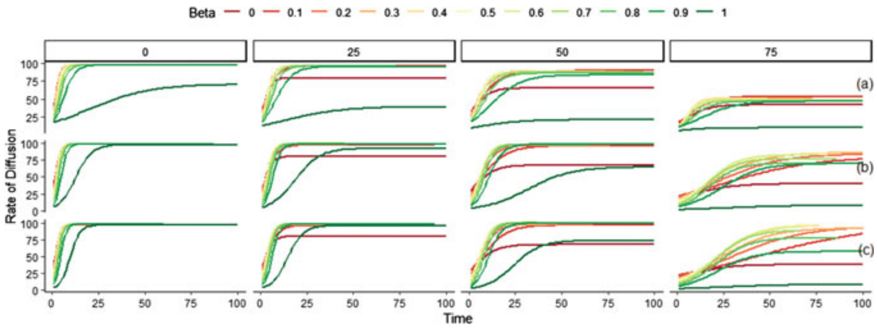

Fig. 44.5 Simulation results split by type of network and share of agents with $v_i \leq \tilde{v}$. Coloured lines represent the diffusion curves by values of β. (**a**) preferential attachment topology with increasing share of agents with low propensity to adopt. (**b**) small-world-high-cluster topology with increasing share of agents with low propensity to adopt. (**c**) small-world-low-cluster topology with increasing share of agents with low propensity to adopt

QIII: The Role of Propensity to Adopt

In the scenario QIII, we simulate the adoption process with no financial constraints ($c_i = 0$ for all agents) and with an increasing share of agents with propensity to adopt lower than the adoption threshold $v_i \leq \tilde{v}$. Recall that when an agent propensity to adopt is lower than the threshold, the adoption is possible only if more than 50% of its neighbors have adopted.

Figure 44.5 shows that even if the number of agents with $v_i \leq \tilde{v}$ increases and for values of $\beta > 0$, the neighboring effect described above pushes the adoption level over its potential level. The effect cancels out when we account for income (QII) and when we consider only EB ($\beta = 0$). Overall, the neighbor effect is stronger in small-world topologies. The differences among network topologies is more prominent in the 50% scenario, where the preferential attachment topology hinders diffusion and small-world topologies facilitate it. Among small-world networks, differences in diffusion speed are predominant in the 75% scenario. Low clustering coefficient eases information flows and speeds up diffusion rate, as Fig. 44.5 shows, also when $\beta = 1$, even if the effect takes longer to show. Interestingly, in the latter case (when $\beta = 1$) the imitative effect is locked in the neighborhood of the first adopter and we observe a remarkable decrease in the pace and speed of diffusion. Neighbors' influence might hinder diffusion even more when there is homogeneity among neighboring individual. In particular, a higher v_i implies a lower q_i and therefore a lower imitative effect.

Discussion and Conclusions

The paper merges three approaches to depict the determinants of the technology adoption with the aim of appreciating their effect on the rate and total level of adoption. We have considered the traditional purely economic perspective together with the behavioral and epidemic approach. We have run an agent-based model to evaluate the relative role of three approaches and to assess the robustness of the findings that derive from each of them taken in isolation. The agent-based model provides interesting theoretical results that also have policy implications.

First, our results challenge the common finding that preferential attachment networks result in lower level of adoption and slower adoption processes. We find that this outcome only occurs when we assume that the adoption of a technology is uniquely determined by imitation. In all other cases, i.e. when behavioral and economic motives matter, the preferential attachment topology gives higher levels of adoption without any relevant delay in the speed of the diffusion process. This leads to reconsider the idea that small world networks are superior to preferential attachment in terms of diffusion. Overall, from a policy perspective, it seems that relying only on imitation to support adoption merely captures a fraction of potential adopters.

Second, in the same line, our model suggests that when the share of low-income population (e.g. with an income that does not allow to afford the technology) is above a certain threshold, the imitative driver is not enough to trigger widespread adoption. As demonstrated by Beretta et al. [5], to overcome this issue, a policy intervention should target adopters on the basis of social or geographical proximity and increase their financial resources (e.g. general subsidy or proportional transfer by high-income neighbors to low-income neighbors). This would allow to reach the critical mass of adopters and, therefore, to foster diffusion.

Third, as opposed to the case of income constraints, the neighboring effect triggers diffusion above the share of agents that, according to their propensity to adopt, would not be willing to adopt. Based on this result, we claim that interventions that make the action of adopting more visible might be effective at increasing individual propensity to adopt by strengthening peer effects [21, 29]. Furthermore, when the initial threshold of individuals who engage in the desired behaviour is low (e.g. when imitation is locked-in the neighborhood of the first adopter), a norm-based intervention framed in a dynamic way (e.g., 'more and more people are adopting the technology x') might be effective at promoting adoption on a large-scale [24], with a probability of success that is higher the higher the degree of homogeneity of the target population [6, 7].

When dealing with actual populations, the assumption of acting on homogeneous groups is a strong limitation to the policy effectiveness. From this viewpoint, our model constitutes a test-bed for simulating the effect of such interventions in heterogeneous populations. At the same time, by pivoting only on a few variables (income, propensity to adopt, and topology of interaction), our model unveils avenues for future research susceptible of empirical validation. Moreover, the modularity of the model also allows to simulate more diverse and sophisticated declinations of the behavioral (e.g. by including cognitive biases in the choice of adopting) and economic (e.g. by considering discounting effect) components.

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Chapter 45
EMLab-Consumer—Simulating Energy Efficiency Adoption Decisions of European Households

Emile Chappin, Ivo Bouwmans, and Emma Deijkers

Abstract This paper introduces EMLab-Consumer, an agent-based model developed in the H2020 project Cheetah, on energy efficiency of households. The model builds on the theory of planned behavior, a large European survey and a variety of choice models generated from the same survey. It studies adoption of a number of energy efficient appliances and heating systems in 8 EU countries, under a variety of policy interventions. The paper describes the model and first outcomes on smart thermostats.

Keywords Energy efficiency · Households investments · Agent-based modelling · Choice models · Survey

Introduction

EMLab-Consumer

A recent review of studies using agent-based modelling on energy efficiency decisions in households showed studies still have a rather narrow focus in terms of barriers modelled (lack of capital, a lack of information, high upfront cost), on subsidies, technology bans and information campaigns and particular residential technologies [1]. Earlier work shows the role of non-financial criteria used in the decision-making of energy efficiency and energy reduction [2, 3].

This paper introduces EMLab-Consumer, an agent-based model that simulates household investments in appliances and heating systems. The model contains different types of agents: households, suppliers, appliances and technologies. Households own appliances, e.g. a thermostat, a fridge and a heating system. Over a period of decades, households make use of their appliance and invest in replacement. They also interact with friends: the households are embedded in a social network and

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exchange preferences regarding energy efficient technologies. Technologies define how energy efficient the appliances are. Appliances are the actual items households buy, which can be a fridge, thermostat or heating system. As these appliances break down over time, the household may decide to replace it while more efficient technologies appear on the market.

When a household decides to replace an appliance, they decide on which technology to purchase and where to buy this. The simulated logic is based on utility functions from choice experiments generation from the Cheetah survey, combined with elements from the theory of planned behavior: in their decision households are limited in the number of options they consider, the amount of shops they visit and they are also influenced by their friends. Technologies may differ in size, volume, capacity, energy label, electricity usage. Households consider the properties of the current appliance they are replacing.

Various policies can be applied within the model, to study their effectiveness and efficiency. Some policies may affect retail prices through the provision of subsidies, while others may affect the options that are seriously considered by the households or the options that are allowed on the market.

Outline

The article is structed as follows: in secttion "EMLab-Consumer" describes the model, in section "Adoption of Smart Thermostats: 8 EU Countries – Subsidies" gives first results. The paper ends with conclusions and an outlook.

EMLab-Consumer

Overview

A brief explanation of a run is shown in Fig. 45.1 (previous page). A household starts out having certain appliances. They check if one of their appliances is broken or if they just want to replace one of their current appliances other reasons. If this is the case, they first select the shops at which they would like the buy their appliances. Based on the stock of these shops they select the options for which they determine their utility. Based on among others the utility the choice for a certain appliance is made. This process goes on for each household till the simulation stops. Technologies improve over time and policies affect these decisions.

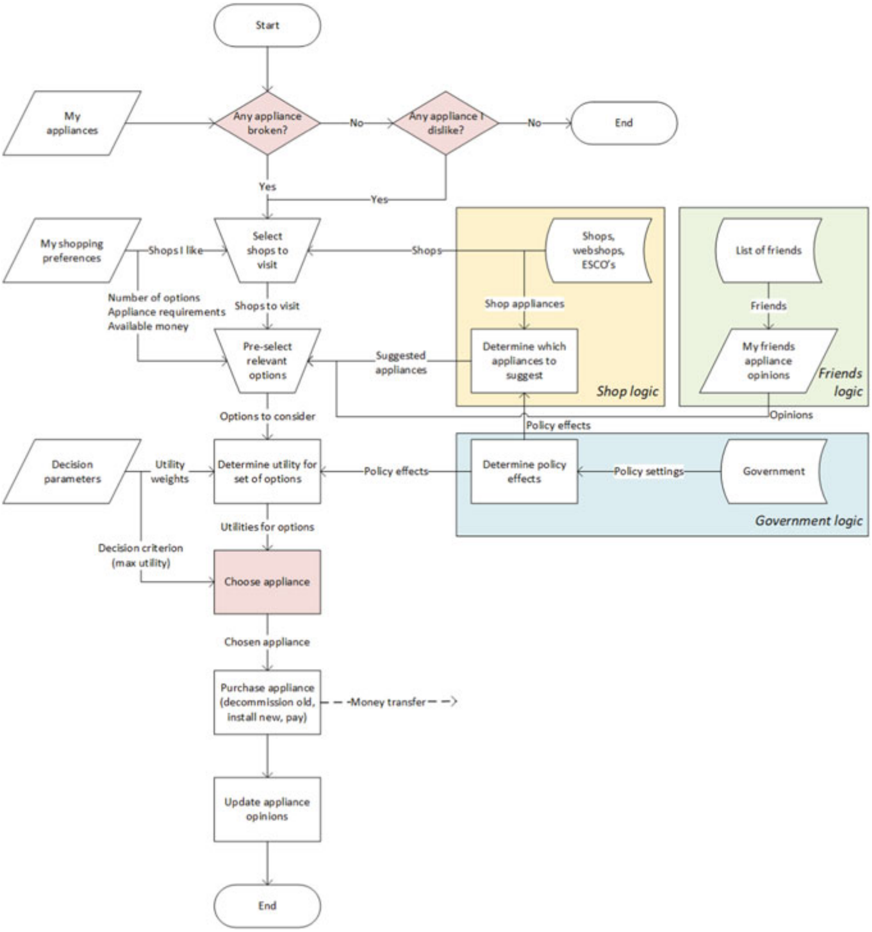

Fig. 45.1 Flowchart of a run with EMLab-Consumer

Agent Types

The first breed are **households**. They are the ones that own the appliances and that have to decide which new appliance to buy or lease and where to do this. Each household has a large number of characteristics, influencing their decision. The households also have general restrictions for the appliances they buy, some of which are based on the appliances they owned at the start of the run. Households are part of a social network. They are set in a scale free network. This means the size of the network doesn't influence the properties of the network. A household has a value assigned for the "minimal number of friends they have". During the model set-up, they can make more friends. After the set-up the number of friends remains the same. Whether you start a friendship with someone is based on "preferential attachment".

This means that if someone already has a lot of friends, the chances are higher that you want to become friends with them.

The **suppliers** are another breed. They store the appliances at their shop. Here the households can buy the appliances they want. Each supplier has their own stock of specific appliances, which they are connected to through links. Suppliers also create links with the households they sell their appliances to. There are three types of suppliers: web shops, shops and ESCO. After a type of supplier sells an appliance to a household, they become the “preferred supplier” of that household. A household then also takes the color of their last preferred type of supplier.

The third breed are **appliances**. This is what suppliers sell and households buy. There are three types of appliances in this model: fridges, thermostats and heating systems. TVs and washing machines can be added to the model later on. Appliances have a certain lifetime. At the end of its lifetime the device breaks down. Its status then changes from “operating” to “decommissioned”. The household then has to decide on a replacement from a supplier, who’s appliances have the status “for sale”. After the household has decided on an appliance, it is ordered and bought through establishing a link between the household and the appliance. The status of the appliance is set to “operating” again.

The fourth and last breed are the **technologies**. They define how energy efficient the appliances are. Newer and more efficient technologies are introduced to the market every other year. Older technology models are sold with discounts. Each technology has a certain energy label, which states how energy efficient they are. The color of the technology represents its label. The technology an appliance has, influences a household’s decision on which device they buy. Each household only considers appliances of a certain label.

Households Decision Making Scheme

When the old appliance of a household breaks down, they have to decide on which new appliance they get and where. This is the key process of the model and is influenced by a large number of factors. As the first step a household selects the suppliers, at which stores they want to get their appliance. Each household has a list of suppliers they consider. The selection for this list is influenced by the various options of “supplier selection” to choose from in the facility screen. These options are: “having the same supplier”,” having the same type of supplier” or “considering all suppliers”. This gives a longlist of all the available appliances in the current year those suppliers hold.

Next in choosing an appliance there are some general technology-based restrictions applied to the list of appliances these suppliers have to offer. These are the following:

- A new TV should have at least the same width diagonally, as people don’t want a smaller TV than they already had.

- A new fridge cannot be much bigger than the old fridge, because then it would not fit in the same space anymore.
- A new washing machine is selected on whether its size is reasonable for the households size.

The outcome of applying these restrictions on the previous list of appliances available by the chosen suppliers is the ‘long list’. Next a number of these appliances on the “long list” will be added to the “short list”. The initial short list is a selection of the suppliers products he chooses for the customer. The shortlist is then expanded, when a household asks their friends and neighbours which appliances they own. Some of these appliances are then added to the ‘short list’, if they also were on the households “long list” already. Each household has an assigned value for the number of options that can be on their “short list”.

Utility Functions from Choice Experiments

Finally, the appliance a household buys is chosen from the ‘short list;’, based on the utility functions which are generated on the basis of the Cheetah survey. For each type of appliance, a utility function is constructed, the parameters are specific for the countries that are part of the survey. This section will further specify which aspects are considered when buying an appliance. Details regarding the utility functions and parameter values are adopted from [4].

There are several variables that influence which **fridge** households buy. First of all the size of their family. A second contributing factor is the income of the household. The environmental behaviour of a household in also included in the function. Households rate *volume* of the fridge in litres, the length of the *warranty* in years. Furthermore, the energy label of the fridge is taken into consideration and whether a subsidy is available, and, finally, the customer rating of the fridge.

Several parameters affect the **heating system** that households buy. First of all, the *price* of the heating system is important, including any rebate. Second there is the *age* of the buyer. The values of the *subsidies* from the government and the energy provider in Euros and the *expected cost savings* in Euros the new heating system provides are relevant. The installation time in days and the duration of the warranty in years are also included.

The variables that influence which **thermostat** people buy are: their *age,* their income, the net *price* of the thermostat, whether it is *recommended* by an independent expert, or by the energy provider, whether it is *remote controlled* and whether is *displays* the energy saving when the temperature is modified.

The Final Decision

The Cheetah survey also concluded that households are limited in the number of options they consider, they consider some of those that friends have, they can limit the number of shops they visit, which all are in line with the theory of planned behaviour [5]. The utility is calculated for a limited set of options, accordingly. Optionally, 'alpha' can be used alter the degree in which the results of the utility functions influence the decision on the appliance. High values of alpha cause the probability that a household chooses the appliance with the highest utility value to approach 100%. When the alpha is one, the probability of each appliance being chosen is exactly according to the utility values. When alpha is 0, appliances are chosen at random.

Policies

Within the model there are various ways to influence the environment in which the behavior takes place. There are also various policies that can be enabled, and modified specifically for each technology type. One of the policies influences which labels are allowed over the years for each type of appliance. In some policy options the minimum allowed energy label of an appliance gets raised faster, while during other options the minimum energy allowed label stays consistent for a longer time.

Another policy measure is the subsidy for households, when buying an appliance of certain labels. The amount of money, the number of years the subsidy is given, the minimum label of appliance it applies for and the type of household it applies on (none, low-income or all households) can be changed by sliders on the interface. The subsidy influences the households' choice in appliance, as it makes buying a more sustainable option more attractive.

Implementation and Data

The model is implemented in NetLogo. The model is data-free and all parameters, houseshold data, technology data, utility function data, and default policy parameters are read from text files at the start of the simulation. The model combines data from many sources (appliance data on the basis of public websites, household data from a large survey, etc.) The setup of the model allows for expansion in terms of policies, technology types, etc.

The model code is published on https://github.com/ejlchappin/emlab-consumer and through https://emlab.tudelft.nl.

Adoption of Smart Thermostats: 8 EU Countries – Subsidies

Simulations for each country of the adoption of smart thermostats are illustrated below (Fig. 45.2). These are results from over 170,000 runs, varying country, subsidy levels, whether the subsidy is only available to poor households or not. Results of other technologies are not presented in this paper, but are included in the same set of runs, which explains the high number of simulations.

Households consider purchasing a smart or regular thermostat using the utility function conceptualized earlier. As the initial conditions vary (e.g. the properties of households, the benefits they may have from a smart thermostat, whether they own a smart thermostat already), as well as the utility function parameters, the adoption curve for the countries differ, as well as the effect a subsidy has.

First results show differences in penetration rates, where Romania shows the largest adoption potential, and Poland the lowest. Furthermore, the effect of subsidies appear (almost) none in Romania, Germany, only little in Italy, Spain, Sweden and a somewhat effect in France, Poland, Sweden and the UK. The effect of the subsidy level varies: for the UK a subsidy of 30 Euros is efficient, whereas in Sweden and Poland there is an additional gain to go to 60 Euros.

This illustrates that within exactly the same model, location-specifics matter a lot, details with how a subsidy is implemented. In general, the effect of a subsidy is limited, which suggests the non-financial aspects of the decision, the fact that there still are up-front costs, and other barriers captured implicitly in the utility functions.

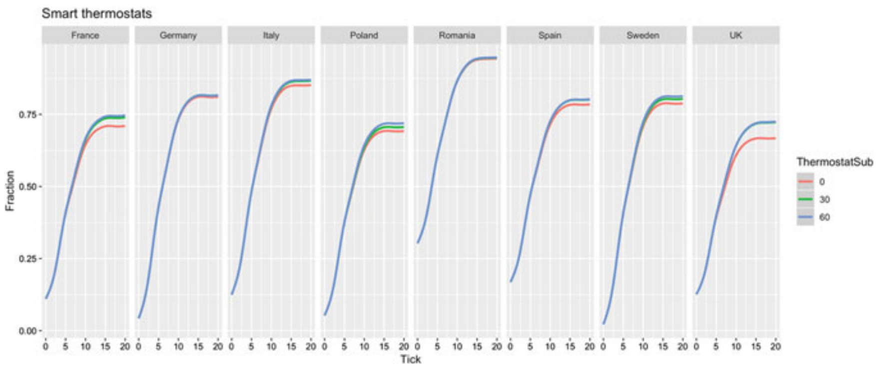

Fig. 45.2 Smart thermostat adoption in different countries, under different subsidy levels, over simulated time (in years)

Conclusions and Outlook

This paper presents an agent-based model of energy efficiency decisions in households, rooted in the theory of planned behavior and connected to a large survey of EU households, capturing 8 EU countries and utility functions for adoption decisions.

We have shown results on smart thermostats, illustrating differences between the effects of subsidies in 8 countries. The model is flexible and can be extended to include many other policies.

Future work includes a systematic analysis of this work in the context of other techno-economic models, simulations for other technologies, in particular fridges and heating systems, a detailed analysis of sensitivities and policy robustness and a detailed discussion of differences between countries. Furthermore, we expect to show a detailed policy analysis, with a wider variety of policies, also targeting at shops, which implies simulating more refined behavior of shops.

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Chapter 46
Simulating Innovation Networks of Lithium Batteries as Key Technologies in the German Energy Transition

Bert Droste-Franke, Markus Voge, Gabriele Fohr, Tanja Nietgen, and Davy van Doren

Abstract The objective of this paper is to present the features of a SKIN-based model that is being developed to simulate innovation networks of lithium batteries in Germany, being prepared to address relevant questions for the improvement of innovation processes in the technology sector.

Keywords Innovation networks · Key technologies · Lithium batteries · Simulation laboratory · German energy transition

Background

Although Germany has shown high ambitions to become leading in Europe in the production of battery-systems, there are still challenges regarding the initiation and optimization of involved value chains. To address these challenges, research has been conducted within the project "Network Analysis and Simulation of Innovation Dynamics for new Key Technologies in the Energy Sector" (InnoSEn), funded by the German Federal Ministry for Economic Affairs and Energy (BMWi). In the project, innovation networks of lithium batteries were analyzed and modelled as being one of the major key technologies for balancing demand and supply in the German energy sector [1]. We adapted the agent-based model "Simulating Knowledge Dynamics in Innovation Networks" (SKIN) to evaluate measures for improvements in the structure of the German innovation networks. The model includes actors involved in the development and commercialization of energy system technologies, as well as their behavior in innovation networks and related knowledge flows. By asking "if–then" questions, the model allows for the analysis of impacts and measures to overcome identified innovation barriers.

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The Overall Approach

The structure of the InnoSEn project followed the so-called Innovation Lab workflow. In this approach, as a first step, innovation barriers and potential measures are identified and translated to questions to the model. In a second step, the SKIN model is adapted to be able to answer the questions accordingly. In a third step, simulation experiments are defined and carried out to analyze optional measures via "if–then"-questions. In a fourth step, intermediate results are assessed to identify further valuable improvements to the model before, in a last step, final results are assessed.

We focus here on the questions derived in a mixed-methods approach, brief descriptions of some model modification and calibration activities, combined with presenting preliminary simulation results.

The Questions to the Model

In order to structure the area of analysis, the innovation system of lithium batteries has been analyzed by framing technological innovation system elements and functions on basis of the Technological Innovation System (TIS) approach. Knowledge generation and diffusion are defined as central TIS functions that may drive or inhibit the deployment of a new technology [2–5]. Based on this framework, questions to the model were derived from various empirical sources. Besides literature review, actor analysis, patent analysis and project data analysis, a workshop with high level experts from the field was carried out to evaluate the retrieved data. In addition, this workshop was used to derive a final set of innovation barriers and improvement measures, which were then translated to concrete questions for the simulation experiments. Concentrating on the analytical core of the SKIN model—namely cooperation and knowledge exchange processes—the following questions were derived:

- How should a cell production be designed and embedded? (possible goal: gain and exchange experience effectively)
- How should cooperation be managed along and across the value chain (e.g. allowing for feedback)?
- What are the impacts of …
    - increased financial support: storage usage, research, production?
    - improving IP regulation (more openness in cooperation / open innovation)?
    - introducing new elements like knowledge brokers / networks / consultancy in order to provide qualified/realistic information?
    - solutions for import dependency on upstream primary and processed products?
    - reliable standards?
    - positive developments in electro-mobility?

Modifications of the SKIN Model

The basic SKIN model is an agent-based model in which firms are represented by agents which own a specific set of knowledge consisting of the so-called “kenes”. A kene is a knowledge vector of a certain capability, ability and experience, situated in an environment of market, material resources and collaboration networks [6]. For the project, the model was adapted to key energy technologies by introducing new agents and characterizing them and their specific knowledge based on empirical findings. Furthermore, collaboration of the agents with other important players like research institutions and producers of technological inputs were specified, as well as the strongly regulated market conditions in the energy field.

In order to address the derived questions in the InnoSEn project, the basic SKIN model was modified in various ways:

1. In order to better capture knowledge exchange between the various important actors in the field, differences in exchange intensity in various formats are considered, distinguishing directly applicable and explicit knowledge. Also, absorptive capacity is taken into account by a distance measure.
2. In order to represent product quality more realistically, the relationship between product quality and expertise was modified. For this, a formula for expertise dependent on available directly applicable knowledge was introduced.
3. In order to be able to model the presence of large diverse corporations, mother firms were introduced. Mother firms have daughter firms that manage their own knowledge and produce a product, while mother firms receive revenues, pay costs and taxes, found new daughters, and buy start-ups.
4. In order to capture start-ups and spin-off dynamics, a module was developed that allows the creation of new firms. These new firms are either based on unused knowledge from the kenes of existing agents, or are characterized by a newly acquired knowledge base (based on [7]).
5. In order to address questions of cooperation along and across the value chain, a directed and subdivided product space was introduced, corresponding to various products of the relevant value chains.
6. In order to be able to model battery characteristics produced by the agents within the simulation experiments, assumptions for technical parameters and their potential improvements were introduced. The technical parameters represent the link to analyses of market values for stationary applications and other sectors.

Calibrating the SKIN-Model

The main calibration procedure represented the characterization of actors according to their cooperation and collaboration with regard to research projects [8] and patents [9]. In addition, agent specific data was used related to the sectors of economic activity, characteristics of their activity in the area of lithium batteries, and general economic data. Furthermore, technical data of existing and foreseeable future lithium battery technologies were considered.

Modelling Knowledge Generation and Exchange

As example for model modification we show here some details on how we model knowledge generation and exchange in firms and research institutes.

Firms and daughters of mother firms gain specific practical knowledge from production of goods and gain scientific knowledge from doing incremental research on their own. Such research is performed on their own in case that the product is not sold, or together with partners in publicly funded research projects. Radical research is done when their capital is below a certain threshold. The amount of knowledge increases with experience in production and in research projects. It influences the quality of the products produced applying this knowledge.

Research institutes carry out incremental research in publicly funded projects. The amount of knowledge increases when participating in research projects.

If not used in production or in research projects, the amount of knowledge decreases and can ultimately be forgotten.

In the model, knowledge exchange takes place with previous partners, suppliers and customers during cooperation for production and collaboration in funded research projects. The amount of knowledge received depends on the minimal distance of the new capacity to the capacities which the actor owns already, considering absorptive capacity linearly increasing by decreased distance. The directly applicable knowledge exchanged, includes particularly tacit knowledge. Furthermore, the less the firm already knows, the more its expertise increases with the same amount of knowledge exchanged.

First model runs show that foci on specific knowledge domains in research projects lead to its increased usage for production. Peaks of knowledge used in research projects appear also in the knowledge used for production (s. Fig. 46.1). If a reduced absorptive capacity with higher distance is assumed, wave structures can be observed in the knowledge applied for production (s. Fig. 46.2).

Conclusions

In order to be able to address questions of dynamics in technological innovation systems, we made substantial modifications to the basic SKIN model. Preliminary results for the modifications related to the generation and exchange of actor knowledge show that there is an influence of knowledge derived in research projects on knowledge used for production. This dynamic cannot be captured by the basic SKIN model. Future research includes further development of new modules, more extended

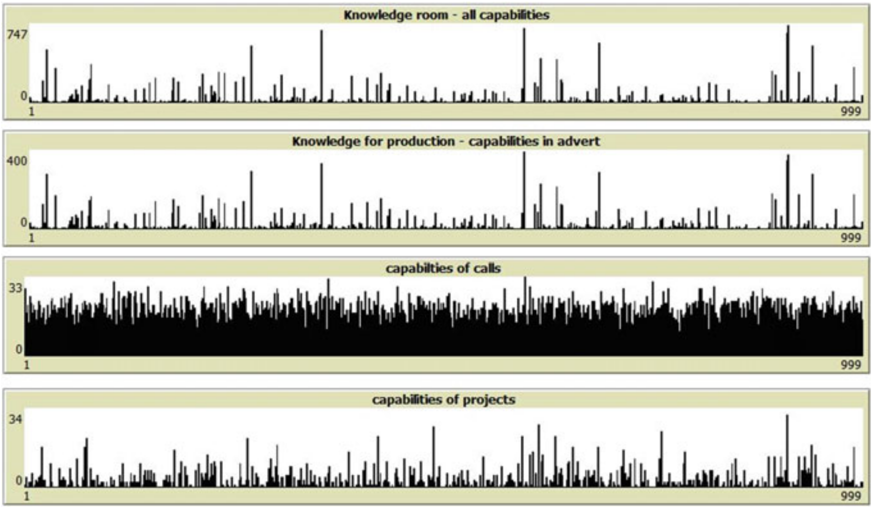

Fig. 46.1 Distribution of capabilities (capabilities 1 to 999) in research projects (fourth plot) compared with the complete knowledge space (first plot) and knowledge used for production of goods (second plot), without considering absorptive capacity with distance of knowledge

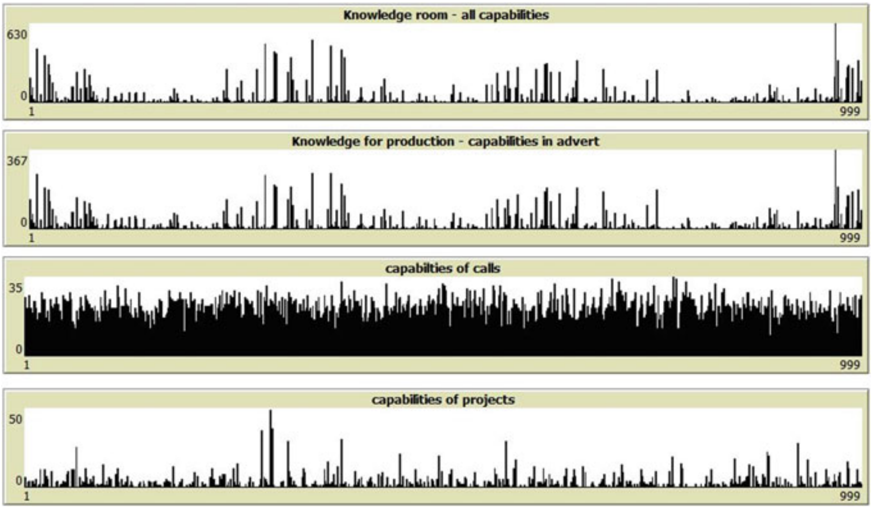

Fig. 46.2 Distribution of capabilities (capabilities 1 to 999) in research projects (fourth plot) compared with the complete knowledge space (first plot) and knowledge used for production of goods (second plot), considering reduced absorptive capacity with distance of knowledge

calibration of introduced processes and actor types, and setting up experiments to address the challenges of the energy sector in Germany.

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Chapter 47
Open and Integrative Modelling in Energy System Transitions—Conceptual Discussion About Model Reusability, Framework Requirements and Features

Geo Kocheril, Friedrich Krebs, Lukas Nacken, and Sascha Holzhauer

Abstract Computational modelling supports decision makers and stakeholders in understanding and governing socio-economic processes of energy system transitions (EST), and there exist numerous EST-specific models and frameworks with different disciplinary approaches. Many of these models are often not reused or extended for new research questions. In this article, we give reasons for reuse and integration of these models and approaches. Furthermore, we discuss which requirements and features support improved reusability, extension and integration of models and frameworks. We conceptualised essential requirements (e.g. modularity, coordination, consistency) and features of an open and integrative modelling framework (IMF). We could not identify an overarching integrative modelling framework (IMF) which met these requirements but we identified existing resources such as exemplary frameworks, concepts, protocols or standards for a potential IMF. Exemplary IMF features are coupling interfaces (CI), basic modelling interfaces (BMI), ontologies (e.g. OWL), formalisation (e.g. ODD, MoHub, UML, LP) and open-source licensing. Some promising paradigm-specific frameworks and scientific communities for a future IMF are identified.

Keywords Energy system transition · Model reusability · Integrative modelling · Framework requirements · Model coupling · Open modelling · Agent-based modelling · Optimisation

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Introduction—Challenges of Energy System Transitions

Complexity in socio-economic processes of energy system transitions (EST) towards a sustainable energy system arises e.g. from the interplay of collective environmental goals, individual investment decisions, technological options and regulatory effects on markets. Computational modelling support decision makers and affected stakeholders in understanding and governing this complexity. Within the still emerging field of Socio-Technical Energy Transition (STET) different modelling approaches have been discussed and evaluated [1, 2]. Furthermore, an interdisciplinary, collaborative research framework that facilitates model development was proposed, but an overarching integrated (model) framework is still lacking [1–4]. The question remains, how to efficiently reuse and extend the many existing modelling resources.

Integrative Modelling Framework (IMF)

Reasons for Reuse and Integrating Model Components and Models

Several modelling approaches address EST processes [1, 2, 4–7]. We focus on common approaches in the context of EST: agent-based modelling (ABM), system dynamics (SD), energy systems optimisation models [ESOM 2, 5]. The typical use case of a specific approach may indicate maturity and advantages in terms of computational and implementation efficiency in their field of application. Whereas there are reasons to address different areas (investment behaviour, technology options, energy costs, policies) specifically, models of a particular paradigm often share common components like energy market representation, technological profiles, or spatial representation. Reusable and tested model components reduce modelling efforts and improve the quality of a specific model implementation [8]. Furthermore, several model parts are often interconnected in the EST domain. An integrated and coupled EST domain model, connecting different parts of the energy system like power sector and mobility sector or stakeholder investment behaviour and market regulation, can show additional relevant dynamics. An integrative modelling framework (IMF) with reusable and connectable components in the EST context may improve model implementations for specific use cases at development stage [3, 8, 9]. However, the beneficial integration of different models and approaches in an open and integrative modelling framework, levering their most advantageous features with respect to the model purpose, has not yet been shown in EST [3, 4, 9, 10].

Requirements and Features of an Integrative Modelling Framework

A modelling software framework is a reusable set of software components together with an underlying conceptual structure. Based on this structure, the modelling framework provides a less-modifiable core infrastructure and explicitly extensible components. Such a framework provides generic functionality like an *agent component* in an ABM framework or a linear program component in ESOM. As a general requirement, modelling frameworks should provide an infrastructure following the concepts of *modularity* and *connectivity*, which allow the modeller to straighter reuse, extend and connect framework components internally and externally. As opposed to a monolithic design, a modular architecture design is characterized by connectable and extendable components. Regarding *connectivity,* an IMF should enhance connectivity functions between framework components and model modules by providing standardised application programming interfaces (API) or coupling interfaces (CI). *A s*upportive *modelling architecture (software)* simplifies the integration of different modelling approaches, model- and framework components. *W*e focus on two aspects of an IMF: the *coordination* and *consistency requirements.*

(a) Coordination requirements: to couple and to integrate model components or submodels, coordination functions are required. These functions can be provided by interfaces (CI, API) such as the standardised Basic Modelling Interface (BMI [9, 11]) or Functional Mock-up Interface (FMI [12]) for direct coupling or by a central coordination component. An IMF should provide coordination infrastructure (1) to enable potentially relevant dynamics of coupled and integrated model modules [9] and (2) to ensure data consistency requirements in terms of shared data. Multiple types of coupling of model modules are feasible, such as one-way coupling, two-way or n-way coupling incorporating multiple exchanges between multiple model modules. The *frequency* of these couplings is also an important integrative feature: simple one-time initial coupling, prescribed periodic coupling, or dynamic two-way feedbacks are distinct features. An additional important aspect of an architecture design is the interplay of various coordination types and frequency options. Are the different framework components interacting directly and accessing the shared data each in a stand-alone design? Alternatively, components are supported by a central coupling coordinator with interfaces (CI) providing shared and synced data [9].

(b) Consistency requirements: we define consistency requirements as an absence of inconsistence at the data level and at the model assumptions level. At the data level, important EST scales of temporal, spatial or techno-economic dimensions need to be harmonised and synchronised. At the model assumptions level, assumptions about the structural relations and dynamics in EST modelling such as interaction rules of agents or market mechanisms should be compatible or at least free of contradictions. Transparency and open modelling features are required for consistency- and reproducibility checks of framework components and model modules. This includes an open documentation of data structures, of implicit and explicit assumptions and of the program flow itself. One way to accomplish the transparency goal is to open-source

Table 47.1 Overview of requirements, framework architecture features, potential manifestations

Framework requirements (support, infrastructure)	Modelling architecture features of an integrative framework and possible manifestations for EST
Modularity	Modular architecture in contrast to a monolithic design
Connectivity	Soft coupling: general APIs, coupling interfaces (CI), Basic Modelling Interfaces (BMI [9]), Functional Mock-up Interface (FMI [12]), central coupler script or component; or hard wired inflexible direct coupling of models or components
Coordination infrastructure for coupling model components (design, type, frequency)	Coordination types: direct CI or coupling coordinator supporting one-way, two-way or n-way coupling and different frequency options (below)
	Coordination frequency: initial, prescribed, periodic, dynamic two-way feedbacks
Consistency at data- and assumptions level	Data consistency: shared and synced data base Transparency, open modelling: documentation, formalisation (ODD, MoHub, UML, LP), open source, open data [19, 20] (RAT)] Semantic consistency: ontology and OWL [21]

the code and provide explanatory documentation. Formalised documentation such as an UML diagram [13], ODD + [14, 15], MoHub [16] or a mathematical formula in a linear program [17, 18] enhances the ability to check, and reproduce the model's structural assumptions in terms of semantics and ontology. Additionally, making used data and source code publicly accessible (open data) improves transparency, reproducibility and consistency of coupled and integrated model components as well. The principles of and arguments for open modelling are similar and relevant for a reliable IMF in the scientific community [19]. Table 47.1 summarises features, generic and specific requirements of an IMF.

Findings, Discussion and Outlook

In our ongoing research of EST at the Department of Integrated Energy Systems (INES) we have experienced (1) that there are meaningful use cases for model reusability and an IMF, (2) that there is a research and framework development gap regarding an overarching interdisciplinary and integrative modelling framework (IMF) and (3) that there exist promising approach-specific frameworks and resources for integration and coupling. Coupling features (e.g. BMI, FMI) and open modelling like formalised documentation (e.g. ODD + D, MoHub, UML) are addressing parts of the IMF requirements. The existing paradigm-centred model frameworks such as EMLab [22], FAME [23–25], NetLogo [26], Mesa [27] in the ABM domain and Oemof [28] and PyPSA [29] in the optimisation domain form a valuable basis within a modelling paradigm scope for a potential IMF. Key requirements, features and exemplary manifestations of such an IMF architecture are shown in Table 47.1.

We focused on exemplary and typical modelling approaches in the context of EST, though there are other relevant approaches like evolutionary economics [2, 30, 31] or enhanced approaches e.g. Integrated Assessment Models (IAM) or even integrated approaches like Socio-Ecological Systems (SES) [2, 7]. We focused on one result of integrative modelling in [2, 3], stating that the integrative SES modelling approach showed favourable results [2] due to the combination of approaches like ABM and SD [32]. Many modelling approaches differ in their focus in the shared context of energy system transformation, an IMF may integrate the approaches and existing EST models advantageously.

Scientific communities such as the SSC/CoMSES [33], openmod initiative [34], Oemof (open energy modelling framework [28]), and the emerging Open Modelling Foundation (OMF [35]) may advance model reusability and the IMF idea. Hence, the base is laid and incentives are strong to realise an open IMF architecture in the context of EST. The results obtained so far, existing frameworks and resources, ongoing conceptual research and zeitgeist of open science are promising for such a future IMF. In summary, an integrative framework may be useful not only in terms of resource efficiency or replicability, but also in terms of addressing relevant dynamics of coupled sub-systems. An IMF may also bridge disciplinary isles and modelling paradigms.

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Part X
City Life

Chapter 48
Conceptual Framework for Modeling Complex Urban Systems—From Theoretical Assumptions to Empirical Basis

Marcin Wozniak

Abstract Growth of simulation methods in social sciences lead to a turn in the way we think about experimental approach in humanities. Simulation experiments inside artificial urban environments are one of the emerging research fields that may result in particularly interesting conclusions. The reason for this is straightforward link to the city governance and urban planning or, in general, the quality of life in cities. In this paper, we develop the universal conceptual framework for building agent-based models of the real cities: Complex Artificial Urban System (CAUSE). The geographical space in CAUSE is projected through GIS data. Agents' behaviors in the virtual sandbox replicate the major economic activities of humans. By assumption, we focus on the labor market and real estate market—these two crucial urban markets are modeled through the agent-based matching function approach. Inhabitants of the artificial city try to achieve the highest possible level of satisfaction maximizing individual utility function. This function is based on geographically adjusted five-level Maslow's pyramid. Analysis of such urban sandbox will help to address the vital questions about the role of physical city environment in both: the cities' economic performance and the decisions made by their inhabitants. As a result, CAUSE-based models could support the decisions made by policy makers to improve the quality of city life.

Keywords Urban simulation · Geographical information systems · Urban economics · City governance

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Introduction

Due to the massive evolution of both computer hardware and software, simulation in socio-economic science has become much more sophisticated, complex and realistic. One of the new simulation fields, which has appeared recently, is the technical possibility of putting artificial individuals (called agents) in real geographical spaces. Such fractions of Agent-Based Models (ABM) that link to geographical data were defined as geospatial simulation or just geosimulation [1]. In geosimulation, agents provide dynamics and geographical data determines a shape of a sandbox, from which the whole system evolves.

According to Zia et al. [2] there are three approaches to represent the geographical space in Agent-Based Models. The first approach is via creating network between the agents. The network represents the walkable space and the movements are along the network. The second option is via cellular automata approach, in which cells are both space and agents. In this approach move is represented by changes in the state of given cells. The third approach is combining Geographical Information System (GIS) data with ABM. Such an approach is very promising and very realistic.

In social sciences, geosimulation may be both very attractive (also visually) and a very powerful research method due to the fact that the actors (agents) interact in the real space. Despite the method being tempting, it suffers from some serious drawbacks. The most common are methodological shortcomings, which often come from immaturity of the method. As an illustrative example, let us take Tseng et al. [3] who simulated human life in an artificial New York City in order to investigate mutual interactions of inhabitants. Their 3D model was impressive, but it was too broad and lacked human-space interaction. Although complex and comprehensive, it lacked in-depth statistical and econometric analysis of output data. Additionally, the connection with urban economics or behavioral sciences is very weak. Although developed for a narrow application, not to miss visionary and inspiring model by Torrens [4]. Author develops GIS-based Salt Lake City sandbox to study urban design shape egress with concern for the smallest details of agents' movements (e.g. acceleration, collisions with others) and urban space (cars, buildings, trees).

On some closer research field, paper by Lyu and Vries [5] is also worth mentioning. The authors implemented in the model population, roads of different types, and four land-use classes (industry, office, commerce, green). On a basis of input parameters, the model generates desired urban layout in terms of transport and traffic optimization. The model, although preliminary and deprived of real city application, provides some general direction for further developments in the urban agent-based simulation.

One of the pioneers' papers is Zia et al. [2]. The authors simulated evacuation scenario in the European City of Linz using high-performance parallel computing and cellular automata approach. The large-scale ABM model projects the geographical space and replicate the full population of the city (200,000 agents). In addition, authors implement several aspects that influence human behaviors. The agents are equipped with different physical (age, sex) and cognitive (instinct, experience, trust) attributes.

In this paper, we link to presented research. The aim of this paper is to develop conceptual foundations for developing large-scale computational ABM of city life: the Complex Artificial Urban System (CAUSE).

Due to economies of scales, the cities provide a significant share of national production and higher productivity. EUROSTAT data show that Warsaw contributed 17.1% of the total GDP of Poland in 2016. In the same year, Rhine-Ruhr metropolitan region contributed 15% of the total GDP of Germany. In turn, Praha contributed 35% of the Czech GDP [1]. The world GDP leader is the city of Tokyo whose gross product is equal to the gross product of the whole of Spain and contributed 25% to the GDP of Japan [6]. According to the OECD by 2050, 70% of the world's population will live in cities (rise from 55% in 2015). Thus, the national GDP would also increase on account of cities the rising share of GDP.

Cities are the workhorses of our economy, and at the same time, cities are far from ideal. The most common urban problems discussed in literature are transportation system, pollution, segregation, crowds, unemployment, allocation of trade and services or simply poverty [7]. Some recent research has even proven that the increase of inequality in cities has led to the fall of the middle class [8]. More and more often, the term urban crisis has been starting to appear in scientific debate [9]. Linking these issues to both: rise of the population in the cities and emerging economic perturbations lead to the conclusion that advanced urban research is highly essential [10].

Recently, there has also been a growing discussion about digital twin cities—virtual replicas of real cities that allow for simulating improvements before implementing them. However, this physical dimension of the city is only one of the several components of which the urban fabric is comprised. Fact is that cities' management and urban prediction is limited due to the enormous complexity and massive interactions between city components [10]. In our framework, we want to highlight following general research problems:

1. What is the role of urban space in the economic performance of the cities?

1a. How urban environment affects economic decisions made by city inhabitants?

1b. How can we reshape urban environment to improve economic performance of the city?

We believe developing CAUSE helps to answer these vital questions. The framework allows for building agent-based models of cities that will provide simulated paths (what-if modeling) of the development under given geographical conditions to provide an experimental approach in dealing with problems of modern cities. The experiment allows to quantitatively asses the multidimensional determinants of cities' growth and decline with the particular focus on micro-level geographical space, which has so far been neglected.

Our framework combines the most important social elements of everyday city life and set it in the GIS space in the unified simulation model. Such an approach allows identification and assessment of interaction between agents and space that may affect city performance (positively or negatively).

CAUSE Framework

CAUSE Background

The general assumption of any type of Agent-Based Model is that individuals and their environment are explicitly represented in a computer program [11]. Actions and cooperation of multiple agents create the complex phenomena according to Aristotle's paradigm that the whole is more than the sum of parts. Heath et al. [12] point to two key elements of ABM that are: agents with their behavioral rules and the world—the scene where the action takes place. In CAUSE, the scene is the city explicitly represented through GIS data and projected through several functional layers. In turn, creating interactions' routines for agents in such models is defined as moving humans' functions (mental and physical) into virtual approximation [13]. The key point of any ABM is to use reasonable engines that drive the agents' behaviors in the virtual sandbox [14]. In CAUSE, we propose a modification of Maslow's pyramid to derive agents' utility function and drive their behavior in the artificial city.

CAUSE Intuition

Imagine that the virtual area that looks like a city that is already familiar to you. The space is filled with buildings, shops, roads, parks with trees, cars and peoples. This artificial construct has the same geography as your city. Therefore, there is a specific spatial distribution of business districts, residential and recreation areas, trade centers, roads and sidewalks. As an implication, each district of this city has unique characteristic, which is a function of many parameters like real estate and rental prices, population density, age, wages and distance from the city center. Inside the artificial urban fabric, inhabitants are engaged in their everyday duties. They navigate the spaces on their way to work or home. Maybe they are seeking a job or prefer unemployment. Food is bought and consumed by inhabitants to obtain energy and deal with daily activities. Capital and labor are exchanged for money or transformed into goods in the production process. In turn, money is exchanged for other resources and services. Similarly, to the flow of cells in the bloodstream, the roads and pathways assure proper functioning of the whole system. City inhabitants like blood cells move resources between different parts of the urban tissue. Such a city is a highly dynamic living system with definite boundaries and dynamics.

CAUSE Mechanics

Assume that each day in the artificial city is 1440 ticks—like 1440 min per 24 h in reality. Between the first and the last tick of the day, several activities take place.

Routine daily circulation of agents and several common activities are the key tasks that needs to be imitated. Intensity of activities depend on the day's pattern. In the morning, people rush to work, firms are supplied with resources; in the afternoon the move towards dwellings and recreation areas intensify. Like in a real city, streams of pedestrians and cars are larger during the day and decrease at night. Consequently, production, trade and other functions of city calms down at night, inhabitants regenerate, the whole habitat braces itself for another busy day.

CAUSE Geography

The general idea is that any city could be transformed into virtual sphere by uploading GIS land-use and land-cover data and adjusting initial parameters. CAUSE model consists of five main classes of geographical objects of different types. They interact to produce the shape urban area—the stage where the action takes place. Technically, these objects are:

(a) Living hubs—parts of urban fabric functioning as dwellings; premises of households; specific parts of the cities where agents rest, sleep, etc. characterized with real estate prices, rental prices, city transport access, living conditions (a synthetic indicator which includes population density, distance from city center, etc.)
(b) Production & services hubs—parts of the city where people work, firms produce and labor is exchanged for money. Characterized with city transport access, rents, number of vacancies, skill demand, etc.
(c) Trade hubs—parts of the city where people work, money is exchanged for goods and services. Characterized with a range of stock, rents, pricing and consumption options
(d) Recreation hubs—parts of the city where people can regenerate and refill the energy.
(e) Movable space—walkable elements of the city (paths, roads, walkaways)

CAUSE Inhabitants

Agents and households (city inhabitants). Households may be single, heterogeneous agent or multiple agents if living together. Characteristics of household members will consist of a few important social, economic and demographic parameters: e.g. age, education level, labor market status and job preferences, income and leisure activities.

We assume that there is a common background of needs for all the people around the world. The background is the derivative of Kenrick et al. [15] modification of the popular Maslow [16] concept. In CAUSE, it is simple agents' pyramid of needs, which consists of four levels:

(a) Physiological needs—food and rest. Satisfied through cyclically spending money on specific goods and services.

Fig. 48.1 Building the agents' utility function in CAUSE

(b) Safety needs:
(c) Financial—satisfied through the job market (e.g. wages; income/expenditures ratios; savings/investment ratios),
(d) Housing—satisfied through the real estate market (e.g. own/rent a property, rental prices).
(e) Belonging—friends and relationships. Satisfied through creating and sustaining the contact network with other agents.
(f) Esteem and self-actualization—social prestige, feeling of accomplishment, achieving full potential. Satisfied through the activity on three levels: job market, real estate market, friends and relationships. If agents achieve optimal status on these levels accumulatively, they succeed in satisfying esteem and self-actualization needs (Fig. 48.1).

In the real world countries and cities differ in several socio-economic characteristics (e.g. wages, prices, types of available vacancies etc.). As an implication, citizens satisfy those general set of needs in a different ways and the appropriate level of satisfaction is different in different geographical locations. Thus, in CAUSE, agents will maximize their utility with a location-specific set of behavioral routines.

The agents' economic activity in the virtual will take place on real estate and labor market—two important fields of socio-economic activity, which we want to focus on in the model. Both markets will be modelled through AB matching function approach. The matching function may be used as a mechanism that links agents in the several economics markets. It was widely tested in the economic literature and successfully applied to the both real estate market [17] and labor market [18]. Labor market is a part of human activity that allow households for earning money and consume. In turn, firms produce goods and services, which are sold or exchanged.

Activity on the real estate market is the second part of urban economic dynamics. Similarly, like on the labor market the number of transactions comes from the search behavior of buyers and sellers. However, the real estate matches are characterized with much lower frequency [19].

CAUSE settlers are free to pace the city, however roaming the space is costly. Every day, each agent updates Individual Daily Route (IDR)—the map he or she follows. IDR is dynamically updated on a basis of agent's resources (e.g. energy), external conditions (e.g. travel distance, level of discomfort) as well as topological features of the city (e.g. physical obstacles). The framework that provides foundation for pedestrian circulation in the artificial city is normative pedestrian behavior theory (NPB) by Hoogendoorn and Bovy [20]. In NPB agents optimize their route choices on a basis of common utility maximization concept applied to three extracted levels of walking behavior.

CAUSE Transportation System

CAUSE Transportation System (CTS). CTS is the CAUSE module that ensure fluctuations and dynamics of agents in the artificial city. Its role is to replicate the public transportation system. We want to extend the link-based concept by Wise et al. [21] by adding straightforward geographical dimensions. The transportation links in CAUSE will be constructed on a basis of GIS data (transport units). CTS provides lines for alternating traffic of public transport, and is responsible for the move of vehicles in the city. An agent wanting to move from point A to point B computes the optimal path along walkable space and CTS network then, if necessary, chooses the mean of transport. These route choices are driven by NPB framework elaborated on above.

Instead of Summary: Some Remarks on Implementation

Developing the model of selected city under CAUSE framework may be the challenging task. Complexity and scale of simulation are considerable. To make implementation easier, we divided CAUSE into five submodules (elements): GIS module, Agents & IDR, CTS, Labor market, Real estate market. The first submodule to be implemented is the GIS one (with roads, buildings and other necessary GIS layers). The GIS submodule provides the shape of the sandbox (the given city)—the stage where the action takes place. Other elements will be developed within GIS framework. We assume that each submodel (except GIS, which is the common part of the system) may be separately developed, run and tested. Finally, the submodels can be integrated into complete CAUSE-based city model.

Although one can create artificial city under CAUSE framework from scratch in the one of universal programming languages like JAVA or C + + , we consider focusing on one of the five environments that are actively used and developed for geosimulation purposes [22]. These platforms are NetLogo, Mason, RePast, GAMA and Anylogic. All of them support GIS data, however, these ABM environments differ in many important issues (e.g. the difficulty level of programming, technical support, availability of additional resources like exemplary models or tutorials, type of license). Other important issue is the final level of complexity of the artificial city. The CAUSE-based city model should be a compromise between acceptable simulation time, complexity and the model scale. It might be worth considering developing single district and then moving to larger scale applications.

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Chapter 49
Adapting the Social Force Model for Low Density Crowds in Open Environments

Manon Prédhumeau, Julie Dugdale, and Anne Spalanzani

Abstract The Social Force Model (SFM) successfully reproduces many collective phenomena in evacuations or dense crowds. However, pedestrians behaviour is context dependent and the SFM has some limitations when simulating crowds in an open environment under normal conditions. Specifically, in an urban public square pedestrians tend to expand their personal space and try to avoid dense areas to reduce the risk of collision. Based on the SFM, the proposed model splits the perception of pedestrians into a large perception zone and a restricted frontal zone to which they pay more attention. Through their perceptions, the agents estimate the crowd density and dynamically adapt their personal space. Finally, the original social force is tuned to reflect pedestrians preference of avoiding dense areas by turning rather than slowing down as long as there is enough space. Simulation results show that in the considered context the proposed approach produces more realistic behaviours than the original SFM. The simulated crowd is less dense with the same number of pedestrians and less collisions occur, which better fits the observations of sparse crowds in an open place under normal conditions.

Keywords Pedestrian dynamics · Multi-agent simulation · Crowd model

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Introduction

To design pleasant cities in which to live, it is useful to model urban places that potentially involve crowds of pedestrians, such as public squares or large streets. To model pedestrian crowds, microscopic approaches use agents with behaviours defined at the individual level, allowing both a fine-scale and a larger scale study [1]. These works very accurately reproduce individual movements and the emergent global behaviours caused by the interaction of agents, such as lane formation. Humans are social in nature, largely adhering to social norms. Even in sparse crowds, interactions quickly become complex because each pedestrian trajectory is influenced by many other people. Multi-agent crowd simulation is one of the microscopic approaches that has been used. In existing models agents must move from one point to another, while avoiding collisions with other agents. It is in how to deal with these potential collisions that the models differ. This article focuses on one of the most famous crowd simulation techniques: the Social Force Model (SFM) by Helbing and Molnár [1]. This model uses physical forces to model local agent interactions. The forces represent the internal motivations of pedestrians to perform some actions. This model has been widely used to study very dense crowds or panic situations. It successfully reproduces many collective phenomena during evacuation. However, pedestrians adapt their behaviour to the situation and the SFM has some limitations when simulating pedestrian flows in open spaces under normal conditions. To simulate a sparse crowd (density < 0.3 p/m^2) in a large open area without panic behaviour, such as pedestrians moving in an urban public square, adaptations are needed.

In this context, pedestrians tend to occupy the available space and seek to avoid dense areas in order to reduce the risk of collision [2, 3]. In this paper a modification of the SFM is proposed. The modification considers the visual perception of pedestrians; each pedestrian has a large perception zone and a restricted frontal zone to which they pay more attention. Using their perceptions, pedestrians estimate the density of their environment and dynamically adapt their personal space. Finally, the social force factors are tuned to reflect the perception and the assumption that in open spaces, pedestrians prefer to turn rather than slow down if there is enough space [2]. With these adaptations, the model better fits the characteristics of crowds in an open square place under normal conditions, as reported in the literature [2, 4–6]. The results show that in less dense crowds less collisions occur; this fits empirical observations in sparse crowds where rare bumping events are reported [7]. Moreover, our model is faster and provides a very simple way to vary the characteristics between agents.

This paper is organized as follows. In section "Literature Review", the SFM and its prior adaptations are reviewed. In particular, the limitations of simulating sparse crowds in large open areas under normal conditions are addressed. Section "The Proposed Adaptation" presents the proposed adaptations. Section "Simulation and Experimentation" describes the simulation design, the scenarios and the criteria considered for the model evaluation. Section "Results and Discussion" presents the simulation results. Lastly, section "Conclusion" discusses conclusions and future work.

Literature Review

The Social Force Model and Its Adaptations

The SFM captures the motion of each pedestrian by Newtonian dynamics. In the original model, three forces describe the internal motivations of pedestrians. A desire force represents the agent's aspiration to move towards its destination. A repulsive force comes from other pedestrians (namely "social force") and from static obstacles so that the pedestrian can avoid them when they are too close. A third force models the attraction towards certain interest points (e.g. window displays). The resulting force applied to a pedestrian p is defined as:

$$\overrightarrow{F_p}(t) = \overrightarrow{F}_p^{des}(t) + \sum_{q \neq p}^{N_{ped}} \overrightarrow{F}_{pq}^{soc}(t) + \sum_{b} \overrightarrow{F}_{pb}^{repuls}(t) + \sum_{k} \overrightarrow{F}_{pk}^{attr}(t) + rand \quad (49.1)$$

where q represents another pedestrian among the N_{ped} pedestrians in the scene. b is a static obstacle exercising a repulsive force toward p. k is an interest point for a pedestrian. $rand$ represents random variations that prevent the simulated agents from having a too rigid behaviour. Each force term is detailed in [1].

Some adaptations of the model that focus on specific contexts have been proposed. To match flow rates in very dense crowds, a respect area with a "self-stopping" mechanism has been added to prevent agents from continuously pushing over other agents [8]. In [9], anticipation has been added to the model by using predicted positions. Helbing, Farkas and Vicsek worked on several adaptations of their original model, for example simulating escape panic situations [10]. A new force models the physical force when a collision happens between two panicking pedestrians. This force prevents agents from physical overlapping when all other forces are very strong. The force combines a "body force" to represent the physical body and a "sliding friction force" to make colliding agents turn to opposite sides instead of pushing. The authors also worked on an unified model to represent normal and panic situations, with the addition of a nervousness parameter [4]. In [11], the authors proposed an interaction law from controlled experiments with pedestrians performing avoidance in a corridor.

The Reference Model and Its Limitations

As pointed by Lakoba, Kaup and Finkelsteinet [12], some SFM parameters produce unrealistic behaviours if applied to a small number of pedestrians. They proposed modifications to avoid the following problems: physical overlapping or too strong body force if a collision happens; social force independent of the density and of pedestrians' orientation.

We reuse some of their ideas in the work described in this paper. A physical collision force was added in order to prevent overlapping pedestrians. In [10], the factors used for the body force and the sliding friction force are $k = 1.2 \times 10^5$ kg/s^2 and $\kappa = 2.4 \times 10^5$ kg/m/s respectively. These parameters make pedestrians very rigid and although this is suitable in the panic scenario, such values result in unrealistically high contact force in a sparse crowd. In [12], they reduced these parameters to $k = 2.4 \times 10^4$ kg/s^2 and $\kappa = 1$ kg/m/s. They validate their model with 100 pedestrians who have to exit a room by one door. In our context, these parameters are adapted as we do not want pedestrians to be projected during contact. After simulation tests, parameters values are set to $k = 12$ kg/s^2 and $\kappa = 24$ kg/m/s. The values were chosen by hand and can be refined with real data in future work. In real crowds, pedestrians simply rotate their shoulders in a shared effort to avoid the collision [13].

Although most crowd models use a circle of 0.7 m diameter, it is more realistic to take into account the human body form. The shoulder width and body depth of pedestrians follow uniform distributions respectively from 39 to 51.5 cm and from 23.5 to 32.5 cm [14]. These new shapes were used in the computation of social forces. Indeed, when walking through a crowd, pedestrians consider their own body size and the body size of other pedestrians to estimate the distance physically separating them. To calculate this physical distance, the distance between their positions was computed and the radius of each pedestrian ellipse was subtracted. Unlike a circle, the radius of an ellipse depends on the pedestrian's orientation angle. The following equation is used to find the radius of p, in interaction with a neighbour q:

$$r_p = \frac{\frac{w}{2} \times \frac{d}{2}}{\sqrt{(\frac{d}{2})^2 \times \sin^2(\alpha) + (\frac{w}{2})^2 \times \cos^2(\alpha)}} \tag{49.2}$$

with w and d the body width and depth of p and α the angle between p orientation and the direction from p position to q position.

The third problem identified by Lakoba, Kaup and Finkelsteinet is that the social force is independent of the crowd density and the orientation of pedestrians. In the original SFM the selected parameters mean that the social force between pedestrians who are located only 50 cm away is very small, which is not realistic for a less dense crowd. In [12], the parameters are adapted to represent the fact that a pedestrian feels a greater social force from obstacles in front of him than from behind. Another approach to treat this issue is presented in section "The Proposed Adaptation". We believe that as the crowd density increases, pedestrians are more willing to get closer to other pedestrians. Based on empirical observations from video data and on [2, 3], a second hypothesis is discussed: in sparse crowds, pedestrians are also more willing to turn rather than slow down as they approach a crowd. In brief, the base model used to build the adaptation presented in this paper is the SFM [11] including a physical collision force to prevent overlapping [12] and an ellipse body shape.

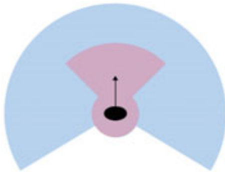


Fig. 49.1 Pedestrian perception zone in blue and attention zone in red

The Proposed Adaptation

The baseline observation is that with the SFM, pedestrians in low crowd densities maintain very straight trajectories and many collisions occur, unlike in reality. The assumption behind this is that pedestrians slow down maintaining their trajectory rather than moving away, even if it means entering a dense area with a high risk of collision. However, our hypothesis is that in an open space, where pedestrians can spread out, they will tend to occupy the available space and seek to reduce density in order to reduce the collision risk [3]. To test this hypothesis, perception is added to pedestrians so they adapt their personal space to the crowd density and consequently modify their behaviour.

A Refined Perception

In the initial SFM, pedestrians perceive all other agents and the social force is lessened with the distance. To be more realistic, pedestrians were given a perception zone of 220° up to a distance of 7 m [15], adding to a 360° 1.5 m wide zone. This represents the vision field of pedestrians, their auditory perception and the fact that they can rotate the head. Pedestrians do not pay the same attention level to all areas around them. Instead a lot of attention is paid to the "Information Process" zone [16]. Thus a finer zone is added in front of the pedestrians, called the attention zone, to which they pay more attention than the rest of the perception zone. This zone corresponds to a 90° 4.5 m wide zone plus a 360° 1.5 m wide zone. Therefore, pedestrians are more attentive to their close surroundings in their current direction (see Fig. 49.1). This new perception allows the pedestrians to differentiate between more important obstacles and the off-centered ones. In addition to increasing realism, by considering only the perceived neighbours the simulation time is reduced.

A Scalable Personal Space

Humans have a personal space corresponding to the region surrounding them which they regard as psychologically theirs [15]. As crowd density increases, pedestrians are more willing to approach other pedestrians. In this work using their perceptions, pedestrians estimate the density of the crowd and dynamically adapt their ellipse size, representing their body shape and their personal space. In a dense crowd, there is no margin around the agents, the ellipse is equal to the body shape. If a pedestrian passes a few centimetres from another pedestrian, there will be no feeling of intrusion. This is what is observed in heavily crowded situations where pedestrians are willing to forego their personal space and accept being close to other pedestrians, even strangers. On the contrary, in a dispersed crowd, the margin around the agent increases: if there is enough space, pedestrians will not normally brush against each other. In this case, the ellipse corresponds to the agent's body and its extended personal space.

The agents estimate the crowd density by using their perception zone as defined in Fig. 49.1. To determine the perceived crowd density, the number of agents currently present in this perception area, which corresponds to their neighbours, is calculated. The surrounding density in pedestrians per square meter is obtained by dividing the number of neighbours by the perceived area.

To define the size of the personal space according to the density, we use the concept of Level of Service (LoS) [17]. The LoS is a qualitative measure of the traffic service quality, defined from A to F. A corresponds to a free flow where no adaptation is needed to avoid collisions and F represents a very crowded space. The level values have been corrected many times and several versions exist depending on the considered configuration. In this paper the values defined for the walkways and sidewalks in the Highway Capacity Manual (HCM), a model that is recognized and widely used by urban planners, are used [5]. The LoS A corresponds to a maximum density of 0.18 p/m^2, LoS B is a maximum density of 0.27 p/m^2, LoS C has a maximum density of 0.45 p/m^2, LoS D corresponds to a maximum density of 0.71 p/m^2 and LoS E has a maximum density of 1.33 p/m^2. The LoS defined for walkways was used since it considers mainly frontal collisions. A more accurate ranking could be done if the same information was available for large pedestrian streets or public squares.

It is assumed that a pedestrian's personal space is egg shaped, as people are more exigent in terms of respecting their frontal space [18]. To represent this, a combination of two ellipses is used: a small ellipse for the back, when the angle is greater than 90° from pedestrian orientation and a larger ellipse for the front.

A function was defined that uses density to obtain the three margins around the agent body that represents the agent's personal space (see Fig. 49.2). The LoS was used to get a maximum personal space in LoS A, and a non existent personal space in LoS E and F. On each side of the pedestrian, a space is defined reflecting the observations that pedestrians do not need a lot of lateral space between each other to cross. The space behind the pedestrian is more important than the side space because pedestrians do not follow each other too closely in the street. The front space is the largest space. The personal spaces of two interacting pedestrians is considered; if they are aligned laterally the space in between them is twice the individual lateral space. These values are inspired from the experiment of [18] and will be calibrated with real data in future work.

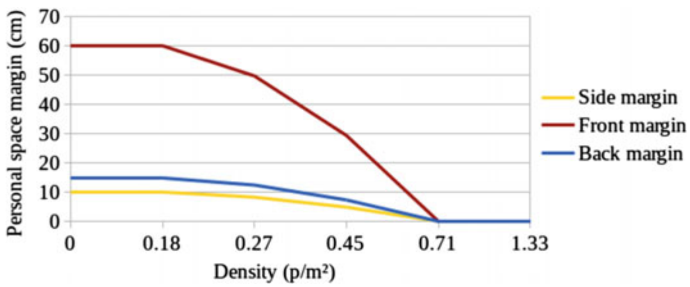


Fig. 49.2 Margins around the agent body as a function of density

A Revised Social Force

The reference SFM produces very straight trajectories while in real life dense crowds pedestrians adapt very quickly and slalom to follow the fastest path [8]. Indeed, pedestrians change their behaviour according to the density of others around them [2]. If the density increases, pedestrians walk faster and change their direction at a greater degree than with low flow. The social force factor is tuned to reflect the presence of the attention zone described in section "A Refined Perception" and the hypothesis that in an open environment, pedestrians are more dynamic and likely to turn if there is space. When computing the social force with the perceived neighbours, the velocity factor is divided by 10 because the original velocity factor slows down pedestrians too much. To compensate, with the neighbours in the attention zone the angular factor is multiplied by 2 and the velocity factor is reduced by 2 only. This reflects the observations made in [2]. The force parameters were tuned by hand over three scenarios and these values yielded the results that better fits with observations. In future work they will be refined using real data.

Algorithm 1 presents an overview of the refined approach.

Simulation and Experimentation

All experiments were run using Pedsim_ros [19], an open source crowd simulator that implements the SFM [11]. Some features were added to compare the SFM in section "The Reference Model and Its Limitations" with the approach proposed in section "The Proposed Adaptation". Except the adaptations presented above, all parameters used are the ones from [11]. The simulation time step is 0.04s and the desired velocity follows a normal distribution with $\mu = 1.34$ m/s and $\sigma^2 = 0.26$ m/s, which is the observed average walking speed [6].

The differences between the two compared models are summarized as follows. In the SFM, the agent size is the agent's body size without personal space. To compute the social forces, a pedestrian considers all the other agents. In the proposed approach,

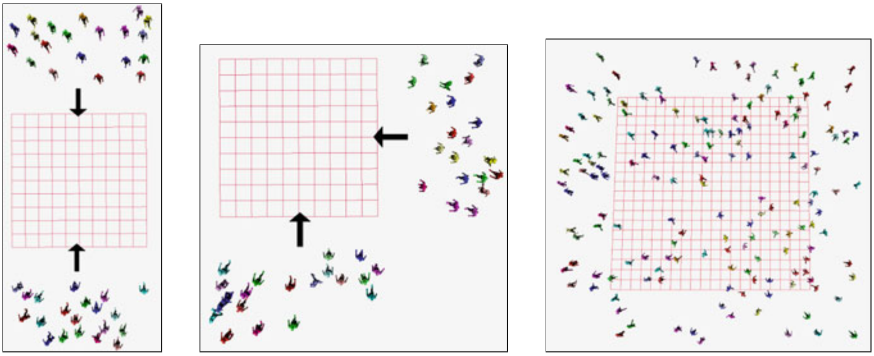
Algorithm 1: Overview algorithm

```
input  : agents: all agents in the simulation
begin
    for a in agents do
        Perceive neighbours in perception zone
        Compute perceived_density in perception zone
        Compute personal space p_space according to perceived_density
        for n in a.neighbours do
            Compute distance between a.p_space and n.p_space
            force = social force exerted by n on a
            if n in attention zone of a then
                force = force increased
            end
            if a and n bodies overlap then
                force + = body force + sliding friction force
            end
            a.F_soc += force
        end
    end
end
```

the agent's body size and its personal space, which varies according to the perceived density, are considered. To compute the social forces, a pedestrian considers its perceived neighbours and distinguishes between neighbours in the attention zone from more distant ones in order to adapt its avoidance behaviour.

Three scenarios are considered that occur in an open urban place (see Fig. 49.3): two crowd flows in a frontal crossing, two crowd flows in a perpendicular crossing and a disorganized crowd with pedestrians crossing a big square place from different directions. For each scenario, we studied three densities which are common in public places or large pedestrian streets: very low density (LoS A), low density (LoS B) and moderate density (LoS C). For very low density, 10 pedestrians cross 10 others in the frontal and perpendicular scenarios and 80 pedestrians are in the big crowd. For low density, 20 pedestrians cross 20 others and 160 pedestrians form the big crowd. For moderate density, 30 pedestrians cross 30 others and 240 pedestrians compose the big crowd. Each simulation case has been replicated 100 times to obtain significant results.

Experiment measures are conducted for a central zone (red grid in Fig. 49.3). Thus only the interacting pedestrians are considered during crossing. Average values and standard deviations are computed. The number of collisions (when the bodies of two agents touch each other) that happen in the central zone are counted for 10 s, from 5 s to 15 s to let the agents reach the zone. The density and the velocity in the central zone are averaged for 3 s, between 5 s and 8 s, to let the agents reach the zone. Longer times are not measured because the fastest agents have already left the area and only the slow ones remain, which biases the measurement. In the case of



(a) Frontal (b) Perpendicular (c) Big crowd

Fig. 49.3 The three scenarios with low density at simulation time t = 0 s

the frontal crossing, the lateral spreading is measured to check if the agents take up more space.

Results and Discussion

Figure 49.4 shows the average measured density for each scenario for both models at the same initial density, i.e. same number of pedestrians. For the frontal scenario (triangle markers) and the perpendicular scenario (square markers), the proposed model, represented by the lines in orange-red tones, produces crowds that are significantly less dense than the SFM, shown in blue lines, regardless of the initial density (p-values < 0.001). For the big crowd scenario, both models produce the same measured density (p-values > 0.5). The lower density produced by the proposed model can be explained by a better use of the available space. For the frontal scenario, for instance, the lateral spread is slightly larger with the proposed model than with the SFM (p-values < 0.05). The lowest density obtained with the proposed model is possible because agents tend to spread out in a wide and open space [3].

We then studied how the number of collisions evolves with the density for both models. In the frontal and the big crowd scenarios, no collisions occur at very low density with both models. For low density, some collisions happen with the SFM (5 collisions in average in 10 s for frontal scenario and 3 collisions in 10 s for big crowd scenario) while very few or no collisions happen with the proposed model. At moderate density, the number of collisions in the SFM becomes important while in the proposed model it stays low (13 collisions instead of 5 in the big crowd scenario and 15 collisions instead of 4 in the frontal scenario). In the frontal scenario, the proposed model gives a lower density than the SFM, so that for the same number of pedestrians, the density does not exceed 0.3 p/m^2. More densities will be studied in future work.

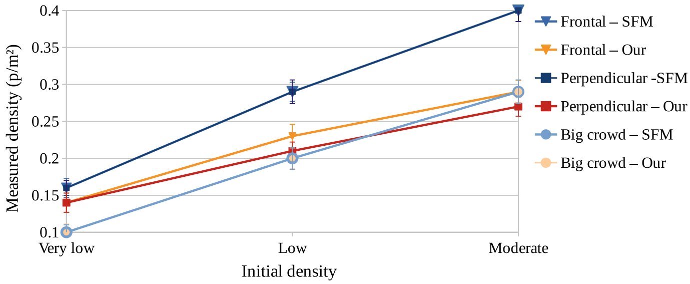


Fig. 49.4 Measured density depending on initial density, scenario and model

For the perpendicular scenario, in both models and for all measured densities, no collisions appear in the median result. Nevertheless the proposed model introduces some rare collisions at moderate density of 0.27 p/m^2: on average, 2 collisions for 10 s. Collisions are very rare in the perpendicular crossing scenario for two reasons. Firstly, there is less body surface for a possible collision with a perpendicular crossing than with a frontal crossing. At a frontal crossing, pedestrians are facing each other and must avoid collisions by taking into account their, and the oncoming pedestrian's, shoulder width. At perpendicular crossings, pedestrians must avoid collisions by taking into account their shoulder width and the body depth of the arriving pedestrian. The second reason is due to the way the social force is calculated. If two pedestrians arrive perfectly ahead, they slow down but continue to move forward and sometimes they turn too late and the shoulders of the pedestrians touch. If two pedestrians cross perpendicularly, this model limit does not apply. This reflects the observations: it is more common and socially accepted that pedestrians touch each other shoulder to shoulder during frontal crossing, rather than a pedestrian touches the chest or back of another pedestrian with his shoulder [13].

For the frontal and the big crowd scenarios, the proposed model produces significantly less collisions than the SFM for the same initial conditions and the same density (p-values < 0.01). This confirms that the SFM is suitable for congested panic situations, where collisions frequently occur. Note that experimental data concerning the number of collisions in crowds was not found. However, it is reasonable to assume that pedestrians do not collide with each other in normal conditions at low density. Thus, the proposed model appears to perform better than the SFM. The rare collisions with the perpendicular scenario at moderate density could be verified if more collision data were available. A number of collisions greater than zero is acceptable because in dense conditions, some pedestrians may pass very close to each other or even touch. In reality, many collisions are avoided by a slight rotation of the shoulders [13].

The average speed of agents according to the measured density and the scenario was compared for the two models (see Fig. 49.5). For the frontal scenario, the agents in the proposed model are faster than those using the SFM (p-values < 0.001). Their speed better fits the pedestrian speed in the HCM 2000 [5] for walkways and

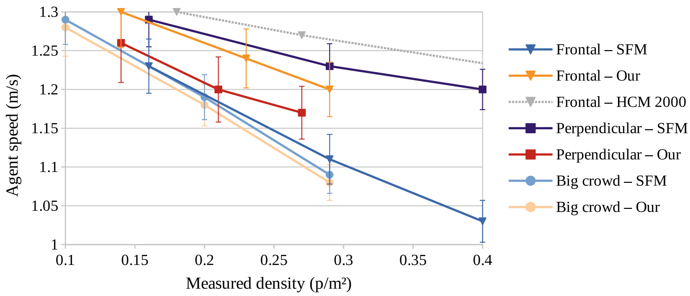


Fig. 49.5 Agents speed depending on measured density, scenario and model

sidewalks, where the interactions are frontal. For the perpendicular scenario, the proposed model produces slower pedestrians than with the SFM (p-values < 0.001). This result requires further validation but is conceivable as it is harder to cross a perpendicular flow than a parallel one, where the formed lines are easy to follow. In the big crowd scenario, the SFM and the proposed model show very similar speeds in all densities. This speed complies with the average walking speed in pedestrian zones [6].

A video showing the differences between the SFM and the proposed adaptation is available.[1] At moderate density, lane formation is observed in the two models. In moderate density situations, some impatient pedestrians try to overtake others if they find a gap [4]. This phenomenon appears in the proposed model.

Finally, a very positive point about the proposed model is that it results in faster simulations. The computational performances of both approaches were assessed on standard PC hardware (Intel Core i7-7920HQ, 4.10GHz). The big crowd scenario was simulated with 100, 200 and 500 pedestrians during 15 s. For 100 pedestrians, both models run in 15.02 s (i.e. close to real time). For 200 pedestrians, the SFM approach runs in 20.30 s while the proposed approach runs in 15.02 s. For 500 pedestrians, the SFM runs in 126.97 s while the proposed model runs in 66.51 s. This confirms that the SFM slows down quickly as the number of agents increases. The adapted model is faster since only the close neighbours are considered for the social forces. In the new model, the density has more influence on performance than the total number of agents.

Conclusion

This paper introduced a modified social force model to simulate a low density crowd ($<$0.3 p/m^2) in an open environment under normal conditions, such as pedestrians moving in an urban public square. The modified model considers the pedestrians'

[1] https://youtu.be/Rk2R76VFId8.

perception, with a large zone and a frontal zone to which they pay more attention. Through their perception, pedestrians estimate the crowd density and dynamically adapt their personal space. Finally, the social force is tuned to reflect pedestrians preference to avoid dense areas by turning rather than slowing down. Simulations were performed on scenarios with densities ranging from 0.1 p/m^2 to 0.4 p/m^2 in order to compare the number of collisions, the density and the velocity with the reference SFM. Simulation results show that the proposed model produces less dense crowds of more dynamic pedestrians with less collisions. This better fits the experimental observations for a sparse crowd [2–7]. The proposed model is faster and provides a simple way to vary sizes, perception and attention levels among agents. Although works have analyzed people movements in corridors, pedestrian trajectories in open urban environment are needed to further calibrate the model parameters. The collisions count will be complemented by other validation metrics, such as a quantitative comparison with video sequences. Usually simulated crowds flows go from a large place to a narrower street to study bottlenecks. The proposed model can also used to study the spreading of pedestrians from a street to a wider place.

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Chapter 50
Urbanization from the Bottom-Up

Victor Peña-Guillen

Abstract House consolidation is a process of self-help building where house state is improved progressively from initial precarious conditions. It is conducted by low income households located at informal land developments in the periphery of Lima, Peru. An agent-based analogy of the consolidation system is devised to provide an experimental setting at block scale. Initial states are grown up towards consolidated conditions through diffusion within a network of interacting households. Emergent spatial and temporal trajectories of state transition resemble actual process. The study of influence between neighbors allow to investigate two features of the decision to upgrade: income stream and family needs.

Keywords House consolidation · Epidemic diffusion · Urbanization

The Consolidation System

Informal Urbanization at Block Scale in Lima

The urban population in Peru has grown from 68.7% in 1990 to 78.7 % in 2015 [1]. Single-family detached houses hold the major proportion in this country, i.e., 76.5% of total individual housing units. Informal development of residential areas is a well recognized provider of single-family detached houses for urban poor. The role of informal urbanization and house consolidation have been particularly determinant in shaping Peruvian urban policies in the last 60 years [2]. This long lasting national housing policy recognizes self-help house building as a valid mechanism for progressive house supply, which is driven in response to changing housing needs and resources availability within an individual household.

In the case of Lima, Williams [3] found that consolidation is an independent and progressive phenomenon, and stated the need of a more dynamic approach to

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explain it. Tokeshi et al. [4] identified contagion of similar house typologies that are copied between nearby households. Peek [5] tracked typical single-family houses growing-up across the process. The social simulation approach, employed in this study, investigates the extent of how social interactions and influence weights up in the decision to upgrade, and in the spread of consolidation within the space of the housing block.

Urbanization from the Bottom-Up

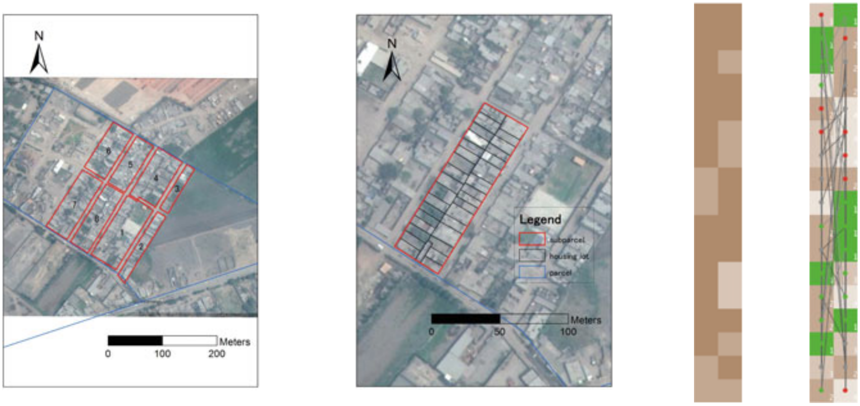
The physical change in houses located within informal sub-divisions is better observed at block scale. Schwirian (1983)[6] citing Suttles (1972) states that the face-block is the most basic form of city neighborhood. As individuals gather within the regular space of the block, proximity is credited to exert influence in householder's decision to upgrade. The representation of consolidation at micro scale as a socio-spatial mechanism, provides a research devise that acknowledge individual decision-making and social interactions regarding land use change [7]. Moreover, its dynamics generate patterns of upgrading conditions in space at upper aggregated scales across time [8]. Thus, resulting heterogeneous patterns of informal urban spaces are the result of individuals operating in decentralized and independently ways.

Method

Structure of the Consolidation Model

The model provides the ability to conduct dynamic simulations of the consolidation process by considering spatial and social dimensions. Internal elements and operation of state transition process are implemented using the susceptible-infected-recovered-susceptible (SIRS) algorithm. SIRS is an epidemic diffusion mechanism developed by Kermack and McKendrick (1927) [9] and improved by Dietz (1967). This epidemic model provides an analogy of diffusion of state transition through a network of social contacts within the housing block.

The initial settings of the Model of Consolidation are derived from actual house conditions and its spatial configuration across the block. The diffusion parameters are taken from the aggregated number of state changes, which in turn are translated to transition probabilities. The space of the block is represented by a cell grid, it replicates the regular space of an informal block (Fig. 50.1). The households relations are represented by a network structure, which is attached to the grid; therefore as the cell change its state the coupled node do as well.



(a) Parcel (b) Block (c) Grid (d) Graph

Fig. 50.1 Actual block setting (**a**, **b**) and the analogy of consolidation (**c**, **d**)

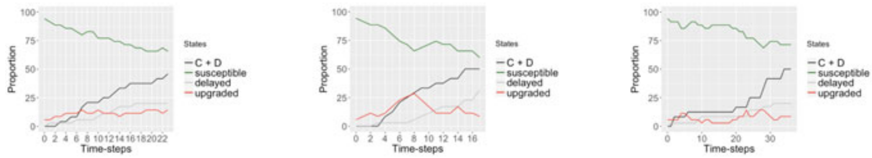
Operation of the Model

The infected state on the node represents the condition of the already upgraded house. The non-infected state corresponds to the susceptible node that could be upgraded depending on the occurrence of two conditions (income stream and social influence). Finally, the resistant state replicates the node that delays upgrade. The probability of "infection" is defined by the contagion parameter called Upgrade-spread-chance (USCh); this is the necessary and sufficient requirement for simulation, considering that in case USCh = 0 there is no operation in the model. It replicates the actual case where households have neither the needs nor the resources to upgrade. The adapted algorithm allow nodes to get any of the states asynchronously. A household could have the chance to get "susceptible" and therefore be "infected" again by their fellow neighbors that are in a higher construction state. However, the chance to maintain its state while facing the influence is also present. This last option replicates the case of houses that do not improve its condition, and could be explained as a result of either the lack of resources or having no needs of house space.

Results

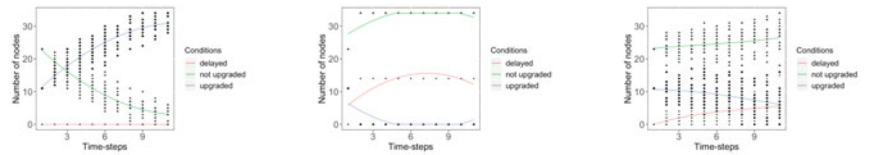
Spatial Configuration and State Transition Trajectories

Simulation outcomes reveal temporal trajectories that reproduce actual house consolidation across states (Fig. 50.2). The emergent spatial configuration in the block



(a) Run 1 (b) Run 2 (c) Run 3

Fig. 50.2 Diffusion conditions on nodes and consolidated trajectories (C+D) at block scale



(a) No resistance and no recover (USCh = 49, GRch = 0, RCh = 0)

(b) Full resistance and full recover (USCh = 49, GRch = 100, RCh= 100)

(c) Empirically-derived transition settings (USCh = 49, GRch = 24, RCh= 35)

Fig. 50.3 Experimental factors considered in the decision to upgrade

shows cells that are changing states in locations that are already upgraded during the initial stages of simulation. It is worth noting the increase in the number of nodes corresponding to the delayed condition in all experiments, while the number of upgraded nodes decreases.

Factors in Upgrade Diffusion

Two extreme cases provide the justification for the use of epidemics in the representation of income streaming factor (Fig. 50.3). First, constant stream income (full), is replicated by assigning gain-resistance-chance (GRCh) a zero value. Second, variable income stream, replicates the opposite condition of consolidation by assigning GRCh factor a value of 100. Constant income stream may be a necessary condition for investment but not sufficient.

Discussion

This investigation employs three empirically-derived transition probabilities to replicate house state transition: upgrade (USCh), get susceptible (RCh), and delayed (GRCh). These diffusion probabilities reflect social behavior of transmitting the decision to upgrade. Spatial patterns show no clustering of upgraded houses; moreover, patterns across simulations generate variable regions within the grid that suggest path dependence. Path dependence highlights the decision reliance on individual features and aggregated block configuration rather than only social influence generated by diffusion. Further work is required to investigate the extent social interactions and influence weights up in decision to upgrade together to family needs and income stream.

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Part XI
Simulating Mobility

Chapter 51
The Effect of Urban and Rural Mobility Behaviour on Congestion and Emissions Resulting from Private Motorized Traffic

Simon Plakolb, Georg Jäger, Christian Hofer, and Manfred Füllsack

Abstract In this study we investigate the different effects of urban and rural mobility behaviour on congestion and emissions. For this we use a mesoscopic hybrid agent-based network traffic model to simulate traffic in a city on a 1:1 scale. The main advantage of the used model is that it does not need origin-destination data as an input, but rather calculates this information based on mobility behaviour. This makes it possible to produce a population of urban agents, but giving them typical rural mobility behaviour. This changes how much they travel, what method of transport they use, as well as the reason and length of their trips. We can directly compare the resulting congestion, CO_2 emissions and NO_X emissions with local and temporal resolution and investigate the differences. We find that mobility behaviour has a paramount effect on the traffic system. Simulating an urban area, but using rural mobility behaviour, leads to an increase in emissions of roughly 70% inside the city limits and heavy congestion throughout the city. This result highlights the importance of understanding and shaping mobility behaviour when looking for a sustainable solution to the problems of transportation and mobility.

Keywords Traffic · Congestion · Emissions · Mobility behaviour · Modal split · Traffic model · Agent-based model · Network model

Introduction

Traffic and transportation is responsible for a large amount on global CO_2 emissions, as well as emissions with a more local detrimental effect to human health [19, 23, 31, 35], like NO_X [22]. Additionally, traffic jams and congestion are a problem in most cities that cannot be solved easily.

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Since large-scale experiments are not viable for huge traffic networks, traffic research largely relies on models. Since traffic systems feature non-linear behaviour, caused by internal and external effects [33], they need sophisticated modeling approaches. The two main approaches are the bottom-up approach of microscopic modeling and the top-down approach of macroscopic modeling [3, 18]. Additionally, there are models that try to combine the advantages of both microscopic models (fine resolution and much information) and those of macroscopic models (large scale, fast computation), called mesoscopic models [12, 17, 29].

Finding realistic origin-destination data is a crucial and difficult step for most state of the art traffic models like the commercial VISSIM [8] or the openly available MATSIM [15] and SUMO [21]. Common solutions to this problem are surveys [28] or using Bluetooth data [2, 6] or mobile phone network data [5, 20]. In this study we choose a different approach. We use data about the mobility behaviour of people to generate origin-destination data directly within the model. This enables us to investigate the effect of a hypothetical and different mobility behaviour, for which no statistical data is available. Therefore, our model is perfectly suited to investigate the differences between urban and rural mobility behaviour.

This paper is organized as follows: The utilized model will be sketched in section Methods, which also gives details on how we extract and modify the mobility behaviour data. Results of our simulations are presented in section Results and later discussed in section Discussion.

Methods

Model

The model is used to calculate both congestion as well as NO_X and CO_2 emissions resulting from private motorized traffic in an urban area. The main difference to other mesoscopic agent-based traffic models is that we do not need origin-destination data, but are able to generate this information based on mobility behaviour [13]. This approach enables us to investigate scenarios that are out of scope for most other traffic models. Here we will compare urban and rural mobility behaviour by simulating traffic in an urban area, in this example the Austrian City of Graz. First we will calculate a baseline by using the real mobility behaviour of the citizens of Graz. In a second step we change the mobility behaviour to the behaviour of one of the neighbouring, rural counties, while leaving the population density constant. Thus we can directly see the influence of the mobility behaviour on the traffic system.

The description of the model will closely follow [12]: The first step will be to generate a traffic network from map data. Next we generate the ways for the agents based on their mobility behaviour. Finally congestion and emissions are calculated with local and temporal resolution.

Traffic Network Generation

The data foundation of the traffic network is map data extracted from Open Street Maps [24]. We use the OSMNX package [4] to translate this map data to a spatial network, that already includes all relevant data like speed limits and the number of lanes for each segment of road as edge properties.

In addition to the network itself, we also need to know the fastest paths between each and every node. Since this information is needed often during the simulation, it is useful to calculate and store it before the actual simulation run, using usual shortest path algorithms [34], weighted with the average travel time of each edge, to correctly find the fastest paths, which are not necessarily the shortest. If computer memory is an issue, it is also possible to only store the length of the shortest paths, and calculate the full path only when it is needed.

Way Generation

In most traffic models ways are extracted from origin-destination matrices or other origin-destination data. Here we use a more sophisticated technique: We extract data about the mobility behaviour of Austrian citizens from the survey Österreich Unterwegs [30], a survey in which 18 000 respondents reported on their mobility behaviour in great detail, giving information about all their trips on two different days, including their used method of transportation, the reason for the trip, starting time, duration, distance and more. Additionally, we also have demographic information about the respondents, namely their place of residence, so that we can infer if they life in an urban or a rural environment.

Based on this data we generate archetypes, i.e. sets of trips that describe a typical, realistic day of mobility. We generate one agent for each citizen (1:1 scale), distribute them throughout the city according to the population density and give each one an archetype. Then all agents perform their trips. For every edge of the network, we store information about which cars used this section of road for every hour of the day. This will later be the foundation for calculating congestion and emissions. Since at this time, the agents plan their routes without any knowledge about congestion, this is only the first step in an iterative process. After this first step we gathered information about which roads are heavily congested and which are not and in a second step the agents can then react to this congestion by finding alternative, faster routes. Theoretically it would need many iterations until this process converges, but it was shown in [11] that the biggest improvement is produced by the first step, while further iterations have only a minute effect. Thus, even with only one iteration it is possible to generate realistic traffic jam avoidance behaviour [7].

In addition to the traffic generated by the citizens themselves, we also need to include commuters coming from outside the city. We extracted statistical data about the commuters from [27]. They enter the city in the morning from an appropriate entry point and leave it in the evening through an exit point.

Congestion and Emissions

We now have complete information about which cars used which segment of road during which hour. If we want to calculate emissions based on that information, the first step is to calculate the congestion for each road segment at each point in time, since heavy congestion or even stop-and-go traffic have a significant effect on the resulting emissions [16].

We start by calculating the capacity of each road segment. The hourly traffic capacity C_h [14] can be calculated using [9]

$$C_h = L_{\text{eff}}\, 750\, \frac{\text{cars}}{\text{hour}} \quad , \tag{51.1}$$

with L_{eff} being the effective number of lanes. It is calculated starting from the actual number of lanes, but if this number is unknown, it is possible to approximate values of 2.6 for roads wider than 7.5 m, 2.0 for roads between 7.5 and 5.5 m and 0.8 for roads narrower than 5.5 m [14]. For one-way roads this number is already the effective number of lanes, for all other roads the number is halved. Next the hourly capacity is compared to actual number of cars using this road, leading to the road utilization factor a:

$$a = \frac{V_h}{C_h} \tag{51.2}$$

The road utilization factor gives insight into the state of traffic flow: a smaller than 0.75 is free flowing traffic, a between 0.75 and 0.9 can be seen as congested traffic flow and a larger than 0.9 means stop-and-go traffic [14].

In addition to the congestion on each segment of road, we also need the fuel consumption of each car. This is calculated from the engine type, the age of the car and the size of the car (see [12] for details on this process). Combined with the congestion status of the road, the fuel consumption gives direct information about CO_2 emissions. However, if we are also interested in NO_X emissions, we need to consider the average NO_X emission of the used engine, which is not directly proportional to the used fuel. We use the European exhaust emission standard [25] to extract this information. However, these values, measured under lab conditions, need to be adapted, if we want to find the actually produced emissions. A study investigated this discrepancy [32] and found that while petrol cars tend to emit less than the norm would allow, diesel cars emit significantly more. We use the values found in [32] to include this effect and to gain realistic result for NO_X emissions.

Changing Urban to Rural Mobility Behaviour

In order to investigate the difference between urban and rural mobility behaviour, we need to make some modifications to the baseline scenario to equip the urban agents with rural mobility behaviour. For the baseline scenario we use archetypes generated from the information about citizens of Graz. For the rural scenario we only use archetypes generated from people from a rural environment, in this case the neighbouring county of Graz Umgebung. When generating the agents we leave their number and distribution in the city constant, but give them a different archetype, leading to different trips.

The model distinguishes between trips inside the county (where the agents only move inside the network) and trips to or from a different county (where the agents enter of exit the network). Since the county Graz Umgebung is larger than Graz, it could happen that a trip is longer than the maximal distance between two nodes within the network. If this happens, the trip is separated into two smaller trips, so that it is possible to stay within the investigated network.

Results

Before we present the results of the simulation, we will investigate the difference in urban and rural mobility behaviour more closely. This is best seen in a histogram that shows the daily chance of a trip of a given distance, in addition to the used method of transport (car or other) and weather it was within the same county or not. Such a histogram is shown in Fig. 51.1.

The average number of trips each day is similar: Summing up over the x-axis yields 2.4 trips a day for rural and 2.8 trips a day for urban behaviour. However, the distribution is completely different: For urban behaviour shorter trips are more likely and those trips have only a small chance of being made by car. For rural behaviour, using a car is more likely, trips tend to be longer and have a higher chance of leading outside the county.

In order to see the effect such a behaviour would have on the city, Fig. 51.2 shows a comparison of the average congestion resulting from urban behaviour (left) and the average congestion resulting from rural behaviour (right). One can see that especially the roads leading to and from the city are heavily congested for rural mobility behaviour. Reason for this is the increase in trips leading to a different county. Also other roads feature more congestion, mainly because of the prevalent use of cars for short trips.

We also calculated the resulting emissions, which can not only be used for comparing the different types of mobility behaviour, but can also serve as a way of evaluating our model.

In order to evaluate the baseline results of our simulations, we use statistical data from the Emissionskataster [10], which reports on the emissions of both CO_2 as well as NO_X inside the city limits originating from private cars. To adjust for the time difference between the statistical data and the simulated year, we use trends from Austria's national inventory report [26] for CO_2 and from Austria's annual air emission inventory [1] for NO_X. Table 51.1 compares these statistical values to our simulation results, showing a good match for the baseline scenario.

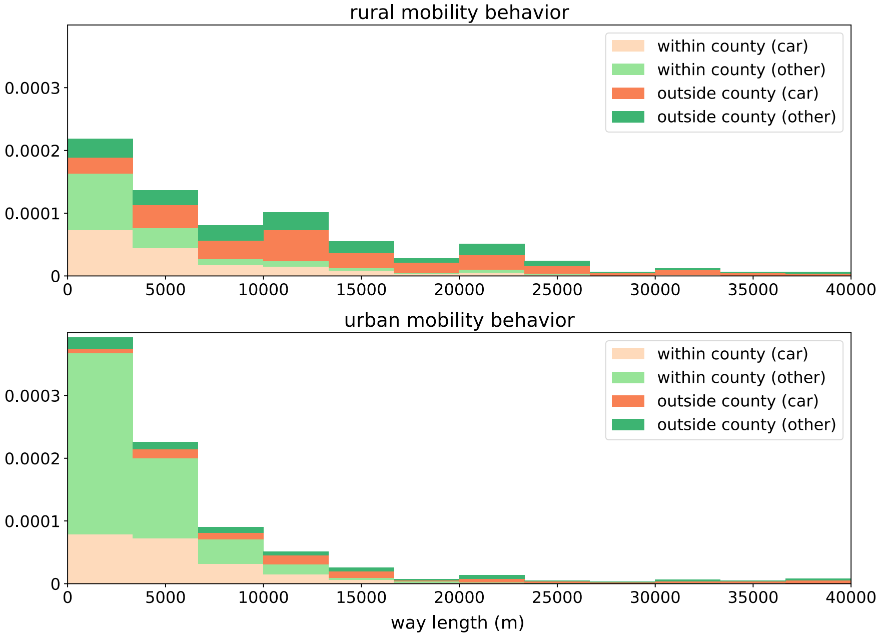

Fig. 51.1 A comparison of rural and urban mobility behaviour. For urban behaviour, trips tend to be shorter; for rural behaviour the trips are longer and the chance of using a car as means of transport is higher

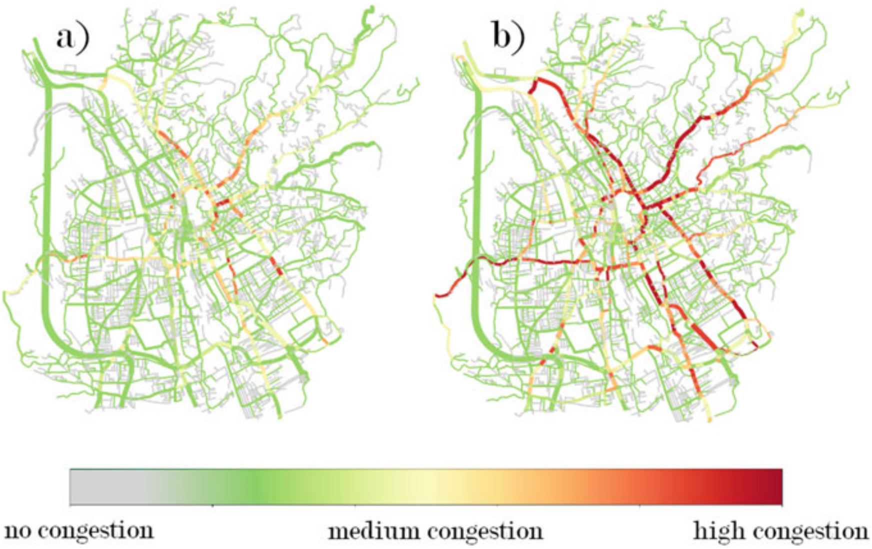

Fig. 51.2 A comparison of the average daily congestion within the city if the agents use urban mobility behaviour (**a**) and rural mobility behaviour (**b**)

Table 51.1 Resulting emissions

	Statistical data (adjusted)	Urban Mob. behaviour	Rural Mob. behaviour
CO_2	238 kt/a	220.9 ± 0.7 kt/a	380.0 ± 7.8 kt/a
NO_X	512 t/a	524.1 ± 2.9 t/a	875.8 ± 19.3 t/a

Additionally we see the increase in emissions for rural mobility behaviour. Both CO_2 emissions as well as NO_X emissions increase by roughly 70%. This is much more than would be expected from the average trip length alone, since congestion leads to non-linear effects, further increasing emissions. Note that only the emissions inside of the city limits are within the scope of the model. Additionally, also outside the investigated region, emission would drastically increase using rural mobility behaviour, but even within the city the effects are tremendous.

Discussion

In this study we used a mesoscopic agent-based model to investigate the role of mobility behaviour for congestion and emissions in a traffic system. Specifically we looked at the divide between urban mobility behaviour, which is dominated by shorter trips and less use of a car, and rural mobility behaviour, where the average trip length is longer and cars are more widely used for trips.

In order to compare the effects of this different behaviour beyond a statistical analysis, we used the model to simulate urban agents with rural mobility behaviour. This way the non-linear effects of the system become visible and we can see that behaviour that is possible in rural areas with low population density becomes completely unsustainable in an urban environment. Not only would it increase the resulting emissions by roughly 70% inside the city limits, but furthermore it would lead to stop-and-go traffic nearly throughout the city.

There are several limitations and simplifications the model uses that need to be mentioned. While the choice of starting point for each agent is based on population density, the target of each trip is chosen randomly among the viable targets. This means that this choice scales with the density of nodes, i.e. the amount of intersections in a region. While this of course correlates with the real traffic density, this could be further refined by including information like workplace density or commercial density. This would lead to a more realistic distribution of the trips throughout the network, however, the total length of all trips would remain constant, since it is extracted from mobility data. Additionally we do not include any information about possibilities for public transport or bike lanes. Even though the number of public transport and bike trips is correct, their spatial distribution might not be realistic. This simplification is necessary for two reasons: On the one hand it saves computation time, which is relevant if we are interested in a full-scale model of the city. On the other hand, this keeps the model flexible enough to be used on arbitrary cities or traffic systems, where such information might not be available. Again, it is important to note that these simplification only affect the positioning of the trips, not their length, number, or mode of transport, so that the effects on the final result, i.e. the emissions from private motorized traffic, are small.

This study substantiates the notion that, while technical innovations and new technology may help in solving the problems related to traffic, also mobility behaviour plays a paramount role in every traffic system. Therefore, changing or influencing the mobility behaviour of people is a powerful tool in reducing emissions. Giving incentives for people to use methods of transportation other than cars or reducing the number of trips necessary each day (telecommuting, online shopping, etc.) might yield better results than optimizing the engines of cars or the traffic flow within cities. In any case, it is extremely important to understand mobility behaviour and recognise the difference between urban and rural environments. Only then it will be possible to devise policies or other means of shaping mobility behaviour to find a sustainable mobility solution.

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Chapter 52
Simulating Governance of Complex Transportation Systems

Kay Cepera and Julius Konrad

Abstract For this study we developed a traffic-simulation based on the SimCo simulation tool and ran different governance scenarios regarding the effects of the distribution of real-time traffic data among drivers. The scenarios were based on interviews with experts from diverse fields, including a navigation service provider, the German Federal Highway Research Institute, and public transport providers. We found that a coordinated form of governance between private firms and local authorities benefits all parties. To analyse the impact of such a coordinated mode of governance, two scenarios were implemented. Firstly, drivers would get real-time traffic information and secondly, they would also receive information on emissions enabling them to change their route accordingly. We found that the use of real-time data does indeed decrease traffic jams, and thus increases network efficiency, but it also increases emissions. This trade-off between network efficiency and emission reduction is prevalent in all our findings.

Keywords Agent-based modelling · Governance · Mobility · Transportation · Sustainability

Introduction

The digital society produces and processes large amounts of data that lends itself to the investigation and governance of complex systems. Computers evaluate this data and apply algorithms to generate recommendations for actions with almost no latency. Therefore, this procedure can be framed as real-time governance.

This has been establishing itself as common practice for several years in the field of transportation, where real-time guidance from a control centre is combined

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with self-organisation, meaning that components of the system make autonomous (and automated) decisions. Yet, there is little empirical research so far on the social mechanisms within and the efficiency of this new mode of governance.

This paper hence addresses the following questions:

- How efficient is real-time governance compared to classical, fully centralised or decentralised modes of governance?
- What scope of action are the individual actors using this governance mode left with?

To answer these questions, we combine our multi-level model of governance [1] with agent-based modelling (ABM) to simulate and compare different scenarios. From a sociological point of view, this design allows us to focus both on the macro-level (concerning efficiency and CO_2 emissions) and the micro-level (concerning the issue of whether actors remain autonomous in their decisions or become dependent on governance).

Theoretical Context

This section briefly presents a conceptual model of the governance of complex socio-technical systems [1] that will be used as a framework for the following simulation. Within this model, we refer to the macro-micro-macro-model of James Coleman [2], the Institutional Analysis and Development (IAD) framework of Elinor Ostrom [3, 4], and the Model of Social Explanation (MSE) of Hartmut Esser [5].

Model of Social Explanation

The first element of our theoretical framework is the aforementioned MSE, in which actors act and interact haphazardly, causing changes in system structure to emerge, spontaneously aggregating from their interactions. They aim to reach individual objectives (e.g. getting from point A to point B) and perceive the structure as the situational context that is limiting their scope of action [6]. In the context of our paper, these structures can be understood as interdependent levels of a multi-level system.

Control

The obvious deficit of this model for the purposes of governance is that it is unable to model the influence of control. In this context, we see control as an attempt by external actors (in system A, e.g. climate policy or urban planning), to purposely influence the state and the processes of system B (e.g. transport) [1].

Here, an impulse coming from System A is being put into System B to intentionally influence the structure and/or the actors and their actions. Hence, the strength of the impact of this impulse is linked with the actor's willingness to change their behaviour due to external influence [7, 8].

The success of control is therefore dependent on the individual acceptance of the system in control as well as on personal traits of the controlled actors. These points are supported by the findings of an empirical study we conducted, focussing on the role of trust concerning actors' willingness to modify their behaviour [9]. Simulating the governance of complex systems therefore needs to be done in line with this circumstance and reflect different types of actors. These principles can also be applied to a multi-level setting: System A (in control) can, similarly to System B (being controlled), be grasped with the Model of Social Explanation, so that internal macro-micro-macro processes leading to the exerted control become visible [1].

Coordination

Coordination plays another important role in the governance of complex systems. "In contrast to control, coordination is decentralized and multidirectional" [1]. Simulating coordination requires the consideration of both spontaneous and reflexive coordination. The former emerges throughout a short period of time and is driven by the pursuit of an actor's individual purposes (cf. ibid.). As Kroneberg [10] states, actors performing spontaneous coordination hence react to situations in an automatic-spontaneous mode while maintaining their focus on the situation without the acknowledgement of external effects.

In contrast, reflexive coordination is determined by actors striving to reach a common goal and therefore considering other actors as well as past, present and future characteristics of the situation [1]. To accomplish all of this, actors perform in a rationally calculating mode [10].

Governance

Following Weyer's [1] concept of governance, we see governance as a multi-level combination of the principles of control and coordination. The different levels contain both a control structure that determines the negotiation systems between actors and the performance structure where actual actions are carried out [7]. Governance therefore defines goals via negotiation and implements them via regulation at the same time [1].

Figure 52.1 shows an adaptation of our model of multi-level governance to the case of German transportation systems. In this example, governance is performed

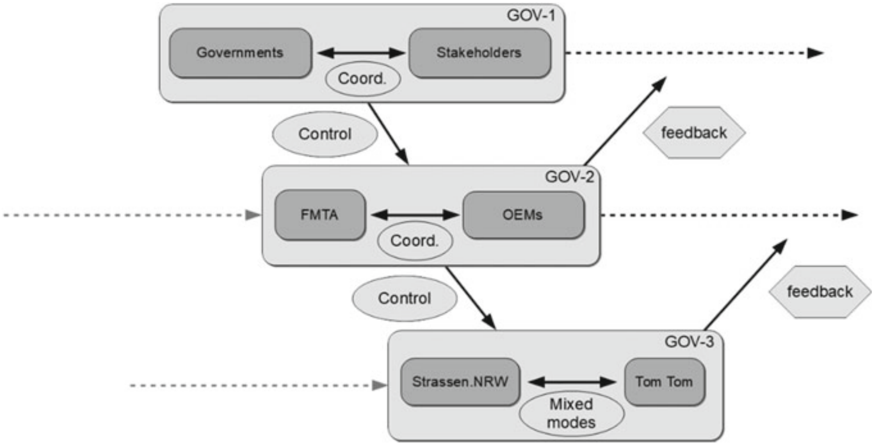

Fig. 52.1 Sample multi-level model of governance of transportation systems [1]

on three interconnected levels. On the first level (GOV-1), negotiation processes between the governmental actor and stakeholders take place.

These actors draft the future shape of mobility, identify necessary changes (such as reduction of emissions) and negotiate feasible means for the achievement of these changes (such as funding guidelines for new transport concepts). With these measures, the actors of the first level execute control towards the second level (GOV-2). On this level, actors such as the Federal Motor Transport Authority (FMTA) interact with commercial actors (e.g. OEMs) and incorporate the set goals into practical norms that frame the operation of the transportation system. Hence, this level is a regulatory instance that then controls the framework for the practices carried out on the third level (GOV-3). On this level, both federal and private service providers (such as the German State enterprise Strassen.NRW or the navigation provider Tom Tom) offer mobility services that facilitate the everyday operation of the transportation system. This model shows that all levels of the complex system need to take what is happening on the other levels into consideration and include this as feedback in their actions.

Real-Time Governance

Concluding this theoretical section, we see governance of transportation as a process that is likely to be implemented in real-time in the near future. This means that opposing traditional governance modes, planning and execution of governance actions are no longer done sequentially over longer periods of time but take place across very short timespans. Following Kopetz [11], real-time governance therefore implies that a system automatically generates and evaluates feedback data of subsystems within the time limits of its environment, empowering these subsystems to optimise their performance. This leads to the possibility of a centralised governance of decentralised processes [12, 13], in which individuals autonomously make own decisions.

In the case of transportation, this means that the system uses algorithms to recommend actions derived from the individual actions of the actors inside the system. For instance, traffic image information systems [14] can recommend routes to optimise the system's net efficiency, while drivers are still free to choose their own routes.

Simulation

To capture all mentioned aspects of real-time multi-level governance with ABM, we rely on our own simulator SimCo, which has been developed at TU Dortmund University in recent years. The model is explained in detail [15] using a variation of the ODD protocol. Therefore, only the aspects relevant to our research questions will be introduced in this section, before the examined scenarios and the results are presented.

SimCo

SimCo ("Simulation of the Governance of Complex Systems") has already been used for several experiments on risk management and system transformation, mostly in road transportation [15, 16]. Also, for this research, SimCo is a first step towards covering the whole picture of the multi-level architecture.

SimCo operates on the basis of the aforementioned theoretical context (see Fig. 52.1). Therefore, governance measures do not necessarily have a direct impact on the structures of a socio-technical system, but rather influence decision making of actors at the micro-level which then leads to emergent effects on the macro-level. SimCo has been developed as a general-purpose framework. It contains dimensions that are freely programmable, allowing us to conduct experiments with various scenarios, e.g. shifting road transportation towards sustainability.

In these scenarios, agents' transport mode choices are important. They are shaped by their individual perception of situational constraints as well as their individual preferences. Situational constraints may change due to systems dynamics (e.g. in case of congestion) or due to policy interventions (e.g. in the case of banning diesel cars to reduce nitrogen emissions).

Agents take decisions with bounded rationality and under uncertainty, referring to multiple evaluation criteria [17]. Behavioural alternatives are evaluated by assigning a utility to every possible consequence and agents ultimately choose the option with the highest subjective expected utility (SEU) [18]. This SEU value of an option consists of a u-value according to the valuation of the possible consequences and a p-value, representing the actor's estimation of how likely the consequence follows from the option [19]. Following Kron [20], "agents may select the second-best choice if its SEU value is not too far below the best choice, representing a "fuzzy logic"" [15].

Infrastructure Network

The infrastructure network of SimCo consists of the following elements: nodes that resemble daily attraction points for the agents such as cinemas, universities, parking spaces, houses or workplaces. The edges of the network are connections between the nodes that in this context resemble streets that can be used by the agents to move between the nodes. For this purpose, agents can use different technologies such as cars, public transport or bicycles. The parameters of both nodes and edges can be changed by controls that allow certain technologies to be banned from use on a particular edge or the simulation of dynamic tolls based on the technology used. This functionality is one of the central elements regarding the simulation of certain scenarios.

For the scenarios (see section "Scenarios") we use a network of 600 nodes (intersections or points of interest) connected by 2.622 edges (roads). This network is not based on a specific city or location, but rather an abstract prototypical road system.

There are two types of nodes in the network: home nodes and task nodes. Home nodes are used to switch transport technologies and task nodes are the simulated aim of the agent's journey. To reach this aim, each agent has to travel from a home node to three task nodes and then return to a home node. While not depicting specific chores, task nodes can be compared to workplaces or grocery stores.

The network allows for interactions on different levels: between social components (such as users or operators), between technical components (such as nodes, edges and controls), as well as between both types of components (for example when users are visiting nodes and using technologies) [15]. Following the rules of Haight's [21] Basic Diagram of Traffic, one of these interactions is that the time an agent needs to travel a route depends on the occupancy of the road. This mechanism is used to simulate congestion.

Modes of Governance

SimCo simulates three different modes of governance that differ significantly in terms of control intensity: the mode of self-coordination, where agents follow their own rules of decision making and thus act with the greatest amount of independence among these modes. In this mode, operations are monitored with regard to the performance of the whole system, allowing for the governance mode to be changed if certain parameters exceed defined limits.

The mode of soft control provides a medium amount of independence using stimuli or incentives (such as dynamic pricing) to raise or lower the attractiveness of certain actions (such as the choice of transport technologies) for the agents.

If soft control does not achieve the desired performance, there is also a mode of strong control that uses constraints (such as banning a particular technology from certain edges). This mode obviously grants the least amount of independence.

Agent Types

In order to simulate different types of users with individual behaviour, a survey with 506 participants was conducted, allowing an identification of different agent types as illustrated alongside their preferences in Table 52.1.

These findings are in line with previous studies [23] and result in the following five types: Pragmatic agents, whose main preference is fast transportation; eco-friendly agents; indifferent agents, who do not show any specific preferences; the so-called "penny pinchers", who prefer both cheap and fast transport; as well as the comfort-oriented convenient agents, who value comfortable and fast transportation.

The shown preferences are also numerically linked to different modes of transport according to the results of the survey, where the respondents were asked to assess modes of transport to the displayed attributes.

Due to this methodological setup, users' perception of different modes of transport is considered rather than the technology's actual attributes, i.e. to improve the practical value of our findings.

Table 52.1 Mean preferences of actor types, ranging 1-10 [22]

Actor Types	Preferences				N	Share (%)
	Cheap	Fast	Eco-friendly	Comfortable		
Pragmatic	3.7	6.8	2.4	1.2	119	24
Eco	4.4	2.0	7.6	1.9	123	24
Indifferent	4.0	4.6	2.8	4.2	157	31
Penny-pincher	9.0	4.7	3.7	0.7	58	11
Convenient	0.6	6.4	0.2	6.8	49	10
					506	100

Scenarios

Regarding scenario building, we conducted a series of expert interviews and focus groups with members of both federal and private providers of transportation services such as TomTom, the German Federal Highway Research Institute or municipal transport enterprises, as well as policy makers and administrators.

According to these interviews, future transport will require a greater measure of control due to increasing demands on efficiency and emissions. This leads to the assumption that decentralised self-governance may not be enough to meet future demands, hence implying the necessity of a centralised instance that performs control over certain stimuli. Practical instruments for this can be navigation devices, other in-car technologies or apps [24].

To simulate an incrementally increasing amount of imposed control, we developed three scenarios that we examined with SimCo, comparing their outcomes to the base scenario that was already tested in our previous studies [15, 16, 25].

Base scenario means that agents have access only to information concerning the state of nodes directly connected to the node where they are located. This means that they have no knowledge of the state of the system as a whole and have to operate relying solely on local optimisation. Under these conditions, agents aim to fulfil their agenda of reaching three task nodes (see section "Infrastructure Network").

The *extended base scenario* provides agents with an overview of the network without any knowledge of the current state or changes thereof. This scenario resembles classical route planning in advance of a journey. This mode of routing is used by 80% of car drivers in this scenario, reflecting the finding that around 77% of Germany's drivers regularly use routing services [26]. In contrast to the agenda mentioned above, agents now aim for a designated home node at the end of their journey, working through task nodes on their way. The implementation of this scenario was realised with a shortest path algorithm using the NetLogo Network Extension [27].

The *intelligent navigation scenario* provides agents with a navigation system that has access to real-time traffic data and therefore an overview of both the network and the state of nodes and edges. Differing from the previous scenario, the navigation system can now dynamically change the route at every node and hence respond to the traffic situation, maintaining the designated home node as the destination. This is implemented in the navigation system by adding an edge weight parameter that resembles the rate of road usage. This means that congested edges require more travel time. Using this factor, the navigation system calculates a (new) optimal route considering real-time traffic each time an agent reaches a node that is not his destination.

The *coordinated mode scenario* is an extension of the intelligent navigation scenario. In this scenario, politically motivated goals are included in the suggestions of the navigation system. In our case, the goal is the reduction of local emissions. Our approach here is to make road emission levels less 'attractive' for the navigation system to choose. Highly polluted roads therefore become less frequented by navigation users until pollution fades. For the implementation of this scenario, a second edge weight parameter was added which is then adjusted according to the emissions that occur on an edge. We also vary the depth of impact of the political measures on the scenario.

Experiments

Every run is 8,000 ticks long, while 144 ticks resemble one day leading to a simulated timespan of roughly two months [15].

Initially there is a total of 6,000 agents divided into the different types according to the proportions in Table 52.1. To simulate situations of congestion, we increased the number of agents in every scenario in steps of 1,000 until a total of 12,000 agents was reached. Following this pattern, every scenario was simulated ten times with different seeds (to decrease randomness), so that the capacity and resilience of the system could be examined under changing conditions. Also, the depth of impact in the coordinated mode is varied between 10 and 50%, compared to the edge weight that contains traffic information only.

As macro-level indicators, we used short-time edge emission and occupancy metrics (short-time referring to one day of 144 ticks in this context) as well as metrics for the modal split and an average of agents stuck in traffic. As micro-level indicators, we used the SEU values of the agents, the modal split of single agent types and a metric of the correctly addressed nodes, acting as a metric of individual goal achievement. Starting from a home node, correctly addressed nodes are three task nodes followed by another home node before starting over again.

Results

After conducting all experiments, we compared all four simulated scenarios with regard to changes inside the scenarios in emissions, occupancy, the modal split and goal achievement. The changes were measured between the default situation with 6,000 agents and a maximum population situation with 12,000 agents. It shows that all simulated scenarios are sensitive to changes in population. Emissions as well as occupancy and congestion increase as population rises. While these increases are not particularly surprising, it was also shown that the scenarios behave differently when population levels rise. In the *base scenario* the modal share of cars decreases in line with population while congestion and emissions rise. In the *fixed routing scenario,* the share of cars is higher and stays higher regardless of population. Also, emission and congestion indicators are highest in this scenario. The *intelligent navigation* and *coordinated mode scenarios* can handle a rising population the best. The congestion is lowest in these scenarios and the emission levels do not rise as much as in the fixed

Table 52.2 Summary of results

Deviation from base scenario at 12,000 agents	Emis-sions on edges	Emissions on edges and nodes	Edge occu-pancy	Over-occupied edges	Agents stuck	Modal share car	Correctly ad-dressed nodes	SEU mean
Fixed	-2.5	14.7	-12.9	-7.4	27.9	22.8	-32.6	3.7
Intelli-gent	4.8	2.1	7.9	-4.1	-13.6	9.4	0.6	1.8
Coordi-nated	4.1	2.9	6.2	-3.3	-10.7	9.5	-1.8	0.8
Unit:	Percentage points (pps.)						Percent (%)	

Positive:			Negative:		
<5%	>5%	>10%	<5%	>5%	>10%

routing scenario. Furthermore, the modal share of cars decreases with population levels similar to the base scenario, even though the decrease is not as high. Overall these findings show a classical rebound effect. The real-time traffic information used in the intelligent routing scenarios (3 and 4), leads to a higher network efficiency (less congestion) but also to a higher usage of cars that does not decrease in line with population levels to the same extent as in the base scenario. The utility of driving stays high even though more agents use the road network.

Table 52.2 shows a direct comparison of the tested scenarios at 12,000 agents to the base scenario. The numbers shown are deviations from the values produced in the base scenario. The green and red markings indicate positive or negative developments in terms of political desirability.

The *fixed routing* scenario at first glance shows a misleading small decrease of 2.5pps in emissions and a decrease of 7.4pps in over-occupied edges. This, however, is due to the inefficiency of the navigation in this scenario. There are roughly 28pps more agents stuck than in the base scenario and the edges are less occupied. This means that agents in this scenario are unable to reach less congested nodes, which is also causing a worse modal split than in scenario 1 because agents can no longer reach nodes that enable them to change their mode of transport. On the micro level this means that agents can mostly satisfy their initial preferences regarding the mode of transportation but are far less able to reach their desired nodes and therefore less able to achieve their goals.

Compared to the base scenario, intelligent navigation decreases the number of over-occupied edges by 4.1pps while also reducing the number of agents stuck by 13.6pps. Unfortunately, it also leads to a small increase in emissions as the road network is now able to host a much larger number of vehicles. This also leads to a deterioration concerning the modal split as the use of cars is 9.4pps higher. On the micro level, agents' goal achievement in terms of correct nodes and SEU values does not change considerably compared to the base scenario.

The *intelligent navigation* leads to a sustainable improvement in network efficiency. The *coordinated mode* cannot completely unite the conflicting goals of low emissions and high efficiency. While emissions on edges are slightly lower, emissions on edges and nodes are higher than in the intelligent navigation scenario. Apart from that, the congestion indicators are not as good. Compared to the intelligent navigation scenario the number of over-occupied edges and agents stuck is not as low. This means that the decrease in emissions (that is higher for lower population levels not shown here) is only made possible by a trade-off with network efficiency rather than being achieved by the scenario itself. On the micro level this scenario can also not successfully improve agents' goal achievement. In fact, the numbers for correctly addressed nodes slightly decrease by 1.8%.

Conclusion

With respect to our research questions, we can conclude that real-time governance has the ability to partially solve the conflicting goals of low emissions and high net efficiency. However, it should be pointed out that this is accompanied by a decreasing scope of action by individual actors and, for some criteria, can be achieved just as well or even better using intelligent navigation.

Comparing the tested scenarios based on the results in Table 52.2, we show that a coordinated mode leads to a good balance between emissions, occupancy (and therefore network capacity) and congestion, while maintaining a good number of correct nodes.

Intelligent navigation meanwhile achieves the best overall net efficiency, and the second-best overall emission values. Taking emissions on edges and nodes, and the high number of agents stuck, into account the fixed routing scenario was not found to be convincing on any of the indicators. Our reference, the base scenario with fully decentralised self-coordination, shows best results focussing on emissions on edges and nodes only. Yet this scenario (similarly to the scenario of fixed routing) is unable to cope with the emergent system overload when the population level is high.

Table 52.3 shows a categorised comparison of the three scenarios deviating from the base scenario that serves as our reference. The comparison applies for 12,000 agents. The indicators and ratings are based on the presented results and, for a better overview, transferred into our own scale which ranges from poor to good. This means that a 'good' scenario deviates most positively from the base scenario among the three compared scenarios.

This comparison reveals the limitations of the tested configuration of a coordinated mode: While the balance between emissions, capacity and congestion is best at 6,000 agents, it becomes inferior to intelligent navigation when 12,000 agents are simulated. This is due to a higher number of agents getting stuck on nodes while waiting to enter on edges, causing a higher amount of emissions on nodes in the coordinated mode.

Transferred to a real-life scenario, one could possibly argue that start-stop systems in combustion engines or hybrid cars could reduce this problem and hence increase

Table 52.3 Comparison of scenarios to the base scenario at 12,000 agents

* Poor ** Medium *** Good	Fixed routing	Intelligent navigation	Coordinated mode (50%)
Total Emissions	*	***	**
Occupancy	*	***	**
Agents stuck	*	***	**
Modal share (car)	+22.8%	+9.4%	+9.5%
Correct nodes	*	***	**

the feasibility of a coordinated mode. With regard to current share numbers [28] this does not seem to be a very significant factor at present.

As far as future research is concerned, a possible approach could be to share our results with government agencies in order to maintain the feedback loop mentioned in 2.4. Thereby different forms of coordinated modes (or even new scenarios) could be developed together with transportation stakeholders. These newly developed scenarios could combine features of those already tested with new input and then be returned to simulation for another feedback loop. This could lead to an iterative innovation process in the governance of transportation systems.

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Chapter 53
Simulating the Adoption of Electric Vehicles Under Consideration of Person-Related Variables

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Keywords Mobility · Investment decision · Technology diffusion

Introduction

The simulation of technology diffusion has different applications, for example in marketing or economics. Yet, also in the field of energy transition simulating diffusion becomes more important, as the energy transition depends on a variety of technologies, namely renewable energies (photovoltaic and wind), heating technologies like heat pumps, but also on alternative vehicles such as electric vehicles or hydrogen cars. Energy system models like REMod [1] can provide information on future technology needs and mixes under consideration of the climate protection goals of the government by representing the energy system, including all sectors, technologies and their relations, in techno-economic terms. One urgent question is whether the future technology needs will be covered, which is dependent on the investment decisions of single individuals or companies. An extended analysis on individual variables such as the level of information or sociodemographic variables, e.g. age, enable an implementation of target oriented measures towards the technology needs. In this work, a method is presented and discussed, which enables the simulation of technology diffusion until 2050, its comparison to a target system as well as the segmentation in sub-groups according to person-related variables, based on the example of private

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passenger cars and the respective investment decision into conventional vehicles (CV) (gas and diesel), battery electric (BEV) and fuel cell electric vehicles (FCEV).

Methods

In the following, (a) the necessary empirical data collection, (b) the calculation of the purchase intention and its diffusion as well as (c) the segmentation of individuals into different groups is presented.

Data Collection

A Germany-wide representative (gender, age, education, net income, federal state) online-study was conducted in August 2017 with 1922 participants via a market research institute. In this study, different aspects of mobility and purchase behavior were examined of which only relevant parts are reported here. The study was a combination of a questionnaire and a discrete choice experiment which was programmed with Sawtooth Software. The questionnaire covered the person-related information, such as socio-demographics and attitudinal factors, whereas the choice experiment contained the technology-related aspects, such as price and range of the conventional and electric vehicles. Participants could indicate their preferred car segment (small class, medium class and upper class) for the choice experiment.

Simulating Market Diffusion of Passenger Cars

For modelling the market diffusion, the following steps are realized: 1. Scenarios for the attribute developments (price, range, etc.) are identified from today until 2050. 2. Calculating the individual utilities for the attributes of the passenger cars for the different alternatives (CV, BEV and FCEV). For the results displayed in this paper, we use the partial utilities of the single attribute levels from the discrete choice experiment which are calculated by Sawtooth following a hierarchical Bayes approach [2]. The sum over all partial utilities is displayed in the total utility for each alternative and individual per year. 3. The logit rule [3] is used to calculate the preference share for each alternative vehicle type. 4. The stock model calculates the change in the passenger car vehicle stock until 2050, considering a total stock growth factor. In dependence of the growth factor and the number of cars that drop out (following a Weibull distribution) the number of new cars per year is determined. Multiplied with the preference share, the new ratio between the vehicle types is calculated.

Segmentation

As the aim of this study was to simulate technology diffusion not only from techno-economic variables, the results from the questionnaire need to be integrated into the diffusion model. Therefore, variables that have a major influence on technology adoption, such as interest for technical innovations and the perceived personal knowledge on these technologies, were used for segmenting participants into groups with different characteristics. For example, participants were artificially split into two groups via a median split, one being informed quite well on electric vehicles and the other half being less informed.

Exemplary Results

The market shares of the different vehicle types (for the vehicle class of minis, small cars and compact class) are exemplarily displayed in Fig. 53.1. The graphic shows that the assumed targets for alternative passenger cars (coming from one exemplary scenario of the energy system model REMod) can't be achieved with the underlying preference shares of individuals. BEV and FCEV achieve around 42% in this case. Besides the influence of the single technology attributes, like the purchase price or range, also the individual variables have an influence on the preference shares of the vehicle type alternatives.

Figure 53.2 displays the influence of the variable information on the preference share. The preference share for BEV and FECV for the full sample is 64%, for the better informed half of the sample 70% and for the less informed half 62%. If all individuals were informed equally well as the better informed half of the sample

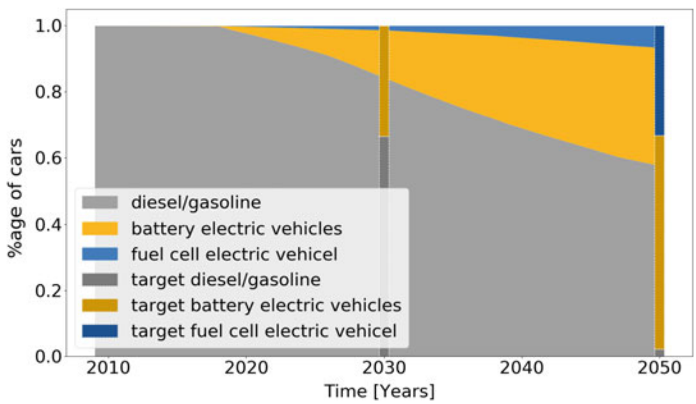

Fig. 53.1 Market shares of different vehicle types for minis, small cars and compact class from today until 2050, resulting from the simulation of technology diffusion

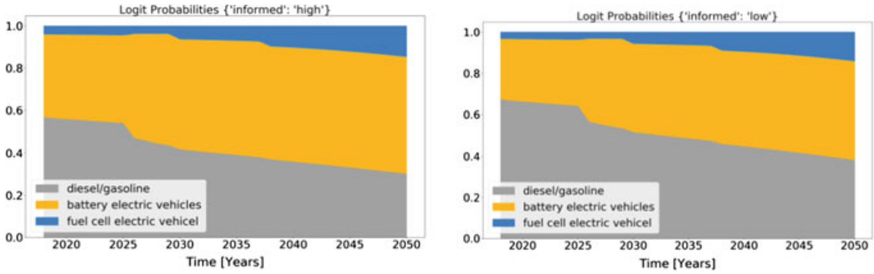

Fig. 53.2 Simulated preference shares for different vehicle types for the car class minis, small cars and compact class from today until 2050 for well-informed individuals (left) and low-informed individuals (right)

about electric vehicles or hydrogen cars, the market share in 2050 would be about 5% higher, in our example.

Conclusion

Using utilities of different technology attributes in a logit function is one way of displaying vehicle diffusion and has been applied in previous research. However, it is of advantage to be able to segment people into different categories to check for differences in adoption behavior. The presented approach is one way of trying to incorporate person-related variables into techno-economic modelling. With this approach in our example it could be shown that simply a higher degree of information would lead to 5% higher shares of BEV and FCEV vehicles in 2050. This approach can, therefore, be used to analyze the effects of different measures (like information campaigns) on the technology diffusion. Nevertheless, the uncertainty of the results should be carefully considered as the time horizon until 2050 is high.

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Chapter 54
An Exploratory Comparison of Behavioural Determinants in Mobility Modal Choices

Khoa Nguyen and René Schumann

Abstract The rising demand for mobility in the 21st century creates a challenge for interdisciplinary researchers. As a result, the number of papers devoted to the application of agent-based technologies in the transportation engineering domain has grown enormously. However, there is still a need for modelling platforms that are capable of exploring the influence of different psychological factors on individual decision-making. By utilising our current mobility simulator—BedDeM, we propose an experimental method to test and investigate the impact of core determinants in Triandis' Theory of Interpersonal Behaviour on the usage of different transportation modes. Comparing the results with a calibrated population of Swiss household data, we conclude that *Intention* and *Affect* have a positive effect on the usage of private vehicles, while *Habit* and *Social factors* can encourage people to travel with public or soft transportation modes.

Keywords Agent-based modelling · Modal choice simulation · Multi-agent system · Behavioural theory.

Introduction

Identifying the underlying mechanisms of decision-making is a fundamental challenge for social science researches. Under the subject of household mobility, different projects have been carried out to investigate the effects of individual determinants on modal choices of daily commuters (e.g. [11, 13, 20, 27]). These often suggest that

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making travelling choices is a complex process, in which multiple aspects (such as cognitive, affective, social, habit etc.) should be considered in any future studies.

Agent-based modelling is a method of investigation of social phenomena that blend the knowledge of social sciences with the advantages of computational simulations. It allows an elegant treatment of heterogeneity in the population and enables the modelling of complex data processing while considering multiple factors and dynamic information [6]. In the domain of mobility however, most applications have been focusing on the topics of *traffic simulation* [4, 5] or *management and control systems* [19]. There is still a lack of research efforts that emphasise on understanding the roles of behavioural determinants and their relationships in daily transportation-related choices [6].

We have been developing an agent architecture that utilises the Triandis' Theory of Interpersonal Behaviour (TIB) [26]. Its implementation platform—Behaviour-Driven Demand Model (BedDeM)—offers a mechanism to measure the impact of different individual determinants on short-term transportation modal choices (i.e. car, bus, tram, trains, walking, biking). In this paper, we demonstrate this capability through a series of setups to activate/deactivate the core elements of TIB in agent's decision-making and compare the collective results after simulation. The current agent population contains a mapping of qualitative data in Swiss Household Energy Demand Survey (SHEDS) to all TIB's determinants, which is designed to reproduce the travelling patterns in Mobility and Transport Microcensus (MTMC) [17]. Hence, performing the experiment on this baseline can provide a practical insight into real-life situations where people often rely on a small set of factors to make their decision on modes of daily transport.

After considering some of the popular related projects in simulating mobility-related decision-making (see section "Related Work"), we present a specification of BedDeM processes that are relevant to the case study in section "The Behaviour–Driven Demand Model (BedDeM)". Next, the experimental setup and its results are discussed in section "Experimental Procedure". We then conclude our experience and suggest further development in section "Conclusion".

Related Work

In this section, we focus on the group of models that deal with mobility-related modal choices. Agent's goal is to select an option from a set of alternatives. The result of the deliberation process is a particular action or utilities/probabilities of all the options. In this case, the agent-based method is usually bottom-up: starting from evaluating an option using explicit individual determinants, then combine them to establish context-depending behaviours.

One popular approach is enhancing the agent's preferences, strategies and likelihood of making a particular decision with discrete choice models. The projects in the mobility domain often make use of *random parameters logit* [12] to assign predicted probabilities to outcomes of a set of alternative options. Examples include

[1, 9]. By incorporating empirical data (such as observed choices, survey responses to hypothetical scenarios or administrative records), it becomes a flexible framework for estimating the parameters of choice behaviour that is capable of capturing the statical patterns. However, without comprehensive support from a socio-psychological theory, these models cannot be utilised to explain the effect of each determinant on individual decisions. Non-computing experts often have difficulties understanding the underlying implications of different modelling scenarios and associated assumptions [14].

Another class of agent architectures aims to reproduce a more elaborate decision-making process by assigning agents with beliefs, values or world views that correspond to observation from ethnographic data or stakeholder's assessment. One of the most well-known architecture is the Belief-Desires-Intentions (BDI) [21] model. Padgham et al. developed a BDI system to allow agents to respond to the feedback from the environment instead of keeping predetermined modal choice [18]. Other works of Bazzan et al. [7] and Balmer et al. [3] also include a layer of BDI-based high-level component in the agent's decision-making. However, this architecture is often criticised for the lack of experimental grounding [10] and the agent choice of being homogeneous, completely rational and selfish [21]. From our present understanding, there is not a project that utilises more complex cognitive architecture, such as CLARION [24], ACT-R [25] or SOAR [15] for modal choice simulation. Nevertheless, we also not consider these to be sufficient options since none of them is currently covering all major aspects of human decision-making (i.e. cognitive, affective, social, norm and learning) [2]. Plus one would require knowledge in formal logic to interpret the result patterns, which is often not trivial for social scientists.

The Behaviour-Driven Demand Model (BedDeM)

As an effort to produce a more comprehensive agent architecture that can be utilised to capture qualitative data, we decide to implement Triandis' Theory of Interpersonal Behaviour (TIB) [26] in our platform—BedDeM. Its tri-level presentation (see Fig. 54.1) proposes a way to combine and evaluate different psychological aspects of decision-making, which is utilised to create an architecture that can calculate the likelihood of an agent to perform a particular action. We are developing BedDeM's first application for the domain of mobility using Repast library for agent-based modelling [22]. Its main purpose is to generate yearly demands at the individual household level that can be interpreted at the granularity of the historical evolution of mobility for Switzerland. At the current milestone, an agent population can be generated using qualitative questionnaires in SHEDS [23] and calibrated to the travelling patterns in MTMC [16]. More details of this procedure can be found in [17]. The two main mechanisms relevant to the experiment are described below.

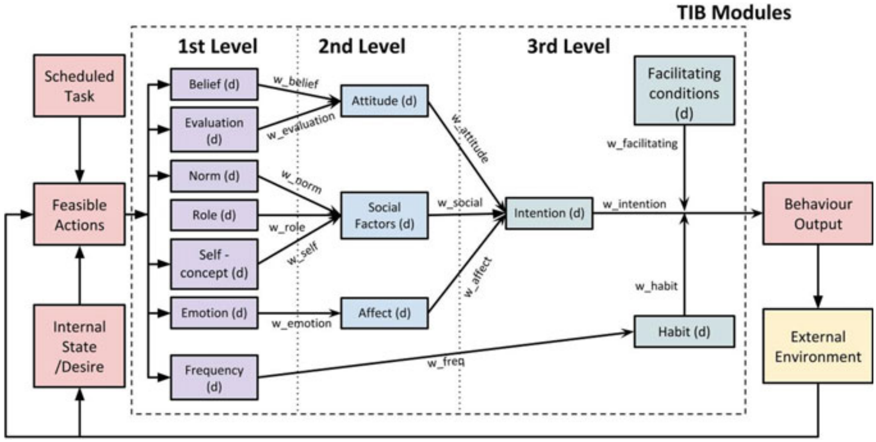

Fig. 54.1 Current agent's decision making mechanism with TIB Module

Decision-Making Process

A full decision-making cycle is illustrated in Fig. 54.1. An agent first selects an isolated decision-making task from the list that is sequentially executed. Its personal desire/goal is then combined with means provided by the external environment to generate a set of possible options. For all determinants (d), each option (opt) is computed by comparing its property with other's ($R_d(opt)$). In the first level, this can be done using either a real numerical system (for determinants such as price or time) or ranking function (for determinants such as emotion). Both can be derived from empirical data (e.g. census/survey) or calibrated with expert's knowledge/stakeholder's assessment.

The results for these determinants are then normalised and multiplied with associated weights (called w_d); the sum of which becomes the reference value for the option in the next level (see Eq. 54.1). The weight, in this case, represents the importance of a decision-making determinant compare to others at the same level and emphasises on the heterogeneity of individuals. In the experiment setup, we can deactivate the irrelevant determinants by simply assign their weights to 0.

$$R_d(opt) = \sum_{a=1}^{A}(R_a(opt)/(\sum_{o=1}^{O} R_a(o)) * w_a) \tag{54.1}$$

where
- $R_d(opt)$ is the reference value of an option (opt) at determinant d.
- A is the set of the ancestors of d (i.e. determinants connects with d in the previous level).
- O is the set of all available options.
- w_a is the weight of ancestor determinant (a).

The combination process then continues until all options reach the behaviour output list; the reference value of which can be interpreted as the probabilities that a particular action is performed. If the agents are assumed to be deterministic, it would pick the option that is correlated to best-evaluated value. In case the options are given the same value, the agents would choose a random one.

The Mobility Simulation

An overview of BedDeM's application for mobility domain is shown in Fig. 54.2. After receiving processed information regarding the population and environment from the Configurator, the simulation process starts with a central controller creating all the agents with all their attributes and assigned them to their respective regions, from which information of agent's schedule and traffic are based on. As we use MTMC [16] and SHEDS [23] as inputs for the configuration phase, agents in this study represent households in Switzerland. Clustering these data entries also provides a way to calculate the recommendation for agents from the same network [8] (i.e. R_{role}—see Table 54.1).

Each agent then processes its individual schedule and creates decision-making events to be activated. At the time of simulation, the controller triggers these activities in an event-driven manner. In this current developing stage, no learning technique is applied for feedback loops inside the agent's decision-making process. Agents

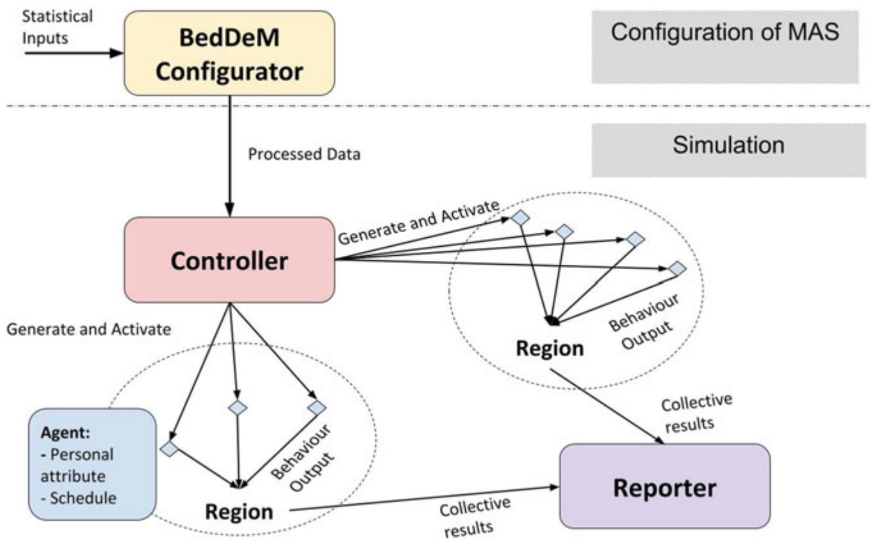

Fig. 54.2 An overview of BedDeM model

Table 54.1 Mapping of TIB's determinants and statistical data [17]

Determinant	Measuring property/Ranking function (R_c)	Corresponding question in SHEDS (w_c, i.e. importance of each determinant with scale 1-5)
Facilitating condition—*Inconvenient connections*	R_connections = Is the trip consist of multiple public connections (0/1 value)	w_connections = Inconvenient connections by public transport (e.g. long and/or multiple transfers)
Evaluation—*Price*	R_price = Cost of travelling	w_price = Choosing the cheapest option
Evaluation—*Time*	R_time = Duration of the trip (including the journey to station)	w_time= Travelling as fast as possible
Norm—*Environment Friendly*	R_norm = Motor type of the vehicle (Gas/Electric/No motor)	w_norm = In the Swiss society, it is usually expected that one behaves in an environmentally friendly manner
Role—*Environment Friendly*	R_role = Recommend from others in the agent's network (most used)	w_role = Most of my acquaintances expect that I behave in an environmentally friendly manner
Self-concept—*Environment Friendly*	R_self-concept = No data available—calibrated with historical data (see [17])	w_self = I feel personally obliged to behave in an environmentally friendly manner as much as possible
Emotion—*Enjoyment*	R_emotion = Vehicle's comfortableness/luxury	w_emotion = I enjoy this way of travelling
Frequency of past behaviours	R_freq = The number of usage over a certain period	w_freq = I am used to taking this means of transport

simply keep track of the number of times its used a vehicle for trips of the same purpose. In addition, After all the tasks finished, a reporter component collects the final results, which mainly consists of the kilometres for different modes (i.e. car, bus, tram, trains, walking, biking).

Experimental Procedure

The experiment setup for the agent's decision-making procedure can be found on Fig. 54.3. As mentioned in section "Decision-Making Process", the reference value of an option (opt) for each determinant (d) is calculated using Eq. 54.1—$R_d(opt)$. It requires two components from determinants of the previous level—their reference values for that option ($R_a(opt)$) and weight(w_a). Since the first level determinants do

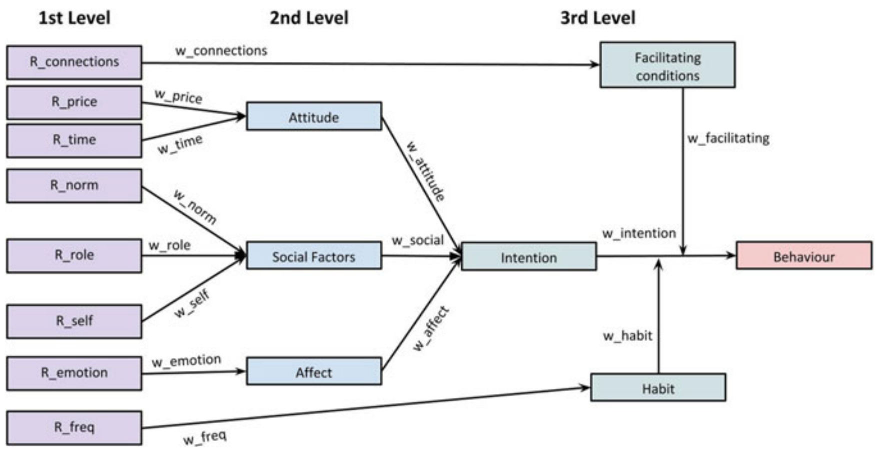

Fig. 54.3 Experiment setup in the agent's decision-making

not have any sub-connections, $R_a(opt)$ and w_a are derived from available properties that can be measured or ranked and qualitative questionnaire in SHEDS [23] (see the mapping in Table 54.1). The next few levels of mapping and calibration process of the reference population to MTMC [16] can be found in [17]. At this milestone, they are kept relatively simple to reflect the information in data sources and allow the impact of each determinant to be highlighted in the final results. More complicated mappings can also be configured similarly by adding/removing relevant nodes in the figure.

Setup

In this paper, we want to focus on observing the impact of core determinants in TIB, i.e. attitude, social factors, affect, facilitating condition, intention, habit. This can be achieved by adjusting the corresponding weights in the models, i.e. *w_attitude, w_social, w_affect, w_facilitating, w_intention, w_ habit* (see Fig. 54.3 and Table 54.2). This exercise is performed on the calibrated deterministic population described in [17]; in which mode, agents choose the best alternative for their trips. By keeping the weight(s) of the main determinant(s) as calibrated values and others to 0, the agent will only take into account that key determinant(s) in decision making and ignore the rest. In the first half of this setup, we focus on the second level of TIB, which connects to *intention* in the third level. Hence, w_intention is kept as in [17]. This is also applied similarly to w_attitude, w_social, w_affect in the second part to ensure *R_intention* remains non-zero. All trips are scheduled within one year so there is currently no difference in agents' accessibility to modes. Seasonal changes is planned for a future developing stage.

Table 54.2 Experiment design

Main determinant(s)	w_attit-ude	w_social	w_affect	w_facili-tating	w_inten-tion	w_habit
Attitude (At)	as [17]	0	0	0	as [17]	0
Social Factors (SC)	0	as [17]	0	0	as [17]	0
Affect (Af)	0	0	as [17]	0	as [17]	0
At + SF	as [17]	as [17]	0	0	as [17]	0
SC + Af	0	as [17]	as [17]	0	as [17]	0
St + Af	as [17]	0	as [17]	0	as [17]	0
Facilitating Conditions (FC)	as [17]	as [17]	as [17]	as [17]	0	0
Intention (I)	as [17]	as [17]	as [17]	0	as [17]	0
Habit (H)	as [17]	as [17]	as [17]	0	0	as [17]
FC + I	as [17]	as [17]	as [17]	as [17]	as [17]	0
I + H	as [17]	as [17]	as [17]	0	as [17]	as [17]
FC + H	as [17]	as [17]	as [17]	as [17]	0	as [17]

Results

After the simulation, the total kilometre results of all mobility modes can be obtained (i.e. walking, biking, bus/tram, train, car, others). Comparing reference results in [17] against the outcomes of each setup above would give us an idea about the impact of the main determinants. The mapping in Table 54.1 and percent composition of the modes can then be used to interpret the meaning of the difference in each test.

Attitudinal, Affective and Social Determinants:

Table 54.3 and Fig. 54.4 show the results of running BedDeM with the reference population and with one or two determinants of the second level turned on. In the *Attitude(At)* test case, a large number of car users switched to the more cheaper options (bus/tram, train and walk). From Table 54.1, this determinant consists of 2 elements—time and cost. Although they are slower in speed, public modes do offer a more competitive price in the current market. The difference in time does not seem to play a major role in the agent's decision. This shift can also be observed in the *Social factors(SF)* test case with more than 40% decrease in car usage. As they provide the place for socialisation and are acceptable environmental friendly options, public transports see the most increase in number, whilst soft mobility usage sees a small decrease. When *Social factors* combines with other determinants (i.e. At + SF and SF + Af), we can observe a minor decrease in car's number. With the main focus on *Affect(Af)* determinant, more agents pick car than the other modes due to its convenience, comfortability and privacy. This also explains the figures

Table 54.3 Result of comparing the second level of TIB's determinants (All units are in 10^9 kilometres)

Main determinant	Car	Bus/Tram	Train	Walking	Biking	Others
Reference population	73.09	4.07	23.2	2.67	4.91	4.42
Attitude (At)	45.77	16.0	33.86	6.22	5.9	4.58
Social Factors (SF)	40.57	17.34	45.1	2.45	1.85	5.03
Affect (Af)	82.32	1.51	15.55	2.32	6.37	4.29
At + SF	37.97	16.9	47.22	2.88	2.22	5.16
SF + Af	69.44	3.38	27.19	2.81	5.12	4.42
At + Af	77.84	3.45	17.95	2.96	5.87	4.29

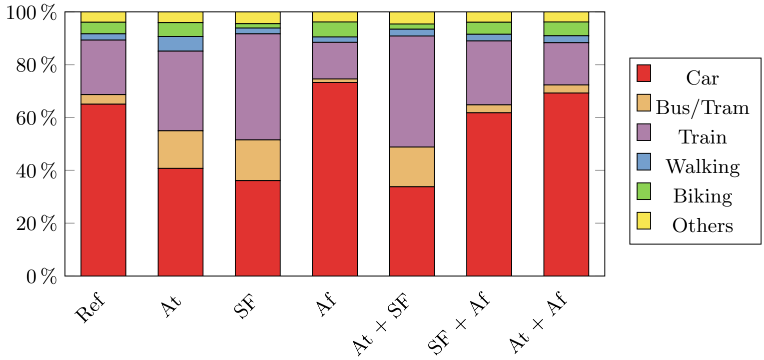

Fig. 54.4 Percent composition of modes in the tests of second level of TIB's determinant

when two determinants are combined. When *Affect* is not considered (i.e. At + SF), the car usage goes down. When it is put together with others, the number increases significantly (up to 40%). We conclude that *Affect* is the main driver for car, while *Social factors* can encourage people to use more public transport, especially for environmental reasons.

Intentional, Habitual and Facilitating Condition Determinants:

The results of the third-level determinants' tests can be seen in Table 54.4 and Fig. 54.5. Although we put the "inconvenience of public connections" as the criteria for *Facilitating Condition(FC)* (see Table 54.1), there is still a large number of households favour public transport and walking over car. It would mean this particular condition does not affect the final decision significantly. *Habit* test case also has a lower percentage of private vehicles compare to the reference. In contrast, *Intention* emerges as an important factor for car usage since the final figure of this mode is 10% larger than that of either *Habit* or *Facilitating condition*. It can be confirmed in the

Table 54.4 Result of comparing the third level of TIB's determinants (All units are in 10^9 kilometres)

Main determinant	Car	Bus/Tram	Train	Walking	Biking	Others
Reference population	73.09	4.07	23.2	2.67	4.91	4.42
Facilitating Conditions (FC)	46.18	16.03	33.44	6.2	5.94	4.56
Intention (I)	67.72	4.12	28.12	2.77	5.21	4.42
Habit (H)	50.92	13.96	32.34	5.97	4.33	4.83
FC + I	67.82	4.16	28.0	2.76	5.2	4.42
I + H	69.23	3.45	27.73	2.63	4.9	4.42
FC + H	51.05	14.09	31.75	6.1	4.48	4.88

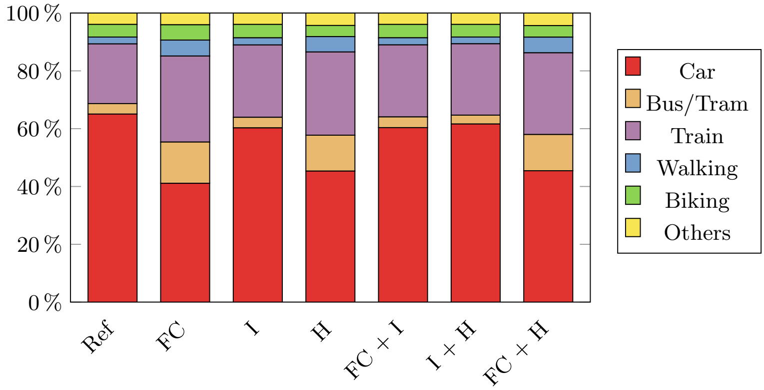

Fig. 54.5 Percent composition of modes in the tests of third level of TIB's determinants

combination cases where *Intention* is present, i.e. FC + I or I + H. Both of them have a higher number of car trips than other scenarios with only *Habit* or *Facilitating condition*. In TIB, *Intention* refers to the deliberation process of human decision-making, as oppose to *Habit* which causes people to act on impulse. The simulation results at this level seem to indicate that the public and soft transports used to be popular in the past and only started to be replaced as more private vehicles became available in the studied year.

Conclusion

In this paper, we demonstrate the ability of our simulation platform—BedDeM—to perform experiments that aim to capture the impacts of the core determinants in TIB on the usage of different transportation modes (i.e. car, tram/bus, train, walking, biking, others). Mapping in Table 54.1 is then used in conjunction with the differences between experimental outcomes to provide interpretations for all scenarios. The current preliminary results observe the figure of car increase when the agents invoke *Affective* factors in the second level of TIB. The same pattern can be found where the agents put their *Intention* first by performing the deliberation process rather than acting based on past behaviours. In the other hand, *Social factors* and *Habit* appear to be the reason why the majority of Swiss households choose public or soft transports.

The current model is still, however, missing some features, including *learning* and *variability*. Agents do not have self-learning ability and mostly rely on the frequency of past behaviours as *Habit* determinant. We are developing the agent's adaptability by changing its perception of certain values or determinant weights depend on the feedbacks (success/failure) received from environment. Coupling this along with traffic rate or different infrastructures in each Canton can provide a more realistic view of the shifts in behaviours of the agents. In term of model's variability, it involves expanding the mapping between the first level determinants with SHEDS and MTMC data (see section "Experimental Procedure"). This can be accomplished through our collaboration with a sociologist to derive a more precise description of TIB's elements and generate more agent profiles in the current population. In addition, investigation on the effects of changes seasonal schedules and agent's accessibility to different modes (e.g. public transports do not work well in winter condition, new routes become available) is planned for the next stage.

There are also some promising research directions for our mobility platform. With the new innovation in technology and an increase in environmental awareness, it becomes more common for people to have access to electric or hydrogen vehicles. Using the same decision-making architecture, we can study the long-term transportation choices (such as purchasing a railcard or a new car), plus their influence on the daily routine. The model can provide a good indication of the roles of determinants in future scenarios (such as new infrastructures or government policies). In addition, the same experiment can be performed on different application domains (e.g. tourism) where TIB's determinants can potentially play a major role in the agent's decision-making.

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Chapter 55
Testing Optimization Scenarios of Cruise Passenger Ground Transportation Using Agent-Based Models and Crowd-Sourced Data

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Across the world, cruise tourism has become one of the fastest growing businesses over the past decades. Especially major port European cities like Hamburg, Marseille, Helsinki or Genoa benefit from this furtherance, whereas their urban development needs to react to the new conditions. An essential measure of quality in cruise tourism is the level of customer satisfaction, which is influenced by the transit experience between the different modes of transportation connected to a cruise travel [1, 2]. The 'first impression' upon embarking on a cruise ship determines largely the overall personal cruise experience, and along with disembarkation, are the main periods in which the social and economic impact of cruise tourism can be produced for the port-city hosting them. Our project views the embarking process of cruises in port cities from a passenger perspective by way of supply-chain modeling of the multimodal ground transfer related to urban mobility. In a first phase, we develop spatial models based on a GIS platform that represent infrastructure settings, location and function. Thereafter, we extract crowd-sourced data from external sources and process them as socio-spatial information input regarding the activeness of specific places under scrutiny. Combining the spatial model with the input data, we model the behavior of the 'agents' involved in the process and derive Agent-Based Models (ABM) that

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portray the socio-spatial system behaviors and interactions. By the modification of any of the mentioned inputs –spatial setting or activeness data– we can test the effect of specific spatial or process planning interventions on the overall system behavior.

Addressing a major research deficit in the overall research on cruise economy and planning [1], we not only focus on synergies between different urban mobility and transportation systems, but also provide for the generation of alternative planning scenarios and predictions and thus support adequate decision-making on the side of planners and managers.

Challenge: Cruise Passenger Transfer in Hamburg

Hamburg, as Germany´s second largest city and with a strong economy based on trading, logistics, and media industries, goes through a transformation of its industrial and economic profile. Cruise tourism which transfers over half million passengers per year [3] strongly impacts Hamburg´s socio-economic fabric as well as multimodal land transportation flows [4]. The point of departure of this research is a striking misfit of port capacities in terms of cruise passenger numbers, and the capacities of directly linked transportation infrastructures that bring passengers from the urban transfer points to the three cruise terminals.

In our preliminary research carried out with local stakeholders active in the cruise and harbor business, Hamburg Central Station has turned out a main challenge for cruise tourist transfer. The size of the facility and affluence of people is in stark disproportion: it represents a particularly small facility in relation to the vast affluence of people, reported to be ‘*overloaded’* or ‘*operating on the edge of its capacity’* [5, 6]. An improvement of the current situation, however, cannot be expected in near future—thus necessitating alternative measures in view of Hamburg´s cruise business development. On top of daily congestions in the Central Station, cruise tourism poses further negative impact meaning thousands of extra persons per day on season peaks. Tourists report a lack of comfort and orientation at the very first step of the arrival, which contributes to the decision of taking the first available bus shuttle to the cruise terminal [7] –instead of spending more time in the city– limiting the economic impact of ‘cruise tourism’ to cruise operators and cruise-related business only.

On that background, we hold that a procedural perspective and dynamic form of modeling is necessary to grasp the peculiarities of Hamburg Port and its synergies with the city’s socio-economic, functional and morphological fabric. The multiple activities of ports will certainly affect by way of chained processes entire city operations and urban systems. Ports need to actively integrate multiple procedures with view on individual actors as well as on the overall structural network [8], implying to reframe the description of port processes beyond limits of the port itself, and to connect it, among others, to the vital transfer processes happening at Central Train Station. A comprehensive solution is required that defines the multiplicity of individual actors within a structural network. Agent-Based Models (ABM) provide a promising avenue not only for visualizing and quantifying critical situations such as the bottleneck at Hamburg Central Station, they can also help to improve and optimize chain processes and flows, and predict the potential effects of new interventions and planning schemes.

Procedural Approach: Establishing the Port City Model

In a series of stakeholder workshops, we developed a procedural scheme that represents the routes and transportation modes used by passengers when embarking and disembarking, noticing a convergence of paths towards the Central Station, since it is one of the main nodes where passengers arrive by long-distance train or trains from the airport. We established documentations of (1) the routes and transport modes influencing the process, (2) the chains of events from the passenger perspective, (3) the desired 'what if' scenarios, that we further investigated with the models developed in the further process of the project. To explicate the linkages between Cruise Centers and the urban systems, we established a matrix for the available transport connections between origins and destinations, which were integrated in the subsequently established model.

In order to visualize and simulate the above described relational network, we endeavored in creating ABMs that would bring together our process description with additional quantitative data on cruise passengers established by crowd-sourced data intended to quantify the activeness of places at their initial state, and to establish the modal split and route choices. To do so, a combination of Telecom tracking data, posts gathered from the social network Instagram, and a summary of data extracted from person-counting sensors and vehicle parking records were utilized (Table 55.1).

The process gathering Telecom data was focused on back-tracking of users from departing cruises to their origin in the city and detection of users starting their trip at the Central Train Station in passengers from ten different cruise vessels in dates avoiding major events in the port e.g. Port Anniversary.

Table 55.1 Summary of quantitative data sources

Telecom: Cruise passengers	1. Modal split ground/underground/ferry 2. Quantification of people with origin train station 3. Activeness curve of cruise passengers in the train station in time 4. Route from train station to cruise terminal followed 5. Arrival times at the cruise terminal, and length of the trip
Instagram	1. Activeness curve of non-cruise passengers in the train station in time
Pedestrian-counting sensors	1. Quantification of people in the train station per da 2. Probability of flow in pedestrian routes
Terminal parking records	1. Modal split bus/car/taxi 2. Vehicles arriving and leaving by minute

A similar methodology was followed to retrieve images posted on Instagram, which were used mainly to quantify the activeness related to non-cruise passengers in the Central Station. To do so, we downloaded a sample of pictures with hashtag or location pin related to the Central Train Station, and filtered pictures posted by users with presence in the Central Station and any of the cruise centers or cruise vessels on the same day, assuming potential relation to cruise tourism.

A summary of data retrieved from pedestrian-counting sensors was used to establish the most frequent pedestrian routes in the Central Station area and its surroundings unrelated to cruise tourism. In this context, the total number of persons visiting the station per day was distributed per minute proportionally to the Instagram activeness curve, and guided through the most frequent walking paths following proportion to the pedestrian-counting sensors.

Finally, terminal parking records were used with the aim of detailing the modal split of passengers when arriving at the terminal through ground transportation and help modeling the return of empty vehicles in their turnaround routes, when they travel empty to pick-up new passengers (Fig. 55.1).

In this case, since data gathered was detailed enough, no human decision-making at individual level was modeled further than simple choices e.g. passengers queuing in the shortest line. As building a realistic model of complex and unpredictable human cognition and behavior is a challenging task [9], the purposeful assumption of simplified actions is acceptable when no decision-making modeling is needed. So we have defined basic triggers in the model as mutually chained actions, instead of modeling complex human cognitive processes. We established a simple Agent-Based Model representing the current condition of Hamburg Central Station and its urban environment. Taking the viewpoint of cruise passengers, our model describes how this specific segment of passengers arrives and departs, and how related transport businesses operate the round trips between the station and cruise terminals.

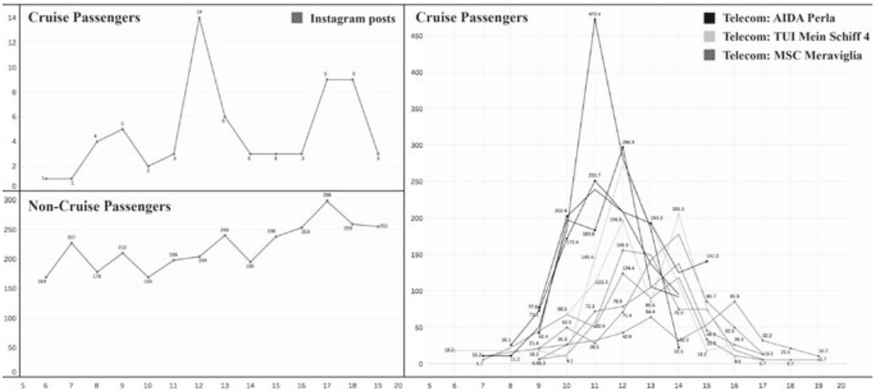

Fig. 55.1 Comparison of temporal activeness in Hamburg Central Station extracted from Instagram posts (left) and Telecom data tracking related to passengers traveling on specific vessels (right). Time peak at noon coincident for cruise passengers (right and top-left)

Conclusions

With the model established in accordance with above mentioned rules and procedures, we able to carry out first test runs and simulate different scenarios of chained processes and spatial interventions, which allow first tentative interpretation of results. As we expected, we could show clear effects on the movement flows and waiting times in accordance to the different intervention scenarios. The planned intervention in the Central Station is to increase the size of the Welcome Center and bring the bus shuttles closer to it—thus address the two main bottlenecks. Even though the number of taxis and shuttles were also reduced, an overall increase of efficiency would result from a direct intervention that focuses on the bottlenecks, bringing reduced waiting times and significantly shortened queues.

With our model we have managed to establish a first tentative agent-based model that is able to simulate and describe the positive impact that various alternative scenarios could have in contrast to the current state. Despite our input data were aggregated and extrapolated bearing certain segmentation, we were able to quantify the impact of the scenario-proposals in comparison to the current-situation. Also we validated a conceptual process of pre-simulating that would be applicable before actual decision-making would happen. In regards to the multimodal land transportation linked to cruise tourism in Hamburg, the modifications tested with the different scenarios would enhance cruise transfer comfort and satisfaction from the passenger perspective and raise the efficiency of the chained-processes, thus eventually benefitting both tourists and stakeholders involved. Therefore, ABM suggests itself as a tool for planning support and decision-making already in early stages of discussions and deliberations.

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Chapter 56
Mobility Fee—Creating Better Cities, Creating a Better Future!

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Abstract The following paper explores an alternative to financing public transportation in densely populated urban areas through ticket sales as a possible incentive to increase the usage of public transportation with the intent of reducing car traffic and pollution in urban spaces. It addresses the option of collecting a "mobility fee" from residents of an area to replace the revenue generated by ticket sales. Since the fee as it is envisioned in this paper would be collected from residents regardless of whether they actually use public transportation, this method would result in the usage of public transportation itself not being associated with any additional monetary cost. The text elaborates on several theoretical approaches regarding the utility and viability of this concept. Using population data from the city of Mainz and budget data from the Mainz public transportation agency, the authors calculate a monthly fee capable of substituting ticket sale revenue of the local public transportation network in Mainz. Based on these calculations, a mobility fee of 15 Euro per resident of Mainz above the age of six would be sufficient to exceed the ticket sale revenues generated by the Mainz public transportation agency. Instead of trying to make people prioritize environmental concerns over personal convenience, the mobility fee aims to make environmentally friendly behavior more convenient than its alternatives by removing the financial cost and effort of buying a ticket from the decision-making process of urban travelers.

Keywords Ecological mobility · Public transportation · Solidarity

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Introduction

Mainz, as many other cities, does not meet the Air Quality Guidelines of WHO [1]. Especially individual traffic is a major contributor to air pollution, which is expected to increase in the future due to growing cities. Although, the urban public transport in Mainz is already well developed, 37% of the total traffic consists of motorized individual transport [2].

Beside the advantage of flexibility, motorized private transport has negative side effects on many levels. It is cost intensive for car owners as well as for the community providing roads, parking lots, etc. and it reduces air quality in urban areas. In addition to high costs and pollution, motorized mobility takes up a lot of room in a city. To create a better future within cities, we developed a concept to reduce air pollution in urban areas in the long term by reducing motorized individual transport. The concept aims for behavioral changes. Our intervention is called *Mobility Fee* intends to facilitate a transition from using a car to public transport. Mobility Fee entails a solidary model through a monthly compulsory contribution from every resident registered in Mainz to enable access to public transport. The intervention can drastically reduce air pollution in urban areas and thereby revalue cities as spaces for human habitation.

The following text will give a brief overview of our concept. Afterwards we will outline three theoretical approaches to explain how the intervention could cause behavioral changes: The Habit Discontinuity Hypothesis by Bas Verplanken, the Low-cost Hypothesis by Diekmann/Preisendörfer and the Theory of Planned Behavior by Icek Ajzen. Following that, we will provide an empirical background as well as data about and calculation of the Mobility Fee's financial viability. After a short explanation of the solidarity principle and the relevance of demographic change we will give an example of additional measures to reduce emissions which would benefit from the introduction of our Mobility Fee before reaching our conclusion.

"Mobility Fee"– Solidarity System for Urban Public Transport.

The approach Mobility Fee, based on the German "Rundfunkbeitrag", is about an obligatory fee which would have to be paid by each resident registered in Mainz. The resident registration office sends a demand to each registered citizen with information about the Mobility Fee, which includes a monthly payment between 15€ and 22€. Hereupon every citizen from Mainz is allowed to use the entire public transport system of the „Mainzer Mobilität ", including buses and trams. The approach will incorporate specific arrangements for children/pupils, pensioners, people with a disability and welfare recipients. The Mobility Fee tries to incentivize the use of public transportation, especially for short distances in their everyday life instead of using a car, e.g. to go for a shopping trip or visiting the cinema.

The intervention tends to discourage old routines of using a car and should animate the residents to use buses and trams more often, because they have already obligatorily paid for it. If every citizen has to pay a Mobility Fee, the cost is much lower for everyone than the current prizes per person. So, the approach of the Mobility Fee is based on the solidarity principle. Additionally, the fact that everyone already has a ticket, saves a lot of time for searching for the right ticket or comparing ticket prizes.

Theoretical Background

Habit Discontinuity Hypothesis

As human beings, a lot of what we do in our everyday lives is structured by our habits. We often do things the way we are used to do them instead of thoroughly evaluating the benefits and disadvantages of the ways in which we perform our daily routines. Since our everyday lives compose, by their very nature, the vast majority of the things we do, the impact our habits have on how we pollute our environment can be considered significant. Due to the relevance of our habits in how we conduct our daily lives, approaching the issue of pollution from the angle of breaking those of our habits which involve a lot of pollution appears to be a promising way to reduce pollution in the long term. Now the idea of breaking harmful habits to address pollution and climate change is far from new but, as we all know from experience, breaking those habits requires a lot of effort, which people often cannot or will not expend in order to break said habits. This issue is exacerbated by the fact that habits perpetuate and even strengthen themselves: the longer we are used to doing something a certain way, the more we get used to doing it that way. Fortunately, there appear to be ways in which breaking habits can be made easier, with one such way being outlined in the *Habit Discontinuity Hypothesis* introduced by Bas Verplanken. The Habit Discontinuity Hypothesis suggests that, since habits are shaped by the relatively stable contexts (where we live, what our interests are, who we live with etc.) in which we acquire them, destabilizing or changing these contexts can make it easier for us to re-shape our habits, which were shaped within and applied to their previous contexts.

A large factor in urban pollution is motorized traffic, especially the use of cars in our daily commutes. As an integral part of our daily lives, the mode of transportation we use in our commutes is largely determined by our habits. We rarely make a conscious decision on how to go to work in the morning. We tend to have a *normal* way of doing it, and most days we do it that way without considering the alternatives. Part of the context by which our travel habits are shaped is of course the location of our home, as it is the place, we usually start our commutes and errands from and a place to which we usually return at least once per day.

In a study published in the peer reviewed open access journal [3] in 2016, the authors explore the effects of changing one's place of residence on one's choice of transportation. The study analysed the 'Understanding Society' dataset which contains long term data concerning a representative set of over 18 000 residents of the United Kingdom. Using this dataset, the authors investigated how pro-environmental attitudes and recently moving to a new home influence our choice of transportation. The results of the study indicate that the probability of using a car is much lower right after people move to a new home, but drastically increases within the first two years at the new residence, with a slow but continuous increase of car usage within the following years. Furthermore, the study shows that while pro-environmental attitudes have a strong influence on car usage right after moving to a new home. Said influence decreases over time as well, indicating that habits grow stronger over time and can eventually overcome the influence of behavioural intent in the long term [3].

These results strongly suggest that there is a temporal *window of opportunity* to further incentivize breaking our travel habits soon after we change our place of residence, ideally establishing new habits concerning our choice of transportation that rely less on using cars. In an effort to use this window of opportunity, we suggest a localized Mobility Fee in densely populated urban areas as we outlined above. The following chapters will further elaborate on this idea and its financial viability using the city of Mainz as an example. This approach would combine the habit-breaking potential of the changed behavioural context in a new place of residence with a financial incentive to use the local public transport network, facilitating the establishment of habits which promote the use of more environmentally friendly modes of transportation.

Low-Cost-Hypothese (Diekmann/Preisendörfer)

As a starting point for the Low-Cost Hypothesis serves the assumption that "environmental concern" [4] has an increased effect on environmental behavior in situations which are barely inconvenient and do not involve high costs. In contrast to financial benefits, attitudes affect the environmental behavior less strongly. But with lower situational costs a transformation from attitudes into equivalent behavior is getting more probable and easier for individuals. In high cost situations, ecological awareness is insufficient to have an impact on attitudes and the respective behavior. Cost is not seen in the narrower sense. Accordingly, high- and low-cost situations are not only defined by financial expenses, but they moreover include components like comfort and time investment. Further, Diekmann and Preisendörfer assume an "interaction effect" [4] which implies that the effect size from attitudes on behavior modifies corresponding to the expense factor of the situation [4]. The relevance of pro-environmental attitudes consists in giving environmental behavior a value. If value and behavior do not coincide it can provoke "cognitive dissonance" [4] which would reduce the individual's utility. This process mainly takes place in low-cost-situations. In high-cost-situations on the other hand the cost factor dominates and outweighs the disbenefit of a missing analogy between attitude and behavior. Transferred to the decision-making process concerning the choice of transport mode, the Low-Cost Hypothesis upholds the concept of the Mobility Fee. Diekmann and

Preisendörfer avail the hypothesis that the less often a behavior is practiced the more costly it is. According to their empirical results, the choice between using one's own car and public transports is classified as a high-cost situation as abandonment of a car is the rarest conduct among their 16 enquired modes of environmentally friendly behavior [5]. The aim of the Mobility Fee consists in transforming the utilization of public transports into a low-cost-situation due to the cessation of high-priced tickets and making the usage more comfortable. When the Mobility Fee is already payed obligatorily, using public transport does not involve any additional payment whereas going by car still results in costs for fuel and possibly parking. In terms of other non-financial cost factors like time and convenience an expansion of the public transport system which would come along with the Mobility Fee would ensure shortened waiting time and make the utilization of public transport more efficient and therefore more attractive. Hence, the cost reduction for the ecologically friendly behavior alternative leads to the direct effect of a greater demand for the less expensive conduct and moreover to the indirect impact that people transform their ecological awareness easier and more often in actual behavior [5].

Theory of Planned Behavior (Ajzen)

The "theory of planned behavior" [6] describes the emergence of actions and assumes that intentions affect actions which are under volitional control. Therefore, intentions are composed of the factors attitude, subjective norm and "perceived behavioral control" [7]. Attitudes comprise beliefs in positive or negative consequences which a behavior involves and represent an advantage or disadvantage to the individual. The subjective norm includes expected expectations of the social environment and society. Perceived behavioral control describes the level of difficulty to behave in a certain way which is based on eases and conceivable barriers [8].

Intentions are the main predictors for actions as they represent the fortitude of a volition and measure the effort an individual is willing to expend. Along with intentions availability, opportunity and resources as external factors are central to operational intents. The concept of synergy of intention and ability is based on the assumption that the perceived behavioral control is of greater interest than the actual behavioral control [7].

This perceived control works as a precursor for actual behavioral control provided that restrictions are regarded [9].

In terms of the Mobility Fee concept the perceived behavioral control is the part of the theory of planned behavior which is of paramount importance. As the theory reveals, circumstances have a relevant impact on conduct. As a change in general attitudes towards environmentally friendly behavior is hardly enforceable by urban development or mobility management, the Mobility Fee focuses on the external factors which restrain or facilitate the performance of a specific behavior like the utilization of public transport instead of using one's own car. The discrepancy between environmental awareness and environmental behavior which will be further outlined in the following passage concerning the empirical background can also be transferred to a discrepancy between intentions and empirically observable behavior. With regard to the empirical results which show that due to ecological awareness 15–20% of the variability of environmental behavior can be explained, underlying circumstances still have a highly relevant position [10]. The Mobility Fee aims to reduce possible restrictions which can discourage individuals from preferring the utilization of public transport over choosing the own car. It does apply for example to the improvement and expansion of the public transport network with the goal of enabling more people to easily have access to public transport. That requires frequent bus and tram connections including those serving the periphery. People who go to work for example are usually bound to a specific time. If public transport only offers infrequent or unreliable connections this can be a restriction which does not allow people to use it. In addition to that and regarding the fact that with the Mobility Fee every citizen in Mainz automatically has the right to use public transport, the constraint that a ticket is required disappears.

Empirical Background

Previously depicted theories for behavioral change show the discrepancy between environmental awareness and environmental behavior. A mobility questionnaire from 2016 displays the tendency of Mainz residents to use motorized individual transport even though 70% of the survey group evaluate the Mainz public transport system as very good/good with an average school grade of 2,0 [11]. 33.8% of the people go to the city center by car for free time activities such as cinema, theater or sports [11].

These results show the inconsistency of attitudes and actions. Therefore, it is necessary to connect environmental behavior with positive or negative monetary incentives. Empirical studies have illustrated the different effects of soft vs. hard interventions aiming for a sustainable mobility. Hard interventions can for example be price policy, reduction of parking lots, increase in supply or simplification of the ticket system. Soft interventions in contrast, represent prevention campaigns and target group specific marketing [12].

The Mobility Fee as a monthly compulsory contribution counts as a hard intervention combining price policy as well as simplification of the ticket system. The concept is based on decoupling of payment and usage since the amount of payment is not depending on usage anymore. With the obligation to pay, you do not have to worry about ticket tariffs and ticket purchase any longer. Referring to the so-called flat rate preference, people tend to purchase a flat rate independently of their expected use [13]. Once they have decided on a flat rate, the probability of its usage increases. It also has an impact if you have to pay for something in advance. A prior payment causes a rise in usage. This rise is declining over time. This phenomenon is called Sunk-Cost-Effect [13]. Hence, it can be effective to decouple expenditure and usage to initiate a flat rate feeling but it is also beneficial to remind the user every month with his payment to use public transport that he has already paid for. The personal monthly payment transaction in this context has a huge advantage compared to a free admission financed by taxes. Moreover, the monthly compulsory contribution of the Mobility Fee creates an artificial low-cost situation because there are no additional financial expenses and less other opportunity costs. This low-cost situation helps to choose public transport since lower costs make a transformation from ecological attitudes to equivalent behavior easier [4].

Referring to a modal split the test group with a type of Mobility Fee used public transport significantly more frequently [13]. Particularly this group switched from car usage. Contrary to the expectations the test persons did not use public transport for unnecessary fun rides. The modal split also shows the obtained effect that the transition happens rather from motorized individual traffic to public transport than from non-motorized traffic (e.g. bicycling or walking). The study expects an increase in public traffic of 10–30%, mainly in expense of motorized vehicles [13].

An evaluation of the NRW-Semester ticket confirms these results as well. In general, 80% of the students are satisfied with the ticket due to its potential benefits as well as ecological and solidary arguments [14]. The implementation leads to a modal shift and other positive side effects. Because of the ticket, students travel further and more often, so their quality of life increases [14]. The evaluation also calculates the effects on climate protection. As a result of substituted car traffic, the emission reduction could be estimated at 8,2 tons of CO_2 per day [14]. Additional reductions could be caused by a reduced car population and a long-term modal shift. It is assumed that students keep up their sustainable mobility behavior even after their graduation because of positive experience with public transport [14]. These positive experiences are assumed to shape habits that are trendsetting for students, their environment and further generations [14].

After considering theoretical and empirical facts, the next chapter will focus on the feasibility of the Mobility fee within the border of the city Mainz.

Specific Calculation and Demographic Data

In the city of Mainz, there are 220.151 [15] registered inhabitants who would have to pay the Mobility Fee. There are four categories of people including different increments of prizes. For children, who are younger than six years, there would not be any commitment to pay the Mobility Fee. From age six until 18 the fee will cost 15€ per month. At the age of 18 the monthly payment will be 22 € for teenagers and adults until 65 years. Pensioners and people at the age of 65 and older will pay less, the Mobility Fee only amounts to 15€.

Students of the Johannes Gutenberg—University, the University of Applied Sciences and the Catholic University of Applied Sciences already pay a tuition fee per semester which includes a contribution for the public transport. So, students who are registered in Mainz would not have to pay the Mobility Fee. The study of Prof. Günter Meyer from the Geographic Institute of the Johannes Gutenberg—University in cooperation with the city of Mainz found out, that 69% of the 40.000 students, who are studying in Mainz also live in Mainz [16]. This means for the calculation of the Mobility Fee, that 27.600 students pay the public transport via their tuition fee and not the regular Mobility Fee. An additional contribution is made by 12.400 students that are not registered in Mainz but pay the tuition fee anyway (Table 56.1).

In 2017 the Mainzer Verkehrsgesellschaft, which is a subcompany of the public utility company of Mainz, generated **46.000.000€** through the sale of tickets [17], which would have to be replaced by the Mobility Fee.

As the chart (Tab.1) illustrates, the different groups of people who are classified by their age, which is associated with different prices of the Mobility Fee, the Mainzer Verkehrsgesellschaft could generate 42.239.100€ per year with just the payments of the registered citizens. In addition, there will be approximately 4.800.000€ from the students Mobility Fee which is included in the tuition fee. There is the potential to obtain **47.039.100€** per year in place of the current income from ticket sales.

The categories of the Mobility Fee are aimed at relief of families and are adjusted to the demographic change, which is also seen in Mainz with a high number of older

Table 56.1 Calculation of the Mobility Fee

	0–6 years old	6–18 years old	18–65 years old	Students in Mainz paying tuition fee	65 years and older	
Number of citizens registered in Mainz	11.697	20.322	120.250	40.000	37.973	
Mobility Fee per month	0,00 €	15,00 €	15,00 €	10,00 €	15,00 €	
Current tariffs per months (MVG)	0,00 €	47,75 €	69,53 €	/	55,50 €	
Mobility Fee per group and per month	0,00 €	304.830 €	2.645.500 €	400.000 €	400.000 €	
Total Mobility Fee per group and per year	0,00 €	3.657.960 €	31.746.000 €	4.800.000 €	31.746.000 €	
Total Mobility Fee per year						**47.039.100€**

Source: Own calculations based on [15–17] people, for whom using public transport is probably safer than using their own car. Also, other arrangements for people with specific disabilities are conceivable.

The city of Mainz is one of the largest cities in the Rhine Main Area. In this case, it is important to not see Mainz as an isolated city, but also as a part of a huge metropolitan area, that is very well connected with a route network of public transport systems. For citizens of the adjacent cities of the Rhine Main Area, there could be the opportunity to pay a Mobility Fee voluntarily too, which could additionally increase the revenue of the Mainzer Verkehrsgesellschaft.

Solidarity Principle and Demographic Change

As mentioned, the concept of the Mobility Fee is embedded in the principle of solidarity. That means in this case, that the amount of the fee depends on the demographic position of a person in society. The calculation illustrates, that there is the financial opportunity to reduce the costs for children under six years, students from the age of six up to 18 years and pensioners older than 65 years. Conversely, adults from age 18 until 65 would have to pay a higher Mobility Fee, which enables the price deduction for younger and older citizens. This shows that the relief of specific groups of people has to be compensated by a larger group of citizens, who are on average more financially independent. Besides the solidarity principle, also the current demographic change should be addressed. The Mobility Fee minds the fact, that the population is going to be older. There is the prediction that the group of citizens who are 65 years old or older in Rhineland-Palatinate will increase from 21% of the population in 2010 to 29% in 2030. Simultaneously, the percentage of under 20 years old will decrease from 19% in 2010 to 17% in 2030 and only 15% in 2060 [18].

The large group of older people, which increases steadily as already mentioned, has to be supported, not only financially but maybe also in the decision process of giving up their own car in showing them the flexible alternative of the urban public transport system with the easier and more cost-efficient access through the Mobility Fee. In addition to the higher numbers of older people, the demographic change includes lower numbers of children, which means that not only the older generation should be supported, but also families. The free access to the urban public transport for under six years old children and an only 15€ payment per month for children between 6 and 18 years, creates a family-friendly version of the Mobility Fee by providing a financial support for parents.

In this context, the possibility of higher reliefs for a specific number of children, for example three children or more, could be discussed (comparison to the German “Kindergeld”).

Conclusion

The Mobility Fee provides a variety of advantages to all parties involved. Citizens of the area in question have unlimited access to their local public transportation system at a cost that is far lower than that of equivalent tickets in the current system, without expending any of the effort and planning involved in purchasing said ticket. Granted, we are talking about a fee that is taken from people without requiring their consent. But that is far from unheard of in societies where almost everyone is already paying other non-consensual dues such as taxes or public health insurance. Considering that a lot of the infrastructure in western societies is built and maintained specifically to accommodate cars, one might even argue that subsidizing the public transportation network with an obligatory fee is not too different from subsidizing private car usage by maintaining this infrastructure through taxes. Additionally, the Mobility Fee has the potential to be a financial relief for families. Many parents already rely on public transportation to bring their kids to school. Due to the solidary nature of the Mobility Fee, the reduced monthly rate envisioned in this concept is far below the usual rates paid by students for equivalent tickets under the current system. This would make the use of public transport more attractive to parents, especially considering the fact that they have to pay the fee whether they use it or not. This could lead to more parents encouraging or requiring their children to use public transport, which not only reduces the amount of traffic but also contributes to the emergence of environmentally friendly travel habits among children. The MVG as a participating actor in this process could benefit from far higher financial stability. Instead of varying ticket sales, their base income would be highly predictable and stable as long as the fee is adjusted to inflation. The transitory period will entail a few issues for the MVG, particularly regarding the administrative structure and acceptance of the fee among the population. Temporary issues of this nature are barely avoidable for any political measure of similar scale. The increased usage of public transport would necessitate a larger capacity of the MVG transport network, which would most likely be achieved by acquiring additional vehicles and personnel. While this would constitute additional cost for the MVG, they could likewise expect additional income: since the entirety of the current income generated by tickets would be covered by residents paying the Mobility Fee, every single ticket sold to non-residents would generate additional income for the MVG.

The most obvious environmental benefit of the Mobility Fee is the reduction of emissions by increasing the attractiveness of public transportation as an alternative to car usage. Furthermore, reduced traffic has a variety of other advantages for residents regarding quality of life. Less traffic means less noise, less accidents, less traffic congestion resulting in faster travel with less emissions per kilometer and an increased potential to designate pedestrian areas. Clearly the Mobility Fee can't solve urban pollution all by itself. It is a mere step in a marathon that lies ahead of future societies, but it is a crucial step. It doesn't rely on people doing things out of idealistic convictions, it doesn't just rely on people consciously choosing environment over convenience, instead it *makes* the less polluting option more convenient.

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