

# Using the affordance concept for model design in agent-based simulation

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**Abstract** When designing an Agent-Based Simulation Model a central challenge is to formulate the appropriate interactions between agents as well as between agents and their environment. In this contribution we present the idea of capturing agent-environment interactions based on the “affordance” concept. Originating in ecological psychology, affordances represent relations between environmental objects and potential actions that agents may perform using those objects. We assume that explicitly handling affordances based on semantic annotation of entities in simulated space may offer a higher abstraction level for dealing with potential interaction. Our approach has two elements: firstly a methodology for using the affordance concept to identify interactions and secondly a suggestion for integrating affordances into agents’ decision making. We illustrate our approach indicating an agent-based model of after-earthquake behavior.

**Keywords** Agent-based simulation · Model design · Affordance theory · Agent activities · Theory of motivation

**Mathematics Subject Classification (2010)** 68T42 · 68U20 · 68N19

## 1 Introduction

During the last decades, Agent-Based Simulation became one of the most prominent paradigms for microsimulation. The overall conceptualization of a system is hereby based on many units of which each has its own explicit state, is governed by its own behavior model and may interact with others. In general microsimulation, these units can be cells, processes, tokens, etc. The overall system is simulated and analyzed on a detailed level

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simulating units' behavior and interplay. Agent-based simulation can be seen as a form of microsimulation in which these units are conceived as "agents", resembling situated, autonomous actors [17]. Agents are modeled as units that explicitly retrieve information from their environment using sensing and perception and similarly explicitly manipulate the environment when acting and interacting with others. Decision making is based on a more or less explicit agent architecture that determines how an agent selects its actions also based on its own agenda. There is meanwhile a wealth of literature introducing agents and multiagent systems in a general way such as [42] or [40].

There are multiple reasons why Agent-Based Modeling and Simulation became so popular. In contrast to other microsimulation approaches e.g. such as Discrete Choice Models, Cellular Automata, Queuing Systems or Petri Nets [19], a modeler can formulate the behavior of low-level units in a flexible and heterogeneous way without the need for regarding uniformity, rationality, stability of connections/interactions or restrictions on processable information. Thus, Agent-Based Simulation often offers necessary freedom in model design.

However, a side effect of modeling constraints is that they also provide some form of guidance to less experienced modelers. An agent-based simulation model may include any detailed feature of an entity's behavior and interactions. Thus, the modeler is free to choose the level of detail, yet without inherent guidance. Clearly such modeling choices have consequences on the effort and complexity of implementing, testing, calibrating, documenting and justifying the model and its results. The problem is intensified by the generative nature of agent-based simulation models [7]. This means that the individual agents' behavior and interaction *generate* the behavior on the overall simulation system during simulation. Not just a description is followed, calculated through and visualized over time. Non-linear feedback loops between lower-level agent behavior and system level dynamics may be generated by the interactions in the simulation. Thus, for efficient modeling producing reliable models, it is important to determine interactions between agents and between agents and their environment in a systematic and grounded way.

This means, the identification of relevant interactions and their particular design in a simulation model is one of the central challenges in developing agent-based simulation models. Appropriate abstractions form the centerpiece of each methodology supporting the development of agent-based simulation models. They provide heuristics which elements of the original system need to be modeled and how those elements can be used in a model. Too low level elements in a modeling language can hardly help – at least not more than a high-level programming language would. Too restrictive, high-level concepts may be confusing to modelers if they leave room for interpretation or do not perfectly fit to what the modeler actually wants to formulate.

This article presents an approach for designing interactions between an agent and its environment based on the "affordance" concept. Originating in ecological psychology, this idea ties perception of environmental features to potential agent activity. Relevant environmental features are hereby perceived by the agents as such. This is in contrast to traditional approaches that process sensor data mapping data to symbols for reasoning to eventually determine which environmental entities are relevant for particular activity options.

The overall idea of "tagging" environmental entities with information supporting complex agent behavior can be clearly positioned into the area opened by [41] putting the environment of a multiagent system into the focus of research: Elements of the environment are explicitly handled during model-development as well as in the final simulation model. Although the relevance of an explicit environmental model has never been doubted in agent-based simulation, this emphasizes the development of the environmental part of overall model as a central step of a development process.

In the following, we first introduce the affordance concept and justify why we believe that it is useful for agent-based simulation model development. This is followed by a description of how we suggest to use affordances in Section 4, also elaborating on a generic agent architecture and a related environmental model concept. After a short sketch of a process for model design, we elaborate on identifying relevant affordances. We then exemplify the process with a short glance on a rather complex model capturing how a population of agents may behave during the first 24 hours after a disaster that destroyed relevant infrastructure. For illustrating how affordances are used dynamically in the decision making process, a randomly chosen agent is followed through the first simulated hours. The contribution ends with a discussion of critical issues to be tackled in the future. This article is an extended version of [16] placed in a greater context in simulation engineering. This article also contains a more elaborated example and discussion.

## 2 Affordances

### 2.1 The affordance concept

The question how (human) agents are situated in their environment perceiving environmental features and elements and interacting with them, is a central one in psychology. Originally introduced by Gibson [8], the concept of “affordances” is the basic element of one of the two major research directions for explaining situatedness. An affordance denotes some perceivable elements in the environment that invites a particular activity of an animal or human. This idea forms the basis for a theory of direct perception which states that a perception is tied to something that exists in the environment, instead of being produced by sensor data processing that results in symbols that the agent can use for reasoning [38].

The original affordance concept allows for refinement and various elaborations exist. So, for example Chemero [5] presents his view on affordances as intuitively perceivable relations between abilities of organisms and features of an environmental situation. A perceivable constellation in the environment with particular features *enables* the execution of a particular ability of the organism. It does not automatically trigger an activity. The organism – the agent – has the choice to actually perform a particular behavior. The idea of affordances can be well illustrated by using examples such as a bench that affords sitting on it. But also some horizontal plank which is sufficiently fixed on an appropriate height affords that.

### 2.2 Applications of the affordance concept

Over the years, the affordance idea has gained importance in several areas in which interaction is central: In human computer interaction it forms the basis for the idea that a user must be able to perceive what he/she can do with a particular element. Norman clarifies in [28] the difference between perceived and real affordances. Environmental entities may play diverse roles for a user. Perceive-ability of affordances determines the object’s usability. Locatelli and Vizzari [23] go further by proposing the concept also for collaborative contexts in ubiquitous computing.

Affordances express the relation between environment and (human) activity. So, their idea is also highly relevant in geo-information science. Ontologies for capturing potential activities and observations are proposed and used for example for fast and user-friendly information retrieval [30], or for enhanced analysis of the spatial environment, as e.g. in

the “walkability” or accessibility analysis of [12] or for a methodology to capture “places” based on what humans can do at that place in [14]. Schneider [37] suggests to create a semantic reference system for geographic data defining for example a junction based on what this construct affords in a road network in terms of navigational choices or entry and exit channels. Channels are hereby defined as bundles of sections that afford movements.

In particular studies in the area of intelligent robotics have used affordances [36]. The idea of a direct connection between a robot and rich environmental representations was first proposed in the area of “behavior-based, reactive” robotics; a research area that emerged towards the end of the 1980ies (for a recent survey see [11] or not so recent case studies in [27]). Instead of sophisticated reasoning, the robot reacts on information available in the environment. This information contains what can be done with a particular element. Thus, for robotics in particular “object affordances” are relevant. They capture what type of affordances are provided by objects with particular features: e.g. “contain-ability” is defined as the ability to hold solids or liquids transferred to. This affordance is associated with the geometric condition of high convexity. A cup then for example is an object providing such “contain-ability”. So, if the robot recognizes that a particular perceived object is a cup, it directly connects this with the information that the object may contain a liquid. *AfNet* is an open database of affordance feature descriptions of common objects (<http://theaffordances.net/>).

In cognitive robotics, affordances do not just provide a higher abstraction level for interaction with and communication about environmental objects. It is also helpful for human’s (and other robot’s) activity recognition and anticipation [20]. The explicit representation of affordances of objects also provides high-level descriptions that facilitate automated planning of activities. Especially in dynamic and not fully a priori known environments object affordances can help to determine which object can substitute others, etc (see for example [1]). Often those affordances are part of an environments’ ontology predefined by a human expert; recent research suggests to automatically learn what can be done with an object from manipulators’ trajectories or other forms of observations (see for example [10, 39]).

### 2.3 Affordances and agent-based simulation

In agent-based simulation the idea of affordances forms a basic concept for a number of approaches and applications, mainly capturing environmental aspects that enable agent mobility, but also agent activity in general. Raubal [33] focuses on identifying the right ontological concepts – determining the elements of the environment – and epistemological concepts – determining what the agent might know. His application is the identification where and way-finding might be problematic for humans in complex environments such as airports. Clearly, the correspondence between concepts used in the simulation model and the ones used by real humans is essential. Aligned to the original terminology of Gibson and based on interviews with travelers, Raubal identifies categories of “substances”, i.e. environmental entities, and “affordances” which represent what the substances may offer. He analyzed affordances more deeply and categorized them into physical, socio-institutional and mental affordances. It is also interesting that other travelers can afford talking-to. In that way he does not restrict his affordance model to the agent-environment interaction, but also includes simple agent-agent interaction, basically treating other agents as environmental entities. In [34], Raubal and Moratz elaborate these ideas further into a functional model of how affordances could be embedded into the abstract reasoning of an agent. They locate reasoning about them between the skill layer and the deliberative layer of a robotic agent architecture.

Paris and Donikian [32] present an elaborated agent architecture that integrates affordances on different levels of decision making ranging from reactive behavior on the level of steps to planned behavior on higher cognitive layers. All relevant information for interaction with the environment is stored in their concept of “affordances” that the agent also uses for planning. Affordance information is also used for organizing realistic interaction of a group of simulated people for example forming a realistic queue for waiting to access an ATM machine. The decision making architecture is integrated into a crowd simulator for scenarios of sophisticated visualization of human activities at train stations. Other examples can be found in Joo et al. who propose in [13] affordance-based Finite State Automata. They use affordance-effect pairs to structure the transitions between states in which a simulated human may be. In an evacuation scenario, an agent follows a given route to the exit, but checks at every step that necessary affordances are fulfilled using affordances to evaluate different local options. Kapadia et al. [15] use “affordance fields” for representing the suitability of possible actions in a simulation of pedestrian steering and path-planning behavior. An affordance is hereby a potential steering action. The affordance field is calculated from a combination of multiple fields filled with different kinds of perception data. The agent selects the action with the best value in the affordance field. A particular interesting approach is suggested by Ksontini et al. [21]. They use affordances in traffic simulation generating virtual lanes of occupy-able space. This is an important advance for agent-based mobility simulation for capturing realistic human decision making beyond strict adherence to legislation as it enables shared usage of road space, overtaking, avoiding badly parked cars, etc. The agents reason about what behavior is enabled by the environmental situation. The affordances offered by the environment are explicitly represented by those virtual objects that offer driving on them. Papasimeon [31] connects affordances to a BDI architecture for identifying options for space occupation supporting navigation and movement for pilots.

Cornwell et al. [6] argue that based on affordance theory a semantic decoupling of the agents’ individual point of view (as necessary for a believable emotional behavior) and the scenario setup can be achieved. Their goal behind using affordances was to easily feed knowledge about how to behave and with whom and why to interact into an emotional agent architecture. An agent may perceive environmental objects in different ways captured by perceptual types. Each of these perceptual types affords individual actions. Those actions have anticipate-able effects on the goals of the agent. Cornwell et al. demonstrate that this concept if embedded into the PMFServ agent architecture, makes scenario modeling more efficient because a fixed definition of scenario-specific behavioral and emotional models is avoided and building new scenarios is facilitated. Also, Heckel and Yougblood [9] argue for gaming applications that smart objects associated with corresponding (virtual) affordances appear to be a useful and efficient approach to developing realistic gaming environments. Similar motivation can be found in [3] who demonstrated how virtual affordances in combination with smart objects can facilitate extensibility of virtual worlds as well as their efficient simulation. Affordances are also proposed in the CIGA framework integrating agents with complex reasoning architectures into Virtual Reality environments [29]. They form an element of a model ontology providing the agents with understanding what they can do with the objects populating the virtual environment.

Although they do not apply the term “affordance”, the idea of using environmental entities for intentionally storing information to be used by simulated agents is present in existing research. For example [2] manage relevant information for activity selection in a particularly structured environment. Another prominent framework in the area of agent programming is

based on the “artifact” abstraction – which is seen as a basic building block of the agents’ environment which may also support and trigger agent activities [35].

In the following, we will introduce an application of the affordance concept in agent-based simulation model design. We will use the concept for capturing potential (purposeful) interactions between agents and their – also non-local – environment and hereby extend the idea of direct perception that is inherently connected to the original idea. This widening of term usage may be confusing as we not just involve object features on a physical level. Using a different term or adding a qualifying adjective may be a solution to avoid confusion. We decided for using the term “abstract affordance” whenever we refer to our particular usage of affordance. We will omit it in more general statements. The idea of explicitly handling the relation between environmental entities and objects and agents’ activity is so clearly captured by the term “affordance” that we did not want to invent a new term.

### 3 Why affordances for modeling?

Similar to Cornwell et al. [6], we came across affordance theory not because of a particular theoretical predisposition in simulating humans, but because it helps us solve an engineering problem. The idea of decoupling and thus making agent-environment relations more flexible forms the center of our proposal for interaction engineering. Affordances enable a way of structuring interaction based on the reason why an agent interacts with a particular entity. Thus it has the potential to lift the engineering of interactions to a higher level beyond physical interaction of sensing and reacting. We assume that explicitly capturing affordances is suitable for facilitating the identification of reasons behind interactions in the original system. It is useful for designing the interaction with the simulated environment on a higher level of abstraction than specifying an environment model for agents’ low-level sensing and information processing. With abstract affordances, the modeler can handle the reason for interaction explicitly as he or she directly focuses on the environmental features relevant for agent decision making and activity. Abstract affordances represent a high-level relation between agent and its environment to then produce actual interactions during a simulation run.

As interaction formulation takes place on a higher abstraction level, we assume that this supports in particular:

- a higher level of complexity in behavior formulation than would be possible in reactive approaches. It also helps to integrate agent-environment interaction into more sophisticated agent architectures. This not only supports adaptivity of behavior with environmental changes, but also flexibility of modeling as agent and its environment are explicitly coupled with the abstract affordance relation.
- clarity in model design as it lifts interaction engineering from programming to higher, more knowledge-engineering like levels.
- extension of models as interaction is clearly motivated and flexible. Introducing new object types does not result in re-programming agents’ decision making, but in adding an explicit description of the role that these kind of objects can play in the agents’ activities. Knowledge about when and how agents interact is explicit. Thus, iterative model development is supported.
- re-usability of models in the same way as their extension. When and where interactions happen is justified by their connection to agent activity; this facilitates documentation of agent behavior in their environmental context.

The abstract affordance concept is not connected to a particular agent architecture. So, it is not obvious how abstract affordances could be practically used for producing those positive consequences. This will be elaborated in the next sections.

## 4 Towards an abstract affordance-based framework

For actually achieving an abstract affordance-based design of interactions in an agent-based simulation model, three perspectives have to be regarded:

- The perspective of the simulated environment: What structures are to be represented in the model of the shared environment for the simulated agents? On which level of abstraction, abstract affordances shall be added to which granularity of environmental objects?
- The perspective of a simulated agent: How an agent determines its activity in a way that it explicitly handles affordances that are relevant for itself finally producing realistic behavior in an appropriately modeled environment.
- The perspective of the modeler and other human stakeholders developing and reviewing the overall model. The modeler ascribes abstract affordances in an agent-environment system; the stakeholders may evaluate whether the particular abstract affordances ascribed by the modeler are relevant and valid.

In the following section we first address the question of how the overall model framework must look like to integrate abstract affordances for guiding agent behavior. Section 5 will then deal with a suggestion for a process to actually fill such a framework for developing a particular agent-based simulation model.

### 4.1 Basic agent-based simulation model framework

Before discussing details of the interaction design, we need to clarify some underlying assumptions about the way how we conceive agent-based simulation models. Our view is coined by the AMASON meta-model [18]:

On a generic level, an agent-based simulation model contains partial models for all entities and a model of the shared, explicit environment. Each entity possesses a state that may change over (simulated) time representing some form of physical unit, that one may call “body”. The state of the body may be partially visible to other entities representing features that may be relevant for potential interaction partners. Some of these entities – the agents – have the capability to perceive, reason about and act on the shared environment as well as on other entities and their visible features. This additional component may be called “mind”, ignoring all potential philosophical connotations. Perception and action involve processes from both body (sensors need a particular energy level, posture or orientation) and mind (sensor data needs to be interpreted to produce percepts that the agent can reason about). So, not just how the agent reasons about its environment, but also what it can perceive is depending on its physical and mental state. Actions may be decided about in the mind, its execution is constraint by the body as well. Finally the environment decides about the effects of an agent action. All entities populate the explicitly represented environment. The shared environment also has a global state (e.g. for capturing global configurations, such as temperature, etc). The environment supports localization based on a “map” with an arbitrary complex structure (discrete, continuous, graph-like...). This map expresses a coordinate system which is used for defining locality and neighboring-relations. Depending on



the underlying spatial representation of the simulation environment, local perception of relevant entity features may be specified for a particular model in a way that is quite different from the original physical metric environment.

Affordance-based interaction design in an Agent-Based Simulation Model involves the explicit representation of abstract affordances for connecting elements of the environment model with agent reasoning. Assuming that most of the modeling work is done by a human modeler (or a team of human experts), abstract affordances must be named with speaking “labels” suitable to the overall model ontology which determines the overall concept of model elements. The abstract affordance labels connect the environmental model with agent reasoning. Their definition must be a basic step in model design. As in principle redundant elements should be avoided in simulation models, the starting point must be what behavior the agents shall exhibit no matter whether expressed in activities that the agents shall show, goals that it should achieve or conditions to maintain or optimize. So, if the model shall contain agent behavior of e.g. drinking something, there must be some entity or resource in the environment that provides something drinkable. In a more abstract model an agent may have the goal of searching a place for shelter. Consequently there should be an object or entity or place in the environmental model that has perceivable features that eventually may offer shelter to the agent.

This conceptualization of affordances corresponds to formalizations as in [36]. They define affordances as relation instances indicating that there exists a potential to generate a certain effect by exerting particular actions on an object.

In the following we will first discuss the necessary environmental structures, then focus on constraints that govern whether a potential abstract affordance offered is actually relevant for an individual agent. This section ends summing up those considerations into a generic agent architecture that realizes the agent perspective of this overall affordance-based framework.

## 4.2 Environmental perspective: basic structure of abstract affordances

In the original psychological literature [5, 8], the perceivable “environment” is seen as the scene or situation the agent (human/animal) is in. So, one considers an agent-environment system with the local environment of the agent containing everything which is distinct from the agent. Affordances are those parts of the situation connected to the agent context and its potential actions. There are two aspects which need to be emphasized: The notion of environment is different from the environmental model of a multiagent simulation model. The former concerns the locally perceivable (and potentially also remembered) environment of the agent, whereas the latter is independent from the agents’ perspective. As a consequence, the agent may firstly consider abstract affordances that it remembers as it has perceived them before and stored in some form of belief set or mental map. Secondly, the local environment may also contain other agents. In an abstract affordance framework for agent-based simulation models we need to consider both: non-local abstract affordances as well as abstract affordances offered by other active entities. A school may offer information about other agents such as the agents’ children, but only if children are there and did not already leave school. While walking through a museum, the agent may remember that there was a bench in one of the rooms passed some time ago that might have afforded sitting on for resting. Consequently, conditions telling whether a particular object constellation provides relevant abstract affordances are more complicated to formulate and – especially as the relevance depends on the individual – computationally complex.



As indicated, it is not a single object that is to be considered, but a constellation of objects. For example, a cup only affords grasping, if it is accessible for the agent's hand. If it has fallen behind the shelf, the agent may need to move some furniture before the situation affords grasping the cup. Another example illustrating why it would be too restrictive to associate affordance labels to single environmental objects is: A soup in a pot just affords being eaten by an agent if there is a spoon-like device available in reach of the pot. Other conditions may refer to the temperature of the soup or the size of the pot - the latter depends on the individual agent (see next section).

Consequently, the modeler assigns an affordance label to an entity "constellation". A constellation hereby means a group of entities somewhere located in the environment. Each of them has a set of possible states that form consistent combinations that could offer the abstract affordance to a particular type of agents.<sup>1</sup> A constellation does not need to be at the place of the agent, as the agent can remember that it encountered the group before or some other agent has informed it about. The constellation does not need to be permanent, but may only exist during some time while running a simulation. A constellation may also contain other agents. It basically forms a meaningful group in the environment, and is not generated in the mind of the perceiving agent. In the simplest case the constellation contains only one object. Whether a constellation really affords an individual agent's activity depends on the agent, its configuration and its dynamic context. This individual context is expressed in the constraints associated with the constellation of objects and will be discussed in more detail in the next section.

Dealing with constellations is powerful and follows the clear conceptualization of affordances done by [5], yet from a computational complexity point of view it may not be the smartest idea as it results in exponential complexity. In the worst case all subsets of existing entities have to be considered to form a constellation. Without assuming that there must be some form of neighborhood relation between relevant objects, such a concept is simply impossible to handle. We also assume that in usual simulation models only a limited number of entities are necessary to offer a particular abstract affordance. Descriptions may then be reduced to types of objects: For example a hospital may afford medical help only if an entity of type physician is present. In the example below, there will be only abstract affordances with constellations containing only one or two entities.

There are alternatives to dealing with constellations of environmental objects: It could be possible to map a situation with separated objects to a sequence of tackling single objects on a finer level of detail. In such a case the agent would need to do classical intelligent planning: first it shall take the spoon which affords grasping and then holding the spoon makes it possible for the agent to eat the soup. This would be naturally done in for example robotic applications. Such an increase in detail may not be in line with the overall granularity in which the model is best handled for the underlying objective behind the simulation endeavor.

An alternative to constellations would be to generate a "virtual" object containing the full constellation if and when necessary. This is proposed by Ksontini et al. in [21] who generate virtual lanes that an agent may drive on. In the default case a virtual lane corresponds to a

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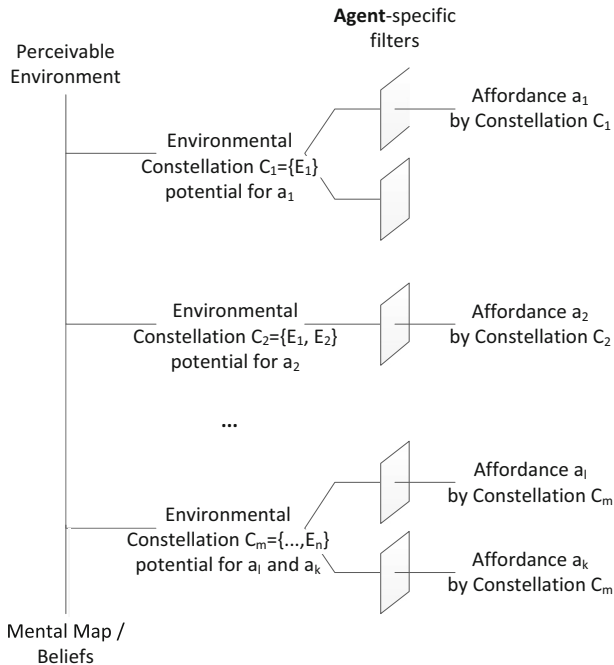
<sup>1</sup>We did not clearly introduce "types" of agents. Yet, one can follow some general intuition. Agents of the same type share the set of possible states and some procedural knowledge (rules, plans) governing their behavior. Heterogeneity comes from different states and/or details (e.g. weights) in the procedural knowledge. The motivation behind using types of agents instead of individual agents is to make modeling efficient and clear. In the "worst" case, a type may just have one instance.

real one, yet if a lane is partially blocked, vehicle agents may divert slightly from the (simulated) physical lanes resulting in realistic mobility behavior. Virtual objects may be a clean and elegant solution for capturing “constellations”, but belong to a more technical design level. In the technical design of the example model sketched below, generating was not necessary. The situations in which a virtual lane is generated, contain much more geometric details and constraints to be handled than in our more coarse-grained model.

Thus for dealing with abstract affordances, the modeler needs to specify meaningful constellations of entities in the environment and associate this constellation with agent actions or activities. This relation is named with a speaking label. Yet the abstract affordance may only be realized by an individual agent, if particular conditions are fulfilled. For actually formulating an abstract affordance, the relation between object constellation and agent activity, needs to be combined with explicit constraints describing under which conditions the abstract affordance relation actually holds. These conditions can be also seen as some kind of filter as illustrated in Fig. 1 .

### 4.3 Agent perspective: individual context

In the following we will discuss the sources for conditions that make the respective abstract affordances relevant for an agent. The basic idea is that agent’s activity needs a particular constellation of entities in the environment to produce the effect that the agent intends to achieve. So interaction with the environment is purposeful. The conditions associated with the abstract affordance need to express two aspects: firstly under which circumstances the

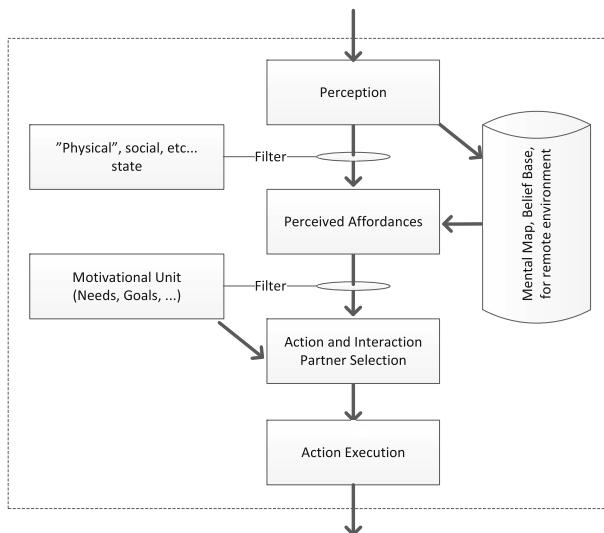


**Fig. 1** Individual agent context for filtering abstract affordances from potentially relevant entity constellations. Only what the agent can actually perceive or remember can be part of such a constellation; An entity can be part of various constellations

abstract affordance is relevant for the agent and secondly it needs to describe under which conditions the intended effect can actually be produced. In the worst case the full individual context can be very detailed containing all features of the situation and state the agent. In practice we assume only local context relevance.

- Physical state of the agent: If the agent has no hands or it may currently not have sufficient energy for lifting things, no affordance of being grasp-able is relevant for the agent.
- Mental state: If an agents' reasoning process is overloaded, it cannot process incoming information that sources such as a newspaper could offer. If an agent does not believe that a supermarket is reachable, it may not consider to buy the groceries that the supermarket affords. In simulation models that explicitly involve agent beliefs about their environment, the perception of abstract affordances must be filtered based on what the agent believes to be feasible.
- Motivational and emotional state: The goals of an agent determine what it finds relevant in its environment. The motivational state is so relevant that it was even shown as an extra component in Fig. 2. It determines not just what the agent may select to pursue, but it influences what the agent expects to perceive.
- Social and institutional state: If the agent is member of a group or organization, playing a particular role, this also influences what expectations the agent may have about its environment. Raubal [33] found such a context so relevant that he introduced "institutional affordances" in his airport scenario: a border official affords the activity of passport control due to its role in the overall institutional setting.

It is important to emphasize that the reasoning of the agent is not just based on what it perceives in a particular moment, but also what it remembers – no matter whether these beliefs still correspond to the (simulated) truth or not. In contrast to for example robotics, missing memories or inconsistent affordance ascription may be part of the model or an



**Fig. 2** Generic agent architecture based on abstract affordances.

important outcome of the simulation if explains or reproduces agent behavior or overall phenomena.

The conditions based on the individual's context filter all abstract affordances of the agent's environment. However, it may not in all models be a binary decision whether the constraints are fulfilled or not fulfilled, but multiple values may be used to describe the suitability of that particular constellation. The agent may use this information of how well the constellation affords an activity for selecting the objects it actually will interact with. Not all benches equally afford sitting on – they may be more or less wet. A hospital may afford medical help – in a more abstract model – only to a particular degree depending on the level of destruction after an earthquake or depending on the particular expertise of the physicians there. The degree of availability can be seen as a function of the constraints associated with a relation between object constellation and agent activities and the particular agent that aims at performing particular activities. The domain of this function can be assumed to be numeric. This number may give important information when the agent selects between different object constellations providing the same abstract affordance. The agent may select the least wet bench for sitting.

#### 4.4 Agent perceptive: impact on architecture

Abstract affordances do not create agent behavior, but they need to be used by the agents' decision making and thus be integrated into an overall agent architecture: An abstract affordance basically represents its agent-specific offer for action. Consequently, that offer is not hard-wired to an actual action or action sequence. The agent has the choice whether or not to trigger behavior or may select between different actions that are possible at the same time.

There is no “standard” way for integrating the abstract affordance concept into the agent's behavior generation: [31] integrates affordances into a BDI architecture, [36] use affordances for capturing scenario specific information in PMFServ, [21] create options that afford driving on that driver agents evaluate and select, etc. In some models - also shortly described above, affordances are used as preconditions in rule-like structure, [32] give a multi-layer architecture involving reasoning about affordances also for selecting between different environmental objects, etc. Affordance-based robotics is often associated with reactive, behavior-based robotic agents directly connecting perception and action on perceived objects. So there is not one universal way of using affordance-based approaches in behavior generation. In the following, we will discuss some generic consequences on agent decision making by suggesting an abstract architecture.

In principle, one may identify two different aspects of decision making that are deeply linked: the agent needs to determine its next action, and if this action involves interaction with the environment, the agent needs to decide which environmental entity to interact with. An agent may decide to now sit down, but on which of the available chairs? If there would be no object that affords the action of sitting on, the agent may not consider sitting down at all. Most agent architectures do not distinguish these two phases. Usually, the agent may associate a chair-type variables with a particular chair instance identified in its environment early in a behavior planning process. Alternatively, an agent may commit to follow the stimulus “emitted” by the nearest or most comfortable chair. In such a traditional decision making process an affordance is basically reduced to a convenient way of managing preconditions for actions. Figure 2 summarizes a more explicit way of explicitly dealing with abstract affordances and thus enabling the agent modeler to more clearly handle interactions in the model.

Some aspects of this architecture need more explanation: Our concept of abstract affordances does not restrict reasoning to affordances associated with directly perceivable objects. Abstract affordances can be communicated or memorized in some belief set that represents aspects of the environment that the agent cannot directly access. Clearly this is not supported by the original affordance concept that focuses on direct perception. Whether and as how suitable an abstract affordance is actually perceived as such, depends on the agent's situation awareness including its physical, social, emotional, etc. state as discussed in the last section. We distinguish between two filtering phases - a principled one that filters on a more principled context – for example the physical features of the agent, and a second one that relates to on what the agent may wants to achieve – depending on its motivational state. In Fig. 2 we give a schematic presentation of this generic agent architecture. For a concrete simulation model one has to concretise the architecture, deciding about particular motivational concepts, formulate their update and actual action selection processes for producing rich agent behavior in a rich simulated environment.

In the example in Section 6 we base our illustration on needs with different (dynamic, numeric) urgency as the basic motivational concept. Needs hereby are directly coupled to abstract affordance options in the environment offering their fulfillment.

## 5 Modeler perspective: model design process

The motivation behind developing an abstract affordance-based approach for agent-based simulation was to facilitate model development by providing a systematic approach to handling interactions in the model. Developing a simulation model imposes different challenges on system development than the design and implementation of a multiagent system in a real environment or a virtual environment – as the underlying objectives are different. For a recent discussion with an environment perspective see [4]. A central question in simulation development relates to the minimal level of granularity and abstraction of the model. The level shall be sufficient so that the model can validly answer questions that a stakeholders may want to ask, but not simpler than that. The idea behind using abstract affordances is to provide a systematic way of connecting intended multiagent system behaviors with the environmental model. This shall lead to a clear environmental model with only limited redundancy, but developed in a systematic way grounded on psychological theories how humans (and animals) perceive interaction possibilities. Thus we assume that this provides a way of supporting a systematic way of identifying a good level of model granularity.

We also assume that dealing with abstract affordances model design can be done on a higher level of abstraction than for example specifying that particular interaction protocol for low level interactions. Abstract affordances express not just that there can be an interaction between agent and its environment or between agent and agents, but also why, with whom and under which conditions. So the modeler explicitly deals with meaningful, potential interactions:

### 5.1 Model design process

A process centered around abstract affordance-based interaction *design* contains the following steps:

1. Specify intentions and/or behavioral repertoire of the agents.

2. Develop a list of affordances (labels) that are needed for this behavioral repertoire or to fulfill the intentions, determining what the environment in general must provide to the agent so that it can do what it wants to do.
3. For each abstract affordance, write down conditions and constraints under which the abstract affordance actually may fulfill its reason to be.
4. Decide what the elements of the environment shall look like: Decide, what object types shall exist and assign them to abstract affordances while fulfilling the constraints and conditions.
5. fill the behavioral gaps in the agents decision making/behavior program - e.g. planning to move to the locations at which an affordance can be used.

A full model development process clearly contains more steps than those mainly related to basic model concept design, dealing with technical aspects that may also depend on a simulation platform used for implementation. Later, technical phases determine domain-specific data structures and protocols as well as actions stating what exactly shall happen if an interaction takes place. Those elements depend on the specific agent architecture clearly defining what form of motivation, planning, etc. is used in the model. Implementation, testing, calibrating, validation, deployment runs, result analysis and so on, are then the usual steps in a simulation study that make the overall endeavor complete.

A process starting from affordances is different from interaction-oriented model development approaches such as suggested in [22]. Focusing on reactive agents, Kubera et al. assume that full behavior can be described based on interactions; complex behavior in which interactions serve a particular purpose and are intentionally selected are hardly supported. A related process can be found in [29]. Van Oijen et al. describe a framework for integrating intelligent agents into a virtual reality environment. They suggest to use an explicit, domain-specific ontology model. Affordances can be elements of this ontology model facilitating the agents' understanding of what to do with their environment. Similar motivation is given for "virtual affordances" resulting in smart objects supporting extension and maintenance of virtual reality applications such as complex visualizations or games (see e.g. [3]).

## 5.2 Identifying abstract affordances

Setting the appropriate affordances for connecting environmental object constellations to agent reasoning is basically equal to the question of creating a consistent level of detail in the model. Up to now this question can hardly be answered on generic level independent from a particular simulation objective and a particular reference system. The identification of abstract affordances guides the design of the overall environmental model. So the level of detail of abstract affordances determines the level of detail of the environmental model and also the number of object constellations that the agent would need to consider when deciding about the next interaction partners.

Which abstract affordances to represent in the model is directly derived from the behavior that agents shall exhibit. We assume that agent behavior can be better observed, agent motivation can be better acquired in for example questionnaires or by system analysis than other elements of the model. Abstract affordances are then identified by a modeler asking about what an agent would need to select and to perform activities or to achieve its goals. So identifying abstract affordances means basically to settle the overall model granularity and abstraction level. Thus abstract affordances are the consequence of an appropriate system analysis. The process described above basically forms a systematic way of doing so.

Nevertheless, there is no simple answer to the question of how to make sure that the modeler can identify the most suitable abstract affordances for its actions. Unfortunately, there is a lot of modeling experience and system knowledge involved. We would guess that in most domains – once the overall level of abstraction is clear, the selection of abstract affordances can come naturally, but there is no guarantee.

Applying similar learning approaches as in robotics (e.g. as described in [26]) in a simulated environment does not really make sense. Perceived sensor data capturing the consequences of actions would enable the agents to reason about their environment which is similarly artificial as the environmental model. Therefore only definition by a human modeler makes sense. Only after definition of abstract affordances, it could make sense to apply some automated process for assigning affordance labels to particular categories of entities or particular object constellation pattern. In domains for which a rich, independent data set for the environment is available such as e.g. traffic simulation with data from OpenStreetMap<sup>2</sup>) this might make sense. One may automatically associate a given classification of environmental objects with likewise given abstract affordance labels using rules or a decision tree. The later could be learnt from example data. The result could be rules such as: “if x is a restaurant, then x affords finding food”.

## 6 Illustration: the after-disaster scenario

We used the described concepts for developing a simulation of civilian behavior during the first 24 hours after an earthquake. Instead of analyzing evacuation processes, we focus on what people might do and where they might move to after such a catastrophic event. The earthquake may have dramatically changed the environment, remembering, identifying and moving to places that afford help or information in any form is the central process of agent behavior. The final vision of this model will be the heart of a decision support tool for disaster helpers enabling them to evaluate for example the best location for establishing support equipment, distribution of goods, etc.

### 6.1 Intentions and behavioral repertoire of the agents

Starting point is the question what activities the agents could perform. We based our motivational model of the agents onto Maslow’s Theory of Human Motivation [25] which formulates a hierarchy of needs. We assumed that directly after a catastrophic event – that does not require immediate evacuation of the population – basic physiological and safety-related needs (on the two lower levels of Maslow’s hierarchy of needs) are the most relevant. After discussions with experts, we added needs related to information acquisition. Thus, we came to the following list of motivations that will guide the agents’ behavior.

- Need for information about family
- Need for medical help
- Need for self-medication
- Need for food and water (physiological needs)
- Need for security of health, body, safe sleep
- Need for security of property

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<sup>2</sup>[www.openstreetmap.org](http://www.openstreetmap.org)



- Need for general information
- Need for mobile phone charging

Clearly this is just a first draft of needs, but it can be easily extended also due to the overall abstract affordance-based approach. For now it is sufficient for illustrating the overall approach. Depending on the particular agent architecture, these needs form the basic goals of the agent or motivate some other form of behavioral program.

In our case we decided for an architecture of competing needs. Each agent handles a set of need objects with a current urgency, thresholds and functions describing the dynamics of the needs' urgency. So for example the need for food or water linearly increases over time; when the agent executes some activity fulfilling the need, the urgency is null-ed. Initially the need for information about family members has the highest urgency, if they are not at the same location as the agent.

## 6.2 Affordances for needs

The next step in the overall process is about how and where these needs may be satisfied. In this step, we basically setup a list of abstract affordance labels. For the needs listed above, the list of affordances might look like in Table 1. The relation is not a 1:1 relation. Most of the needs are linked to exactly one abstract affordance. The need for general information can be satisfied using different means: For example information on the location of the epicenter or the general state of the road network, destructions, etc. can be acquired by searching the Internet, by conservative sources such as radio or television or by talking to other agents.

## 6.3 Conditions and constraints on affordances

The next step is to determine under which circumstances an affordance can be offered by something in the environment. In the case study, the conditions for most affordances are fairly simple and straight forward. Table 2 gives an impression on how this could look like without using a formal language for expressing the constraints.

## 6.4 Environmental model

The next question is how the environment may look like for providing the affordances with their associated conditions listed in Table 2. The relevant types of objects that should be

**Table 1** Assigning affordances to needs

Need for	Corresponding affordance
Information about family	Meeting family members
Medical help	Meeting doctors and nurses
Self-medication	Provides medicaments
Food and water	Provides food and water
Security of body,...	Provides shelter
Security of property	Enables protection
General information	Provides Internet access, Enables broadcast listening, Provides talking to
Mobile phone charging	Provides electricity

**Table 2** Conditions for affordances to be provided

Affordance	Constraints
Meeting family members	Family member(s) must be located at same place as agent
Meeting doctors and nurses	Doctors/nurses are not overloaded, place is not destroyed
Provides medicaments	Sufficient medication storage available
Provides food and water	Sufficient storage of food and liquids
Provides shelter	Building is not destroyed
Enables protection	Something of value left
Provides Internet access	Electricity available, Internet accessible
Provides broadcast access	Electricity available, receiver accessible
Provides talking to	Other (knowledgeable) person at the agents' location
Provides electricity	Electricity available

there – and consequently the level of abstraction of the environmental model – were derived from that list: We may assume relevant entities are places - such as supermarkets or a pharmacy. A place “clothes shop” may only be relevant for its role as a particular workplace. So the overall environmental model does not need to explicitly handle clothes shops. An example list of places that may provide a particular affordance is given in Table 3. Which place is relevant for a particular affordance may be determined in general or in a way specific for the individual agent. These are marked with (A).

With that concept model, the coupling between environmental entities (buildings, places, other agents) and agents is determined, yet not fixed. Using a concrete version of the generic architecture described in Section 4.4, the agent decides about the most urgent need. Then, the agent checks what places it believes to provide the abstract affordance associated with the most urgent need and plans its way to this place.

Depending on the particular abstract affordance and its conditions, whether an environmental object affords something, is not necessarily a boolean decision. Here a degree of availability is defined for each abstract affordance and relevant object constellation. It is set due to the earthquake depending on destruction and may change due to usage (a pharmacy may run out of stack of relevant medicaments) with every agent that wants to acquire them.

**Table 3** What affordances need to be satisfied, determines what kind of environmental entities need to be provided. Places marked by (A) are agent-specific

Affordance	Providing Places
Meeting family members	Family Residence(A), Workplace/School(A)
Meeting doctors and nurses	Hospital, Ambulance
Provides medicaments	Pharmacy
Provides food and water	Restaurant, Supermarket, Family Residence(A)
Provides shelter	Family Residence(A), Public Building
Enables protection	Family Residence(A)
Provides Internet access	Family Residence(A), Public Building, some Restaurants
Provides broadcast access	Family Residence(A), Public Building, some Restaurants
Provides talking to	Other Agent
Provides electricity	Family Residence(A), Public Building

Yet the agent may believe that a place with a particular abstract affordance is fully available until it perceives (or is told) otherwise. Thus coupling between agent and environment is flexible and produces rich observable agent behavior.

## 6.5 Filling the behavioral gaps

In the subsections above, we already indicated how we used the abstract affordance approach in the final implementation. Each agent manages a list of need objects together with their specific urgency dynamic. When it selects a new need for fulfillment, it retrieves places that are tagged with the label of one of the abstract affordances associated with the need from its mental map. The agent then performs activities for fulfilling the need which in this model is done by moving to the place, waiting for being served and then the actual need fulfillment happens. Abstract affordances are explicit labels associated with place types. If the modeler wants to add a new type of place on the map to be used by the agents, the modeler only needs to associate the place type with one of the abstract affordances or introduce a new abstract affordance and link it to a particular need type.

There are also a number of other decisions that the modeler has to take.

- It is a spatially explicit scenario. The agent actually needs to move through simulated space (in the example a simulated road network) for reaching a place where the need can be fulfilled. Thus, a shortest path algorithm is necessary for planning a path through the network.
- While moving through space, the modeler also needs to decide how the agent updates its mental map with new information on places that it passes by.
- It unrealistic, that an agent's need is instantaneously handled at the place when it reaches it. There must be some queuing for access to the sales counter, to public computers, etc.
- During waiting for being served, other needs may become more urgent than the one that triggered the agent's movement. Then a new need is selected with consequent path re-planning, etc.

We also used the affordance idea for determining the availability of a road segment for moving across introducing whether a road segment affords walking on or driving on, etc. Also the road network might be affected by the disaster. The agent stores these affordances in its mental map and only considers those connections that it believes to be usable when determining the route to a selected place. While moving, the agent updates its mental map with the perceived affordance of the different road segments. This corresponds to a more standard way of applying the affordance idea.

Interaction for information exchange happens with other agents that it meets during movement or at places. The agents communicate information about nearby road segment's status and consequently update their mental maps with (eventually) more accurate information on affordance availability. While moving, this perception and update may also trigger re-routing, re-selection of places for the current activity or even re-consideration of needs, for example if the agent does not believe that the current need is fulfill-able any more.

Implementing those data structures and decision making processes is rather straight forward. A first prototype of the model is available using the standard means and language of the SeSAM simulation system.<sup>3</sup> SeSAM was used on a level of abstraction that also an

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<sup>3</sup>[www.simsesam.org](http://www.simsesam.org)

object oriented programming language would provide, in terms of construction of complex data structures. We used predefined plugins providing standard shortest-path algorithms as well as road network data structures, etc.

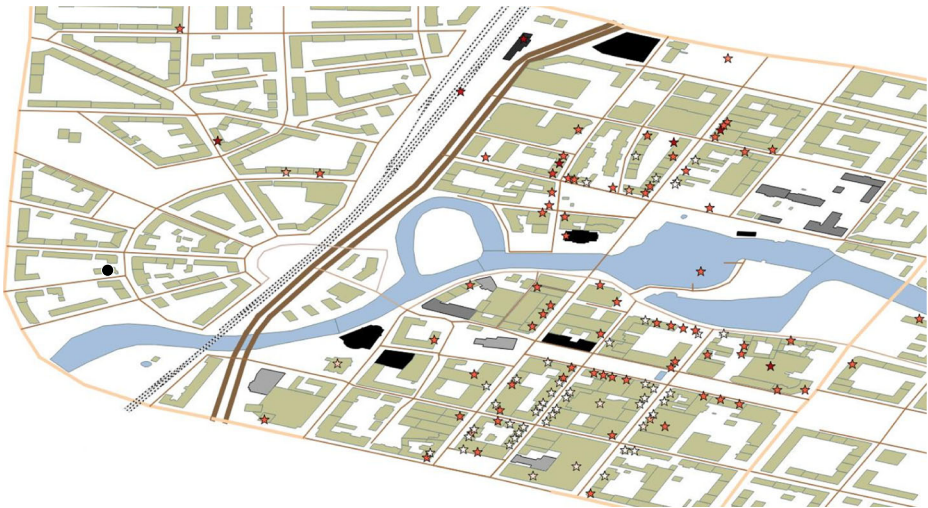
In the next section we will illustrate the initialization and overall dynamics following example agents.

## 6.6 A glance on dynamic agent behavior

For further illustrating how the abstract affordances concept works, we follow the lifeline – i.e. the situated decision making – of a randomly selected agent. We assume that an earthquake happened early in the morning. Most population under consideration stayed at home, some already had breakfast, others not. The agent with the id *a00e* that shall be followed, lives in the eastern part of Örebro. We assume that the earthquake destroyed all bridges and underpasses over the river and over/under the rail tracks, except one bicycle underpass in the center. For a map of central Örebro see Fig. 3.

The agents are initialized with appropriate numbers for the initial urgency values of their needs. Initialization is done randomly, heuristics are used for consistent values. The example agent *a00e* already had breakfast; it lives alone, so it has a relatively high need for general information, yet zero urgency for information about direct relatives. *A00e* has some slight injuries, that it could handle itself provided that it has the means to do. Table 4 gives the initial urgency values for the example agent.

For each of the urgency values there is a need-specific function that updates it. The need for food and water linearly increases, as well as the need for self-medication, mobile phone charging, etc. The need for securing its own property has two values, zero when the agent stays at home and non-zero if not.



**Fig. 3** Partial map of central Örebro, taken from OpenStreetMap. *Green polygons* denote residential buildings, *gray to black polygons* as well as *stars* denote points of interests of different categories such as public buildings, churches, restaurants, etc. The *black circle* on the *left* shows the residence of the example agent *a00e*

**Table 4** Initial urgency values for needs of the example agent *a00e* are randomly determined based on some heuristics

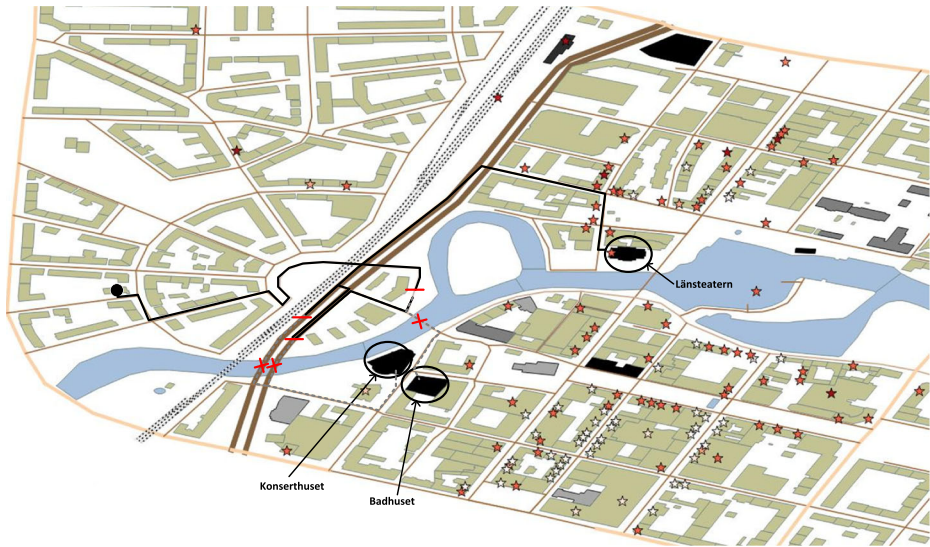
Need	Initial Urgency	Explanation
Information about family	0	We assume that the agent is single
Medical help	0	No need for an ambulance
Self-medication	0.47	The agent has some light injuries, not too severely, but it needs attention
Food and water	0.04	The agent had breakfast before the earthquake
Security of property	0	The agent is currently at home
General information	0.99	The agent feels a high need for information, yet there is no Internet available
Mobile phone charging	0.1	The mobile phone is almost fully charged

Based on that initial setup, the agent evaluates which of its needs exceeds a need-specific threshold. In our example these are the needs for self-medication as well as the need for general information. As the urgency for the need for general information is higher, *a00e* pre-selects this need and determines which of the places is relevant for it. At this point the affordance-need connection comes into play: The agent *a00e* searches its mental map for any place that it believes to either *provide Internet access*, to *enable broadcast listening* or to *provide talking to* authority persons. We assume, that there is no electricity in the agents home. Thus the example agent already updated its mental map believing that its home cannot provide those affordances. Yet *a00e* still believes that all public buildings and some restaurants do (see Table 3). There are seven public buildings scattered on the map that the agent assumes to be relevant. *A00e* now determines the shortest path to each of them given the information in its mental map – believing that all bridges and underpasses are viable –, and compares costs of those paths. Eventually it selects the “*Badhuset*”<sup>4</sup> and starts walking towards it.

So the agent *a00e* follows the shortest path to the selected place. Shortly before reaching a bridge, it exchanges information with another agent who tells it that the bridge is destroyed and the road segment does not afford to cross the river there anymore. The agent updates its mental map and searches for another path to the selected place. As re-consideration is triggered, also the selection of a place associated with the relevant abstract affordance is reconsidered. As shown in the map in Fig. 4, “*Konserthuset*” is an alternative place which is about the same distance. By chance the agent selects “*Konserthuset*” instead of the neighboring “*Badhuset*” believing that both afford general information. The result of the reconsideration is a new planned path to “*Konserthuset*” which unfortunately also contains a broken bridge.

After walking a few (simulated) minutes on the planned path, the example agent is notified that another bridge segment is broken as well; it checks whether it is in its current

<sup>4</sup>which is some form of cultural center in central Örebro



**Fig. 4** Partial map of central Örebro illustrating the movement and plans of example agent *a00e*. From its home, the agent moves towards “Badhuset” for receiving general information about the earthquake and its consequences. Moving on the *black line*, the agent communicates with others and is informed that the planned path will not lead to the point of interest due to a broken bridge (the bridge is marked by a *red cross*, the position where the agent receives the information with a short *red line*). So, the agent re-plans, reconsidering also its choice of destination (now to “Konsertuset”). Also this path will not work as it contains another broken bridge that the agent later learns about; the same happens to the path using the other lane of the urban highway. Finally it plans a path to “Länsteatern” where it eventually arrives

movement plan and recalculates the shortest path and so on. Figure 4 illustrates the actually realized path of the example agent including planned, but not realized routes. If the agent would now believe that no place that is connected to the need with an abstract affordance could be reached, it would re-select the currently pursued need.

Arrived at “Länsteatern” the example agent is forced to wait until it is his turn to access the Internet terminal. While standing in queue (and during its long walk), the health condition of the agent deteriorated increasing the urgency for self-medication. The agent abandons to fulfill the need for information and adopts activities for fulfillment of self-medication. Any pharmacy or hospital affords self-medication. Luckily there is a pharmacy just one block away that *a00e* approaches quickly. Unfortunately the agent is not the only one who wants to buy band-aid or pain killers, so it needs to wait almost a simulated hour. As like during walking, also during waiting the urgency of the needs change, the agent becomes hungry, etc.

The interesting aspect in this description is which information the agent uses for selecting the place for its activities. Based on semantic geographic information connecting categories of place objects with diverse abstract affordances makes the reasoning of the agent transparent and easy to maintain. Changes in the underlying map during model implementation cause hardly any effort as labels such as restaurant or public building were used as basis for connecting them as relevant objects in respective abstract affordances. Those labels were provided in a sufficiently standardized way by the OpenStreetMap data.



## 7 Discussion of next steps

We illustrated a model design strategy around an abstract affordance-based coupling between agents and their environment. Model design is centered around handling interaction between agents and their environment in an abstract and explicit way. A modeler captures the relation between object constellations and elements of the behavior program of the agents and names this relation with meaningful terms. In the conceptual model it remains clear why an agent may interact with whom and particularly, why such an interaction may happen. During a simulation run, these relations then form the basis for actual interactions.

Interaction between agents and between agents and a non-agent environment is at the heart of developing and using of any agent-based simulation model. Basically, we suggest to re-allocate information relevant to determine whether an entity is a potential interaction partner. Instead of specifying potential sensors and reasoning processes, the environment is put into the center of development. One can easily find similar settings to the earthquake model in which such an affordance based interaction development may be useful, for example in land use or travel demand models.

Although the concept of abstract affordances allows handling also non-local affordances in the agent's decision making, there are some implicit assumptions on explicitness of space with local perception of environmental entities. Due to the in the worst case exponential effort of handling object constellations as candidates for setting up abstract affordances, there must be a locality concept and thus some form of explicit space in the model that enables to restrict potential members of those object constellations. Yet, the idea of being to memorize previously perceived affordance locations, may result in that an agent has to consider all possible objects providing an affordance such as "provides electricity" for mobile phone charging. In that case, an additional representation of a social network and corresponding restriction on potential locations may be reasonable. This problem of potential scalability problems – in the model development phase and even worse during the runnable simulation – cannot be solved in a general way, but only for a specific model or a specific domain.

Without testing the affordance-based approach in more and diverse domains, we cannot see more underlying hard assumptions. Most importantly it still needs to be elaborated whether the abstract affordance-based approach is useful also for models with more exploratory simulation objectives. These are models that are not aiming at reproducing real case studies or not intended as basis for decision support tools, but used for learning for example about emergent phenomena. This is clearly an open area in which we need to systematically test the model design approach, as here modeler's skills and expertise is particularly important.

Another issue concerns the question whether classes of abstract affordances can be formulated that - during the actual model design - can be identified. Such a classification may be useful for identifying abstract affordances and may support not so experienced modelers. Our approach presented so far also does not distinguish between passive environmental entities and other agents. It is not clear whether we – from the perspective of one agent's need to create a distinct approach at least for those two types; and whether that would result in different types of affordances. In general the idea has some relations to design pattern for agent-environment interactions. It might be interesting to consider the question how far affordances as high-level, intermediate concept can serve as the basis for interaction patterns connecting agent behavior and environmental structure.

As indicated above, we implemented all the data structures for needs, affordances, environmental entities as well as mental map structures using the standard language provided



by SeSAM; a next step is clearly to create specific re-usable high-level representation based on a meta-model for implementing affordance-based interaction. A clear tool-independent formalization of the concepts is necessary for that as well as for enabling a modeler to specify and potentially verify whether particular interactions can be realized during a simulation run. We believe that given the considerations presented in this article, setting up such a formalization is not difficult, yet depending on the availability of a good overall meta-model for multiagent simulation models. In [18] we started to elaborate this, yet especially the concepts of environmental model appear not to be sufficiently sound.

The abstract affordance-based approach to model design can be extended with related approaches that are less depending on an explicit environment, but are based on direct interaction such as communication semantics or based on organization level ascriptions of viable behavior. Good starting points for that may be norm-based approaches (e.g [24]). We hope that we can formulate a norm-based approach that complements this environment-focused approach with an explicit formulation of high-level behavior beyond the individual agents lifting the point of view to more organizational aspects. Clear semantics in communication forms an essential starting point for that.

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