Analysis and Design of Multi-Level Virtual Indoor Environment

Abstract. Researches in crowd simulation tend to study systems which are more and more complex, large and realistic. Several models are using multi-agent based simulation in which agents are modeling pedestrians. In this case the system's environment is a key concept which represents and manages the virtual world in which the agents are living. This paper proposes the definition of a multi-level environment model via ASPECS methodology. This proposed environmental model is illustrated by example on an airport case study.

Keywords. Multi-level environment model; System of systems: architectures, methodology, applications; Requirements elicitation and analysis of computer-based systems; Application methodology for meta-model analyze; semantic webs, ontology in distributed automation.

1. Introduction

In microscopic crowd simulation, computational times are very high. In one hand this high cost is explained by a complex treatment of behavior's entities. In the other hand it is due to environments more and more complex. For more realistic simulation, environment uses an accurate representation with a large set of entities, which increases treatment time for the various environmental tasks.

Computational time on the simulation of entities' behavior is decreased by several research works. But, treatments of environmental tasks are few studied, whereas them become more and more costly. Multi-level simulation is a solution to find a compromise between resources used for the simulation and its precision. To conceive such a multi-level environment, the software engineering process ASPECS [2][1] is used.

This paper describes an approach based on a multi-level environmental model. Interactions with agent model are based on IRM4S [9]. IRM4S consists in decoupling environment and agents. Agents interact with the environment through perceptions and influences. Perceptions given by the environment are used by agents then they compute the influences and transmit them to environment. Influences are actions that agents would realize in the environment. These can be modified by the environment following a set of laws and other interaction constraints implemented in the system.

In this paper, after related work presentation, a definition of a multi-level environment meta-model is proposed in following the first step of ASPECS. Finally, strong and weak points of our model and perspectives are exposed.

[1] ASPECS: "Agent-oriented Software Process for Engineering Complex Systems (http://www.aspecs.org)"

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2. Related work

2.1. Overview on environment according to level of simulation

There is a wide range of crowd simulation models based on various levels. Four types of models are defined according to three levels of simulatio,n and one on multi-level.

Macroscopic models [7] are most often used to simulate a large set of entities. These models, defined by dynamic equations, allow the representation of very large sets of entities. Microscopic models are used for more realistic simulations. They allow to model endogenous and exogenous interactions. Such interactions might cause radical changes in the flow model. Generally, there are models based on cellular automata [8], particuls models [12], Boids [10] or multiagent systems (MAS) [9]. Mesoscopic models are used to find a better trade-off between accuracy and computational time in the simulation [6]. They may model a large set of entities in real time with groups of simulated entities. Finally, multi-levels models define a set of predefined levels of representation: from two levels [1] to a higher predefined range of levels [5].

Our flat environment model is a microscopic simulation model and simulates individual entities. Mesoscopic level consists in grouping entities and this aspects may appear in our multi-level environment model. Mesoscopic and microscopic levels have many levels of representation. In the case of mesoscopic level the size of group allows to define approximatively the level. For microscopic level, actions and perceptions are applied on one entity, but with more or less simplification following a level of representation.

2.2. ASPECS *methodology*

ASPECS engineering process is used to design our multi-level environment[2] model. It is based on CRIO[3] meta-model [11]. CRIO permits to describe multi-agent systems according to organizational concepts. ASPECS process is composed of three stages: (i) system requirements analysis, (ii) agent society design, and (iii) implementation and deployment.
This paper focus on the first one. The following section describes our environment model according to the ASPECS's system requirements analysis and these diagrams.

3. Environment model

The multi-level model of environment proposed in this paper is extending the flat model JASIM [4]. The main contribution is the introduction of simulation levels for representation of the environment, and its execution. Further, concept of Meta-entity is added and is necessary to use multi-level simulation. During each step of ASPECS, we demonstrate by some examples on the multi-level simulation in an airport environment.

Our goal is to design an environment's multi-level model. It may represent and manage the same environmental tasks as defined in JASIM, but in a multi-level way. More precisely, two types of multi-level approaches are encountered and supported by our model. In one hand a multi-level hierarchical model may be used to represent environment structure. For example, an airport's entity contains a set of halls, which contain in turn seats, etc. In the other hand a multi-level model may be used to execute environmental tasks. Indeed an en-

[2] *Multi-level environment* is named environment in the rest of paper.
[3] CRIO: Capacity Role Interaction Organization

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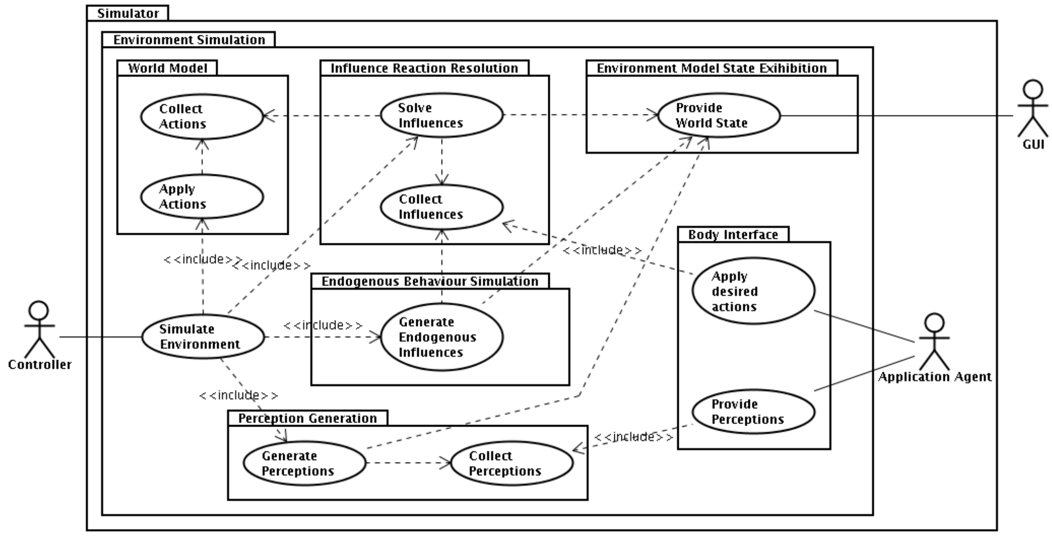

Figure 1. Use case diagram of the multi-level environment simulation with identification of organization.

vironmental task — perception generation or action application for example — may uses different algorithms according to one or more desired precision levels. These levels depend on agent's configurations and internal management policies of the environment. A microscopic simulation requires that tasks are executed on the finest available level of representation. Multi-level simulation makes a compromise between level of representation and available computational resources. This compromise may be defined by user according to computer's resources and simulation accuracy requirement with a given tolerance.

3.1. Definition of requirement domains

Figure 1 shows a use case diagram composed by eleven use cases and three actors. Controller allows to run and control the simulation with basic commands, like play, pause and stop. GUI is a graphic user interface to show the simulation. Application agent defines behavior of an agent in simulation and interacts with environment influence and perception pipelines. At this level of representation, the use case stays the same for mono- or multi-level simulation. There are three collectors. Influence and perception collectors allow to synchronize agents and environment. Action collector exists to synchronize the resolution of influence conflicts and update of internal data structures. Organization is explained in section 3.3 during organization identification. The second step of ASPECS consists to define the problem ontology with a class diagram.

3.2. Problem ontology description

Figure 2 shows the main concepts of an environment and their tasks. Four of them are inheriting from World Manager. They all use a policy to select the best simulation level according to the evaluation of resource costs. *Perception generator* generates perceptions for each agent or group of agents. *Endogenous engine* allows to simulate endogenous interactions, like fire propagation or kinematic, on many levels. *Influence solver* recovers all influences and solves conflicts by transforming them into actions. *World updater* updates all structures according

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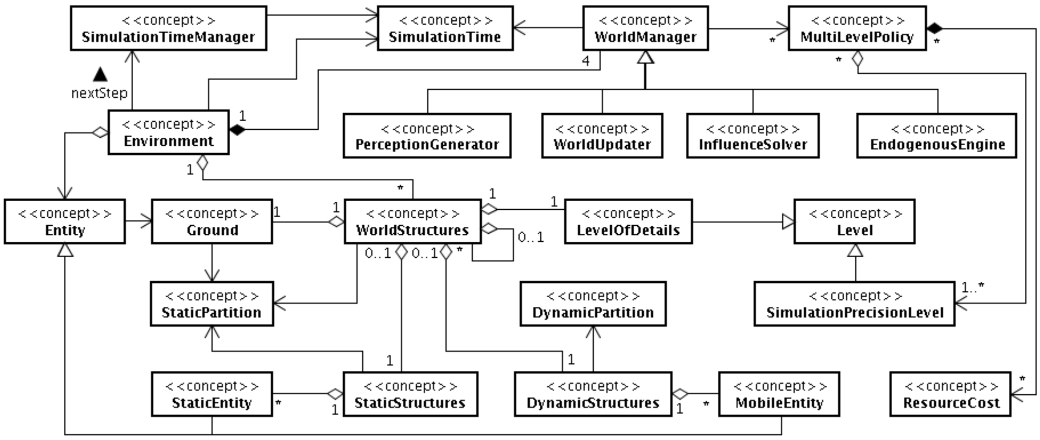

Figure 2. General ontology concepts of multi-level environment.

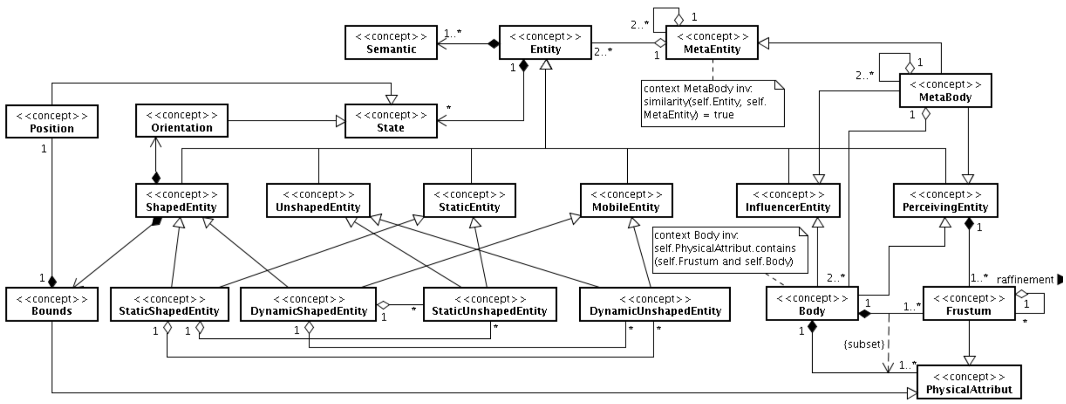

Figure 3. Ontology concepts of multi-level environment on entity part.

to generated actions.

Hierarchical representation of situated environment structure is inspired by [3] and [13]. Top levels are decomposed by static and predefined partitions. At lower levels, static and dynamic entities are put inside two specific sub-structures respectively. Each level may be associated with entities. Entities in top levels are indestructible spatial entities, which contain a set of entities. For example, an airport contains static halls (in a static structure), which contain dynamic pedestrian groups (in a dynamic sub-structure) and seats (in a static sub-structure).

The set of entities are the core of environment, see figure 3. Our model introduces the concepts of 'shaped' and 'unshaped' entities. A shaped entity is a solid object with a single physical representation in the environment. This representation is localized and have bounding volume. In the opposite, an unshaped entity is an object without physical and shaped representation, such as fluid, gas, or wave. A complex entity may be shaped or not and may

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be static or dynamic following case study requirements. More the entities are complex, more the cost of simulation is important.

Classifications of entities according to type of perceptions, type of influences and semantics are necessary to manage an environment. This classification is used to group entities with close perception and it allows the generation various multi-level perceptions. A multi-level perception[4] is a perception used by individual entity. Perception generator generates all perceptions for a group of entities, so that several of them may have the same perceptions.

Group separation and merging are effectuated according to a similarity between group members. This similarity represents distances of size, position, orientation and set of semantics between group members and overall group. This hierarchy according to a similarity value is named meta-entity. These meta-entities are composed to set of entities or meta-entities with a simplification of associated elements, like their shape. For example, an airport have a specific shape and contains two halls meta-entities with a specific shape for each. In fact, the association of hall shapes corresponds to airport shape with more precision. Another elements like fire can appears in all airport, but at a sub-level it can appear only in one hall, etc.

These class diagrams represent a summary of ontology. Actions present in complete ontology are the tasks of management and the build of data structure for initialization. They use a level of simulation follow a configuration defined by user. Each action of management run in function of them goals and an action may be decomposed between many parts according to type of treated entities.

3.3. Organization identification

Figure 1 shows organizations on the use case diagram. Simulator is the main organization, which includes agent and environment models and each one is represented by an organization. GUI and controller actors stay out of the simulator. Environment simulation organizations are the four main features of an environment from JaSIM [4]. In addition, environment model state exhibition is introduced as a new organization and managed relation-ship with external programs (GUI...). Environment simulation organization centralizes environmental tasks via these sub-organizations.

3.4. Interactions and roles identification

Figure 4 identifies roles and interactions in environment simulation, world model and body interface organizations. Environment simulation manages various tasks. It provides a graphic representation of world model. It manages influence and perception pipelines. It has a perception provider and an influence collector for application agents. It generates perceptions for all agents. Influence reaction manager generates endogenous influences, solves conflicts between influences and creates actions updating data structures.

Body interface creates the link between agent model and the situated environment. It allows to transform influences of agent model in multi-level influences and multi-level perceptions (generated by environment) in perceptions fit to agent model. A multi-level influence[5] is an influence for a set of entities. Body interface creates and updates meta-bodies

[4] *Multi-level perception* is named perception in the rest of paper.
[5] *Multi-level influence* is named influence in the rest of paper.

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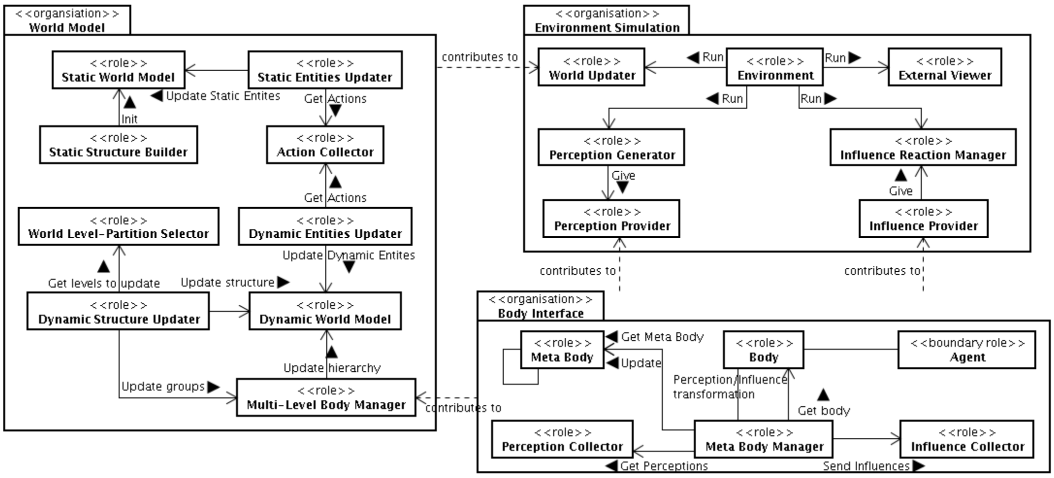

Figure 4. Identification of roles and interactions in some organizations.

via world model organization. Meta-bodies (cf. meta-entity) represent a hierarchy of agent bodies. These meta-bodies are created with new perception parameters according to those of associated bodies and meta-bodies. They represent a classification of body in a hierarchical structure to run multi-level simulation. Meta-body perception is a multi-level perception and meta-body influence is a multi-level influence.

World model has static and dynamic sub-model. The static sub-model contains all immobile entities, but their states may be modified. The dynamic sub-model is more complex and contains all mobile entities. It uses adequate data structures which may adapt partitions according to entity's positions and internal policies — see JASIM [4] for more details. Further, world model is a hierarchy, so, partitioning is effectuated only when it is necessary (high levels may be rarely partitioning).

Other organizations like endogenous behavior simulation, influence reaction resolution and perception generation need a selector of simulation level to estimate the level on each partition of data structures.

3.5. Scenario description

In this part, only one scenario is presented. The scenario of environment simulation, for one step of simulation, consists to apply each role in the following order : (i) generation of perceptions which is applying to the send perceptions to agent bodies, (ii) sending world model state to external graphic viewer, (iii) receiving influences from agent model, and (iv) generation of endogenous influences and resolution of all and finally updating of data structures. The add of multi-level consist to transform task in multi-level.

Perception generator is an important part. It is taking time and consuming a large part of computational resources during simulation. Figure 5 shows the scenario description of perception generator. It requests perception parameters to all meta-bodies, such as frustums. It estimates the best simulation level for perception generation according to resources and configuration of the simulation. This estimation allows to select an approximate set of perceptions to be generated. In fact, it selects a set of meta-bodies and generates associated perceptions. It uses this estimation to quickly converge during the generation. Multi-level

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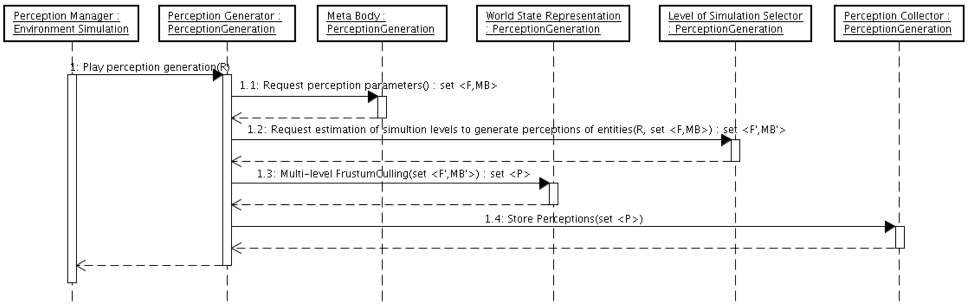

Figure 5. Sequence diagram of scenario description on perception generator.

model is dynamic, so, this generation stays dynamic and depends on available resources and a given tolerance. This tolerance is represented by a percentage of added bias, which is computed according to wish of user and available resources. When resources are decreasing during simulation precision on generated perceptions is going down proportionally. Finally, it stores the set of generated perceptions associated to meta-bodies for agent's usage.

For example, 10000 perceptions are generated during one step of simulation, but available resources are not sufficient and the user is wishing real-time simulation. Perceptions for 3000 pedestrians will be at microscopic level and 7000 pedestrians may have mesoscopic perceptions according to groups of meta-bodies. In others words, 1000 perceptions are computed for 1000 meta-bodies and distributed on 7000 associated pedestrian bodies.

3.6. Role Plan

This part describes planning of each organization. It generalizes scenario descriptions in an activity diagram. Firstly, initialization is realized by building data structures and entity hierarchies. Secondly, planning consists to design one step of simulation. This step follows the order defines in part 3.5. Associated activity diagrams of role plans show sets of activities during the simulation. They allow to know various interaction between roles in the same organization and planning of simulation. Interactions are defined in before subsection and the planning is quickly described in part 3.5.

3.7. Capacity Identification

Capacity identification generalizes the goals of each role, which are necessary to conceive model in keeping a coherence with other organizations. In fact, a role may be implemented by various way, so, it is necessary to determinate their inputs and requirements. The major capacities required by environment simulation organization are the update of world model, generation of perceptions, creation of influences, resolution of influences and communication with agent model via influence/reaction pipelines.

4. Conclusion

In this paper an ontology of a multi-level situated environment is proposed to allow indoor simulations. All the roles, interactions and functions necessary to provide efficient and accu-

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rate perception to agents are explained. Agent actions are also treated and supported via an influence-reaction approach. This paper mainly focus on multi-level simulation and related concepts.
Our model may simulate one or more levels in the same time. It is costly in simulation times when all elements are simulated at all levels, but we assume that it allows to have simulation more realistic. It can have high performance in simulating at one mesoscopic level and it keeps equivalent performances at microscopic level than many models from literature. We search to find the best solution to model our meta-model. Recursive agents feel be a good choice to represent hierarchy in environment and manage various tasks in multi-level.

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