Chapter 5
Geosimulation: Modeling Spatial Processes

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5.1 Introduction

One of the most stimulating epistemological reflections in dealing with reality contemporarily is the fact that we are gauging the world with the images we have in our minds or we have produced as pictures, graphs, photographs, and (cartographic) maps—and not vice versa. A shift from imagining to imaging has been taken place in science and Lebenswelt (Belting 2005, p. 24). The power of imagination derives from images we create utilizing different devices and techniques, methods and rules. The challenges we are confronted with are readability, reliability, transferability, and self-efficacy with regard to the patterns, relations, contexts, and identification we perceive sensually, mentally, and emotionally.

This is especially true in the field of modeling and simulation in general, and geosimulation in particular, with their intuitively captivating illustration of different kinds of processes generating, perpetuating, or changing physical and societal structures in geographical spaces. This allows for a different kind of reasoning about phenomena that surround us as Resnick (1997, p. 49) points out with respect to the application of computational simulation tools: "In short, I am more interested in stimulation than in simulation". Another implicit implication of the changing relationship between imagination and image is the understanding about how we are accessing the world, reality, or the truth. The notion of image points to the fact that this access is always achieved through translations done by intermediaries. Our references to the world are thus permanently mediated and models are one of the most prominent and basic intermediaries.

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Models are defined by three characteristics (Stachowiak 1973): (1) representation; (2) simplification; (3) pragmatism; these in turn confirm the model approach by a self-referential application of the model idea to the model definition. Every model is a representation of a natural or artificial original.

1. The original is not equal to reality but equal to another model. A model does not cover every attribute of the original, but only those whose properties are of any relevance for the modeler.
2. The original is a more or less conscious setting of selected objectives and not a holistic entity. A model is not in itself a representation of the original.
3. One always has to ask "why", "for whom", "for what" a specific model has been created in order to specify the intention of that model. In other words, there is always a close relationship between a model and the modeler's style of reasoning.

The latter epistemology appears to be appreciated as well by archaeologists applying computational approaches to model and simulate ancient socio-spatial phenomena. Lake (2010, p. 12), for instance, by referring to Mithen (1994), ascertains "the intention of the researcher(s) conducting the simulation" as one purpose of using simulation in archaeology. Accordingly, the seemingly distinctive perspectives of a "faulty understanding of the reality we are modeling or [a] faulty modeling of the reality we are seeking to understand" (Costopoulos et al. 2010, p. 2) do in fact coalesce. Putting all three characteristics together, it is not only obvious that the map is not the landscape, but also that the landscape is always a represented, recognized composition. "There is no original [in the sense of reality; A.K.] from which to copy. Yet the end-result is image-like; it is a gestalted pattern which is recognizable, although it is a constructed image" (Ihde 2006, p. 84).

Recognizing and accepting this epistemological and methodological frame implies a couple of empirical and theoretical potentials in terms of gaining new, different and stimulating insights without referring to an absolute reality but enabling a continuous movement of translation between models. Geosimulation in this respect is a spatially and temporarily scale-sensitive observational instrument, making processes and their causes and conditions visible. Though notions of society, space, and time are commonly used both in science and ordinary communication, they are highly abstract due to their intangible nature. Utilizing instruments of observation is not new, but their meaning and mission has changed accordingly. "Whereas telescopes and microscopes render phenomena visible by affecting the scale of 'tangible' entities through optical processes of resolution, simulation renders 'visible' the effects of parameters and forces such as time, dynamic interactions, [. . .]. Thus, simulation, by constructing images, may translate absolutely nonvisual events into a visual media!" (Küppers et al. 2006, p. 8). In this paper then, modeling spatial processes is an attempt to tie spatial intangibles with social intangibles across time by referring to their tangible counterparts.

There has been put much methodological effort to render abstract socio-spatial processes visible. In geosciences in general and archaeology in particular, attempts to geovisualize complex relationships between social and spatial interactions as well as among these are one of the core concerns in order to gaining advanced insights into pattern recognition, knowledge about so far unprecedented (cor-)relations or (statistical) comprehension of simulated results against empirical records. Demands and challenges towards visualization techniques thus remain a wishful and necessary task, most notably within the realm of geovisualization and geosimulation as Aldenderfer (2010, p. 54) convincingly claims from a data acquisition point of view: "Because of the masses of data that can be created by even a modest simulation, we are in serious need of tools of all kinds to help us "see" our results".

In the remainder some theoretical reflections on the relationships of "society and space", "scale and process", and, methodologically, "agent-based modeling and geographic information science" from a geographical-geosimulation angle will be discussed. This is also the prevailing perspective of a couple of theoretical debates in computational archeological literature (e.g. Costopoulos and Lake 2010; Kohler and van der Leeuw 2007).

5.2 Society and Space: Dealing with Intangible Assets and Infrastructures

Spatiality, temporality, and sociality are highly abstract and fuzzy notions due to their intangible nature. They are, simultaneously, core principles in creating order. Space enables ordering by means of juxtaposition; time involves the process of succession, and the social dimension contributes a basis for togetherness (Fischer and Wiegandt 2012; Sennett 2012; Tate and Atkinson 2001). All three dimensions are mutually and interdependently tied together, e.g. the composition of a place depends on the physical structure and the people who assign this place for its use according to their social meanings which may vary over time; togetherness implies that beyond social contiguity there is some kind of spatial proximity, be it geometrical (face-to-face) or topological (social network relationships).

A central challenge for these three layers, their respective independent properties and dynamics, as well as their interdependent relationships, is the quest for patterns and their underlying rules. Another approach is to investigate simple social interaction and local neighborhood rules in order to research the emerging complexity that potentially happens at the macro-scale. There is a large body of literature in the computational social sciences, whose methodological distinction is applying either Cellular Automata (CA) or Agent-Based Models (ABM) in a broad sense. Since it is almost impossible to survey and thus cite all the literature of this field, a subjective selection is presented in the following paragraphs.

A recent and extensive review with an explicit reference to Geographical Information Systems (GIS) is given by Heppenstall et al. (2012). Benenson and Torrens (2004) published an approach entitled "Geographic Automata Systems" which extends common ABM applications towards an explicit and independent implementation of space. Gimblett (2002) edited a volume which discusses potentials of integrating GIS and ABM for simulating social and ecological processes, while Kohler and Gumerman (2000) investigate the coupling of social and spatial processes utilizing ABM, including two contributions (Kohler et al. 2000; Dean et al. 2000) who analyze settlement development and cultural transformations of the prehistoric Anasazi population in today's federal state of Arizona, USA. The CA approach in general has been extensively analyzed by Wolfram (2002), in connection with geospatial topics, like spatial analysis techniques, mainly in urban contexts. Batty (2005) and Maguire et al. (2005) thoroughly discuss opportunities and pitfalls of the CA technique. A specific application example of using agent methodology to simulating visitor behavior in natural landscapes is presented by Gimblett and Skov-Petersen (2008).

Furthermore, seminal publications in these fields are, among others, Troitzsch et al. (1996) and Conte et al. (1997), focusing on social microsimulation, as well as Epstein and Axtell (1996) with their Sugarscape model representing an early bottom-up approach. A recent publication by Squazzoni (2012) introduces the field of agent-based computational sociology, and Epstein (2006) provides a generative social science with an explicit spatial integration if necessary. In addition, there are a couple of conference proceedings, early examples may be Sichman et al. (1998) or Moss and Davidsson (2001). One of the most widely known online journals in the field of agent-based social simulation is the Journal of Artificial Societies and Social Simulation (JASSS, see: http://jasss.soc.surrey.ac.uk/JASSS.html), furthermore services like the Open Agent Based Modeling Consortium (http://www.openabm.org/) or the GIS- and ABM-related blog (http://www.gisagents.org/) provide interested readers with additional information, open software tools or discussion boards. Computational archaeology can well be integrated into this frame of socio-spatial interrelatedness. Janssen (2010), for instance, developed an agent-based model of prehistoric societies embedded into an abstract but explicit spatial context in order to investigate interdependencies of demographic and climate variabilities against potential strategies of social adaptation and adaptability. A similar model purpose has been pursued by Berger et al. (2007) who are interested in community resilience from a socio-spatial functional perspective. They, however, refer to a specific geographical region, the Middle Rhône Valley in France. A CA-based approach for representing the spatial domain has been chosen by Smith and Choi (2007) to simulate the emergence of inequality in small communities. Lake (2000) developed a multi-agent model which equips agents with cognitive spatial maps by integrating a GIS into his MAGICAL software tool in order to derive individual and cultural learning.

All models dealing with socio-spatial phenomena have to begin with a decision about the smallest, indivisible unit. In the social world this may be an individual, a household, company or institution. The spatial world can be composed of points, lines, and polygons, representing cells or areas; spatial units may represent bus stations, parcels, buildings, political or statistical territories, catchment areas, or landscape entities to mention but a few. Both types of individual units (regular cells and irregular areas) can be represented by agents who are equipped with properties and exhibit some rule-based interactions to other agents. There are a huge range of human agents' properties, since agents can be autonomous in their collective behavior or decision making. Agents are heterogeneous with respect to attributes like normative attitudes, opinions, desires, and intentions, as well as age, family status, or income. They can be pro-active or reactive, communicative, mobile or capable of learning and adaptation (Crooks and Heppenstall 2012, p. 86ff; O'Sullivan et al. 2012, p. 114ff; Epstein 2006, pp. xvi–xviii). Nevertheless, the actual implementation of properties depends on the precise model purpose and usually does not emerge comprehensively. Spatial agents may vary in properties as well; for example, they map land-use, land-cover, real estate prices, developed or undeveloped parcels, symbolic or normative ascriptions.

The design and functionality of relations can be complex, since there are three distinct levels of interactions each composed of different quantities and qualities of relationships: (1) interactions among human agents, (2) interactions among locational agents, and (3) interactions between human and locational agents. Though depending on geographical and/or resolution scale and thus on the model purpose, "locational agents" are defined here as the smallest spatial units used in a geosimulation model and can be seen as the spatial counterparts of human agents in the social world. The possibility of conceptualizing a mutually effected social-spatial model framework of interacting individual units is one of the exceptional characteristics of agent-based geosimulation—or, as Epstein (2006, p. 5) puts it in a nutshell: "How could the decentralized local interactions of heterogeneous autonomous agents generate the given regularity?" Apart from the scale-dependent micro-macro link (see Sect. 5.3) a problem arises with heterogeneity and autonomy if they are set as absolute. In fact, a dynamic struggle with their complementary parts of homogeneity and dependency mirrors societal conditions more appropriately, leading to a dialectic synthesis of inter-scaling and inter-dependent processes.

The current state of a human agent, as well as its variation and alteration, is a function of time, spatial, and social conditions. Though a few of these states can be assigned as intrinsic, like age and health status, most of them rely on exogenous influences. Variables like income, family status, housing situation, places of living, working, and recreation, social positions and roles, membership, professional status, and social embeddedness, all refer to a relationship between the single unit and the multi-leveled superior environments. The term "social" indicates a reference to larger entities as communities or societies. Modeling and simulating human agents' actions and behaviors thus needs to incorporate a kind of "social auto-correlation" which reveals social distances among the members of a community or society, representing the interplay of single units and the respective collective. This in turn enables conclusions to be drawn about social phenomena of lifestyles, ethnicities, migration backgrounds, normative and religious attitudes, to mention but a few. ABM methodologies have developed different conceptual frameworks in order to operationalize "social auto-correlation" (see, for example, the review of Kennedy 2012). One approach refers to beliefs, desires, and intentions (BDI; Rao and Georgeff 1995) which contextualize agents' knowledge, perceptions, motivations, and attitudes with social-environmental facts, based on a social constructivist epistemology (for a current review see Searle 2010, who primarily draws on status functions, collective intentionality, and institutional facts as explanatory objectives to derive the macro-level of society). A similar framework is based on physical, emotional, cognitive, and social factors (PECS; Schmidt 2002). “This framework includes a representation of the human mind, specifically perception and behaviours, and mathematical representations of physiology, emotion, cognition, and social status” (Kennedy 2012, p. 175). An approach which predominantly considers human decisions against environmental conditions by analyzing corresponding data is called “fast and frugal” (Gigerenzer 2007). All cases exhibit an awareness of a necessary multi-dimensional and multi-scaled coupling of social entities which is theoretically reflected by, among others, Giddens (1990) and Latour (2005).

This description of a human agent can be translated to a single locational (or place) agent as well. This type of agent may also have some intrinsic properties, for example, soil quality, slope, and land-cover; of at least equal significance is, however, the relational context to other locational agents, i.e. the neighborhood effect (whereby neighborhood is understood here in a broad sense, encompassing geometrical and topological as well as semantic concepts of nearness). Aldenderfer (2010, p. 61) points to this aspect of spatial proximity when advocating true geosimulation approaches as beneficial for archaeological investigations because of their georeferencing capability of social and spatial objects and thus their ability to relax spatial relations to noncontiguous neighbors. This capability restricts Cellular Automata approaches with their inherent concept of neighborhood as being contiguous and cell-like. Housing prices, location and allocation of infrastructures and services, and land-use conflicts all depend crucially on the spatial configuration of single place units. In this regard, spatial auto-correlation is also a meaningful method. Geocomputation and geospatial analysis provide a huge range of sophisticated techniques which aim at investigating (geo-)statistically distance-weighted and directional variations of geo-referenced objects or events. It is beyond the scope of this contribution to give an extensive review of all the available tools in geostatistics and geographic data-mining, thus a brief and selected overview is being presented here (for an introduction to geostatistics see, among others, Leuangthon et al. 2008; Remy et al. 2009; for an introduction to data-mining see, for example, Han and Kamber 2006; Miller and Han 2009).

One approach is point pattern analysis (PPA) which compares an empirical distribution of points representing geo-referenced events with a theoretical (random) distribution (Lloyd 2007, p. 171ff; Wang 2006, p. 36ff). The statistical aim is to examine whether or not the empirical distribution differs from the theoretical one, either representing a (significant) tendency towards clustered or towards regular distributions. PPA is appropriate when investigating settlement structures or archaeological sites in order to gain a better understanding of the spatial (and spatio-temporal) influences of community or social development. Another approach is deterministic interpolation. In general, interpolation attempts to deduce knowledge about a study area by estimating data values for any arbitrary location within the study area by referring to empirical data measured at specific sample points (Johnston et al. 2001). The technique of “referring to” is the sum of a pairwise calculation of the variance between the point of interest (POI; it represents an unknown value) and all empirical points, inversely weighted with the distance between each two points (the POI and one empirical point). In other words, spatial auto-correlation is being incorporated assuming that the closer two points are located, the more similar they are with respect to the data value. Inverse Distance Weighted (IDW) interpolation is one of the most widely used techniques of a deterministic interpolation. This method can be extended by integrating the spatial auto-correlation among all empirical points in order to achieve additional spatial information when estimating an unknown data value within the study area. This alternative is referred to as probabilistic interpolation and Kriging techniques are the most well-known in this field of geostatistics (Remy et al. 2009).

For any agent-based model dealing with socio-spatial simulation it can be concluded that individual human behavior is neither completely self-determined (which would be synonymous to probabilistic and unpredictable in social contexts) nor completely socio-spatially and socio-culturally determined (and thus synonymous to predictable and calculable). The same applies to individual places. A common challenge for agent-based modeling is to choose the appropriate level of generalization, according to the model purpose, the theoretical background, and the available data. Interdependencies between human actions and social norms, between place properties and spatial structures, and between the two realms are constantly floating and fuzzy when observed—and including dynamic temporal processes further complexifies these interdependencies. Furthermore, socio-spatial agent-based modeling deals with intangible assets and infrastructures like beliefs, intentions, togetherness, and neighborhood, trying to visualize these by using "solid" parameters. The endeavor of recognizing spatial patterns in community life and social patterns in spatial structures implies consideration of the betweenness of the poles, heterogeneity-homogeneity/local-global, instead of the poles themselves.

Spatial analysis in general and geostatistics in particular appear to be promising tools in archaeological geosimulation as well. According to Lake (2010, p. 12ff), the purposes of computer simulations in archaeology derive from empirical hypothesis testing, theoretical reasoning on structures, processes, and functions, and from methodological explorations into statistical inferences. Since all three levels of scientific endeavor are capable of dealing with (and do refer to) complex spatio-temporal dynamics, the use of geosimulation techniques outperforms simpler CA approaches by releasing patterns of agents' actions socially (with respect to collective vs. individual action framing) and spatially (with respect to local vs. global spatial framing).

5.3 Scale and Process: Taking Relations and Interdependencies into Consideration

According to Benenson and Torrens (2004, p. 25ff), the human-society and place-space link described in the previous section can be formalized in agent-based geosimulation models at a general and coarse level as follows:

$$G \sim (K;\, S,\, T_s;\, L,\, M_L;\, N,\, R_N),$$

with G = geosimulation model

K = ontologies (e.g., polygon or raster representation of space, agents representing humans or households)

S = set of human and locational agents' states (e.g., income or family status in the former case, housing prices or land-cover types in the latter case)

T_S = transition rules of S; in discrete time steps agents change their states according to their internal characteristics and to their social-spatial environment conditions, thus K, S, L, and N

L = location; geo-referenced specification of human and locational agents

M_L = movement rules of mobile human agents; they depend on K, S, L, N, resolution, and level of abstraction

N = neighborhood; it encompasses (depending on the model purpose) the spatial and social neighborhood

R_N = neighborhood rules; they define the criteria of spatial relations (geometrical and/or topological, adjacency and/or distant relations, vision of agents, etc.) and refer as well to K, S, L, and N

This kind of commonly used agent-based model represents the bottom-up type of simulations which implement social and spatial domains as latent variables of individual human and locational agents. The overall aim is to deduce social and spatial macro-structures from human and local decisions and micro-characteristics, respectively. Arguably the most commonly used concept in urban social-spatial agent-based modeling is Schelling's residential segregation approach (Schelling 1969, 1971) which has gained much attention (see, for example, Bruch 2006; Crooks 2008, 2012; Fossett and Senft 2004; Fossett and Waren 2005; Koch 2009; Laurie and Jaggi 2003; Pancs and Vriend 2007; Resnick 1997). The fascinating and stimulating issue of this model, whose theoretical and methodological foundations can be translated into different societal contexts across historical eras, is this inductive-driven phenomenon of emergence (Holland 1998; Johnson 2001), i.e. that the macro pattern of social-spatial structure cannot be derived from the micro pattern of human motives. The benefit of this type of simulation model is its focus on the processes taking place subtly and gradually. The noticeable and visible result of residential segregation usually allows for a retrospective speculation but does not derive sufficient information about the development. "Schelling's model is excellent because it distils the key features enabling us to understand how segregation might arise. The model does not presume to tell us about the entire working of the social and economic world, but focuses on the task at hand, namely to explain why weak individual preferences are consistent with strong and persistent patterns of segregation" (Crooks 2012, p. 369). Figure 5.1 illustrates a potential outcome of a Schelling-styled segregation process with a preference for human agents of at least 30 % neighborhood identity.

Though the model provides, according to its purpose, many scientific insights about the process itself and the phenomenon of emergence, it incorporates only the individual and local scale in order to simulate urban social-spatial dynamics and changes. The model can only succeed in doing so by presupposing a couple

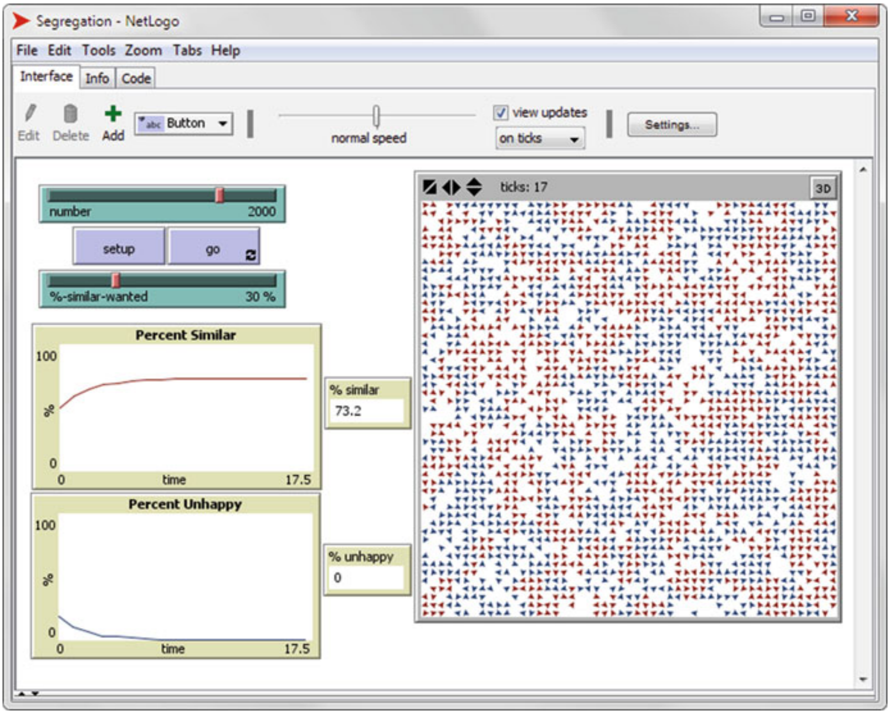

Fig. 5.1 A Schelling residential segregation model. Initially a random-distributed population is assumed with one agent property and two manifestations (*blue* and *red*). The threshold value of neighborhood satisfaction is set to 30 %, below this value agents are forced to move to the next unoccupied cell. After a few time steps the proportion of "unhappy agents" has been reduced to 0 %. *Source*: NetLogo Model Library, see Wilensky (1999)

of preliminaries which do not seem to be necessary, neither with respect to the phenomenon of interest, nor with respect to the empirical original the model is referring to. The following remarks are explicitly related to the problem of social and spatial scaling and do not devalue the model benefits as such:

1. The model takes a randomly distributed population as a starting point which seems empirically unrealistic and epistemologically avoidable. Even if empirical data with spatially high resolution and historically sufficient reliability are missing, it would be more appropriate to assume non-random distributions of population. This can be stated for ancient and medieval societies where guilds and status groups had lived spatially close together, as well as for modern societies with their socially distinct housing areas in urban districts or suburban regions.
2. Furthermore, all agents behave the same way. There are neither within-community nor inter-community differences.

3. It is assumed that social facts as norms, rules, cultural artifacts, and laws mean the same for all agents and are interpreted in the same way which in turn induces identical behavior.
4. There is only one characteristic on which decisions are based; social change is thus excluded, and it is not only the individual decision process which is modeled in a deterministic style with regard to the macro-scale result, but also the macro-scale result as well, since the model stops if all micro-motives are satisfied.
5. In addition, there is one single decision rule and one single threshold value which determines agents' actions. In other words, (residential) satisfaction is reduced to one dimension with one discrete reference measure for all agents, which reduces their scopes of decision-making to pure reaction. Migration should not be considered as the solitary solution to avoid dissatisfaction with a location, because it is a socially far-reaching and expensive decision in everyone's life.

Though depending on the model purpose, it is worth thinking about a more suitable adaptation of agents' behavior in terms of differentiation and flexibility. The aim could be a model approach where social and spatial agents exhibit diverse (individualized) actions within a social range (collectively shared norms or attitudes) changing over time and across space. The well-known archaeological Anasazi simulation model (Dean et al. 2000), for instance, diversifies agents' characteristics but does not use historical settlement locations. The inequality model of ancient societies or communities (Smith and Choi 2007) varies agents' demographic and economic characteristics but allow only two different behaviors (cooperation and defection) which will be inherited by offspring. Lake's (2000) approach, on the other hand, applies a strict individualized agent setting, and criticizing homogenous collective decision making in hunter-gatherer archaeological simulations: "These archaeological studies have not, however, harnessed the full potential of multiagent modeling. [...] In contrast, the MAGICAL software allows each individual to behave according to a potentially unique set of principles, which means that it is possible to simulate individuals thinking and behaving differently according to factors such as age, gender, and social standing." (Lake 2000, p. 109).

From a spatial perspective the problem with a Schelling-styled simulation model is that the neighborhood is conceptualized exclusively geometrically, i.e. space is perceived as being continuously given, without blank spaces, and being evenly important (at least all eight adjacent neighbor cells of a given location, according to Moore's neighborhood; see Iltanen 2012, p. 73; Patel et al. 2012). A topological conceptualization is missing, which takes social relations as networks into account. Furthermore, it is assumed that local knowledge about neighbors is total and immediately updated after each time step which suggests an unrealistic imagination of complete rationality. People may, in addition, migrate, but their social relations with former neighbors may remain significant and reliable, while the relations with new and close neighbors are rudimentary. Finally, both ubiquitous neighborhood and social network relations are unlikely to remain static and stable over time even if no migration takes place. Another spatially and socially influencing force is urban planning and social neighborhood management. These institutions are engaged in avoiding ghettoization, gentrification, gated communities and other forms of social segregation. Social housing and social capital empowerment projects with external partners aim at maintaining vivid and diversified local communities. This in turn could lead to some persistent strategies of individuals or households, although their dissatisfaction level has been increased.

In conclusion, agent-based residential segregation models tend to concentrate on the individual and local scale leaving aside the complementary scales towards society and space. There is much to be said for incorporating macro-scale domains into geosimulation models. Over the entire history of societies there have been social structures and normative rules available which provided for collective order. Ancient and traditional societies had been stratified and segmented by social origin, class, profession, gender, kinship, and local context. Contemporary western societies are characterized as functionally differentiated systems, embedded in globalized and re-localized structures, and today it is education, personal skills, flexibility, financial resources, and technological capabilities that promote social and spatial mobility. Social change towards modernization is highly paradoxical (see Fig. 5.2) making the modeling and simulation of socio-spatial phenomena a complex endeavor.

"Structural differentiation is today an all-embracing phenomenon which increasingly is determined by economic forces of efficiency and optimization. [...] Not only has the spatial and social scaling changed but we also maintain both intimate and distant relationships, face-to-face and virtual, without any specific correlation between distance and emotional nearness" (Koch 2012, p. 10f). The cultural sphere is characterized by a struggle between pluralization and generalization: "On the one hand we are aware of a plenitude of lifestyles, family constellations, and educational institutions which cultivate their own values and norms and by so doing establish specific mechanisms of access. On the other hand a global homogenisation of taste and preference in sports, fashion, music or literature can be recognised. Distinction, thus, is relative to interpret" (Koch 2012, p. 11). Individualization is in constant flux between increased autonomy and dependency. "Dependent autonomy or autonomous dependency extends scopes of acting because one can delegate and/or integrate tasks individually based on personal needs. Mutual out- and

down-scaling **DIFFERENTIATION** up-scaling	pluralization **RATIONALIZATION** generalization
autonomy **INDIVIDUALIZATION** dependency	deconditioning **DOMESTICATION** conditioning

Fig. 5.2 Paradoxes of modernization. *Source*: Own translation of van der Loo and van Reijen (1992, p. 40)

in-sourcing takes place among and between people and institutions but also increasingly between people and machines" (Koch 2012, p. 11). Domestication, finally, means simultaneously deconditioning from natural constraints like surmounting of physical distances due to technological artifacts (e.g. e-banking, e-learning) and conditioning towards these technologies (it is nowadays almost impossible to survive socially without a computer, the Internet, a cell phone, etc.).

There are many more empirical and theoretical examples which advocate a complementary coupling of individual and social scales as well as local and spatial scales. Scholz (2002), for example, proposes a theory of fragmented development, ranging from global to local fragmentation of social and economic activities. He argues that globalization implies simultaneously both homogenization and heterogenization which led to decreased relevance of the national scale but increased relevance of the global and local scale. A universal network of global cities is dominating the economies of regions almost everywhere. The term "global city", however, does not mean that the entire city is part of that global network, but only highly localized places like for example the Docklands and the traditional financial district in London.

Contemporary urban social geography also debates about issues which recognize trans-scaling phenomena. Knox and Pinch (2006) in their book address topics like "patterns of sociospatial differentiation", "spatial and institutional frameworks", "segregation and congregation", "neighborhood, community and the social construction of place", and "residential mobility and neighborhood change" as crucial for modern western societies and thus illustrate the significance of extending agent-based geosimulation techniques by the above mentioned macro-scales.

Apart from other methodological (e.g. resolution; see Walsh et al. 2004) and theoretical topics (e.g. complexity theory; see Easterling and Polsky 2004), it is the relative nature of scale which does not predetermine a specific level of domain, e.g. the individual and local in residential segregation models, and which emerges due to the conflation of different human-social relationships embedded in different local-spatial contexts. Swyngedouw (2004, p. 132f) points to these characteristics of scale from a political point of view: "Scalar configurations [on the one hand; A.K.] [. . .] are always already a result, an outcome of the perpetual movement of the flux of sociospatial and environmental dynamics. [. . .]. Spatial scales [on the other hand; A.K.] are never fixed, but are perpetually redefined, contested and restructured in terms of their extent, content, relative importance and interrelations. [. . .] These sociospatial processes change the importance and role of certain geographical scales, [. . .] and on occasion create entirely new scales".

All variation along the socio-spatial axis of scales is intrinsically tied to time. The simple successive nature of creating order with time becomes a complex concern as time is mutually interrelated with the social and spatial conceptualization of order. Table 5.1 illustrates the three dimensions in a simple linear fashion, but one can easily imagine that each line of the three domains is connected with all lines of the other two (the temporal structuration is according to Bossel 2007, the social according to Luhmann 1993, and the spatial according to McMaster and Sheppard 2004). It is obvious that no single model is able to incorporate all levels with

Table 5.1 Ranges of temporal, social and spatial scales

Temporal scale	Spatial scale	Social scale
Process (cause-effect)	Human body, household	Interaction system, organization
Feedback	Neighborhood	–
Adaptation, self-organization, evolution	City, metropolitan area, province/state, nation, continent, globe	Functionally differentiated systems (e.g. politics, economy, religion, science)

Source: Bossel (2007), McMaster and Sheppard (2004), Luhmann (1993)

all relations, but it would be worth extending pure bottom-up model approaches in geosimulation with top-down approaches, for example by coupling an agent-based sub-model with a system dynamics sub-model. With respect to archaeological models it makes a difference whether one is interested in a local, excavated village in order to reconstruct social structures and the date of the buildings, or if one is interested in the interregional transportation infrastructure of an expanding society over a long period.

5.4 ABM and GIS: Coupling Techniques of Different Methodological Domains

Agent-based modeling (ABM) and Geographic Information Systems (GIS) have both their strengths and their weaknesses when dealing with socio-spatial processes. While ABM intrinsically focuses on temporal processes of mobile (e.g. human) and immobile (parcels) agents but represents geographical space in a cursory manner (Benenson and Torrens 2004, p. 6), GIS offers extensive tools to represent and visualize space but is less suitable to integrate time as a continuous and inherent factor. There have been several attempts in the past decade or so to overcome these respective problems by either coupling ABM with GIS or by embedding one domain into the other. Crooks and Castle (2012) present a comprehensive and current overview of these strategies and concrete applications. This section therefore reviews briefly the most relevant methodological issues.

GI systems are able to store temporal information in several ways (Crooks and Castle 2012, p. 222): The location-based approach stores polygon or raster cell states for each time step, regardless of whether spatial change has occurred or not. Conversely, the time-based approach refers to a given time interval and here spatial change is related to a threshold of significance, i.e. change is only stored if it is sufficiently significant. The entity-based approach is directed towards the shape of spatial entities and their potential changes but not towards the attributes represented by these. Though the relevance of time is highly appreciated within GIS communities a true process representation of it has not yet been satisfactorily achieved (Reitsma and Albrecht 2006).

Agent-based modeling tools on the other hand have begun to implement some GIS functionality in varying degrees. Precursors of this development have been (and still are) Cellular Automata approaches which provide large modeling flexibility if space is conceptualized as a discrete raster grid and neighborhood rules play a dominant role in socio-spatial simulation (Iltanen 2012; Liu and Feng 2012). Software packages as, for example, NetLogo (Wilensky 1999) are able to import raster and vector data for visualization and analysis; polygon representations, however, are not handled as agents and agents' locational information is based on cell centroids rather than cartographic coordinates. Nevertheless, most (open source) ABM software is developing at a fast pace (Crooks and Castle 2012, p. 233ff) towards a more advanced insertion of GIS functionality.

Earlier stage attempts of linking GIS with ABM software have been state-of-the-art. While loose coupling "[. . .] usually involves the asynchronous operation of functions within each system, with data exchanged between systems in the form of files" (Crooks and Castle 2012, p. 224), close coupling "[. . .] is characterized by the simultaneous operation of systems allowing direct inter-system communication during the programme execution" (Crooks and Castle 2012, p. 225).

Meanwhile, sophisticated geosimulation systems are available, both within GIS and ABM. A central force in this respect has been object orientation in programming and in database storage. "The recent availability of an object-oriented approach to composing GIS software, which parallels the structure of ABM programming tools and uses common architectures like the Component Object Model (COM), has facilitated the integration of ABM and GIS tools" (Johnston 2012, p. 9). Crooks and Castle (2012, p. 233ff) provide an overview on ABM software systems like Swarm, MASON, Repast, NetLogo or AnyLogic, to mention just a few; their fields of application vary significantly and thus their capacities for integrating GIS functionality. They conclude: "[. . .] it needs to be noted that while such tools exist, integrating GIS data for ABM is still a difficult process [. . .] and many considerations are needed such as what data is needed, how should the data be utilised, how should agents interact with the data, etc." (Crooks and Castle 2012, p. 245).

For one of the most widely used GIS software packages, ArcGIS, an extension called Agent Analyst has been available for around a decade (it should be mentioned that while Agent Analyst is open source, ArcGIS is a commercial product of ESRI). "Agent Analyst provides an interface that can integrate the functionality of the Repast ABM software libraries with the geoprocessing environment in ArcGIS" (Johnston 2012, p. 11). Geoprocessing synchronizes agent states with mapping and cartographic visualization and allows the whole range of geospatial analysis. It is built as middleware between Repast ABM and ArcGIS. "Repast is used for the creation of the agent rules, object support, and scheduling. ArcGIS is used for data creation, GIS analysis, and display of the simulations" (Johnston 2012, p. 15). This means that generic agents (i.e., mobile human agents) and polygon agents (i.e., spatial agents) are treated as geo-referenced objects.

Thus, a plenitude of ever more advanced software systems are available providing data handling, simulation rules, geospatial analysis techniques, and high resolution visualization capabilities in one product.

5.5 Conclusion

Agent-based geosimulation modeling offers a particular kind of scientific reasoning and implies a specific style of thinking (Axelrod 1997; Resnick 1997). It enables a different access to heuristics, approaching the problem at hand in a way that goes beyond a textual description and explanation, a mathematical formulation, and a graphical visualization, though all these approaches are necessarily included. Geosimulation takes insights of complexity theory seriously into account (Manson et al. 2012) and recognizes interrelations between human and locational agents as crucial forces for our understanding of society and space. Furthermore and according to the "generativist" claim, it embeds socio-spatial relationships in different temporal contexts. Epistemologically, the work of translating from thoughts into formalized programming codes reveals a peculiar opportunity which has been presented by Hegselmann (2012, p. 6) as a continuous flux between scales: "It is a frequent programming experience that code [. . .] unintentionally (!) realises the particular as an instance of a generalisation that goes far beyond the original feature. [. . .] Almost never can we implement all alternatives. But from now on we know that whatever we implement is just an instance of something more general that might be called a migration regime".

Modeling of spatial processes, in an environment of geosimulating software tools, considers—in social science research domains—scales of different type and range. Alterations in space are always a result of, and a meaning for, social changes at different levels and within different temporal regimes. If this is true then the well-known geospatial analytic problem of the modifiable areal unit problem (MAUP; see Openshaw 1984) should be extended to the modifiable temporal unit problem (MTUP) and the modifiable social unit problem (MSUP), too (Koch and Carson 2012). There is no pre-given or pre-determined composition of social, spatial, and temporal scales which is to be used in a specific research problem but which is to be justified by the model purpose and verified and validated against empirical and theoretical knowledge.

Against this background, the use of geosimulation in archaeology provides numerous opportunities since the focus of this discipline is also on interdependencies between spatial, social, and cultural processes. Local knowledge (Geertz 1983) of ancient societies is imprinted in local geographies of sites and infrastructures helping geographers and archaeologists to understand socio-spatial conditions at that time. With respect to research in community resilience an appropriate link between geosimulation and archaeology is finally being suggested. In his books "Collapse" (2004) and "The World Until Yesterday" (2012) Jared Diamond comprehensively describes the techniques of socio-cultural and socio-spatial survival of traditional societies and tribes despite environmental perturbations. The scale link is present here as well. Community resilience can be defined as the "[. . .] existence, development, and engagement of community resources by community members to thrive in an environment characterized by change, uncertainty, unpredictability, and surprise" (Magis 2010, p. 402). The conflation of domains and scales becomes apparent: "Community resilience is the sum of neither resilience potentials of its members nor its environment. Through emergence, structures of resilience are generated at this level which in turn feed back to the local/micro units. This scale-dependent circularity also means that capabilities of crisis management cannot be simply generalised and transferred between scales. Rather, it is a more or less specific coupling of resources and constraints, of capabilities, skills, and resilience mechanisms which leads to more or less specific perceptions, assumptions, and proposals about how to deal with crises, vulnerabilities or risks" (Koch 2012, p. 16). A geosimulation model appears to be conceivable which integrates internal relations of human agents' communities dealing with external creeping transformations and/or sudden shocks by embedding these social systems into adequate (reliable) spatial settings.

Geosimulating archaeological facts or assumptions of socio-spatial structures and processes in varying social, spatial, and temporal scale seems to be a straightforward development in archaeological simulation, though, as Lake (2010, p. 17) states, it "is a minority activity and is likely to remain so for the foreseeable future". Aldenderfer (2010) takes a stand for the use of geosimulation in archaeology in order to suitably link the visualization domain with the knowledge domain. This link subsumes a couple of further reasons as, among others, an integration of large amounts of data of different nature (spatial, social, individual) and of different origin (empirical survey, remote-sensing), an advanced testing of hypotheses by use of visual and (geo-)statistical tools, and—maybe most importantly—the ability to explore dynamic processes. Geosimulation "is explicitly dynamic and, as such, provides a more realistic means by which to use space as not only a frame for action but one that has the capacity to directly modify agent behavior" (Aldenderfer 2010, p. 61).

Geosimulation, with its sophisticated analytical and visualization tools, might thus provide archaeological computational modeling efforts with opportunities to deal with methodological and theoretical problems that had been arisen in the past (Costopoulos et al. 2010; Costopoulos 2010; Lake 2010; Wobst 2010).

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