Reevaluation of intentions of dynamic agent utilizing BDI reasoning in ABAsim architecture

Michaela Pauriková, Michal Varga
University of Žilina
Faculty of Management Science and Informatics
Department of informatics
Univerzitná 8215/1, 010 26, Žilina
paurikova2@stud.uniza.sk
michal.varga@fri.uniza.sk

Norbert Adamko
Simcon, s.r.o.
J. Kráľa 19, 010 01, Žilina
norbert.adamko@simcon.sk

Abstract. *Paper proposes a mechanism of reevaluation of intentions of ABAsim architecture's dynamic agent utilizing BDI (Belief-Desire-Intention) reasoning. Universal and easily extensible solution to reevaluate agent's intentions is presented. Capabilities of dynamic agent are expanded to choose user specified plan to fulfil desire, to reevaluate chosen plan dependent on the state of the environment in which dynamic agent is situated, and to interrupt interpreted plan if the dynamic agent changes its beliefs. The mechanism is implemented as part of architecture library, what makes it easy to use in any simulation model using ABAsim architecture. We present its implementation in simulation tool PedSim developed at the Faculty of Management Science and Informatics of the University of Žilina and demonstrate the functionality in simple scenarios created in the simulation tool.*

Keywords. agent-based simulation; ABAsim architecture; BDI reasoning; reevaluation of intentions

1 Introduction

Decision-making is one of the key abilities of humans in achieving their goals. It may be used when one decides how to pursue a goal or the subsequent reevaluation of those chosen decisions. Implementation of decision-making mechanism into simulation tools for modeling of pedestrian movement and behavior, not only enhances modeling capabilities of such software but, most importantly, it makes it possible to obtain more accurate results.

Pedestrian simulation is relevant method for solving various problems, such as evacuation in emergency situations (Siyam et al., 2020) or studying people's movement in transportation systems (Wang, 2021). Therefore, it is essential to continually enhance the models and provide more precise and detailed interpretations of human behavior. One such enhancement includes the universal mechanism of decision-making and intention reevaluation for dynamic agents. The foundations of this mechanism were laid out in the work by (Varga & Adamko, 2014), and its extension is the aim of this paper.

One approach, by which an agent, representing a pedestrian, can define and manage its intentions, is based upon the BDI (Belief-Desire-Intention) paradigm (Varga & Adamko, 2014). The agent strives to fulfill its desires by achieving its goals, which it does through the execution of defined plans. In our work, we focus on the method of defining various rules for selecting or canceling these plans and reevaluating them during plan interpretation. This mechanism is implemented in the ABAsim architecture (Adamko, 2013). ABAsim architecture is utilized by the PedSim simulation tool, which we will use to demonstrate the effectiveness of proposed mechanism. However, the enhancement of the mechanism is not limited to aforementioned software, but is relevant for any tool based on the ABAsim architecture and can also be adopted by other agent-based architectures as well.

The paper is organized as follows. Section 2 focuses on basic concepts such as agent-based simulation, the ABAsim architecture, and the BDI paradigm. In Section 3, we introduce the proposed extension and compare it with the current modeling approach. Fourth section present the results achieved by applying the proposed mechanism and the last section contains conclusion and introduces future work.

2 Basic concepts

Investigation of properties of complex systems is not intuitive since factors such as emergent behavior come in place. Agent-based simulation belongs to relevant techniques for capturing properties of such systems, experimenting with changes within them and evaluating impact of those changes. When using agent-based simulation, the system is decomposed into autonomous agents. As software agent we consider an encapsulated computer system situated in a certain environment, in which the agent acts flexibly and autonomously to achieve a given goal (Jennings, 2001). The operation of system is achieved by defining behavior and relations between agents. The agents can be classified from several perspectives. According to mobility, we classify agents as either stationary or mobile. Based on their application purpose, one can identify e.g. internet and information agents. The most important classification of an agent for our purposes is based on the level of initiative (Adamko, 2013): reactive and deliberative agents. Deliberative/intelligent agent evaluates the situation and considers an appropriate action using its internal symbolic model of the environment or works according to a predetermined plan.

2.1 ABAsim architecture

ABAsim (Agent-Based Architecture of Simulation Models) architecture has been developed at the Faculty of Management Science and Informatics of the University of Žilina. The application of the ABAsim architecture can be found in simulation software Villon (Klima et al., 2001) and PedSim (Varga & Adamko, 2014). Villon is a simulation tool capable to create detailed microscopic models of transportation terminals. PedSim is pedestrian behavior and movement simulation model. Utilization of ABAsim architecture in both tools enables simple integration of PedSim simulation model into Villon.

The main components of ABAsim architecture are agents of two types: *managing* and *dynamic*. The managing agent is responsible for a specific part of the modeling system. This agent is part of the hierarchical structure of agents, which tries to achieve a common goal through their cooperation. Each ABAsim model must contain at least one managing agent. The dynamic agent represents an autonomous intelligent entity. It can control its behavior in order to achieve given goal. Goal may be assigned by the managing agent or by the dynamic agent itself (if it is not in contrary to the goal assigned by the managing agent). The last important components of the ABAsim architecture are *entities*. An entity usually represents the physical entities of modelled systems without autonomous and intelligent behavior. In an example of an airport service system, managing agent can represent the airport dispatcher, the dynamic agents can represent the visitors, and the entities can represent planes. Example of such system topology is depicted in Fig. 1.

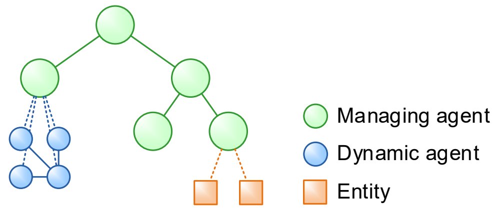

Figure 1. Example of model topology in architecture ABAsim containing managing agents, dynamic agents and entities

Each agent can be decomposed into several components (Adamko, 2013). Core component is agent's *manager* which is responsible for agent's reasoning. Reasoning of an agent can be defined in several ways:

1. explicitly in program code,
2. using ABAgraph (modified Petri net), or
3. by defining components, which are used by manager utilizing specialized kind of reasoning (example is BDI reasoning, which we will discuss later in this paper).

Manager cooperates with *assistants,* which can be classified according to their usage. *Sensors* are used to provide information about the state of the environment, in which the agent operates; *solvers* provide suggestions for problem-solving; and *effectors* perform actions in the environment. Lastly, two internal components responsible for synchronization and communication are part of an agent. The internal structure of an agent is depicted in Fig. 2.

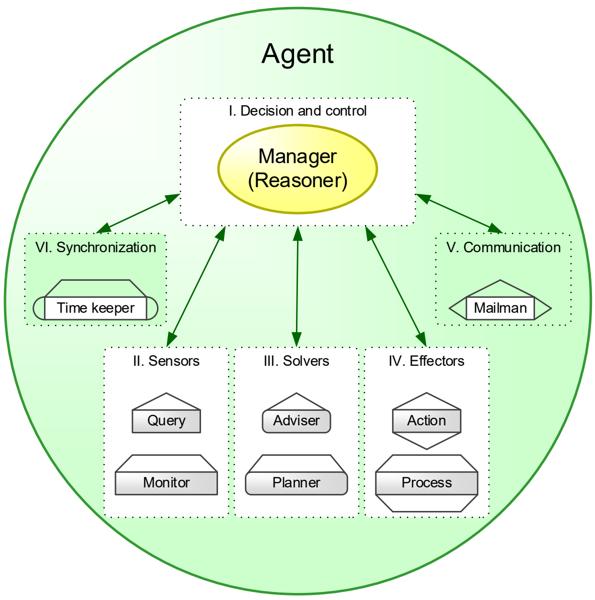

Figure 2. Decomposition of an agent in ABAsim architecture

2.2 BDI paradigm

The ability to manage goals and make decisions according to acquired information is one of the key requirements when modeling human behavior. The principle of BDI, as one of the paradigms utilized to model human behavior, is based on practical human reasoning (Bratman, 1987) (Kinny & Georgeff, 1991) and distinguishes three main components – beliefs, desires, and intentions. *Beliefs* represent agent information about the surrounding environment (beliefs do not need to be necessarily true, e.g. agent may believe that train departs at certain time, however it may be delayed); *desires* are agent's possible goals that can be fulfilled; and *intentions* represent agent's will to fulfill chosen desire using specific *plan*.

The BDI paradigm offers not only intuitive definition of agent's reasoning, but also the possibility of extending it with various plan selection and reconsideration mechanisms. In the ABAsim architecture, only a dynamic agent is capable to reason using BDI paradigm. This is performed by specifically defined reasoner and assistants – *sensors*, whose task is to gather information from the simulation environment. This information is transformed into beliefs and stored in the belief store, which represents the agent's virtual memory and can process, update, and forget individual beliefs. Recall that dynamic agent's task is to achieve a goal set by the managing agent. This goal is treated as a desire (to satisfy order from managing agent) and stored in the desire store as a new desire awaiting to be fulfilled. Intentions are created from desires that the agent is capable to fulfill. Generated intentions are registered in the intention structure. Fulfillment of an intention is performed through set of plans defined for the specific desires. Individual plans are stored in the plan library.

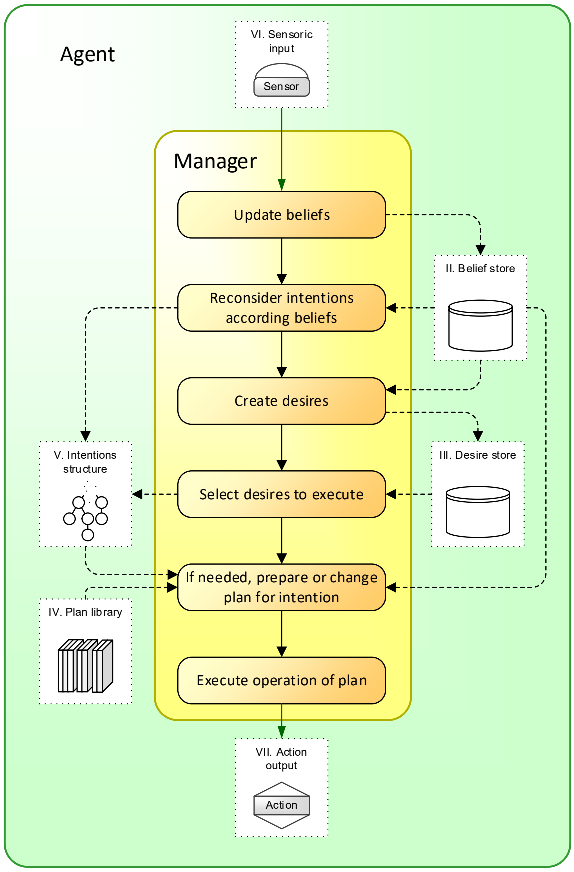

Figure 3: Principle of BDI reasoning

The principle of BDI reasoning, from belief acquisition and formation to successful or unsuccessful fulfillment of a chosen desire, is described in Fig. 3.

BDI plan is the key element that defines agent's activity and the fulfillment of its desire. Like missions (Varga & Adamko, 2019) used to specify agent's strategical decisions, BDI plan is defined in a form of a graph. Plan consists of nodes that dynamic agent interprets (Varga & Adamko, 2014) and thus executes its decision making and perform actions. The nodes are:

- *Start* representing the beginning of the plan, i.e. where dynamic agent starts its interpretation;
- *Finish* and *Abort* nodes representing successful or failed intention to fulfill a desire.
- *Activity* is linked to specific action performed by dynamic agent. The interpretation of an activity node usually ends in future (simulation) time, similarly to execution of events in event-driven simulation.
- *Operation* represents internal agent activity without impact on the environment. Typically, extracting or preparing information from beliefs for later usage in activities is performed when this node is interpreted.
- *Goal* interpretation leads to formulation of new desire, the node splits the execution flow of BDI plan into two branches linked to successful or failed intention used to fulfill the formulated desire.

- *Decision* is used to split execution flow into branches according to decision making process. Every branch is linked to possible value(s) of evaluation of decision. When agent interprets decision, current beliefs are considered.

Formally the BDI plan is an oriented graph $P = (N, B)$ composed of set of nodes N and set of branches B:

$$N = \{n_1..n_k\}; k = |N|$$
$$B = \{b_1..b_l\}; l = |B|$$
$$\forall b \in B: b = (n^{from}, n^{to});$$
$$n^{from}, n^{to} \in N; n^{from} \neq n^{to}$$

We define index set T reflecting types of nodes; and disjoint subsets containing nodes with given T:

$$T = \{Start, Finish, Abort,$$
$$Activity, Operation, Goal, Decision\}$$
$$N^t = \bigcup_{n \in N} n: type(n) = t$$
$$N = \bigcup_{t \in T} N^t$$
$$\bigcap_{t \in T} N^t = \emptyset$$

Lastly, using the out neighbourhood of a node

$$N^+(n) = \bigcup_{m \in N} m: \exists b \in B: b = (n, m)$$

and outdegree

$$\deg^+(n) = |N^+(n)|$$

topology of the graph can be formalized as follows:

$$|N^{Start}| = 1;\ \forall n \in N^{Start}: \deg^+(n) = 1$$
$$|N^{Finish}| = 1;\ \forall n \in N^{Finish}: \deg^+(n) = 0$$
$$|N^{Abort}| = 1;\ \forall n \in N^{Abort}: \deg^+(n) = 0$$
$$|N^{Activity}| \geq 0;\ \forall n \in N^{Activity}: \deg^+(n) = 1$$
$$|N^{Operation}| \geq 0;\ \forall n \in N^{Operation}: \deg^+(n) = 1$$
$$|N^{Goal}| \geq 0;\ \forall n \in N^{Goal}: \deg^+(n) = 2$$
$$|N^{Decision}| \geq 0;\ \forall n \in N^{Decision}: \deg^+(n) \geq 1$$

Dynamic agent's plans library stores prepared plans. The plans are organized according to desires that agent may satisfy using them. To satisfy a desire, multiple plans may be defined. The process of selection of proper plan in given situation plays vital role in agent's behavior. The selection of plan is performed according to agent's preference, which may be defined in many different ways.

3 Reevaluattion of intentions

Consider a person who must get to work. The person may either walk or take some means of public transportation. The person decides to take a walk, since weather seems fine. However, halfway the person had to take a tram because it started raining. The goal remained the same – to get to work. Only the utilized plan used to fulfill the goal has changed from "take a walk" to "take a tram" with respect to current environment conditions. It is an important feature of a simulation tool to enable such reassessment. With it, it is possible to model situations, in which one is unable to complete the goal in the originally intended way but is forced to choose an alternative method to achieve the goal, or even reconsider the possibility of goal achievement itself. Absence of such mechanism can have negative consequences, for example when multiple dynamic agents have the same desire, due to the identical behavior, they would intend to achieve the goal the same way without considering their knowledge or personal preferences. This is insufficient for modeling realistic situations and human reason, that motivated the usage of BDI paradigm.

There are two possible places to reevaluate agent intentions, which we will discuss in more detail in next subsections:

1. *To select a plan to fulfill the desire* (i.e. formulation of an intention). Recall that plans are stored in a plan library. We propose universal extension to the first-fit strategy originally implemented in the library.
2. *To reconsider current intentions according to updated beliefs*. This way it will be possible for an agent to adapt to the current environment conditions as well as to reassess the feasibility of desires in relation to the current state of the environment. The fundamentals of this concept were included in the original implementation of the BDI reasoner of dynamic agent in ABAsim architecture; however, we present universal way to define reassessment using the formalism of BDI plans.

3.1 Selection of a plan

The choice of plan from the plan library depends on the agent's preferences and beliefs. The preferences represent extra information, thanks to which the agent can evaluate the relative quality of the plan to satisfy a desire (Baier & McIlraith, 2007). Recall that dynamic agent can choose from many plans to satisfy sole goal. For this reason, preferences may not be associated with the goal itself. Therefore, (Hindriks & van Riemsdijk, 2009) name the preference as "soft restriction". On the other hand, the goal is a "hard restriction" because it must always be achieved. There are several ways to define plan preferences. It is possible to allow the user to define preferences for each plan separately (Dasgupta & Ghose, 2011). Another approach can be found in (Visser et al., 2015) whose basic desire formula consists of the type of attribute to which the preference applies and the value indicating its priority over other types.

To expand dynamic agent's decision-making capabilities when selecting a plan to fulfil a desire, we introduce agent component named *strategy*. Strategy combines model designer's will to give dynamic agent set of rules when selecting a plan, together with preferences of the dynamic agent. Strategy can be defined for each goal separately. Cooperation of new component with existing components of agents during the reasoning process is depicted in Fig. 4.

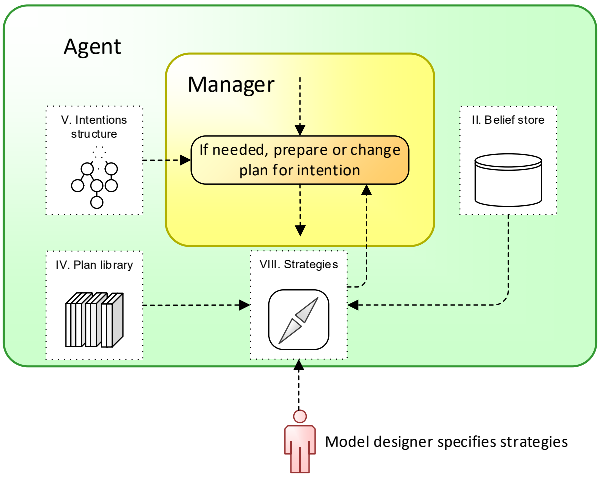

Figure 4. Cooperation of strategies module with relevant components of an agent

This approach was chosen for several reasons. It makes possible (1) to model different reactions of agents to the same goal, (2) to model the need to prefer the plan over other plans as well as (3) to dynamically update preferences according to the beliefs of agent, or (4) to reflect the original implementation (and ensure backward compatibility) and also (5) it enables simple future expansion with a new strategy.

We implemented three basic strategies:

a) *First fit* – to achieve the goal dynamic agent chooses the first suitable plan from the plans library.

b) *Best fit* – to achieve the goal dynamic agent chooses the best suitable plan from the plans library. This is performed based on the priority defined by the model designer. The priority is represented as an integer in the range from 1 to 100. The value 100 represents the most preferred plan, and the value 1 represents the least preferred plan.

c) *Random fit* – to achieve the goal dynamic agent chooses random suitable plan from the plans library. The model designer can specify the probability distribution.

3.2 Evaluation of a plan

Recall example with a person walking to work. The preferred selection of plan "take a walk" over "take a tram" in the first place would be realized via aforementioned strategy mechanism. Note that when the dynamic agent selects a plan via some strategy, only suitable plans can be used, e.g. plan "take a walk" can be considered only when "person has enough time" and "weather is fine". Moreover, the person was capable to drop already taken plan (after it started raining), this leads to another mechanism related to the plans. BDI models such behavior using plan reassessment via trigger and abort conditions of plans.

To expand dynamic agent's decision-making capabilities when performing plan reassessment, we introduce agent component called *evaluator*. Evaluator utilizes beliefs of dynamic agent to evaluate trigger and abort condition. Evaluators can be defined for each plan separately. Cooperation of new component with existing components of agents during the reasoning process is depicted in Fig. 5.

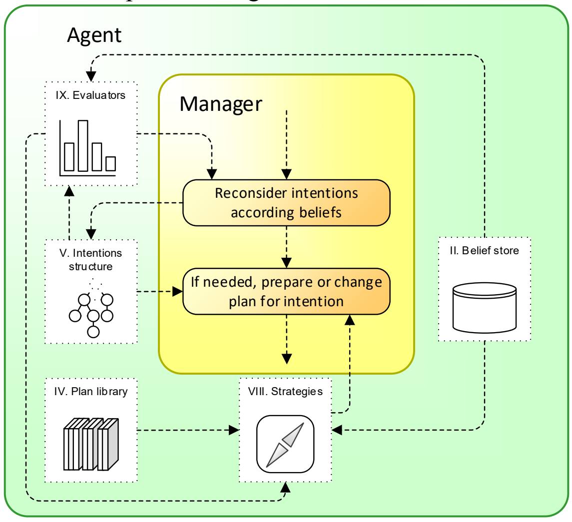

Figure 5. Cooperation of evaluators module with relevant components of an agent

The evaluator represents function, which processes actual state of the agent and return Boolean value expressing weather plan can be utilized (trigger) or it must be dropped (abort).

Analogously to a manager, an evaluator can also be defined in multiple ways:

1. Explicitly using program code,
2. Using *reassessment plans*. If the evaluator is used to evaluate trigger condition, we refer to *trigger plan*, if the evaluator is used to evaluate abort condition, we refer to *abort plan*. Using plans has advantages – especially when building complex conditions that cannot be easily explicitly expressed using sequential approach.
3. Thanks to the universal implementation in ABAsim architecture to defining evaluators, it will be possible to use other sophisticated methods, such as scripts or neural networks, in the future.

Reassessment plan is modified BDI plan, formally $P^{Reassessment} = (N^{Reassesment}, B)$. Modifications can be formally summarized as follows:

Since evaluator is a Boolean function, return value may be only True or False. This leads to modification of meaning of indexing type $Finish$ to $True$(or answer Yes); similarly, indexing type $Abort$ is considered as $False$ (or answer No). Depending on whether one defines a trigger plan (to determine if the main plan is executable) or an abort plan (to handle interruptions during plan execution), interpreting Yes and No node have different meaning. Indexing set of reassessment plan is defined as:

$$T^{\text{Reassessment}} = \{Start, Yes, No, Operation, Decision\} \subset T$$

Nodes of reassessment plan must be of specified type, therefore:

$$N^{Reassessment} = \bigcup_{t \in T^{\text{Reassessment}}} N^t$$

We point out that all nodes of reassessment plan are interpreted in zero simulation time. Therefore, it has no impact on the execution of *actions*. The benefit of this approach lies

- in the possibility to use the same mechanism to define BDI plans and reassessment plans,
- in using of the same interpreter (since the type of nodes available to define reassessment plans are subset of the type of nodes used to define BDI plan),
- in the possibility to share beliefs between BDI plan and reassessment plan.

4 Experiments

ABAsim architecture with proposed modifications is part of the simulation software PedSim. This software is developed at the Faculty of Management Science and Informatics of the University of Žilina. While PedSim is primarily intended for pedestrian simulation, the versatility of ABAsim architecture allows us to utilize proposed mechanism in simulations of other systems as well – if sophisticated decision making of dynamic agents is relevant in those systems. We will use PedSim to demonstrate functionality of the proposed reevaluation of agent's goals.

PedSim provides an easy way of defining BDI plans and reassessment plans using a graph structure. This allows the simple definition of proposed BDI components of dynamic agents. Examples of such definitions are depicted in Fig. 6.

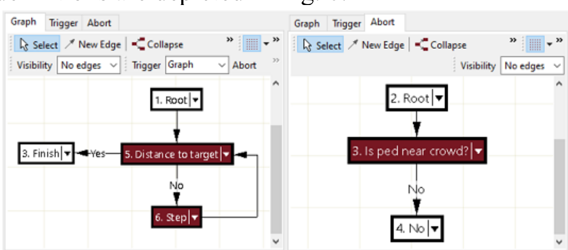

Figure 6. Definition of BDI plan and reassessment plan in PedSim

Proposed approach for reevaluation of intentions has been successfully tested through several experiments. These experiments focused on introducing strategies and creating situations where dynamic agents needed to reevaluate their initial plan choices.

As an example, let us mention a scenario in which we assigned the pedestrian, represented by a dynamic agent utilizing BDI reasoning, a goal to "reach the target area". While walking, pedestrian tried to avoid any crowd that appeared in his path. To monitor the presence of crowds, we utilized specialized sensor (component of ABAsim BDI paradigm) that updated belief "there is a crowd". The sensor was scanning polygonal area for presence of other pedestrians, see Fig. 7 for illustration.

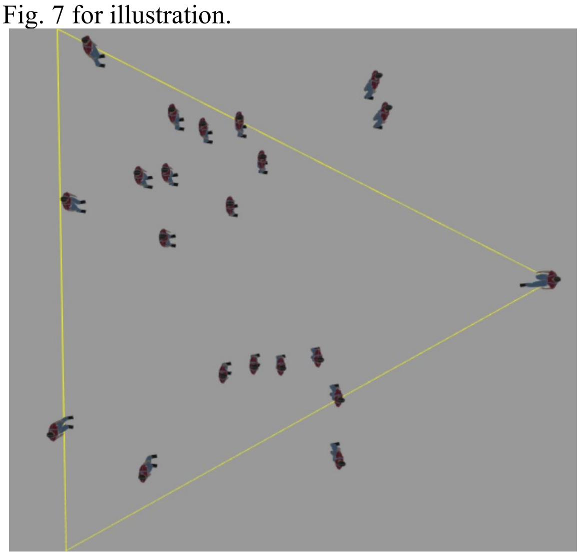

Figure 7. Visualization of polygon used by the crowd detection sensor

We defined two BDI plans with two different routings, as depicted in Fig. 8. First plan (in the figure referenced as "Experiment 3 – Plan 2") was more straightforward, however it led through typically crowded areas. The second plan (in the figure referenced as "Experiment 3 – Plan 3") was designed to avoid those areas, but the resulting path would be longer. Initially, the plan selection process involved a strategy based on defined priorities, with higher priority for the first plan.

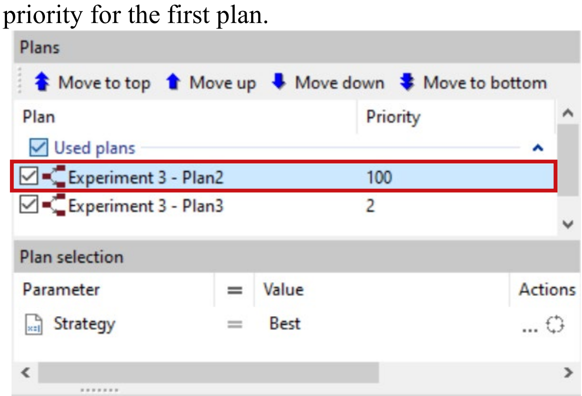

Figure 8. Definition of strategy to select from two plans based on priorities

When the sensor detected a crowd, the evaluator reevaluated the selected plan, decreased its priority and eventually aborted the plan. Subsequently, BDI reasoner changed the plan for the intention by using strategy based on priorities. This led to selection of the other plan (originally with the second highest priority) to fulfill the agent's goal. Validation of the change of plan can be seen in a change of color representing agent's path from red to green, in Fig. 9, where colors are assigned according to used plans. The identification of the crowd on the square (blue area), led to a change in the plans. The pedestrian took longer route, but with higher personal preference according to current conditions caused by the presence of crowd.

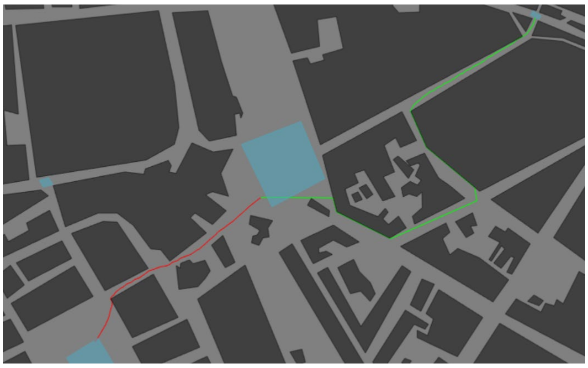

Figure 9. Change of routing plan of a pedestrian according to current situation in the simulation model

5 Conclusion and future work

With a focus on the dynamic agent's ability to reevaluate intentions, we have extended ABAsim architecture and thus enabled the creation of more reliable models based on human reasoning. Tools utilizing proposed approach will be capable to model the behavior of agents in complex systems more precisely.

Proposed mechanism lays foundation for future advancements. One potential direction we see is the integration of artificial intelligence. An agent would be capable of making the decisions and reevaluations based on its experiences and learning from similar situations, without the need for predefined reaction plans by the model designer. This would further enhance the modeling capabilities of simulation tools utilizing the ABAsim architecture.

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