TALLINN UNIVERSITY OF TECHNOLOGY

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Modelling and Simulation of Physical Environment for Training Scenarios in Crisis Management

Master's Thesis

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Copyright Declaration

I hereby declare that this master's thesis is my original investigation and achievement, and it has not been previously submitted by anyone for the defence. All works, major viewpoints, data taken from existing literature and elsewhere that were used for writing this paper are referenced.

03.06.2014

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Abstract

The thesis is based on a research done at Tallinn University of Technology, addressing the development of an agent-oriented system for simulating training scenarios in urban operation. An urban operation is defined as all operations planned and conducted across the range of military operations on, or against objectives within, a terrain, where man-made construction and presence of non-combatants are the dominant features. The research establishes that agent oriented modelling has the potential to deal with the challenges posed by the dynamic nature of urban environment in designing realistic scenarios for the simulation of urban operation. The research proposes the development of realistic training scenarios in the direction of modelling human behaviour using agent oriented behaviour models. In such training scenarios, a software agent can be replaced by a real player. This thesis advances the work in that direction by implementing a highly simplified exemplary scenario of urban operation using an existing agent based modelling toolkit called Repast Simphony. The system simulates a simple building evacuation scenario. Some key characteristics of the scenario are based on the urban operation scenario of the parent work. The implementation is based on platform independent models developed by following the viewpoint framework.

One of the main areas of focus in this simulation is the urban environment. The exemplary scenario simulates a simplified building evacuation operation. The building environment is modelled using a formal method for modelling indoor spaces, called Weighted Indoor Routing Graph. The thesis also discusses two ontologies which support representation of city models - IFC and CityGML, with the aim to consider using industry standard ontologies to model realistic environments in agent based simulations. Based on a preliminary comparative study made on these two ontologies, CityGML is found to be more suitable to model environment in an agent based urban operation simulation.

The future enhancements to this work includes as a first immediate step to use a simple building model in CityGML to create the environment of the prototype application developed for this thesis, which will provide an insight into the technicalities of integrating an ontology with the system. Further onwards, the work can lead to the development of realistic simulations for training scenarios using CityGML models.

Glossary of the Abbreviations and Acronyms

AOM	***Agent Oriented Modelling***
ABMS	***Agent Based Modelling and Simulation***
AUML	***Agent Unified Modelling Language***
CityGML	***City Geographic Markup Language***
IFC	***Industry Foundation Classes***
GIS	***Geographic Information System***
GML	***Geography Markup Language***

List of Figures

List of Tables

Table of Contents

1. Introduction

Social interaction in a population is an important factor that shapes the characteristics of both an individual and the population due to the impact they have on each other. The effect of this mutual interaction may range from symbiotic to catastrophic. In either case the prominence of such outcomes pose a demand to understand and predict the dynamic behaviour of these scenarios. The need to grasp the behaviour of real world dynamic scenarios accompanied by the advancement of research in various fields, especially in the dynamics of social interaction in a population, has increasingly motivated the development of numerous technologies to model real world scenarios. Crisis is one such scenario that is of key importance because of its obvious disastrous impact on society and individual life.

As defined from a management perspective, an organizational crisis is a low-probability, high-impact event that threatens the viability of the organization and is characterized by ambiguity of cause, effect, and means of resolution, as well as by a belief that decisions must be made swiftly. Organizational crisis management is a systematic attempt by organizational members with external stakeholders to avert crises or to effectively manage those that do occur (Pearson 1998). The complexity of the dynamics of a crisis event makes crisis simulation a reasonable and popular method for the study of crisis scenarios and provide training environment for crisis management.

The crisis environment is a real world environment with various autonomous entities e.g. Victims, Rescuers, Animals, Robots, etc. The interaction between these entities, or agents in terms of Agent Oriented Modelling paradigm, is complex and important from the perspective of the dynamics of a crisis event. This structure of a crisis environment makes AOM a suitable methodology for crisis simulation. Agent based simulation of crisis management is a progressive and active field of research (Quillinan 2009).

The work presented in this thesis is based the research done by Shvartsman et al. (Shvartsman 2010), where an agent based simulation is modelled for training scenarios in urban operation. A proposal made in the research is the development of realistic training scenarios in the direction of modelling human behaviour. Such training simulation can replace a software agent by a human player. The benefit of this approach is its usability to observe how real subjects for their decision to behave in certain situation. One of the key elements of such training scenarios is the environment of the simulation. The simulated environment includes the model of the physical environment for the training. The environment in a crisis scenario is of critical importance as it is one of the prominent factors driving the interactions and behaviour of the agents situated in it. The environment of a simulation plays a key role in determining the accuracy of the simulation compared to real scenarios. This poses a demand on the simulation environment to be as realistic as possible to the real physical terrain of the urban operation. In this thesis we take a preliminary step towards realizing this demand and thereby making way to accomplish the vision of the background work.

1.1 Motivation

The uncertainties of a crisis situation pose a challenge to create realistic training scenarios for urban operations. It is difficult to train a person for something that is not defined. It is possible to explore human behaviour with training scenarios where human players can replace software agents. This knowledge about human behaviour can be useful to create computational models of interactive human behaviour, thereby helping to simulate complex socio-technical systems.

The ability to create realistic training scenarios has various beneficial implications, especially in crisis management. Simulating the physical environment is an important part of the training scenario. The work in this thesis is a small but significant step to assist this cause.

1.2 Background

The term crisis management primarily refers to any disaster management in an urban environment in the context of this thesis. The environment mostly includes man-made urban structures like buildings and roads. The urban operation modelled in the original research is to rescue victims from inside buildings.

This agent-based system aims to simulate a training environment to train professionals in the rescue operation. The role of the professional can be played either by human or a software agent. There are different roles that coordinate with each other. The simulation allows altering the attributes of the agent to simulate a different personality of the rescuer based on certain criteria. This is a useful feature, which gives an insight into two important aspects. First, it helps us understand how a particular profile performs in a role. Second, it gives a metric of the overall performance of the operation with a particular set of profiles for different roles.

The system follows the Agent oriented modelling paradigm, which is explained in more details in the subsequent sections of the thesis. The AOM paradigm is compliant with the Model Driven Architecture, thus, it uses various models (as shown in Figure 1 and Figure 2) at different layers of abstraction. These platform independent abstract models provide the premise for a platform dependent implementation of the agent oriented simulation.

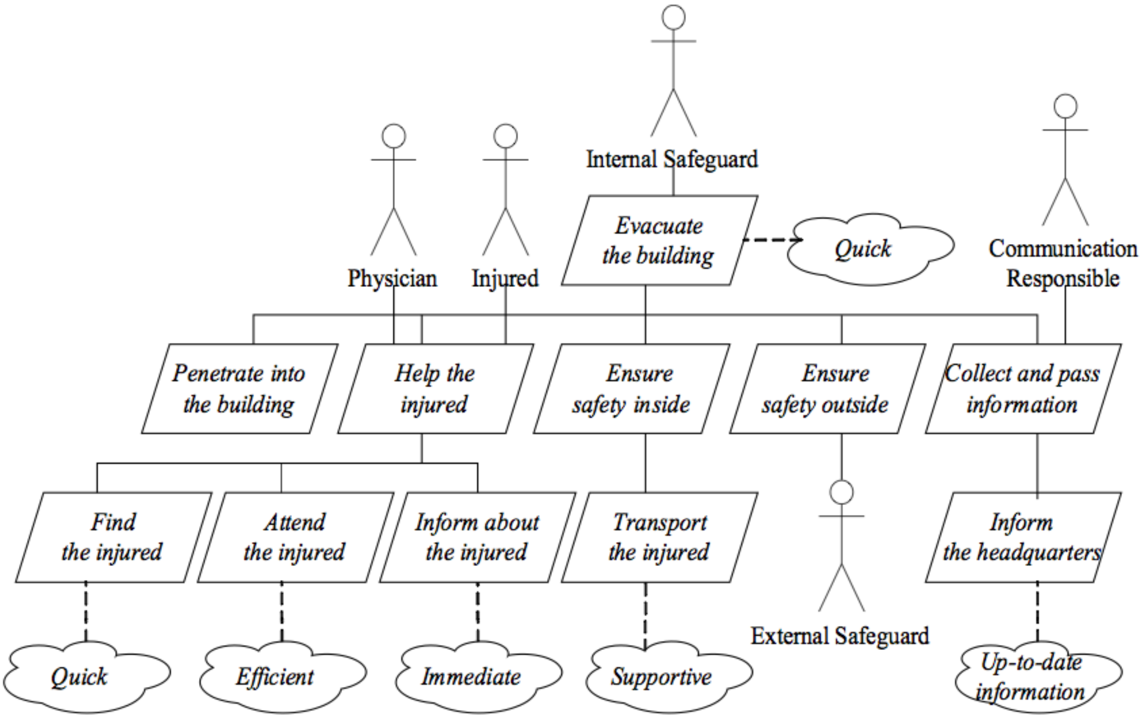


Figure 1. Goal Model

In this thesis a small exemplary scenario of urban operation is developed on an agent based platform. The selection of the agent-based platform was made as a background work. Three popular platforms – Madkit, Repast Simphony and Mason, were surveyed and a high level comparative study was made on them based on their features and the application architecture supported. These three platforms were selected based on the following criteria, which they all satisfy:

- Freeware
- Open source
- Deployable
- Java based

- Experience of research group.

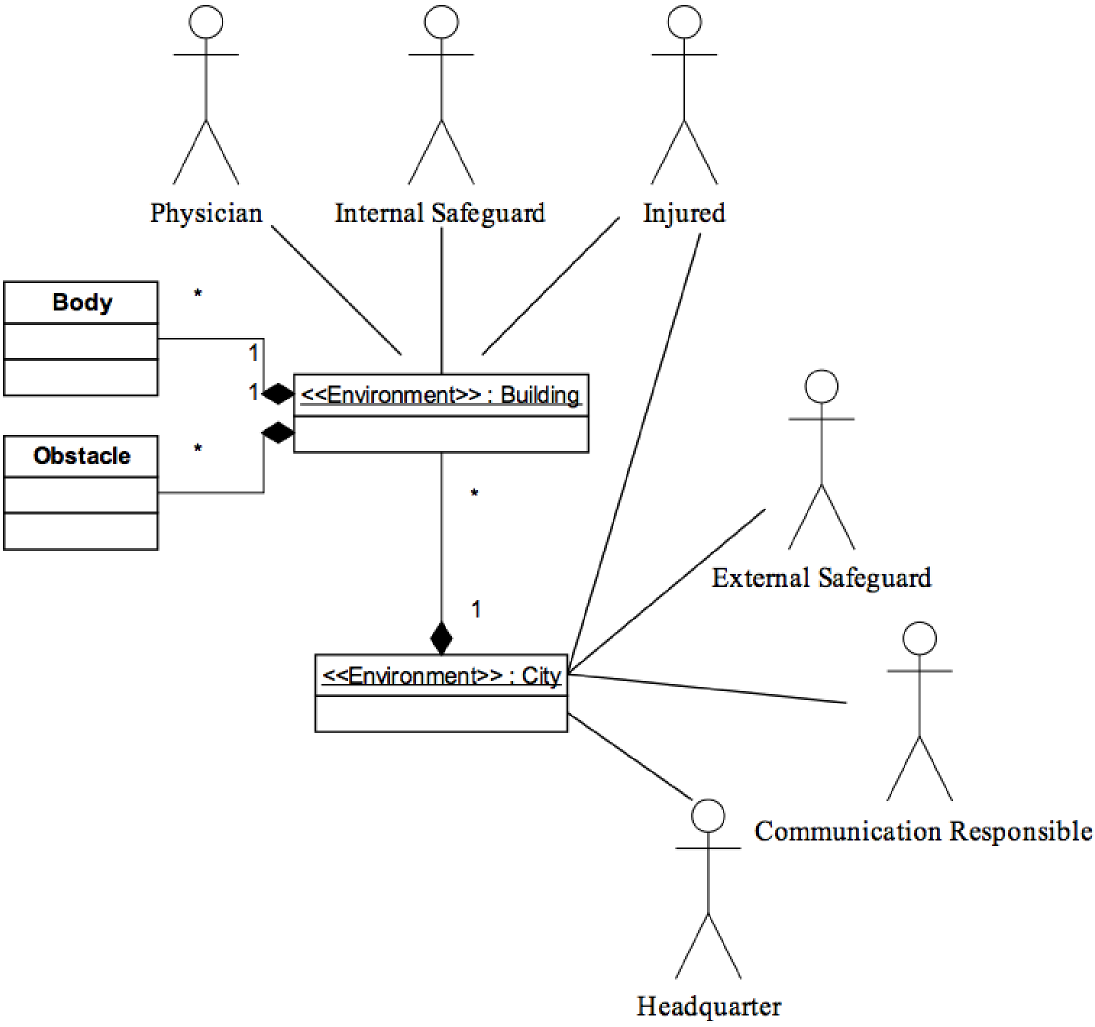


Figure 2. Environment Model

The preliminary study on the platforms selected Repast Simphony as the most suitable one for developing the exemplary scenario. The primary reason for the selection of repast is the direct support it provides for context awareness, which is an important concept in the context-aware crisis management, where the context has an impact on the behaviour and interactions of the agent. Repast symphony provides platform support for the concept of context, which is significant from the environment perspective. The later sections of the thesis will provide more details about the platform.

1.3 Problem Statement

The aim of the urban operation simulation is to provide training scenarios in which both human and software agents can participate. The quality of the training scenario depends on how realistic the system can simulate the dynamics of a real urban operation environment. The realistic nature of the simulation environment is not only in terms of the semantic knowledge it provides but also from a visual aspect. The environment more than any other factor, strongly influences combat identification (e.g., cognitive processes, situational awareness, and visual discrimination), movement and capabilities of (the system of) the contending parties (Shvartsman 2010).

The original research identified the difficulties in realistic training in urban operations due to their asymmetric nature. The work in Shvartsman et al. (Shvartsman 2010) proposes the development of realistic training scenarios to model human behaviour. The use of agent oriented modelling is suggested to explore human behaviour using these training scenarios. The development of training scenarios would require simulation of realistic scenarios of urban operations. Simulation of an urban operation involves simulation of a complex environment, of which, the physical environment is an important part. The development of a realistic urban operation scenario is difficult because of the large scope and complexity of the domain, but never the less important. The thesis is a step towards addressing this specific problem.

1.4 Contribution

The contribution of the author in this thesis addresses the problem in two parts. The first part targets the scope and complexity of the scenario by implements a highly simplified version of an urban operation scenario on an agent based simulation platform called Repast Simphony. The simplicity of the simulation reduces the scope for the initial development. The prototype models a building evacuation scenario with a simple visual environment using “Shapefiles”. Shapefile is a standard format to represent geo-spatial environment data. The system is developed following the viewpoint framework for agent oriented modelling. Agent oriented modelling was chosen to address the complexity of the simulation in terms of the interaction, information and behaviour aspects.

One of the requirements for the simulation is that it should be realistic. Shapefiles can capture the geospatial layout of geographical terrains, based on the location of objects. However, they do not support any semantic structure of urban environments. The realistic expectation from visual environments in simulation of urban scenario demands more advanced means of capturing the environment knowledge. A preliminary comparative study is made on two industry standards, which support representation of urban environments - IFC and CityGML to find a suitable alternative to “Shapefiles” to be used for the simulation in future.

1.5 Thesis Outline

The contents of the thesis further onwards are presented as three main sections – Section two three and four. The first describes the modelling of the physical environment for the training scenarios. It has two parts – the first part provides some required background theory about AOM paradigm and the second part presents the various platform independent models for a simulation system for building evacuation. The next section presents the platform dependent aspects captured in the implementation of the system in Repast Simphony. It has again two parts. The first part introduces two advanced industry standards for representing environment – IFC and CityGML. It also describes a well-known basic format to capture geo spatial information – Shapefiles and its support in a popular agent based simulation platform – Repast Simphony. The section ends with the description of the implementation of physical environment for the building evacuation simulation developed in Repast using Shapefiles. The final section provides the conclusion of the work with proposals for future enhancements.

2. Conceptual Modelling of Physical Environment for Training Scenarios

This chapter presents the various steps into modelling the exemplary scenario for the simulation of a building evacuation operation. The simulation is motivated by the urban operation scenario presented in Shvartsman et al. (Shvartsman 2010). The modelling paradigm used is the agent oriented modelling as described in Sterling et al. (Sterling 2009). The subsequent sections of the chapter briefly describe the concepts related to the AOM paradigm followed by the various models of to capture a complete platform independent view of the system.

2.1 The Notion of Agent

Agent based modelling and simulation is an approach to modelling systems comprising of autonomous interacting agents (Castle 2006). ABMS approach has become popular for modelling and simulation of real world scenarios. Real world scenarios are complex from the aspect of the number of entities involved and the autonomous behaviour of those entities. ABMS provides a way to capture the complexity and bring an order to the apparent chaos by providing a model of the system. The model enables us to control certain parameters of the system to observe and study the effects, which makes this paradigm suitable for simulation.

An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators (Russell 2009). A basic illustration of an agent form is shown in Figure 3 (Russell 2009).

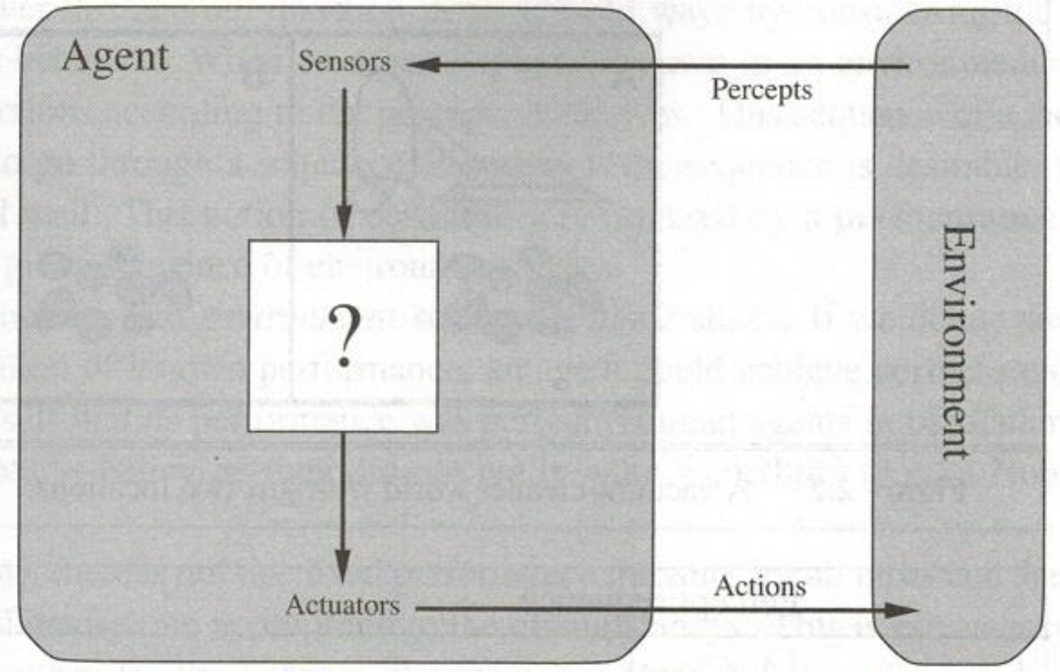


Figure 3. Basic Agent

The agent receives perceptual input, referred as percept, from the environment through sensors and acts upon the environment through actuators. The choice of action of the agent can depend on the entire percept sequence observed to date and not on anything it hasn’t perceived (Russell 2009). The method or function, which maps the percept sequence to an action, is called agent function, which describes the agent behaviour.

The above description of an agent provides an abstract mathematical model of an agent. In the context of ABMS, where multiple agents are involved, the percepts from the environment may include interactions from other agents and similarly the actions may impact other agents in the environment. In AOM paradigm the architecture of an agent has a well-defined structure from the perspective of system design. An illustration of an abstract agent is shown below in Figure 4 (Sterling 2009).

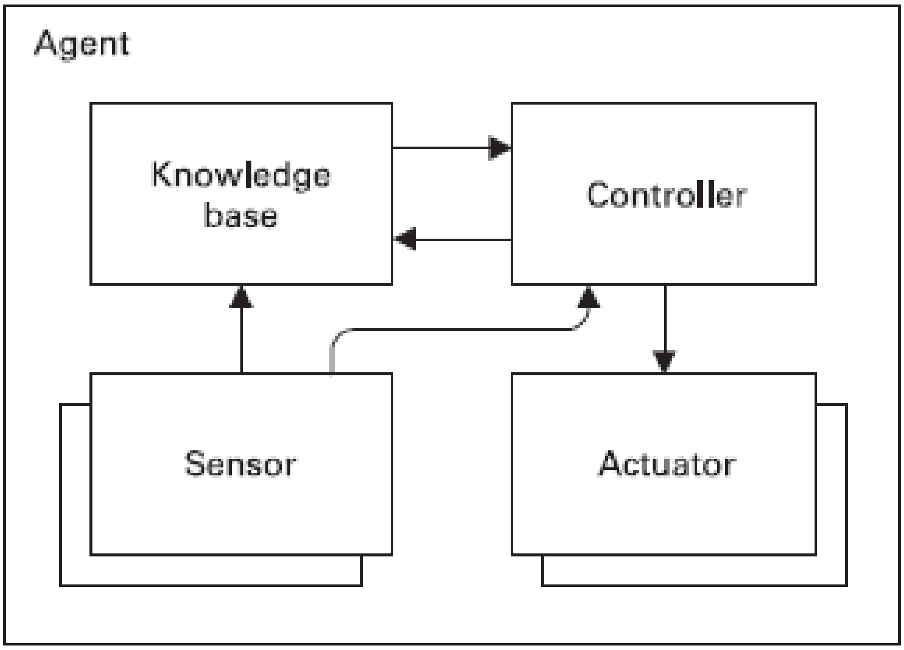


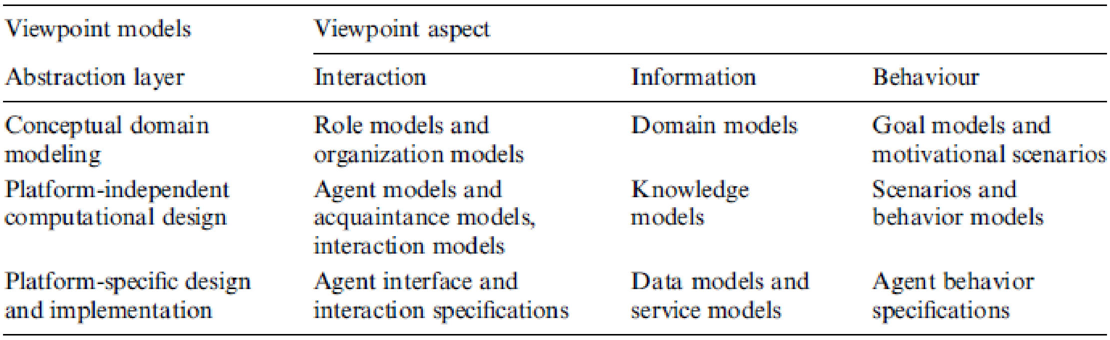
Figure 4. Abstract agent architecture

In the above illustration the percept sequence updates a knowledge base. The agent behaviour is determined by a controller, which performs actions affecting the environment, including messages sent to other agents, through the agent's actuators. It is evident from the concepts discussed above that both from basic an elaborate aspects, environment is an important part of ABMS paradigm.

2.2 Agent Oriented Modelling

Agent Oriented Modelling can be described as a computing paradigm where a system is designed to constitute of agents that satisfy requirements emerging from three broad aspects – Interaction, Information and Behaviour. Each of these aspects is imposed on three orthogonal abstraction layers. This provides us with a conceptual framework, viewpoint framework for AOM (Sterling 2009). Table 1 below depicts the viewpoint framework.

Table 1. Viewpoint framework



Viewpoint models	Viewpoint aspect		
Abstraction layer	Interaction	Information	Behaviour
Conceptual domain modeling	Role models and organization models	Domain models	Goal models and motivational scenarios
Platform-independent computational design	Agent models and acquaintance models, interaction models	Knowledge models	Scenarios and behavior models
Platform-specific design and implementation	Agent interface and interaction specifications	Data models and service models	Agent behavior specifications

The abstraction layers represent three hierarchical levels of abstraction. Each intersection of aspect and abstraction demands one or more models, which capture the details of the specific layer from the viewpoint of the particular intersecting aspect.

The concept of viewpoint framework is important with regards to the problem statement of this thesis in ways of reassuring the importance of environment modelling. Of major importance for this work is the Information aspect, which denotes the knowledge of the environment. A clear, structured and discrete representation of domain knowledge can be efficiently interpreted and used by the agents. This clear representation of knowledge can be described by the term ontology.

Ontology describes the concepts and relationships that are important in a particular domain, providing a vocabulary for that domain as well as a computerized specification of the meaning of terms used in the vocabulary.

Typically ontology describes (Giudice 2010):

- Classes of things in the domain of interest
- Relationships existing among things
- Properties (attributes) of things.

2.3 Agent-based Modelling and Simulation

Agent based modelling and simulation is a paradigm that visualizes a system as consisting of agents and tries to manipulate these agents to simulate a real world scenario. The focus is on the behaviour of the individual agents. The execution of such individual agents produces the overall simulation. However, complex environments as that of an urban environment are characterized by uncertainty and interactions. In other words in addition to the behaviour of the agent, there are intense interaction of agents with other agents and their environment (Shvartsman 2010). Agent oriented modelling provides a method to grasp this complexity of interactions and uncertainty by using abstract models of the system from different viewpoints. The view points are interaction, information and behaviour. This provides a holistic picture of the system beyond individual behaviour of the agents.

2.4 Exemplary Scenario

The paper (Nikolai 2009) provided some valuable insight into the approach of creating exemplary scenario. The exemplary scenario of building evacuation is based the urban operation scenario discussed the in the original research. There are few important considerations for the exemplary scenario given the objective of the work. Firstly, it must try to best simulate an urban operation scenario, however at a miniature scale. Secondly it will use the agent oriented modelling paradigm for its development.

Identifying some key points from the original urban operation scenario and considering them to build the theme of the exemplary scenario realize the first objective. These key points are listed below:

1) *Multiple environments* – The system supports multiple environments (Indoor, outdoor, etc.). Various dynamics associated with multiple environments are simulated in the system. Agents move across these environments in urban operation. They may have different behaviour in different environments. Environments can also be monitored.

2) *Multiple roles* – The system supports multiple roles, which are mapped to different agent types.

3) *Navigation and search* – Navigation within building environment and search for injured victims is one of the key tasks in the system.

4) *Leading another agent* – Another form of navigation where one agent follows another is used in the system.

5) *Interaction with information transfer* – Agent interactions involving knowledge or information transfer between the interacting agents.

6) *Exogenous events* – The urban operation environment has various exogenous events like cave-ins or appearance of strangers.

The system is created with the above key points. In addition to the points to ensure that the exemplary system is able to demonstrate the real system from both functional and non-functional perspectives, an urban operation theme is used.

The system models a simple building evacuation scenario where a guard evacuates victims from the rooms of a building and leads them to an internal shelter. A Shelter is a safe area in build to protect from threats during a crisis situation. An internal shelter is a specially designed and constructed room or area within or attached to a larger building that is designed and constructed to be structurally independent of the larger building and to withstand the range of natural and manmade hazards (Federal Emergency Management Agency (FEMA) 2006). The safe area in this exemplary simulation is a safe-room and the safe-room door. The system is modelled based on the top two layers of the viewpoint framework, which are platform independent. The following sections describe the models used for the systems where it will be shows how the above key points are used in the design of the system.

2.5 Analysis Layer Models

This layer captures the real world perspective of the system. It omits any computational element. The models represent the three aspect of the viewpoint framework.

2.5.1 Goal Model

The goal model for the building evacuation simulation is shows below on Figure 5. The goal model is a graphical presentation of the goals to be achieved by the system. A motivational scenario accompanies the goal model, which is a textual description of the system.

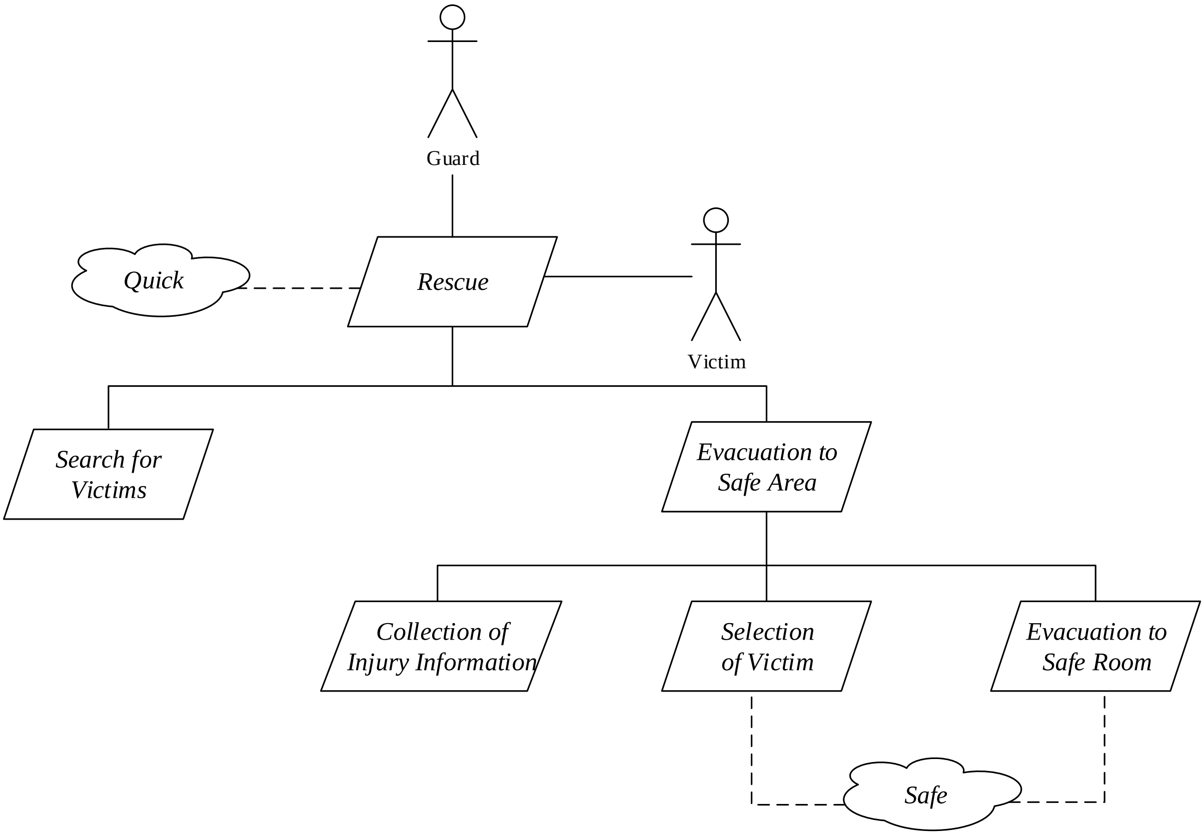


Figure 5. Building evacuation goal model

The primary goal of the system is to “Rescue” and the roles involved in the operation are “Guard” and “Victim”. This satisfies the requirement of multiple roles as per the key points stated above. The primary goal is expanded into sub-goals in the lower layers. The order of the sub goals in the model does not specify any particular order of the execution of goals. The goals “Search for Victims” and “Evacuation to Safe Room” is expanded in other models as shown in Figure 6 and Figure 7 respectively. The quality goals “Safe” and “Quick” associated to specific goals motivates the design of the system to achieve those quality goals.

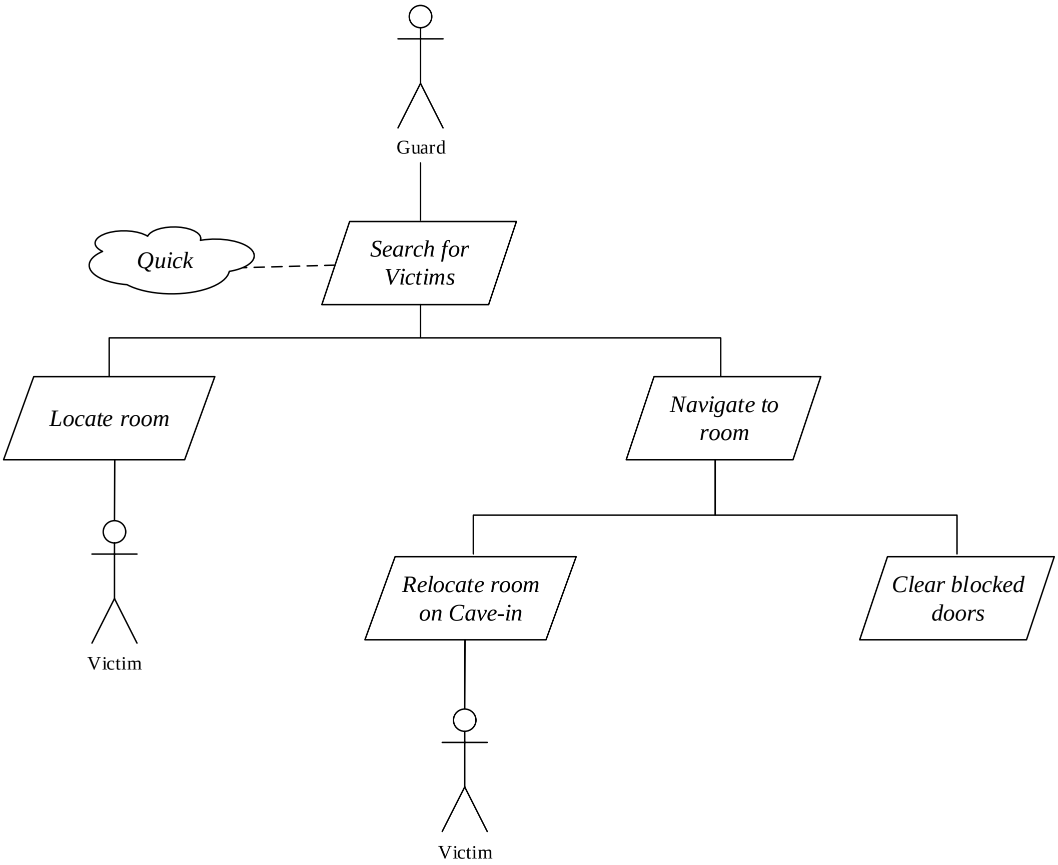


Figure 6. Goal model for "Search for victim"

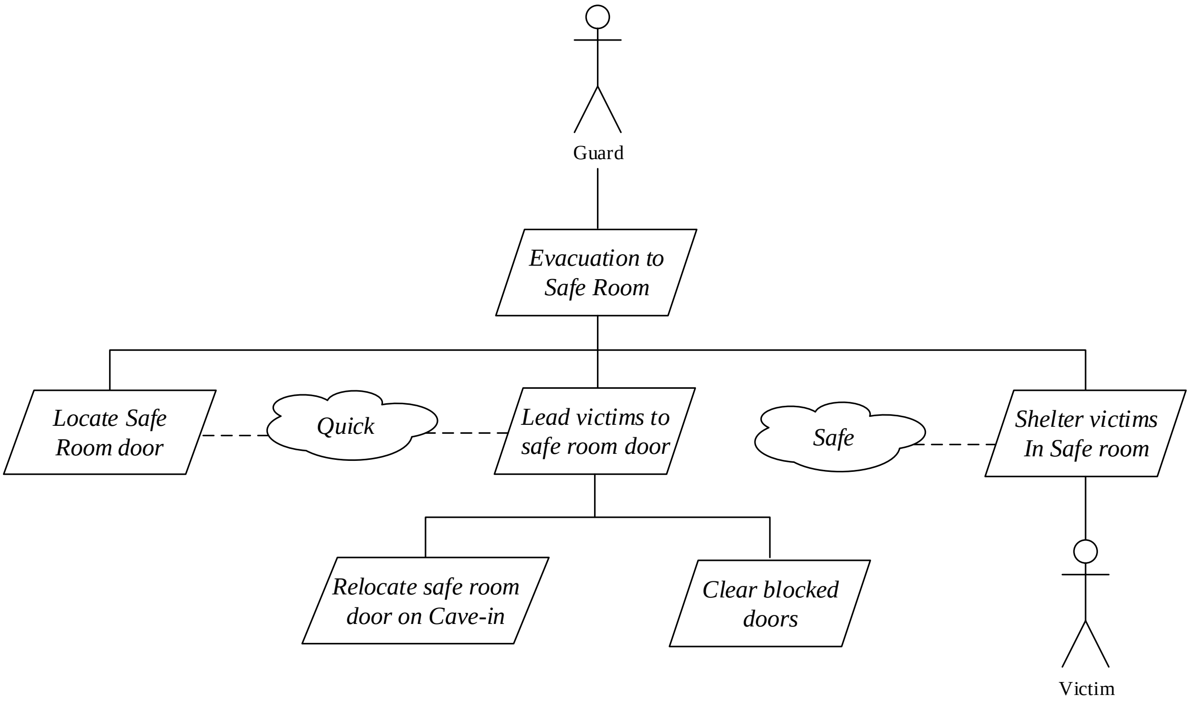


Figure 7. Goal model for Evacuation

2.5.2 Motivational Scenario

The motivational scenario for the system is shown in Table 2. It is a narrative description of the system, which provides a summary of the various activities, and specific details that are not captured in the goal model. The quality description in the motivational scenario specifies the constraints, which are imposed to attain the quality goals.

Table 2. Motivational scenario

Scenario name	Rescue operation
Scenario description	The operation attempts to rescue some victims trapped inside a building. A guard performs the rescue operation. The victims are trapped inside the rooms. The guard starts the operation from the entrance to the building. Once the victims are found in a room the victims are selected for evacuation based on the level of injury. The guard safely leads victims to an internal safe area and ensures the victims enter the safe room. A service is used to find the paths and the rooms to search in the building. The following event occur inside the building during the operation, which is identified as a threat: Cave-ins occur in the building, which blocks the door between two rooms. However, this threat does not apply to the safe room door. The guard performs the following activities: 1) Search for victims. 2) Collect injury information of the victims. 3) Select victims for evacuation as per injury severity. 4) Escort victims to safe area. 5) Clear blocks caused by cave-ins if required. The victim once sheltered in the safe room moves freely inside the safe room.
Quality description	The number of victims being escorted by the guard should not exceed five at a time for safety. The guard must lead the victims to safe area quickly. The guard must ensure safety of the victims during the rescue operation.

The goal model and motivational scenario captures the “behaviour” aspect of the conceptual layer of viewpoint framework. The role models and organizational model provide the “interaction” aspect of the conceptual layer. These models are presented below in Table 3 and Table 4.

2.5.3 Role Models

The role models above elicit the responsibilities and constraints of the roles in the system. The role models for the “Guard” and “Victim” role are captured below.

Table 3. Victim role model

Role Name	Victim
Description	The role of the victim in the building
Responsibility	Follow the instructions of the guard. Move freely inside safe room
Constraints	The victim must remain stationary till instructed to follow the guard. Victim must not leave the safe room. The victim must follow the guards strictly and promptly.

Table 4. Guard role model

Role Name	Guard
Description	The role of the guard in the building
Responsibility	Find victims in the building Collect injury information from the victims. Select the victims to escort based on injury severity. Lead victims to the safe room door. Ensure rescued victims enter the safe room. Clear blocks caused by cave-ins if required.
Constraints	The search and rescue must be quick. Navigation will prefer unblocked routes. The guard must not leave the safe room door before rescued victims have entered the safe room. Severely injured victims will have higher priority in the evacuation. Ensure victims are lead to safe room in shortest time.

2.5.4 Organization Model

The organizational model captures the relation between the roles. The roles in this system are related by a control relationship, in which the guard controls the victim (see Figure 8).

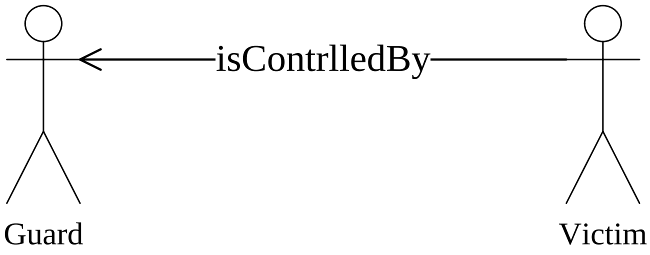


Figure 8. Organization model

2.5.5 Domain Model

The domain model captures the “information” aspect of the conceptual layer. The domain model is of important consideration, especially for this work, because of the significance of environment in urban operations. The domain model captures the domain entities. A domain entity is a modular unit of knowledge handled by a sociotechnical system. A domain entity is conceptually an object type. An instance of a domain entity is hence called an environment object. An environment itself can be modelled as one of the domain entities (Sterling 2009). The domain model captures the relations between the various entities of the system. However, to build the domain model of the systems, it is important to identify the environment and resources in the domain of the system. A resource model, as shown below in Table 5, depicts the information about resources.

Table 5. Resource model

Resources(s)	Roles(s)	Environment(s)
Room	Guard, Victim	Hazard Area
Gate	Guard	Building
Door	Guard	Hazard Area
Route	Guard	Hazard Area
Safe room door	Guard, Victim	Safe Area
Safe room	Victim	Safe Area

The resource model identifies the resources in the system and the various environments they are created or stored. The system identified two environments in a parent environment called “Building”. The two environments – “Safe Area” and “Hazard Area” are domain entities in the domain model. The roles column shows the roles that have a relation with the resources.

The domain model for the system is shown below in Figure 9. An environment itself can be modelled as a domain entity (Sterling 2009). The entities “Hazard Area” and “Safe Area” are environments inside the “Building” entity. The model captures the relations between the roles and resources. As seen in the diagram, there are two parts of the domain model. This is in attempt to capture the hierarchical relation between “Door” / “Safe Room Door” and “Room”/ ”Safe Room”. It has been shows separately not to obscure the main diagram. The entities “Building”, “Safe Area” and “Hazard Area” are underlines to denote their role as environments in addition to domain entities.

One of the issues the author came across during the modelling of domain is with the exogenous event “Cave-In”. Events are not modelled as domain entities but “Cave-in” event is significant due to its relation with the domain entity door. Cave-in blocks a door, which is important information to be captured in the domain model, as “Unblock” is a relation between the door and the guard role. Considering the significance of the event, it was added to the domain model using the stereotype <<Exogenous Event>>

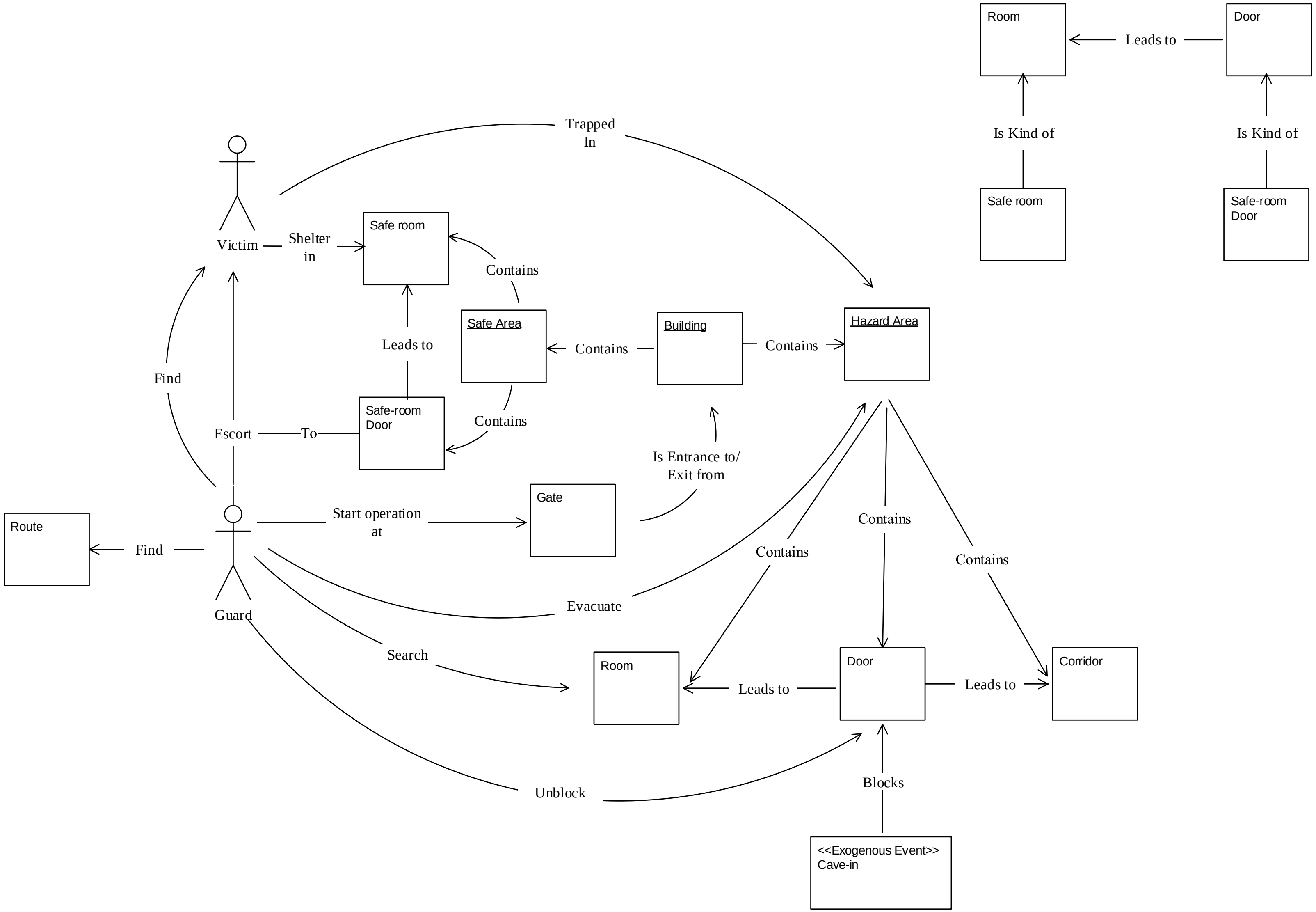


Figure 9. Domain Model

2.6 Design Layer Models

The design models view the system from a platform independent computational perspective. The three aspects of interaction, information and behaviour present the system using a set of models. The subsequent sections describe the models for the design layer.

2.6.1 Agent Models

Agent model is part of the interaction aspect models. It captures the agents in the system, which can play various roles as of the analysis layer. The developed system has two agents – GuardAgent and VictimAgent. The agent models are shown below in Table 6 and Table 7 accordingly. The models describe the roles that the agent will be playing in the system and also the environment considerations, which relate the agent with the various domain resources that it will have to consider in some ways.

Table 6. GuardAgent model

Agent Type Name	GuardAgent
Description	The agent representing as Guard.
Role(s)	Guard
Environmental consideration	Room, Door, Cave-in, Safe room door, Gate, Route

Table 7. VictimAgent model

Agent Type Name	VictimAgent
Description	The agent representing as Injured
Role(s)	Injured
Environmental consideration	Room, Safe Room, Safe room door

2.6.2 Acquaintance Model

The acquaintance model depicts the relationship between the agent types and the roles they play. The model shows the cardinality of the agent types and roles in their relations among each other. The acquaintance model is as shown below on Figure 10.

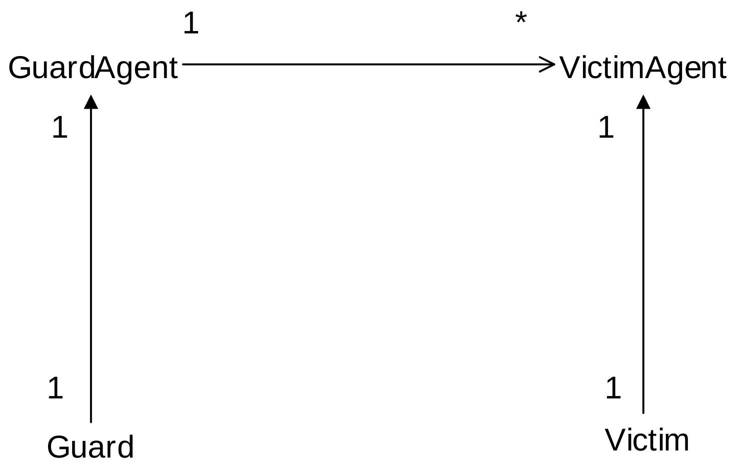


Figure 10. Acquaintance model

2.6.3 Interaction Models

Interaction models as the name suggests constitutes the view of interaction aspect. There are two types of interaction model used for this system – Interaction frame diagram and Interaction protocol. The diagram below (see Figure 11) shows the interaction frame diagram. It captures the various interactions between the guard and the victim, however it does not indicate any sequence of the interaction. In addition to the interaction between agent types it also depicts the interaction on exogenous events, like the one shown for “Cave-in”.

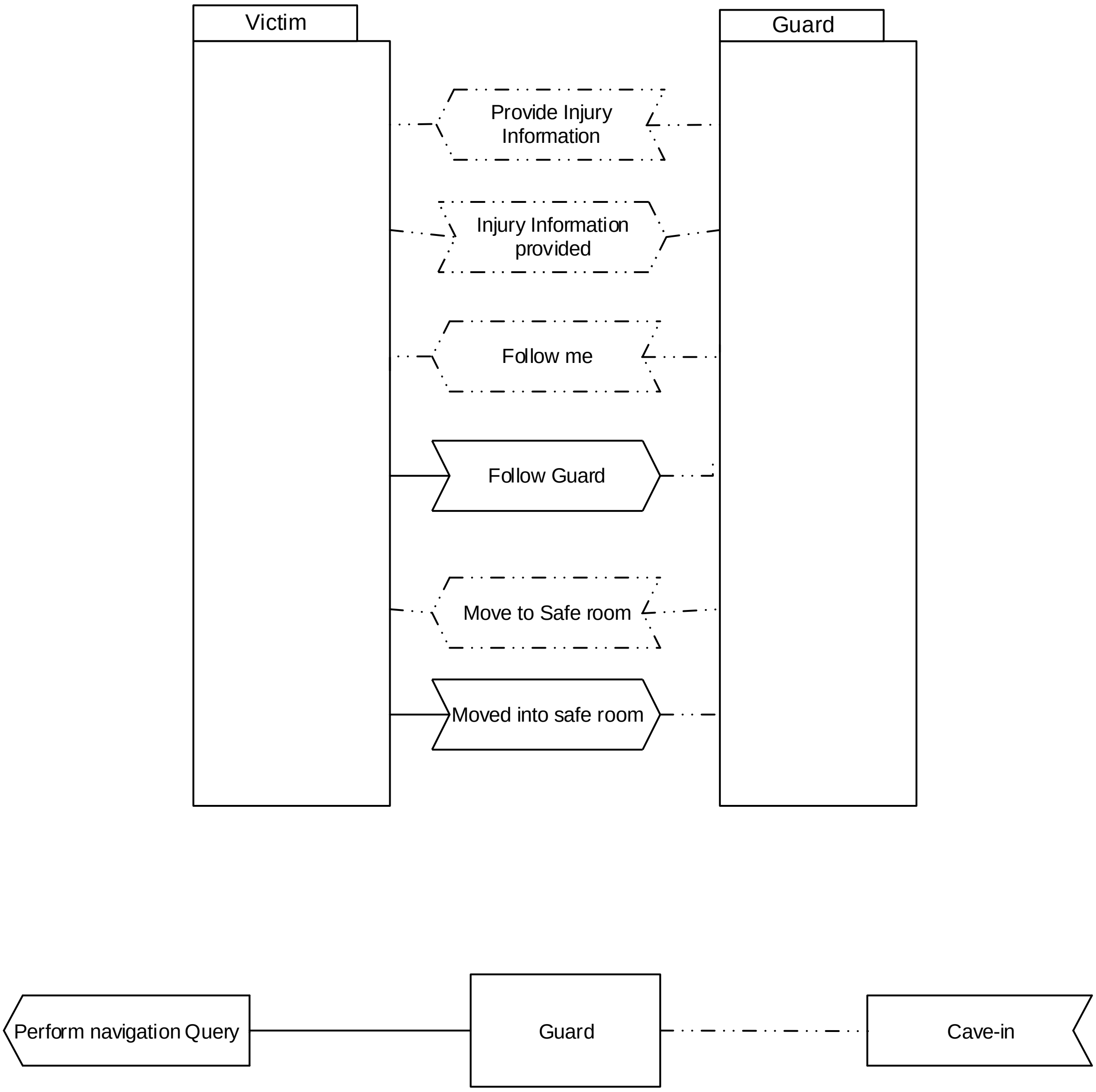


Figure 11. Interaction frame diagram

The second interaction model – Interaction protocol provides the information of the sequence of interaction between the agents. The protocol diagram is elaborate and is capable of capturing details of the communication. The protocol diagram is shown below for the system on Figure 12.

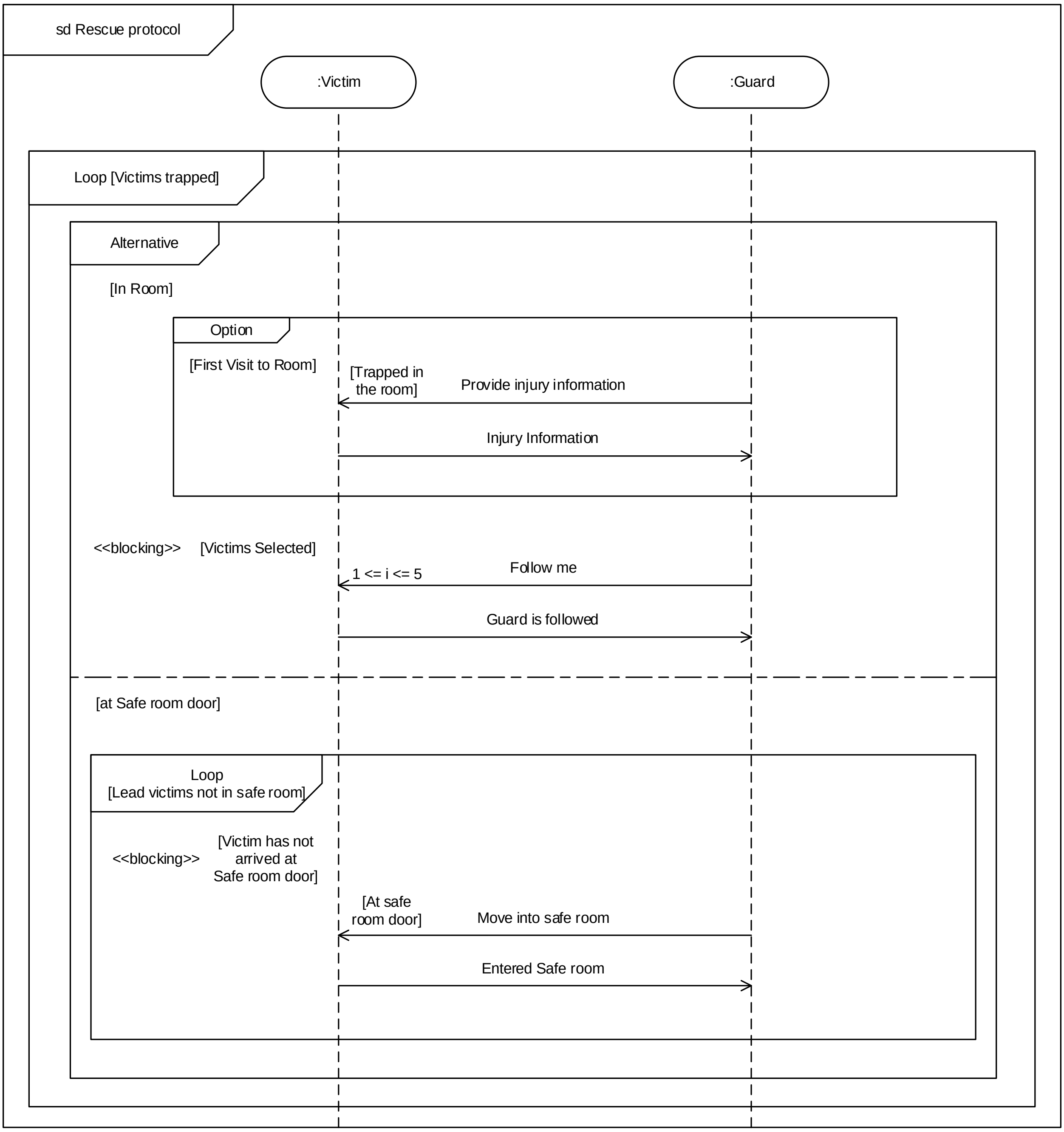


Figure 12. Interaction Protocol

The diagram has constructs for loop, option and alternate flows to capture the sequence and conditions for the interaction between the agents. The notations use the standard AUML notations, explained in Huget et al. (Huget 2004) and Winikoff (Winikoff 2005). The Loop block repeats the interaction till the condition in square brackets is true. The option block executes the interaction only if the guard condition is true. The alternative blocks have multiple compartments, where only one is executed if the guard condition for the block is satisfied. The protocol in addition captures the wait between interaction sequence for a condition to be satisfied using the <<blocking>> constraint.

2.6.4 Knowledge Model

The knowledge model for the system is as shown below. The knowledge mode is a part of the information aspect of the viewpoint framework. It depicts the knowledge resource that agents carry. Many of the knowledge elements are derived from the domain model of the analysis layer. The knowledge model identifies the information that the agents “know about”. The diagram also shows the relationship between the various knowledge items.

Some important points to be considered in the knowledge model are:

- The Building agent object holds the information of all building elements and their relationships.
- The Guard agent does not have full knowledge of the building item, as the guard is not aware of the routes in the building and how they are connected. The guard also has no knowledge about the safe room.
- The Victim has knowledge about the safe room and the location of the guard.
- The service “NavigationService” has access to the building data.
- The guard agent has some data knowledge items of its own. These items are used in executing the responsibilities of the guard.

As shown on the Figure 13, it tries to avoid proposing complex data structure, as it may impose an implementation, which may not be best choice for a specific platform. Therefore the model attempts to capture the knowledge entities and the cardinality relation between them, however not complete implementation details.

An important point observed in the modelling task is that the modelling order of the models of the viewpoint framework can be iterative. The previous models provide the basic information for the next models in many cases. However, it may so happen that in the process of creating a model, some important insights are discovered in the previous models. In this task some important knowledge items like “PathNode” and “VictimInjury” were found during modelling the behaviour models.

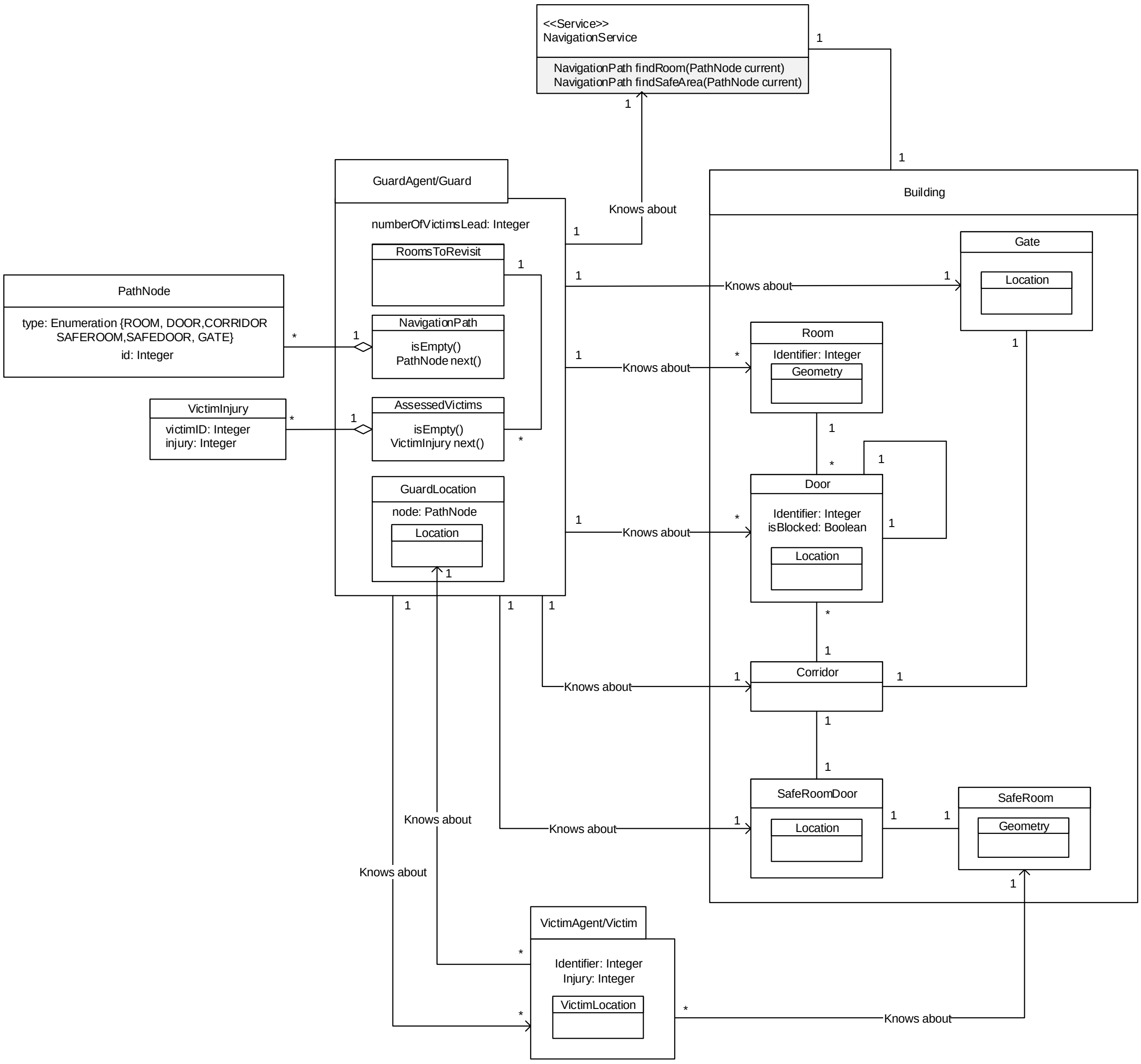


Figure 13. Knowledge Model

2.6.5 Scenarios

Scenarios are part of the behaviour aspect of the viewpoint framework. Scenarios identify the activities involved in achieving the goals by the agents of the system. The scenarios are either triggered or they are executed as part of another scenario. The scenarios for the system are as shown below in Table 8 - Table 18. These scenarios primarily capture the sequence of the activities based on the “Conditions” column, the agents who are taking part in the activity in the “AgentType/Role” column and the knowledge resources that are accessed for the activity. The access is classified as Read (R)/Write (W). It should be noted that presence of a knowledge resource for an activity does not imply that the resource is used on every instance of execution of the activity, it may be accessed only during the first time for example for initialization. An example of this can be found in scenario 1 (see Table 8), where the activity “Search for victims” uses the resource Gate, only the first time when the guard is at the gate.

Another point is that a resource can be mentioned as being accessed for an activity, even if it is used only to check the condition for the activity. An example can be found in scenario 6 – “Evacuation of victims to safety”, where the resource “RoomsToRevisit” is accessed in activity “Collect Injury Information” to check the condition for the activity.

Table 8. Scenario 1

SCENARIO 1					
Goal			Rescue victims		
Initiator			Guard		
Trigger			Beginning of rescue operation		
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
Loop till victims are trapped	2	Search for victims (Scenario 2)	GuardAgent/Guard VictimAgent/Victim	Gate(R), Room(R), Door(R,W), Corridor(R), NavigationPath(R,W), GuardLocation(R,W), VictimLocation(R)	Quick
	3	Escort victims to safety (Scenario 6)	GuardAgent/Guard VictimAgent/Victim	AssesedVictims(R,W), RoomToRevisit(R,W), Room(R), Door(R,W), Corridor(R), GuardLocation(R,W), NavigationPath(R,W), VictimLocation(R,W) SafeRoomDoor(R), SafeRoom(R)	Quick,Safe

Table 9. Scenario 2

SCENARIO 2					
Goal			Search for victims		
Initiator			Guard		
Trigger					
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
	1	Locate candidate room	GuardAgent/Guard, VictimAgent/Victim	Room(R), Door(R), Corridor(R), NavigationPath(W), GuardLocation(R), VictimLocation(R)	Quick

	2	Navigate to candidate room (Scenario 3)	GuardAgent/Guard, VictimAgent/Victim	Room(R), Door(R,W), Corridor(R), GuardLocation(R,W), NavigationPath(R,W), VictimLocation(R,W)	Quick

Table 10. Scenario 3

SCENARIO 3					
Goal			Navigate to candidate room		
Initiator			Guard		
Trigger					
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
	1	Follow the path to the room	GuardAgent/Guard	Room(R), Door(R), Corridor(R), NavigationPath(R), GuardLocation(R,W)	

Table 11. Scenario 4

SCENARIO 4					
Goal			Relocate candidate room		
Initiator			Guard		
Trigger			Cave-in occurred		
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
Guard is navigating to room	1	Locate candidate room	GuardAgent/Guard, VictimAgent/Victim	Room(R), Door(R), Corridor(R), NavigationPath(W), GuardLocation(R), VictimLocation(R)	Quick

Table 12. Scenario 5

SCENARIO 5					
Goal			Clear blocked door		
Initiator			Guard		
Trigger			Reached a blocked door		
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
	1	Unblock the door	GuardAgent/Guard	Door(R)	

Table 13. Scenario 6

SCENARIO 6					
Goal			Evacuation of victims to safety		
Initiator			Guard		
Trigger					
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
First visit to the room	2	Collect injury information (Scenario 7)	GuardAgent/Guard, VictimAgent/Victim	Injury(R), RoomToRevisit(R), AssessedInjured(R,W), GuardLocation(R)	
	3	Select victims (Scenario 8)	GuardAgent/Guard, VictimAgent/Victim	AssessedInjured(R,W), GuardLocation(R), numberOfVictimsLead(W)	Safe
Room has unselected victims left	4	Record room for revisit	GuardAgent/Guard	RoomToRevisit(W)	
	5	Lead victim to safe room (Scenario 9)	GuardAgent/Guard, VictimAgent/Victim	GuardLocation(R,W), Room(R), Door(R), Corridor(R), VictimLocation(W), SafeRoom(R), SafeRoomDoor(R), numberOfVictimsLead(R,W)	Quick, Safe

Table 14. Scenario 7

SCENARIO 7					
Goal			Collect injury information		
Initiator			Guard		
Trigger					
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
Repeat for all victims in the room	1	Collect injury information from victim	GuardAgent/Guard, VictimAgent/Victim	Injury(R), AssessedInjured(R,W), GuardLocation(R)	Safe

Table 15. Scenario 8

SCENARIO 8					
Goal			Select victims		
Initiator			Guard		
Trigger					
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
Loop, till maximum capacity (5 or all, whichever is less) of victims are selected from	1	Select victim with the most severe injury among the unselected victims in the room.	GuardAgent/Guard, VictimAgent/Victm	AssessedInjured(R,W) numberOfVictimsLead(W)	Safe

the room.					
	2	Selected victim follows the guard	VictimAgent/Victim, GuardAgent/Guard	GuardLocation(R), VictimLocation(W)	

Table 16. Scenario 9

SCENARIO 9					
Goal	Lead Victim to Safe Room				
Initiator	Guard				
Trigger	Victims selected from the room				
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
	1	Find route to safe room door	GuardAgent/Guard	Room(R), Door(R), Corridor(R), NavigationPath(W), GuardLocation(R), SafeRoomDoor(R)	Quick
	2	Lead victim to safe room door	VictimAgent/Victim, GuardAgent/Guard	NavigationPath(R,W), Room(R), Door(R,W), Corridor(R), SafeRoomDoor(R), GuardLocation(R,W), VictimLocation(W)	Quick
Repeat for all victims lead	3	Shelter victim in Safe room (Scenario 11)	VictimAgent/Victim, GuardAgent/Guard	VictimLocation(R,W), SafeRoom(R), numberOfVictimsLead(R,W)	Safe

Table 17. Scenario 10

SCENARIO 10					
Goal	Relocate safe room door				
Initiator	Guard				
Trigger	Cave-in occured				
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
Guard is leading the victims	1	Find route to safe room door	GuardAgent/Guard	Room(R), Door(R), Corridor(R), NavigationPath(W), GuardLocation(R), SafeRoomDoor(R)	Quick

Table 18. Scenario 11

SCENARIO 11	
Goal	Shelter victim in safe room
Initiator	Guard

Trigger					
DESCRIPTION					
Condition	Step	Activity	AgentType/Role	Resource	Quality
Victim Reached the safe room door	1	Guard instructs victim to move in to safe room	GuardAgent/Guard VictimAgent/Victim	VictimLocation(R) numberOfVictimsLead(W)	
	2	Victim moves in to safe room	VictimAgent/Victim	SafeRoom(R) VictimLocation(W)	
	3	Victims moves freely inside safe room	VictimAgent/Victim	VictimLocation(W) SafeRoom(R)	

2.6.6 Behaviour Models

The behaviour mode captures the agent’s individual behaviour and the logic, which it executes during its life cycle (execution cycle). The behaviour consists of activities and actions, which are triggered by some conditions called rules. The actions are of three types- physical action, communicative action, and epistemic action. Epistemic actions occur when an entity is updating a data. A double-pointed arrow denotes its notation (>>).

The behaviour model for a part of the building evacuation system is shown in the Figure 14. This model primarily depicts the behaviour of “Search Victim” goal. Some points to note about the model are discussed as follows:

1) The behaviour model is not a series of activities that will be executed in one cycle. Specific activities are executed in the behaviour model based on the rules that are triggers during the execution cycle.
2) One observation found when implementing the model is that, the nested structure of the activities in the behaviour model can be very well represented in the code for the execution cycle of the Repast Agent. The code snippet of the GuardAgent is shown in Figure 15. As can be found from the code, the variable “act” follows the nested activity structure of the behaviour model. There are areas of improvement where no activity is done in some cycles, just to change the value of the variable, however, the code could be easily represented in terms of the model. This is a useful outcome of agent oriented modelling, because the models are platform independent, so this representation can be achieved on any platform.

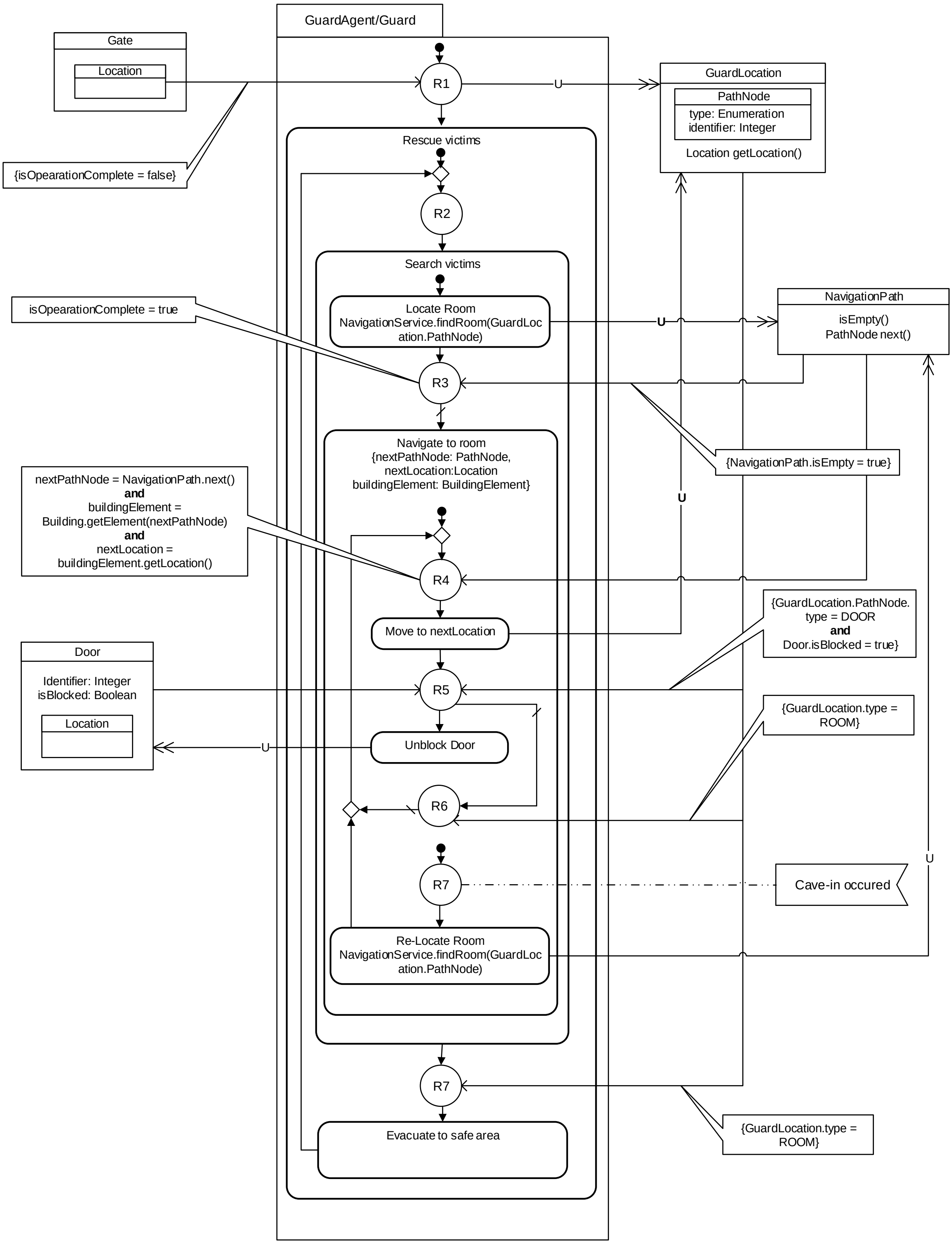
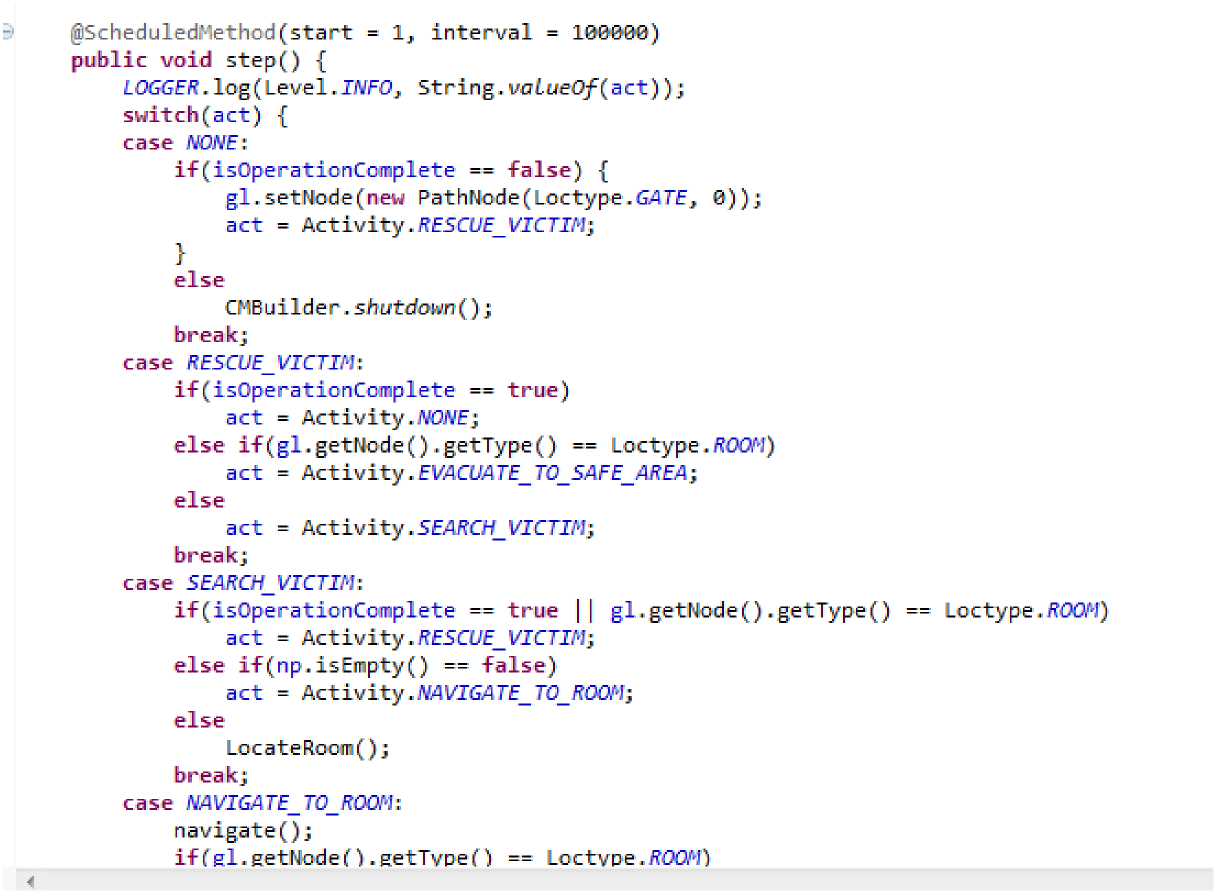


Figure 14. Behaviour model



```
    @ScheduledMethod(start = 1, interval = 100000)
    public void step() {
        LOGGER.log(Level.INFO, String.valueOf(act));
        switch(act) {
        case NONE:
            if(isOperationComplete == false) {
                gl.setNode(new PathNode(Loctype.GATE, 0));
                act = Activity.RESCUE_VICTIM;
            }
            else
                CMBuilder.shutdown();
            break;
        case RESCUE_VICTIM:
            if(isOperationComplete == true)
                act = Activity.NONE;
            else if(gl.getNode().getType() == Loctype.ROOM)
                act = Activity.EVACUATE_TO_SAFE_AREA;
            else
                act = Activity.SEARCH_VICTIM;
            break;
        case SEARCH_VICTIM:
            if(isOperationComplete == true || gl.getNode().getType() == Loctype.ROOM)
                act = Activity.RESCUE_VICTIM;
            else if(np.isEmpty() == false)
                act = Activity.NAVIGATE_TO_ROOM;
            else
                LocateRoom();
            break;
        case NAVIGATE_TO_ROOM:
            navigate();
            if(gl.getNode().getType() == Loctype.ROOM)
```

Figure 15. GuardAgent execution cycle

3. Simulation of Physical Environment for Training Scenarios

This chapter describes the implementation of the system in Repast Simphony. It starts with the explanations of GIS which is a technology used in the implementation.

3.1 Representing Environment

This chapter describes a preliminary study of two ontologies that support the representation of urban environment in 3D. The study has been done with the following objectives:

- A suitable ontology to represent the environment. The ontologies are 3D, thus representing a much more realistic environment.
- The content provides lot more visual and semantic (doors, windows, walls etc.) information than basic shapefiles.
- An objective to decouple the environment from the simulation, where the complex environment can be developed separately in standard industry format and imported into an agent simulation toolkit like repast. This is an objective with a large scope and thus demands lot more work.

3D city models are of two types, design and real world models (M. El-Mekawy 2010). The design models are made for architectural purpose in the building industry to capture the details of the building of the construction. Building Information Modelling is a process that supports the building design models in the industry. Real world models are geo spatial in nature. They capture the geographical information of buildings and other spatial objects. Both these models can represent the details of an environment.

The two most prominent semantic models for the representation of BIM and geospatial objects are Industry Foundation Classes (IFC) and City Geography Markup Language (CityGML), respectively (M. El-Mekawy 2010).

3.1.1 CityGML

CityGML is a common semantic information model representing different 3D urban and geographical objects that can be shared among different applications (M. El-Mekawy 2010). CityGML information is stored and exchanged as GML schema. Geography Markup

Language (GML) is an XML grammar written in XML Schema for the modelling, transport, and storage of geographic information. GML is another format of representing GIS data. It includes both spatial and non-spatial data (OpenGIS® Geography Markup Language (GML) Implementation Specification 2004). City GML captures multiple level of details in the city model, LOD0 to LOD4, where LOD4 is the maximum details.

3.1.2 IFC

IFC (Industry Foundation Classes) is information standard for building industry. Its main objective is to facilitate interoperability in the building industry. IFC does not support geo spatial data. It is primarily aimed for Industry environments.

In this work we focus primarily on the support for building environments. Both these standard have a framework of classes to support the building objects. In the study performed, the following points were identified from sources that supported CityGML for the simulation environment over IFC.

- IFC has large number of classes for the Industry environment, which capture very high level of details that are less likely to be relevant for the simulation or urban operations. For example there are classes for heating, ventilation, air conditioning and structural calculation, however few are for are used for the representation of building an architectural elements. (M. Ö. El-Mekawy 2012). Where as in CityGML the classes are more for building and city environments which are more relevant for the purpose.
- The framework structure of IFC gives high flexibility, which means there is more than one way to connect various classes to for the same structure. This can cause a software implementation to be more difficult, whereas in CityGML the relationship between the classes are static, thus there is only one way to various parts of the building.
- Support for Geographical information in cityGML

Based on the above comparative study, CityGML is selected for future works.

3.1.3 GIS and Repast Simphony

The system developed as part of the thesis work, is based on a popular agent based platform – Repast and a popular spatial data format called shapefile. This section will elaborate some points about these two systems used for the implementation.

Geographic Information System is a computer system capable of assembling, storing, manipulating, analysing and displaying geographically referenced information, i.e. data identified according to their location. The term geographically referenced information emphasize that the information must have a geographic location associated with it. Real world geographic information has three properties – location, attributes and spatial relation. Location refers to the geographic location to which the information refers. The location is always measured with reference to some spatial coordinate system. Attributes refer to information about the location, e.g. population of a location. Spatial relation is the property, which describes the special attributes, e.g. shape of an object or the spatial relation an object shares with other objects. These properties give a structure to the real geographic information for representation in a computer.

GIS data can be represented in two formats, Raster GIS Data and Vector GIS Data. Raster GIS Data represents earth surface as a grid of evenly sized cells. Each cell represents a particular area of the surface. Attributes are assigned to a cell, thus associating the attribute to that portion of the surface the cell represents. The size of these cells decides the quality of the spatial resolution. The smaller the cells or pixels are, the higher the spatial resolution. Raster data is suitable to represent continuously changing attributes e.g. elevation (Rose 2009).

Vector data provide a way to represent real world features within the GIS environment. A feature is anything you can see on the landscape. A vector feature represents a shape using geometry. The geometry is formed using vertices. A vertex can represent a single point or can form a polyline or polygon by interconnecting with other vertices. This form of geometry allows vector data to capture spatial relations among features (Sutton 2009). Attribute is a part of GIS information, thus features have associated attributes. Figure 16 (Sutton 2009) shows a feature hierarchy.

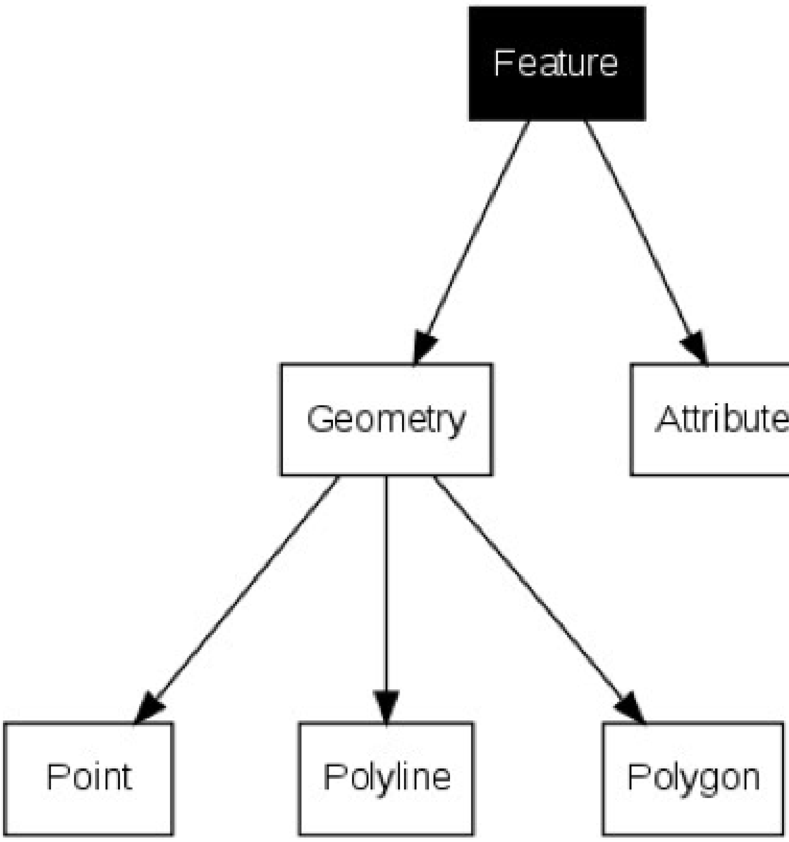


Figure 16. GIS Feature Hierarchy

Topology is defined as the spatial relationship between adjacent or neighbouring features (Rose 2009). One of the most popular file formats to store GIS data is ESRI shape file, which is nontopological geometry and attribute information for the spatial features in a data set. The geometry for a feature is stored as a shape comprising a set of vector coordinates (Environmental Systems Research Institute, Inc. 1998).

Repast Simphony, also referred as Repast S, is a popular agent based simulation toolkit. The design methodology in Repast S is based on two concepts, Context and Projection. The idea of context and projections has provided repast an infrastructure that supports highly modular set of behaviours and relationships (Repast 2009).

The core data structure in Repast S is context. From the modelling perspective, context represents an abstract population. The objects in the context constitute the abstract population of the context and are known as proto-agents. Context does not provide any mechanism for interaction between the proto-agents. Context provides the basic infrastructure to define the population however it does not provide the proto-agents with any concept of space or relation. Context itself can have a state and behaviour associated with it. They can have a hierarchy allowing sub-contexts. These properties make a context more than just a container. Proto-agents can move between contexts. As a result, proto-agents that are designed to engage in behaviour on the basis of their environment can switch behaviours very easily when they migrate into another context. This property of context can be used to integrate the environment model into the simulation with a high degree of logical modularity. Figure 17 shows a possible hierarchy of contexts. Moving the agent between the sub-contexts, “Indoor” and “Outdoor”, can alter the behaviour of an agent.

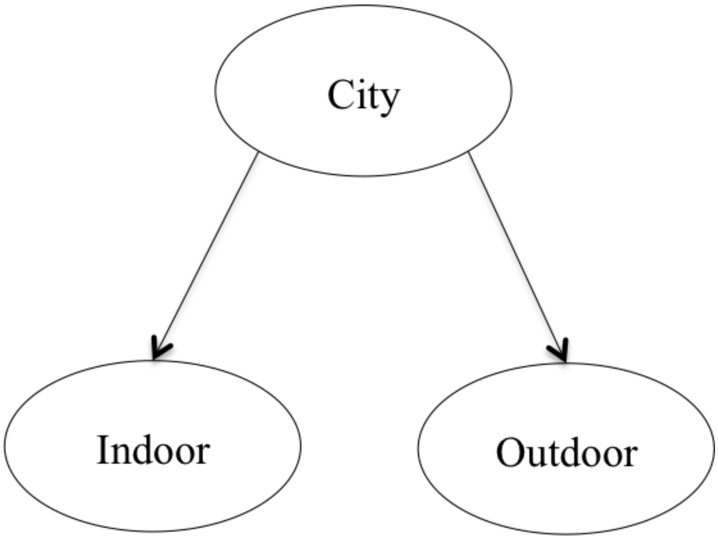


Figure 17. Repast context hierarchy

Projections impose a structure on the population of the context. Proto-agent population is realized once a projection is applied to it. This allows the proto-agents to interact with one another. In other works once a projection is applied, the proto-agents gain the perception of space and relation. Multiple projections can be applied on a context, thereby allowing multiple types of relationship between proto-agents as shown in Figure 18 (Repast 2009)

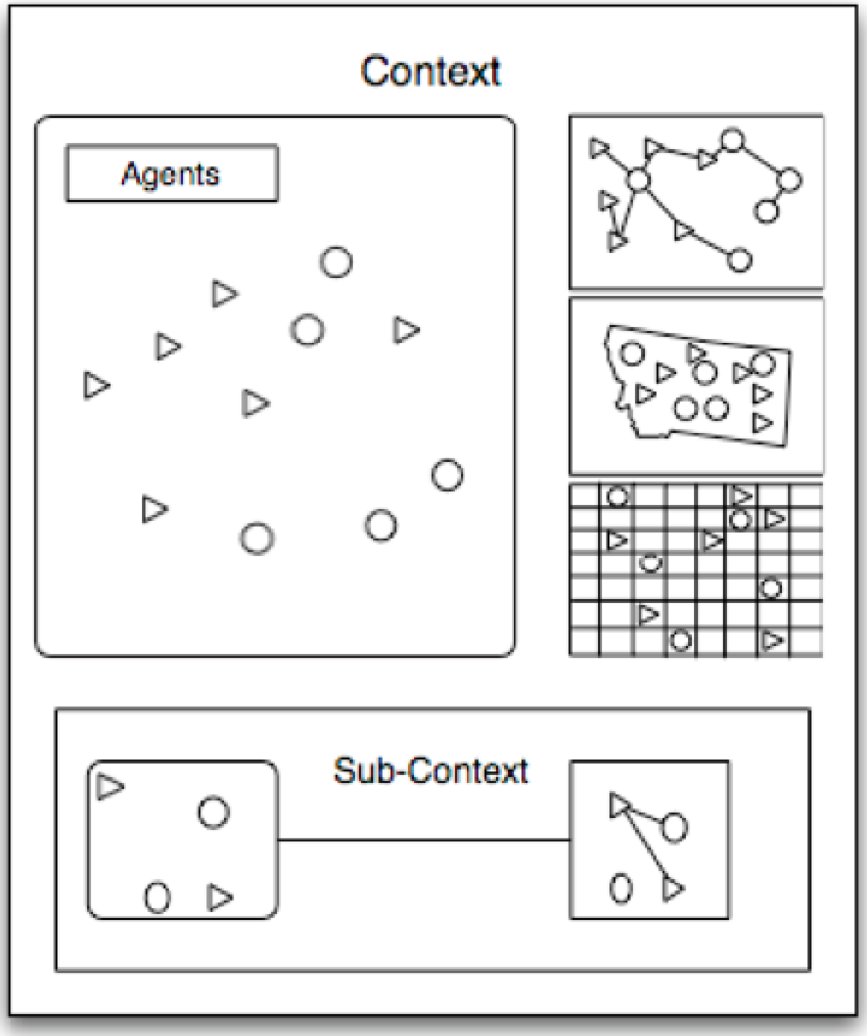


Figure 18. Context with agents, projections and a sub-context

Repast S does not have support direct asynchronous communication between agents, however it provides the feature of “Trigger” and “Watcher” which provide mean for indirect communications. An agent can watch for an event, triggered by a source, and react to it. Direct communication in repast is achieved via synchronous method calls. Repast S does not pose any known constraint on the behaviour model of the agent.

The original work of Shvartsman et al. (Shvartsman 2010) on which this thesis is based on , signifies the need and importance of context aware computing for dynamic environments of crisis scenario. Repast, with its concept of context and projection, provide a very good base for the context specific behaviour. In repast agents can move across contexts, and this move can impact their actions. It is different from “groups” in Madkit Platform (Gutknecht 2001), which is more of an organisational structure. Because of the importance of environment in this work, the support for environment was considered most preferable. Repast supports indirect communication using watchers and triggers, which is a useful feature to simulate exogenous events. Exogenous events are primary part of the environment that is being modelled. Repast has built in support for importing shapefiles, and many other library utilities for network and search, which can be of assistance in modelling the behaviour. Based on a preliminary review of the three platforms, MadKit, Repast Simphony and MASON (S. Luke 2013) – Repast Simphony was chosen for the work.

3.2 Simulation of Physical Environment by Repast Simphony

The focus on the environment in this work has been considered in the implementation of the environment model in repast. One of the best available realistic environments modelling currently available in repast is (Geographical information systems (GIS) data. Repast supports ESRI shapefile to import and use GIS Data. The project Repastcity3 (Repastcity 2012) has provided some valuable insight into various operation of Repast Simphony used in this work. A simple two-dimensional building environment is created using shapefiles for the system. The software used to create the environment is Quantum GIS v2.0.1 Dufour. The environment is as shown in Figure 19.

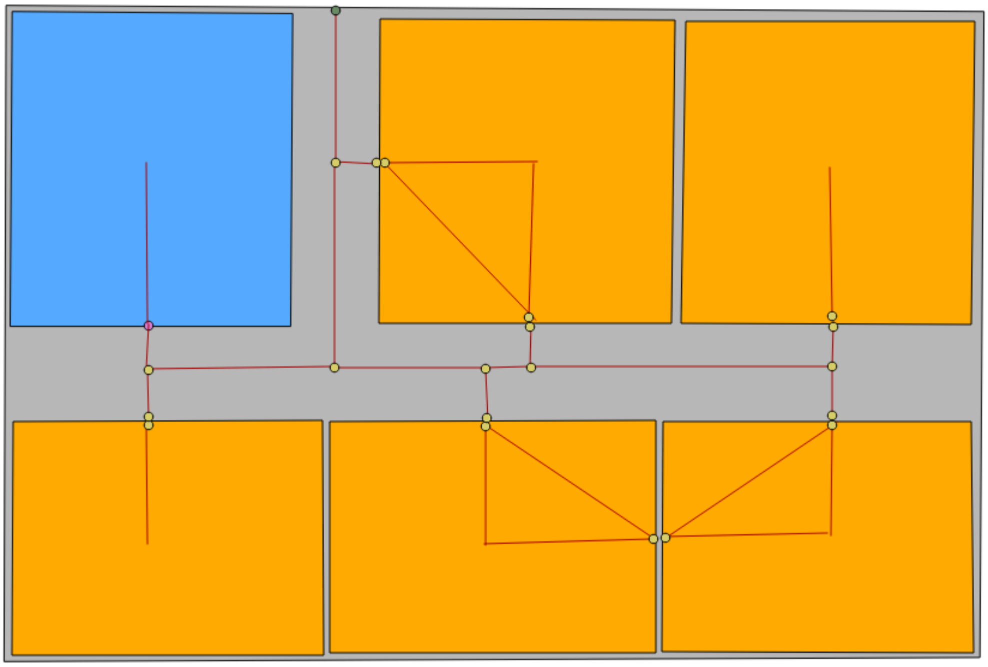


Figure 19. Building Shapefile

The shapefile on Figure 19 has eight layers of objects. The rooms are in orange colour and the safe room is in blue. The grey area is the corridor. The eight layers are for the following items:

- Building area – This is the grey building area, part of which is visible as the grey corridor.
- Rooms
- Safe Room
- Door – The doors are in pairs as light blue dots. The pairing allows the simulation of blocked doors where the route between the paired doors is not considered to find the paths.
- Safe room door
- Corridor – The corridor has multiple points which is used for navigation
- Routes – This layer is added to link the various points in the building which helps to create the route map.
- Gate – This is for the building gate.

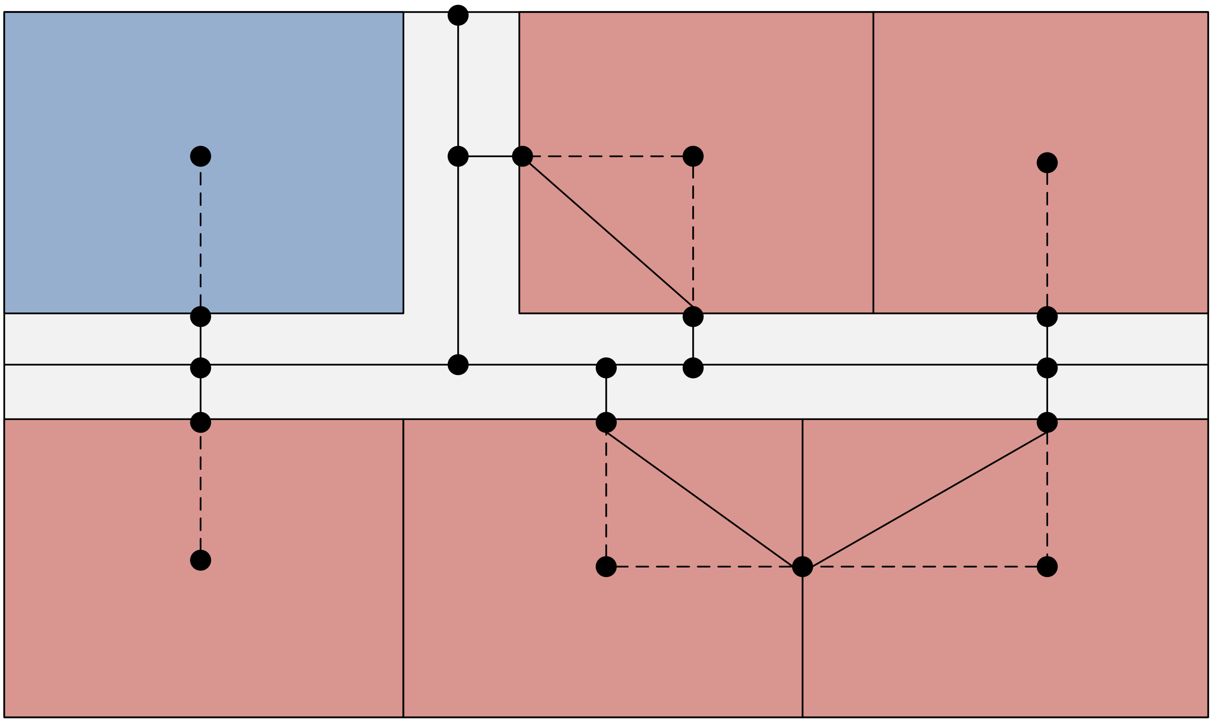
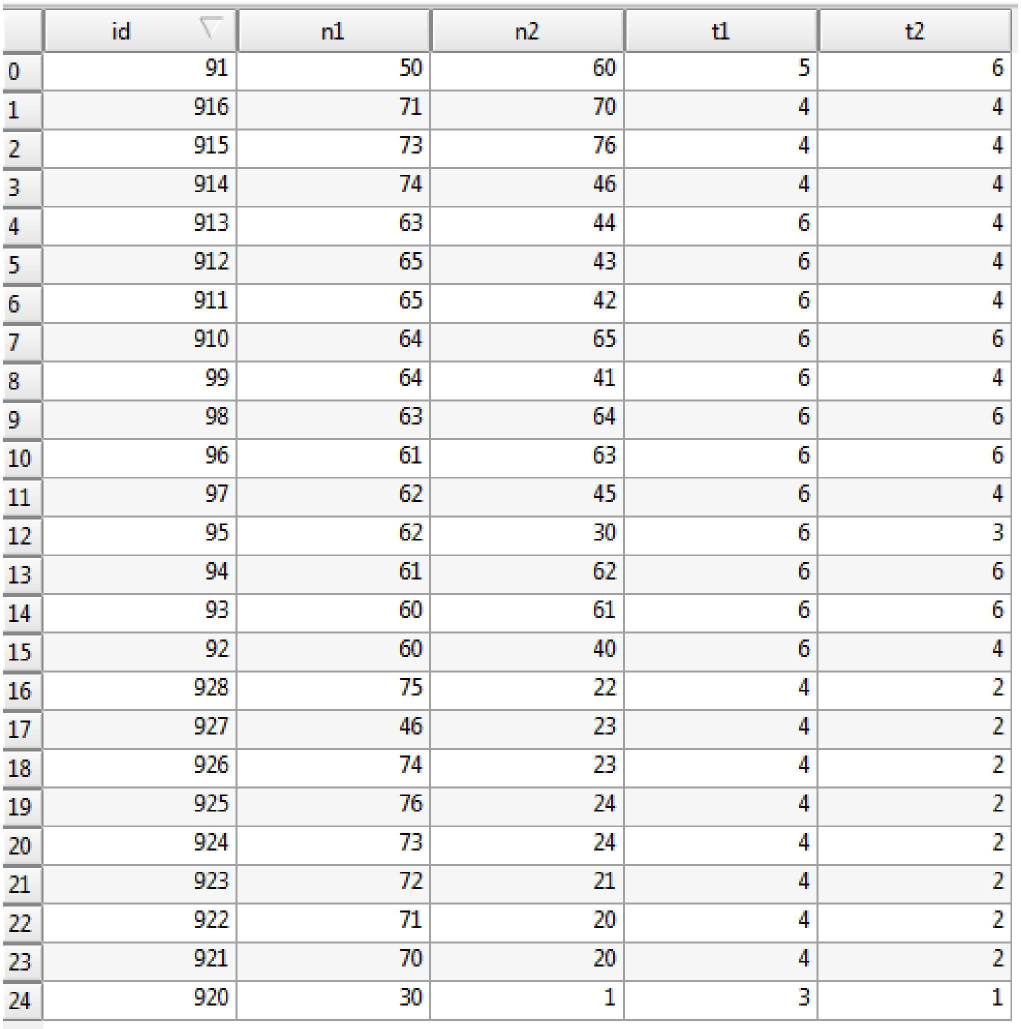


Figure 20. Routing Graph

In repast each layer of the shapefile is read to integrate to create objects of the environment. The building evacuation process involves search and navigation by the guard inside the building. This requires a route map for the task. There are various mapping methods for indoor spaces; however, creating an ideal evacuation scenario is not the objective of this exemplary scenario. Thus a detailed study of indoor space representation was not in the scope of the work. The work in paper by Goetz (Goetz, Using Crowdsourced Geodata for Agent-Based Indoor Evacuation Simulations 2012) has provided some valuable insight into the usage of a formal method – Weighted Indoor Route Graph (Goetz, Formal Definition of a User-adaptive and Length-optimal Routing Graph for Complex Indoor Environments 2011), to create routes in the indoor space.

The diagram on Figure 20 shows the application of the method. The navigation in the corridor in this method is along the central line, which connects to the doors from the point closest to the door on the central line. There are points inside the rooms, which are connected with dashed lines to signify that the dots inside the room are not created in the shapefile. They are the centroids of the room geometry, located using inbuilt feature of Repast. The doors represent paired door in this diagram with edges between them, however they are not relevant to be shown in the route map as they are considered to be of either zero weight (unblocked) or infinity (blocked).

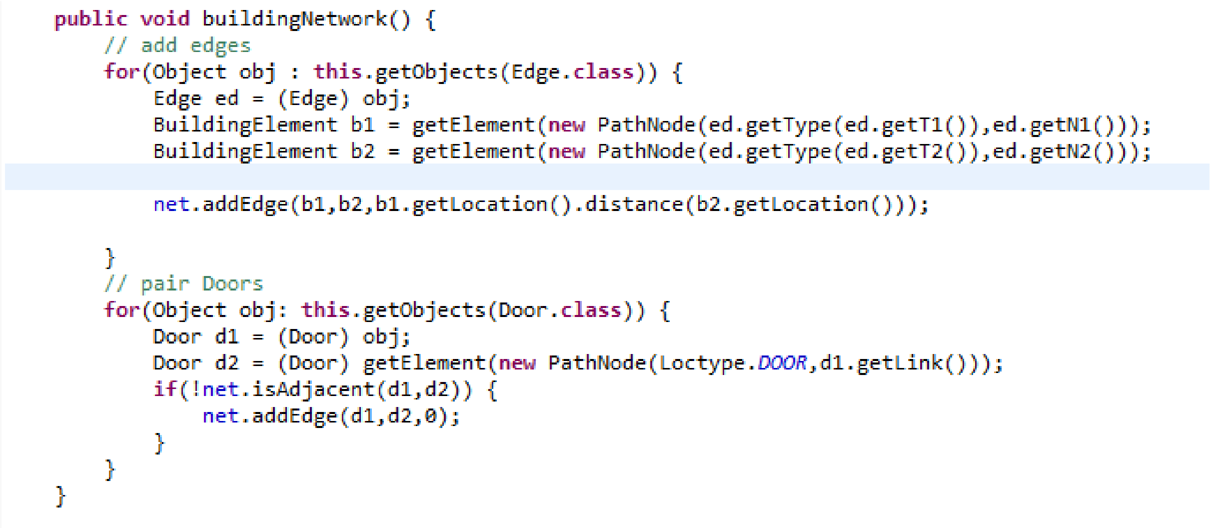


	id	n1	n2	t1	t2
0	91	50	60	5	6
1	916	71	70	4	4
2	915	73	76	4	4
3	914	74	46	4	4
4	913	63	44	6	4
5	912	65	43	6	4
6	911	65	42	6	4
7	910	64	65	6	6
8	99	64	41	6	4
9	98	63	64	6	6
10	96	61	63	6	6
11	97	62	45	6	4
12	95	62	30	6	3
13	94	61	62	6	6
14	93	60	61	6	6
15	92	60	40	6	4
16	928	75	22	4	2
17	927	46	23	4	2
18	926	74	23	4	2
19	925	76	24	4	2
20	924	73	24	4	2
21	923	72	21	4	2
22	922	71	20	4	2
23	921	70	20	4	2
24	920	30	1	3	1

Figure 21. Shapefile Edge attributes

In the application the environment knowledge was mostly stored in the shapefile itself. One of the objects of the work was to find means to distinguish the environment from the simulaton. Shapefile has the feature of storing attributes in the layers. This feature was used to store the entire connectivity map of the rooms, doors and other objects of the building.

Figure 21 shows a table of the layer of edges in the shapefile. Each edge has the property of N1, N2, T1, and T2. The Ns are the node identifiers, which the edge connects, and the Ts are the type of the nodes (Door, Room, Corridor, etc.). This data can be read by Repast and the route map is formed in the simulation environment, as knowledge. Figure 22 shows code snippet, which builds the network, based the data from the shapefile table in Figure 21. Repast has useful libraries support for network, as can be seen from the code “net” is a network projection in repast and it has support for network operations like adding, modifying edges.

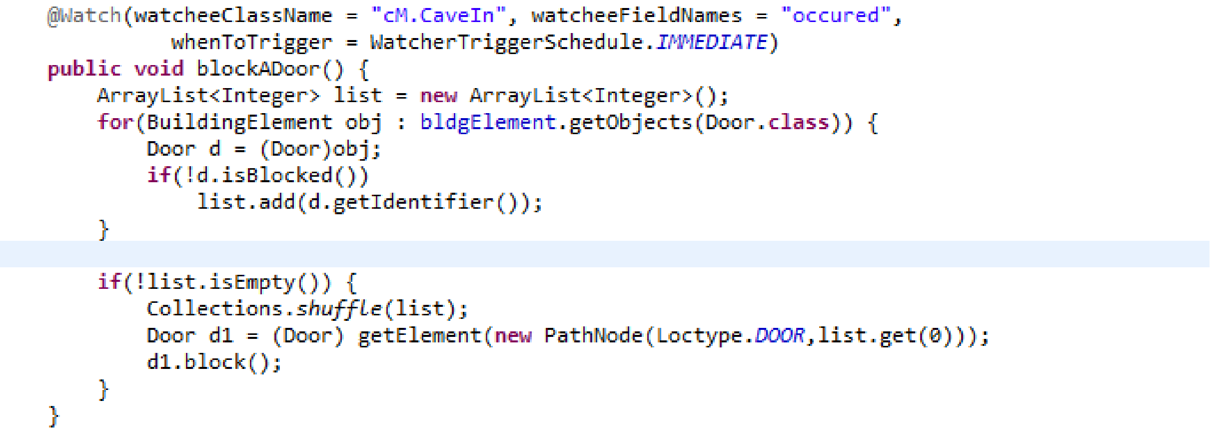


```
public void buildingNetwork() {
    // add edges
    for(Object obj : this.getObjects(Edge.class)) {
        Edge ed = (Edge) obj;
        BuildingElement b1 = getElement(new PathNode(ed.getType(ed.getT1()),ed.getN1()));
        BuildingElement b2 = getElement(new PathNode(ed.getType(ed.getT2()),ed.getN2()));

        net.addEdge(b1,b2,b1.getLocation().distance(b2.getLocation()));

    }
    // pair Doors
    for(Object obj: this.getObjects(Door.class)) {
        Door d1 = (Door) obj;
        Door d2 = (Door) getElement(new PathNode(Loctype.DOOR,d1.getLink()));
        if(!net.isAdjacent(d1,d2)) {
            net.addEdge(d1,d2,0);
        }
    }
}
```

Figure 22. Build Network



```
@Watch(watcheeClassName = "cM.CaveIn", watcheeFieldNames = "occured",
          whenToTrigger = WatcherTriggerSchedule.IMMEDIATE)
public void blockADoor() {
    ArrayList<Integer> list = new ArrayList<Integer>();
    for(BuildingElement obj : bldgElement.getObjects(Door.class)) {
        Door d = (Door)obj;
        if(!d.isBlocked())
            list.add(d.getIdentifier());
    }

    if(!list.isEmpty()) {
        Collections.shuffle(list);
        Door d1 = (Door) getElement(new PathNode(Loctype.DOOR,list.get(0)));
        d1.block();
    }
}
```

Figure 23. Door block trigger

Another feature about the environment as discussed before are exogenous events. In out program it is “Cave-in” which blocks the door. Figure 23 shows the code where the Repast “watch” and “Trigger” features are used to implement cave-in events.

4. Conclusion

The objective of the work was to develop a highly simplified exemplary scenario of urban operation as an initial development of an urban operation simulation with the focus on environment. A second objective was the preliminary comparative study of two popular industry standards for the representation of physical environment to find the one suitable for the urban operation scenario.

As directed by the objective an exemplary building evacuation operation scenario was modelled using agent oriented modelling. Based on that model a simulation was developed on an agent-based platform called Repast.

In the course of the thesis two industry specifications for environment representation - CityGML and IFC were selected for comparative study in terms of their suitability to be used as the environment data for the urban operation environment.

Based on the work done as part of the thesis, some key points are concluded. Firstly, agent oriented modelling using viewpoint framework provided a clear picture of the dynamics of the simulation as it was able to handle the complexity by capturing the various aspects of the view point framework. The models with their structured approach simplified the complex operations and more importantly exposed the areas where there was lack of clarity in the specification from the three aspects of interaction, information and behaviour.

Secondly, the development of Repast Simphony provided support for environment modelling using contexts and projections, thus reducing the development complexity. It provides library support for various functions including networks and geospatial operation. The feature of Repast for importing shapefiles was instrumental for integrating the environment data. The development experience concludes that the complexity of the simulation can be handled with repast, thus it can be used to implement more advanced scenarios.

Thirdly, the preliminary comparative study of the two specifications for environment representations found CityGML to be more suitable for this purpose.

Additionally an interesting correlation was observed between the agent execution cycle code in repast and the behaviour model for the GuardAgent. This correlation in between the activities in the agent oriented behaviour model and the code blocks in the agent execution cycle may be a subject of further exploration in future.

The prototype developed in this thesis can be used in future to integrate CityGML models as the environment. As part of the study a java framework has been found - cityGML4j, this can read and interpret CityGML files.

As a future work a simple CityGML building model will be imported into the repast simulation using cityGML4j library to test the feasibility of an advance environment representation in the simulation developed in this work.

Resümee

Füüsilise keskkonna modelleerimine ja simulatsioon kriisihalduse treeningstsenaariumite jaoks

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Käesolev töö põhineb Tallinna Tehnikaülikoolis tehtud uurimistööl agentorienteeritud süsteemide välja töötamise kohta linnatingimustes toimuvate operatsioonide õppestsenaariumite simuleerimiseks. Linnatingimustes toimuvate operatsioonide all mõeldakse kõiki tegevusi, mida kavandatakse ja viiakse läbi sõjaliste operatsioonide raames olukorras, kus ülesande täitmine toimub maastikul, kus domineerivad inimese poolt ehitatud rajatised ja operatsioonis mitteosalejad. Uurimistöös jõutakse järeldusele, et agentorienteeritud modelleerimisel on potentsiaali aidata lahendada linnakeskkonna dünaamilisest olemusest tulenevaid probleeme realistlike stsenaariumite kavandamisel eesmärgiga simuleerida linnatingimustes toimuvaid operatsioone. Uurimistöö teeb ettepaneku realistlike treeningstsenaariumite arendamiseks inimkäitumise adekvaatse modelleerimise suunas kasutades agentorienteeritud käitumismudeleid. Niisugustes treeningstsenaariumites võib tarkvaraagendi asendada reaalse mängijaga. Käesolev uurimistöö arendab seda eesmärki edasi, rakendades linnatingimustes toimuva operatsiooni ülilihtsustatud näidisstsenaariumit, kasutades selleks olemasolevat agendipõhist modelleerimistööriista Repast Simphony. See süsteem simuleerib lihtsat hoonest evakueerimise stsenaariumit. Selle stsenaariumi mõnede põhiomaduste aluseks on raamtöös kasutatud linnatingimustes toimuva operatsiooni stsenaarium. Rakendus põhineb platvormist sõltumatutel mudelitel, mis on välja töötatud raamtöö suuniste alusel.

Selles simulatsioonis keskendutakse peamiselt linnakeskkonnale. Näidisstsenaarium simuleerib lihtsustatud kujul hoonest evakueerimise operatsiooni. Hoonete keskkonna modelleerimiseks kasutatakse siseruumide modelleerimise formaalset meetodit, mida nimetatakse kaalutud siseruumide graafikaks (Weighed Indoor Routing Graph). Selles töös kirjeldatakse ka kahte ontoloogiat – IFC ja CityGML, mis toetavad linnamudelite

simuleerimist. Eesmärgiks on uurida võimalusi kasutada tööstuslikult valmistatud ontoloogiaid keskkondade modelleerimiseks agendipõhisel simuleerimisel. Tuginedes nende kahe ontoloogia varem läbi viidud võrdlusuuringutele leiti, et keskkonna modelleerimiseks agendipõhisel linnatingimustes toimuva operatsiooni simuleerimiseks sobib paremini CityGML.

Selle uurimistöö täiendamine tulevikus hõlmab esimese kohese sammuna lihtsa ehitusmudeli kasutamist CityGML-s, et luua selle töö jaoks välja töötatud rakenduse keskkonna prototüüp, mis annab ülevaate tehnilistest teguritest, mis on seotud ontoloogia integreerimisega süsteemi. Käesoleva töö edasiarendus võib viia realistlike simulatsioonide arendamisele treeningstsenaariumite jaoks kasutades cityGML mudeleid.

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