

A Visual Language for Spatially Aware Agent-Based Modeling in Crisis Scenarios

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ABSTRACT

We describe a visual language focused on the design of agent-based simulation models, considering a simulation environment where agent modeling is mainly concerned with the spatial aspects and constraints of the scenario. Such environment is used to test and validate specific action plans designed for execution in specific real world situations, e.g., emergency situations. This work uses as a test case the dam break emergency management scenario. In such situations, the emergency response entities must cover the affected area through a set of procedures and follow a set of priorities and criteria. To better understand which strategy best fits a specific scenario, the emergency plan must be tested and validated, thus requiring an explicit representation of the plan. The proposed visual representation of the agents' behaviors offers a friendly environment for the specification of the plan by domain experts, generally with no programming skills. The plan is then forwarded to a simulation engine, used to perform its validation.

INTRODUCTION

A crisis scenario requires a specific response from emergency responsible entities, and such response is outlined and tested through some validation strategy. Given its scale and complexity, some scenarios do not allow validation through physical drills, and a computer simulation is a possible alternative approach.

Some authors (Almeida, 2003; Brady, 2003; Careem, et al., 2007) propose a set of tools and systems aimed at real time decision support or relief measures organization, but all of them assume an ongoing emergency event, and are not focused on the testing and evaluation of rescue procedures. The focus on prior evaluation of such procedures, and on the maintenance of validated emergency plans (EP), would greatly increase the understanding and robustness of the response. The results of EP evaluation can then also be used as a starting point for scenario understanding and prediction in real time emergency management information systems.

Project LifeSaver (FCT-UNL, 2004) is focused on the EP evaluation problem, and designed an agent-based simulation engine aiming at dam break emergency plan (DBEP) validation. In Portugal, civil protection authorities are responsible for the development of DBEPs, documents, describing emergency response for every entity and group of entities involved in the situation response for a specific type of emergency. The case study scenario of the project is the Aqueva dam, in Portugal. The dam is the largest, and holds the largest artificial lake, in Europe. The data used relies on the exhaustive information collection available for this dam (FCT-UNL, 2004; Santos, et al., 2003). In previous work, an agent-based simulation engine was designed and implemented – using the Repast toolkit environment, Java implementation¹ – to evaluate the effectiveness of actions and measures included in DBEPs (Sabino, et al., 2008).

¹ http://repast.sourceforge.net/repast_3/index.html

Agent-based modeling environments with GIS integration have been targeted by several research projects over the last ten years (Gimblett, 2002). A special emphasis on user-friendly interfaces has also been a major concern on the development of systems for crisis management or preparedness (Andrienko, et al., 2008; Nóbrega, et al., 2008), on simulation modeling (Wiedemann, 2000) and GIS management (Martino, et al., 2007).

In the first approach, the representation of the plan was hard-wired, requiring some familiarity with computer programming to express the emergency response knowledge. From past experience and feedback, the requirement of programming skills was identified as a major setback for the system's acceptance in real emergency planning procedures. To offer the user the possibility of defining this representation without programming, a graphical approach to the definition of the plan is proposed.

The scenario representation present in this work follows the proposal of the Phenomena language (Paolino, et al., 2003) that combines a continuous space representation with discrete objects. The plan representation mainly is influenced by the stop and move concepts from Gómez, et al. (2008) and the focus on the visual representation of the operators was driven by the works of from Wiedemann (2000) and Brady (2003). The transparency between the plan construction environment and the simulation engine highly depends on the structure of the plan representation, and many aspects are discussed by Rohl, et al. (2006), Cavalcanti, et al. (2006) and Murakami, et al. (2003).

DAM BREAK EMERGENCY PLANS

A Dam Break Emergency Plan (DBEP) contains actions designed for emergency response entities execution, and the characterization of such entities, i.e., the relevant aspects to the validation procedure. Such aspects are mainly focused on the geographic constraints of the entities. The DBEP representation and proposed LifeSaver contains the characterization of the scenario – geographically and demographically – and the characterization of the emergency response, in order to accurately simulate emergency management procedures in the considered region. The Shapefile (ESRI, 1998) file format is used to store geographic data, and an extensive set of information related with the Alqueva dam has been provided by the Portuguese National Laboratory for Civil Engineering (LNEC – *Laboratório Nacional de Engenharia Civil*) – a partner of the project. In the simulation engine, the geographic information is managed as a stack of geographic features (GF), similar to the layered organization commonly used by most GIS environments. Each GF can be categorized in the simulation context, as being static, segmented or dynamic, i.e., unchangeable, with binary changeable states or continuously changeable, respectively. This categorization enables the representation of all the relevant phenomena in a dam break scenario, or in similar scenarios (e.g., fires) (Almeida, 2003).

In a dam break scenario, the flood wave is represented by a dynamic GF on the GF stack. The roads are represented as segmented and the houses as static. Demographic characterization is also part of the scenario characterization. This includes all the potentially affected people and property, and their known locations.

The actions of each entity mainly represent its relationship and interaction with the GF stack of the scenario. An entity may move according to a set of rules and constraints. Each entity, civil or emergency response, follows a specific stereotype. A stereotype holds information about constraints on the actions of entities. The use of specific stereotypes may constrain entities to only move through a single (or set of) GF. It is possible to represent such entities as firefighter vehicles and boats, each associated with a different stereotype, according to its characteristics. The rules that apply to the actions of entities define the granularity of their movements. It is possible to specify two types of movement: direct path and zones. An entity may move from a specific location to another, or to a

zone, represented by a circular area with a specific centre and radius. Any combination of these two concepts is available. It is also possible to represent simple interactions between entities.

The plan's model may be represented in XML, to guarantee independence between the DBEP modeling environment and the simulation engine. An XML-Schema was designed to validate its structure, and may be easily used by other modeling or simulation environments. This approach follows the strategy outlined by Sabino, et al., 2008, and the concept of integration between modeling and simulation in emergency response, proposed by Jain, et al. (2003).

AGENT BEHAVIOR

In the simulation engine, an agent representation is used for each entity mentioned previously. The definition of an agent class is closely connected to a particular entity stereotype. The authors distinguish between both concepts because each relates to a particular context: entities are a representation of a person, unit, vehicle, etc., in emergency management and agents are a modeling strategy for simulation systems (Ferber, 1999).

In this system, each agent contains a priority queue of actions. Each action refers to a movement in the scenario space or to an operation executed at a particular location. The GF layers are managed through a stack-like organization by the simulator. Each agent may consult the information relevant to its actions, i.e., the GFs defined as its constraints. The agents also interact through a discrete representation of the scenario – generated from the GF set. This discrete layer is used to simulate the flood threat through a cellular automaton, another constraint for the agent operation. All the layers, either continuous or discrete, offer an environment with all the relevant information, required to accurately represent the emergency plan execution (see figure 1).

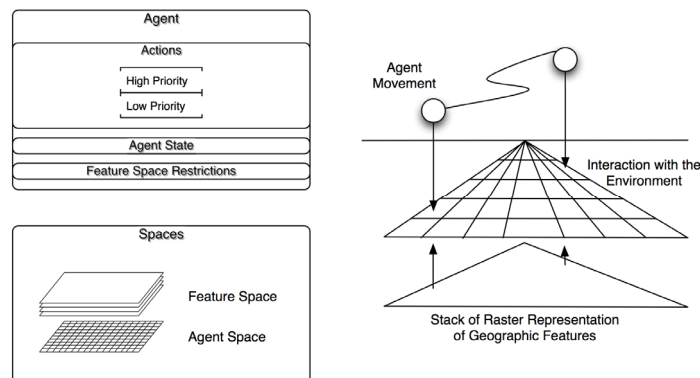


Figure 1: Agents are designed to decide upon information gathered from a stack of geographic features (Spaces).

Two main spatial concepts are involved in the actions of agents: location and zone. A location represents a specific coordinate in the scenario. A zone represents an area with a centre (defined by a location) and radius. Agents may also perform operations, which represent an amount of time to be spent by the agent in a location or zone. Operations are used to model rescue actions performed by the response entities, e.g., building evacuation.

Graphical Concepts

The interface, designed to allow the graphical specification of actions, offers a representation of the scenario's GF set, i.e., a map (see figure 3). There is also an external interface, designed to enhance the interaction between experts and a running simulation (see figure 2), and is described by Nóbrega, et al., 2008.



Figure 2: The external interface displays the scenario in a three-dimensional environment, with several possible interactive actions between the user and the (remote) simulation engine.

The DBEP modeling workflow initiates by loading the relevant information to the construction of the map (see figure 3). The user indicates the location of the relevant GF set Shapefiles. This information is registered in the DBEP. Entities are characterized according to the specification required by the DBEP format (name, id, description, stereotype and geographic bounding features). Their representation on the map takes the form of a square-object.

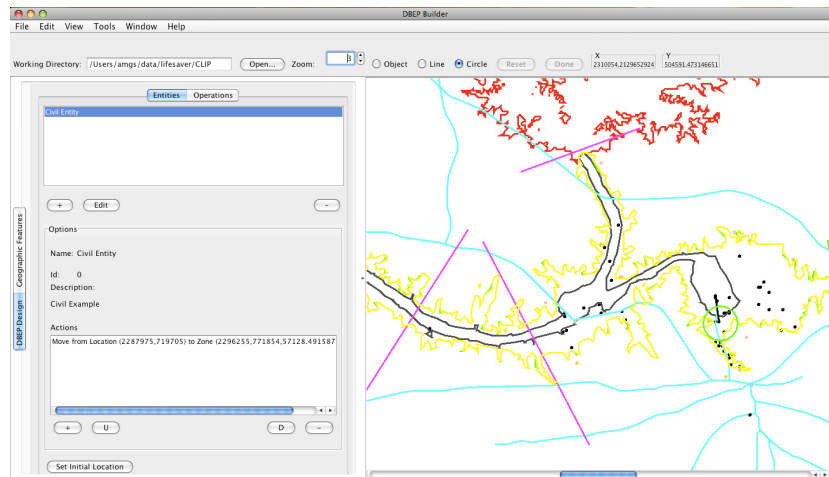


Figure 3: The DBEP builder user interface allows the specification of the scenario's geographic information, used as the main environment for action modeling.

Movement actions are supported by the concepts of line and circle (see figure 4). Lines (i.e., line segment) are drawn over the map from one location to another, and are specified through mouse

input. Zones are centered in a location and the radius is defined by mouse drags over the map. A movement consists on an initial location and a destination. The initial location may be defined by an end point of a line or by the centre of a circle. The same happens to the destination.

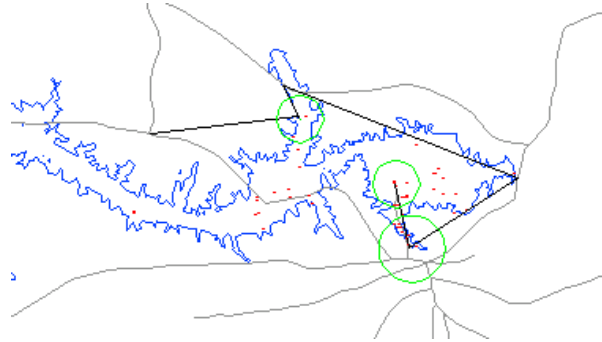


Figure 4: The graphical representation of the operators for action modeling (lines and circles) allows the modeling of movements through absolute locations and zones.

The simulation engine analyzes the definition of a movement and the constraint rules are applied. If an agent is constrained by a segmented GF, a shortest path algorithm (implemented through the Jung library²) is used to choose the best path between the origin and the destination. In the definition of such a movement, the modeler just draws a line from one location (or zone) to another. The simulation engine takes care of its translation into a path in the segmented layer, e.g., a road layer.

An operation has no graphical representation on the map. The assignment of an operation to a particular agent requires two separate steps. First, the operation is defined through a form (see figure 8, upper right form), where times and target stereotypes are assigned. Secondly, any agent of the assigned stereotype may push it to its action stack, and according to its position in the agent's action queue it is performed in the destination location of the previous movement action. Ultimately, an agent's behavior is the result of a composition of movements and operations.

Furthermore, there is also the possibility for the definition of a zone operation. This operation is executed once if no more information is provided. Additionally, a set of points, inside the zone area, may be indicated and will be used to set the execution of the zone operation once for every point. The agent will move between points according to its GF constraints.

DBEP REPRESENTATION

The DBEP formal structure – detailed in Sabino, 2008 – includes a representation of every relevant aspect in the validation scope. It contains a collection of entities for each general stereotype, i.e., rescue entities and civilian entities. There is also a collection of GF elements, and a list of identified locations and zones. GF are classified as a hierarchy of objects, as shown in figure 5.

² <http://jung.sourceforge.net/>

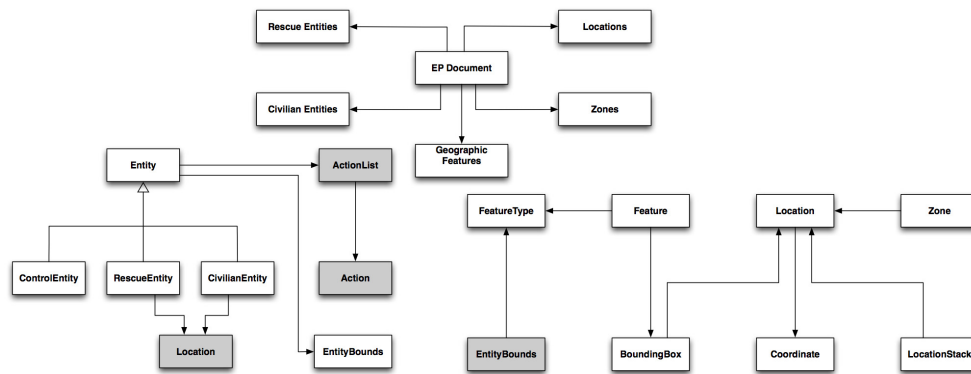


Figure 5: DBEP document object hierarchy, with for entity and geography related information.

The coordinate is a representation of the real coordinates in the coordinate system used by the geographic information data. Coordinates of locations and zones are translated into the simulator's coordinate system, through transformation functions provided by the engine. A bounding box is a square area that delimitates a GF. The scenario characterization requires a bounding box that outlines the limit of the GF set.

The entities hierarchy is structured from (top to down) a generic type Entity to Control Entity, Rescue Entity or Civilian Entity. Figure 6 show the relationships between each set of objects, respectively. Each entity stereotype extends a generic entity object that enforces every instance to contain an action queue and a GF set of restrictions (Entity Bounds). The execution of the actions in the queue is conditioned by those restrictions.

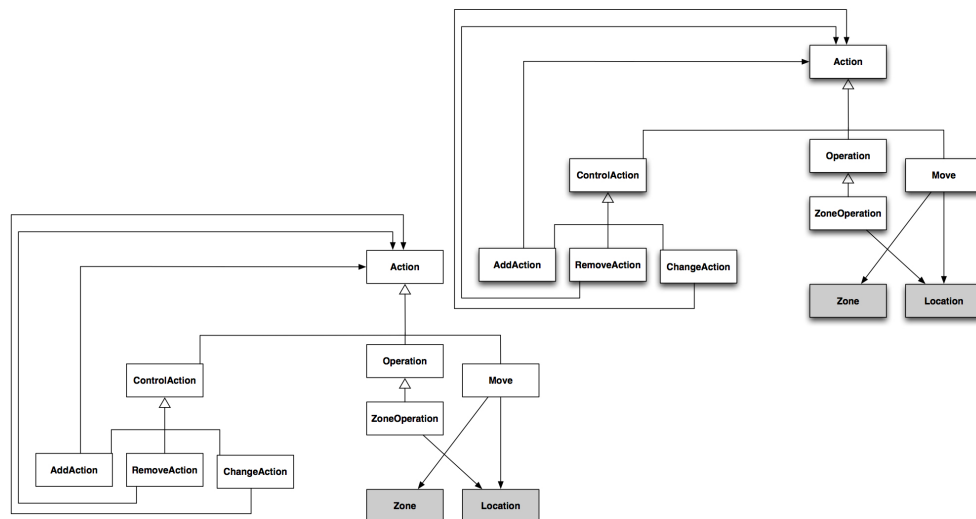


Figure 6: Object hierarchy for entity classes and actions.

The movements and operations extend a generic action object. Identically, the control action (executed by the leader stereotype) extends the generic action. The effect of a control action is reflected upon the action queue of the entities, either by creating, changing or removing actions.

The object schema has a XML representation defined by a set of XML-Schemas, extracted from the discussed structure (see figure 9). This representation enables interoperability between heterogeneous systems, either designed for the modeling task or for the simulation task. It is also targeted to provide a structured plan representation for documentation requirements.

Example Application

To better illustrate the proposed modeling system, an example of plan modeling is presented. **The goal is** to model two entities, one civil and one rescue. The scenario is defined inside the area affected by the flood wave in the first half-hour after the dam break. According to the standard procedures (Almeida, 2003), during this period of time, the civil entities are expected to escape to predetermined safe places. It is not possible to execute rescue entities assisted evacuation procedures in that period of time. The role of the rescue entities in that time interval is to provide assistance to the population that reaches previously identified safe locations. Their main concern is to gather survivors and proceed with the transportation to a predetermined relief facility location.

The civil entity's actions are thus modeled as the following: Wait for some amount of time; Move to the assigned safe location.

The rescue entity's actions are: Wait for some amount of time; Move to a particular zone; Carry entities inside that zone; Move to the relief facility location; Drop entities.

The procedure starts by the definition of both entities. The civil entity is assumed to be moving by foot, and does not require the explicit identification of its geographic constraints. The rescue entity is assumed to be a vehicle, thus bound to the road layer (see figure 8, upper left form).

After the creation of entities, the modeler is now able to define actions. As mentioned, actions may be movements or operations. Operations require the parameterization of a time boundary (see figure 8, lower left form). The simulator must be able to, according to its configuration, maintain the operation execution between best and worst cases. A defined operation may be used by different entities.

Movements and operations are assigned through the same form interface. The priority of either is also a parameter. A movement may combine, to represent origin and destination, the concepts of location and zone.

When the modeler initiates the specification of a movement, the first step is the clear identification of the nature of the origin and the destination. According to the nature of the movement, the interface provides the ability to draw lines and circles. The movement is the result of the composition of such graphical concepts. Every position used in the map corresponds to a real world coordinate.

In the example, whose map is show in figure 7, there is a small (dark green) line segment that represents the movement of the civil entity, from its initial location to a safe point; another, longer, line segment represents the initial movement of the rescue entity to the center of a zone. The zone is centered in the end of the line segment, and is represented by a (light green) circle. The rescue entity drives back to its initial location – a movement that is represented by a line segment that overlaps the initial one.



Figure 7: Movement actions are graphically represented, i.e., the dark green line segments represent movements from one location to another, and the light green circle represents the identification of a target zone.

The organization of the entities' actions is also managed through the interface. It is possible to add, remove and edit any particular action. It is also possible to rearrange the order of the actions in the queue (see figure 8, upper right form).

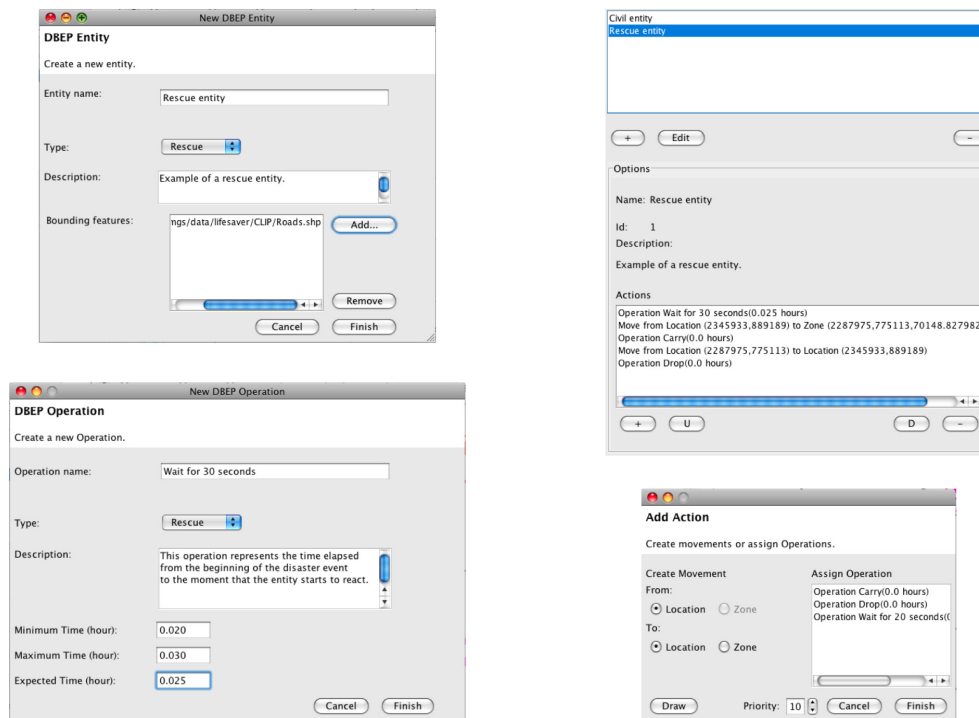


Figure 8: There are forms for the creation of entities, and the construction of its action set. Actions in the set may be reorganized, and consist of either movements or operations. The button labeled "Draw" allows the graphical specification of a movement, according to the chosen schema. The stereotype and boundary features are key aspects for the later definition of actions.

The modeler has the possibility to express several procedures, with different levels of detail. The methodology allows the precise specification of every move for every agent, but it is also possible to express approximate actions, when there is no lower granularity of knowledge. The evaluation of the outlined set of procedures will conclude, or not, if those are appropriate to face the flood wave event –

only after the simulation will it be possible to assess if agents survive the flood or if those actions lead to avoidable dangerous situations.

XML Output

The plan is exported into its XML representation (see figure 9), ensuring transparency and independency between modeling and simulation environments. When the final document is produced, i.e., the XML document, the modeler has the advantage of possessing a structured representation of the plan that is not only valuable for the simulation platform, but also as an EP documentation artifact, enriching the set of information available for the specific scenario.

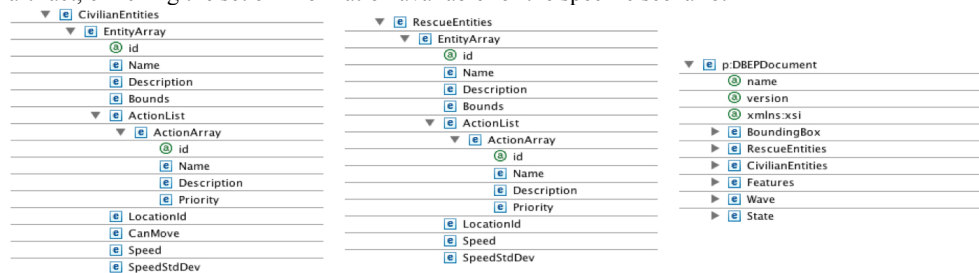


Figure 9: Every parameter, defined in the modeling interface, is registered in the XML representation, and later parsed by the simulation engine.

CONCLUSIONS AND FUTURE WORK

The authors described a system designed to assist emergency management plan modeling professionals, in the particular case of dam break emergency scenarios. The validation of such plans is performed through the use of a flood emergency simulator. This simulator answers to the need for an efficient and realistic strategy for plan evaluation. To do so, it requires a plan representation, which has, until now, been hard-wired to the system, following a model for agent behavior, where the spatial characteristics of the scenario and the possible interactions between the agents and the space are the main concern.

In the presented work, the agent behavior model is formally designed and a set of visual concepts and a graphical user interface is introduced to address the task of (re) formulating the simulation components. A formal representation for the plan has also been conceived, and its correspondence in XML. This work is now ready for complete testing, i.e., the design and validation of a full emergency plan by experts, and some tests should be performed as soon as the Spring/Summer of 2009. There is also interest in refining the current set of operations available for plan modeling, only possible with more expert feedback.

In the future, the authors want to explore the possibility of applying the system to other emergency scenarios, e.g., fire situations. The graphical language validation issue may only be addressed through user trials. Alternatively, the team is studying the possibility of a visual Domain Specific Language definition for the modeling task, following sound procedures that enforce formal validation, proving that such language is (or not) suitable for the task, complementing user trials.

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