Infrastructure Design with Multiagent Systems and Virtual Reality Application to the PSA site

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Abstract

This document presents the works carried out to ensure the immersion of a multiagent system in a virtual environment. The researches undertaken within the framework of this work have been allowed the development of tools dedicated to the simulation and th study of factory area, which are generally in perpetual evolution. This set of tools makes it possible to study various flows circulating on these sites and to highlight the problems which it generate. They offer solutions to refit an existing site in an optimal way or for a preliminary study to the establishment of new infrastructures. These tools provide a study of flows as well as a validation of dimensioning and accessibility of the various industrial infrastructures, this as well under normal conditions of operation as under particular conditions such as the rush hours or the situation of panic (fire, accident. . .). Simulation offers also the advantage of being able to integrate into the models, and to evaluate the impact and the perspicacity of future evolutions of the infrastructures. After a short presentation of the theoritical subjacent models, this paper focus on the first application of these works on the study of the industrial site of PSA Sochaux, one the major french automobile manufacturer.

Keywords: Virtual Reality, Multiagent Systems, Design, Automotive Manufacturer

1 Introduction

In one hand, the virtual reality (VR) could be considered as an new effective environment for the multiagent systems (MAS). Indeed VR is a technology allowing the immersion of a human in a virtual world. It also provides natural and ergonomical interaction's ways to the users, and is an elegant mean to populate virtual worlds with entities exhibiting realistic behaviors (humans, animats...).

In another hand, multiagent-based simulation (MABS) in virtual reality offers tools to answer to several application's domain problems. First of all, the validation - synchronously or asynchronously - of the structural models of an urban environment could be done by an user via his virtual representation, e.g. his avatar (see section 3.2.1, page 5). This checking includes geometrical and spatial coherencies, the adequacy of road signs, and the accessibility of infrastructures. Another kind of interesting usage is the highlighting and the study of emergent behaviors of the real users. The immersion of them could also be used to validate the realism of the model.

This paper focus on one of the first application of these approach: the study of the industrial site of PSA Sochaux - one the major French automobile manufacturer. Greater than 250 hectares, this site is in perpetual evolution: infrastructure modifications, road system adaptations... By the addition of a manufacture's virtual model and a MAS, we are able to simulate day-to-day logistical flows in a realtime and continuous way. This application allows an immersive and real time evaluation of architectural and infrastructural modifications impacts. The bottlenecks could thus be detected earlier than the design stage.

The implementation of this study case lifts three major problems:

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- the immersion of a standard multiagent system inside a virtual environment;
- the guarantee of realistic behaviors for the entities populated the virtual environment;
- the interaction between the users and the virtual world, i.e. with objects or agents.

In this article, for each of these problems, we propose models and experimental results. Moreover we mainly focus on the real application simulation of the PSA site, including 3d modeling and user interface for navigation.

2 Context and Applications

Our problematic is bipolar : the virtual reality and the multiagent systems. A multiagent system is composed by artificial agents. Each of them refers to a software or a physical artefact which must be autonomous, i.e. operationally and informationally closed to its environment [48]. For [2] an agent is an entity which perceives its environment with its sensors and acts on it with its effectors. It must be autonomous (acting without external driving), reactive (ability to respond to external events), goal-driven, situated inside an environment.
The multiagent systems permit to model the behaviors of the agents and the interactions between them. The virtual reality offers mechanisms for the realtime realistical rendering and means for the humans to interact.
This duality of the problematic can also be found in others application domains using MAS inside VR environments:

- virtual teaching [3] with a virtual agent such as Steeve [37, 17],
- scientifical simulation: SIAMES[1], OpenMask[2], ethological emergent phenomena's study [7],
- virtual prototyping [44, 18],
- special effects for the cinema industry or for the video games [36],
- tele-operation [50, 12, 28],
- automatical scenarii building for virtual world [33, 4],
- urban simulation [29, 46, 45, 56, 30, 31, 32, 49, 52, 51].

All there applications have a common point of view: the virtual reality permits to an human to interact with a logical model of a system. It is the starting point of a new generation of user-interfaces which present the information in natural and sometime ludical ways. Multiagent systems are really well adapted to evolve in a virtual environment (VE), not only thanks to their intrinsic characteristics such as autonomy and situation but also because they are computationally efficient, robust, safety, flexible and lower computational costly for large-scale simulation [1].

3 Contributions

In this section we explain the problems which we want to tackle. For each of them a model is proposed and briefly discussed. Our works are on the scope of two issues: the settlement of a virtual world and the interaction between a human and the entities populated this virtual world.

3.1 Settlement of Virtual Environments

3.1.1 Perception Architectures

As introduced by THALMANN, virtual sensors constitute a key tool to implement perception for virtual agents [43]. These agents could be equipped with visual, auditory and eventually tactile sensors. These sensors are at the base of the behaviors of all the agents of the simulation.

[1] http://www.irisa.fr
[2] http://www.openmask.org

Visual Perception To evolve in a virtual world and exhibit high level behaviors, an agent requires several semantical, symbolical and topological data about its environments. To assure these behaviors virtual worlds should integrate these informations in addition to the geometry. Perception is thus a problem in the intersection between the domains of the virtual environment's modeling and the design of architectures for virtual sensors. We argue that vision problems couldn't be solved without the use of an adapted environment model.

The principles of synthetic vision is to simulate the biological vision organs. All these methods work towards a common end : allowing a visual perception for autonomous entities in virtual environment. They are mostly inspired from the 3d-rendering techniques. The first synthetic vision system was introduced by RENAULT et al. [35]. Many works succeeded them since for in particular trying to adapt the synthetic vision to the constraints of virtual reality [47, 42, 26, 22].

WEN et al. presented an adaptation of [35] in which an octree[3] was used to assure the hierarchical scene decomposition [53]. The synthetic vision is thus reduced to a simple intersection test between the agent's view frustum and the object's AABB[4]. But this system is still incompatible with the simulation involving a great number of agents : they spend too much computational time [24].

We have avoided this incompatibility using a synthetic vision method associated to an adapted environment model. Our environment model is inspired from the Informed Environment developped by FARENC et al. [10] and VUEMS presented by DONIKIAN [6]. We define the virtual environment for a multiagent system as an multi-layers architecture (see fig. 2, page 10):

- *3d database*: this level is considered as a database of all the objects into the scene. In most of the case, this database is only used by the rendering engine during the simulation.
- *Metric Environment*: this is the lowest level into the MAS and the highest level into the 3d. Indeed it structures the 3d information into dedicated spatial data trees which could be easily used by the agents, or called by the higher environment layers. The metric environment could be mostly generated prior to the simulation starting.
- *Linear-Graph Environment*: this is an example of high level environment. It defines the space as a set of edges and nodes. Each of them are associated to an surface, i.e. an edge could be associated with a road, a node with a crossroad.
- *Homotopic Environments*: there environments act as layers between a lower and an higher environments.
- *Semantical Environment*: this is a transversal level in which all the object's semantics are specified. It could be based on a simple object-oriented typing or on an urban ontology. Each object from the other environments point to one or more concepts from this level.

Because the metric environment must be designed to assure the fast visual perception for a great number of agents, we focus on it (see fig. 3, page 10). In this environment, the entities have been classified into two categories : immovable (or static) and mobile (or dynamic). For the agents, in terms of geometry, only the bounding boxes of the 3d-objects are really required. We store environmental entities inside adapted spatial data structures inspired from the dynamic AABB tree presented by SHAGAM [38]. The vision process on these structures is reduced to a simple 2d-frustum and occlusion culling. The frustum surface associated to the agent's point of view, is successively tested against the AABB of each node to determine fully and partially visible objects. Then we use a simple occlusion culling algorithm (Z-buffer equivalent) to assure the exact object visibility. The semantic of each perceived object is then extracted from the semantical environment and returned to the requiring agent.

Auditive Perception Another key point for designing believable agents is to allow them to perceive sounds inside their environment.

In parallel to the visual perception architecture, two models for imobile- and mobile-sound sources are developed. These sources emit signals transporting specifical semantics. Each signal is propagated inside a particular spatial envelope.

Some works already focussed on the simulation of the sound physics [43, 27, 5]. But they are still difficult and computationally costly to implement, especially for realtime sound sources. The development of a

[3] a classical spatial data structure used in 3d-rendering. It's a tree to index three dimensions where each node has either eight children or no children.

[4] Axis Aligned Bounding Boxes.

simple model is suggested by us. It is designed to respect the realtime constraints, and enough realistic to not introduce a bias into the simulation results.
The application of a sound perception model could be applied to the simulation of blind men or badly-sighted people, or to the simulation of building-evacuation scenarios without any ambient or spot light.

3.1.2 Behavioral Definitions

The definition of efficient perceptual mechanisms is not sufficient for a multiagent system to properly respond to a problem. Indeed it is necessary to the agents to exhibit realistical behaviors for an external observer. Two major approaches focus on the modeling and the simulation of the agent's behaviors : deliberative agents (or cognitive agents) and the reactive agents [39, 11, 55, 15].
The deliberative agents have the essential property to choose the next action they must realise. This choice is based on internal critera (perceptions, mental state...) and could be very simple (such as a stochastic choice) or based on more complex theories (social or acts of language theories...). For instance the agents could exhibit a Believe-Desir-Intension architecture [54, 34, 25]. With it, an agent has a set of goals and computes several action plans to rich them - eventually by initiating communications with other agents to ask some kind of help on the task realization. Several other works aim to use natural human communication channels to allow the agents to interact with their environment [37, 8], or use ontologies as conceptual and vocabulary basis between the agents [21, 9]. But all their approaches need computational resources which is proportional to the cognitive architecture or to the ontologie complexity for instance. In most of the cases, the cognitive agents are not compatible with large-scale realtime systems.
The property of large quantity of agents is, from our point of view, one of the major characteristics of a multiagent system immersed in a virtual environment. To support this constraint, we propose to use reactive agents with simple or instinctive behaviors. This approach will permit to develop more complex agents, i.e. cognitive agent based on reactives behaviors such as spatial moves. This last is indeed one of the major problem of situated agents. [36] proposes to use potential-fields for the simulation of flocks. [20, 16, 24] propose models for the simulation of crowds. Several works on the mobile robotics and on the usability of multiagent systems to drive autonomous robots use the potential-field approaches too. They associate to each object of the system repulsive or attractive vectors. The moving decision is simply the addition of all the vectors inside the influence area of the agent. This reactive approach has already proved its computatonial efficience and its realism in most of the cases [40]. But several spatial configurations are not truly supported and generate blocking or infinite-loop situations (see fig. 1 page 10 - cul-de-sac...). To solve this problem, [40] introduces an indicator which express if a agent was satisfied or not by the status of its task. Comparing the different agent's satisfactions permits to determine the most unsatified agent. Then all the other agents inside the influence area of this agent switch to an altruism behavior which inhibit the agent's tasks in profit to the unsatisfy agent.
This model of reactive agent initially proposed for autonomous robots has successfully transposed to virtual agents. Inded, this model is only dependent of the perception mechanisms which are already developed for VE. Moreover SIMONIN indicates that, if the perception method respects the realtime constraint, then the satisfaction-altruism model is also compliant with this contraint, i.e. the model satisfaction-altruism is a compatible model with a virtual reality environment [40].
Several approaches aim to move a part of the intelligence from the agents to the environment [10]. This is due to the fact that the environment objects contain their attributes but also the means to interact with them. In such way [19] propose the concept of Smart Object. The agents could not have any knowledge about how an object must work. They only store the mean to interact through a generic interface. We translate this approach into a more holonic point of view[5] [14]. This "agentification" of the environment permits to develop more complex and large models without any restrive constraint on the agent's architectures.

3.1.3 Immersing a MAS into a VE

Modeling of the VE On the user level, the virtual representation of the study area is very significant, especially if this environment is modelled starting from real data, e.g. from a Geographical Information System (GIS). It should correspond accurately to the reality, as well for the geometry as for the texture mapping and the decorations... Based on traditional techniques of realtime computer graphics sciences,

[5] a holon is an agent which could be decomposed into sub-holons

the virtual environment, in which the agents evolve, is a 3d-model. It is made up from various objects modelled in 3 dimensions, and each of them are made up from triangular facets. However, the study area is generally very large and the number of objects in the scene (agent representations, buildings, decorations...) can be significant, so various computer graphics techniques must be implemented in order to preserve a fluidity in displacement, i.e. places and portals [23, 41], BSP Tree[6]...

Multi-level simulation The multiagent-based simulation (MABS) differs from many other kinds of computer-based simulation in that the simulated entities are designed and implemented in terms of agents. MABS models are usually regarded as microscopic simulation models, in opposition to the macroscopic models of simulation based on flows, Markovian processes, queueing systems, Petri networks...
But it is utopian to simulate at a microscopical level a whole city or a large industrial area where the number of agents - or entities - could easily exceeded 20.000 entities on a traditional IT-platform, i.e. without a cluster of calculators. We argue that the solution is inevitably in hybrid solutions: simulations including intrinsically different levels of simulation. We have already developed an application integrating three levels of simulation: micro (e.g. vehicles), meso (e.g. roads and streets), macro (e.g. factory). Today we work on a more general model where the quantity of simulation levels depends on the available IT-resources and on the complexity of the organizations in which the agents are implied. These models are integrated on a model of holonic environment and holonic agents' organizations[7].

Interface between the MAS and the VR platform Always with the aim to guarantee a realtime system, calculations are shared between several units to allowing charge balancing. It permits also to physically separate the different treatments and to specialize the computers according to their tasks. For example a computer could be dedicated and optimized for the graphical part and the other machines for the MAS... This way imposes however the development of communication techniques between the calculators. It must being subjected to the constraint of realtime. We must thus prevent the bottlenecks and optimize the transmissions of messages. A first development uses only the traditional socket messages. However, in order to increase the possibilities of the architecture, we currently work on a CORBA realtime core version.
The visual perception component previously presented could also be seen as an interaction mean between a MAS and a VE. Indeed its high-level functionst, i.e. methods for requesting a perception inside a space, are perceptual primitives from the agent's point of view. By this fact, the visual perception component is a part of the MAS environment and allow the agents to directly and transparently interact with a virtual environment.

3.2 Realtime Human Interactions with the Agents

3.2.1 Avatar definition

The interaction and the immersion are the two fundamental characteristics of all virtual reality application [12]. It is essential for the user, since his real universe, to immerse himself in this virtual environment in order to interact with it or with the entities which populate it. With this intention, the user needs an existence in the virtual universe: the avatar - his graphical representation and his interactional vehicle inside the virtual world.
Within the framework of our developments, we conceive an avatar allowing the user to freely move inside the virtual universe. It is concretely realized with the devices of our laboratory's VR platform, namely a system of optical motion capture[8]. The user drives his avatar in an instinctive way with a Flystick[9] device. However, the core of the development is sufficiently modular to allow the use of other devices.

3.2.2 Interactions Avatar-Agent

In the multiagent system the avatar is regarded as an agent. Its interface is similar to that of the other agents. Its behavior on the other hand is the responsibility of the user, who controls it via the interaction

[6] Binary Space Partition Tree
[7] for more details on holonic multiagent systems, please see [14]
[8] ART system: `http://www.ar-tracking.com`
[9] 3d joystick used by the ART system

means described in the above section. The avatar is regarded as an agent identical to the others. Consequently it can communicate with the whole of the multiagent system. One of the main problems is to provide to the user several intuitive ways of interaction which enable him to maintain, via its avatar, a simple level of communication with the other agents. This communication constitutes the support for a possible cooperation between the avatar and the agents.

4 Application to the PSA Site

We detail in this part a range of tools at the disposal of the companies to manage the establishment of a new industrial site or the refitting of an existing one. These tools are located inside the scope of the study of logistic, production or people flows in order to determine the optimal adjustments of the site.

4.1 Congestion of infracstructures

Within the framework of the general study of the PSA Sochaux site (see fig. 4, page 11) flows, the simulation highlights a certain number of malfunctions, mainly in the exchanges between the site buildings. Indeed, we reveal the location of the main production cells and the exchanges generated throughout one day with different time scales. Their localizations specified on the virtual site enable us to study various flows and their frequencies in order to clarify the significant hotspots of the road structure. We detect the bottlenecks in logistic flows and propose an adapted dimensioning of the concerned infrastructures. Our tools also allow as well as possible to position the buildings' production functions according to the volume of their mutual exchanges.

4.2 Accessibility of Infrastructures

One of the main application of our tools is the validation of the infracstructures' accessibility in panic or day-to-day situation. We can check the efficiency and the good location of the road signs inside the site. Our tools also provide an average time of access to the infrastructures for each of the categories of entities evolving on the factory site: pedestrian, vehicles, trucks... By this way we detect the bad dimensioning of the infrastructures for each type of them. For example we validate if the signs intended for the emergency evacuation of an administrative building allow the people under panic to evacuate under the best conditions. This constitutes a complementary tool to the flow study presented in section 4.1. Using these two approaches we can draw up a complete panorama of the factory site in term of bottlenecks, dimensioning (road, corridor...), and infrastructures' accessibility.

4.3 Modification and Validation of Infrastructures

An interesting application of our models is the ability to change the spatial location of the infrastructural buildings and elements. The user could moves a building for studying its influence on its environment. Moreover we plan to propose interactive tools which allow to update or change the infrastructural models (roads, streets, buildings...). With the introduction of a temporal parameter, this set of tools could be associated to scenarios for simulating the past, present or future evolutions of an area. In such a way, we already simulate the PSA site exchanges between the buildings and show the results with chronological or chronomorphical maps[10], i.e. the buildings are colored in adequacy to their time-dependent functions (see figure 4 page 11).

5 Conclusion and Perspectives

This paper briefly introduces our works on the immersion of a multiagent system inside a virtual environment. We describe the different steps to achieve this immersion : perception architectures, agent behaviors, virtual environment modeling... We also present a first framework to provide to the user intuitive ways of interaction which allow him to maintain a simple communication with the whole of the multiagent system. The undertaken research works result on the development of tools intended for the

[10] works in collaboration with the Time and Mobility Agency of Belfort

companies owning large factory sites. These tools enable us to draw up a complete diagnostic on accessibility, the problems of logistic and people's flows inside a factory. We propose adapted solutions in term of adjustment and refitting of an industrial or an urban area.
The simulation enables us to integrate future modifications in terms of infrastructure's development as well as in terms of logistic and entity flows. The possibility of testing these future modifications under normal conditions of use as much as in exceptional conditions (i.e. panic) enables us to finely apprehend the possible consequences of a set of policies.

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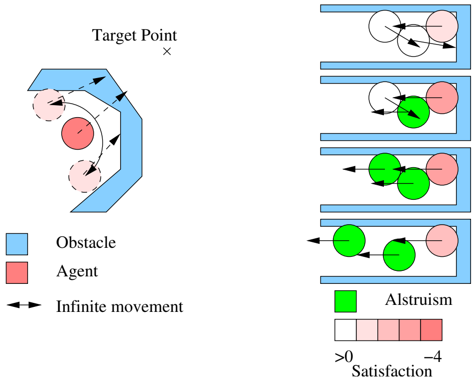

Figure 1: Potential-Field Problem Example

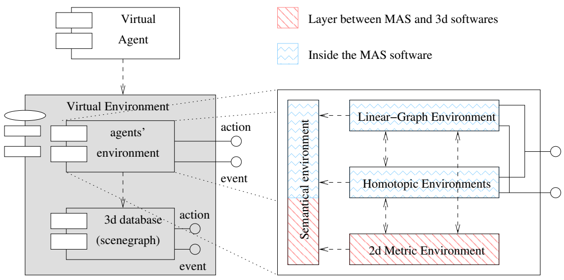

Figure 2: Virtual Environment Components

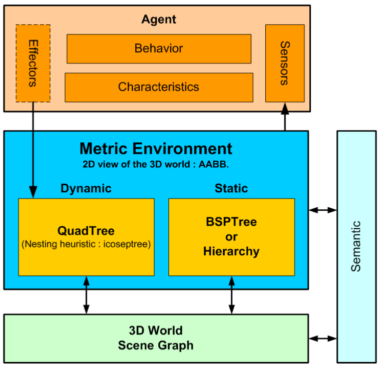

Figure 3: Details of the Metric Environment

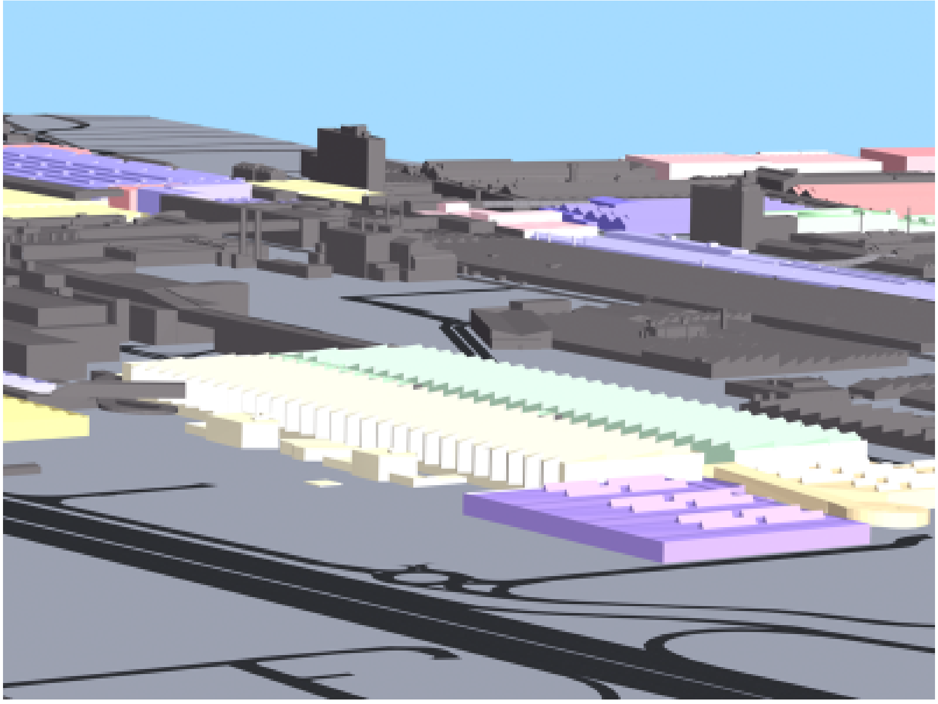

Figure 4: Air Sight of the Virtual Site of PSA

Figure 5: 3D Virtual Environment example