21 VIRTUAL REALITY-BASED SIMULATION OF USER BEHAVIOUR WITHIN THE BUILT ENVIRONMENT TO SUPPORT THE EARLY STAGES OF BUILDING DESIGN

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Abstract

This paper describes the framework of a multi-agent system approach for investigating visualized simulated pedestrian activity and behaviour within a building. This system can be used to support the assessment of design performance. Visualization is of critical importance in improving the readability of design representations. Performance indicators of buildings depend on user reactions to design decisions. One way of addressing this problem is to develop models that relate user behaviour to design parameters. For example, simulation models of pedestrian behaviour could be developed to support planning decisions related to the location of facilities in shopping malls, not yet existing. This approach gives a better view of the early stages of a building design and just as can facilitate the process of evaluating and communicating new buildings designs.

Keywords: *agent technology, micro-simulation, decision support, design process, virtual reality*

INTRODUCTION

Architects are often faced with the problem to assess how their design decisions will affect the behaviour of individuals. Various performance indicators are related to the behaviour of individuals in particular environments. One approach to deal with this problem is to develop a system that relates user behaviour to design parameters. Consider the design of a shopping center. Critical performance indicators related to user behaviour include the distribution of visitors across the center, ease of navigation, and pedestrian expenditures as a function of layout, and functional characteristics of the center and its shops. A simulation model would allow the designer to assess how its design decisions influence pedestrian movement, and hence these performance indicators.

The paper discusses the framework of a multi-agent system approach for investigating visualized simulated pedestrian activity and behaviour within a building. This simulation takes place within a virtual reality environment. The approach will lead to a system that may serve as a toolkit in the design process for a better understanding what the design looks like, and perhaps more importantly how users will behave in that particular environment.

The motivation of our research project is very similar to Pilgrim *et al* (2000), who quote a CIB-report (CIB TG24) on the use of virtual reality (VR) in the construction industry. In this report, the section on building performance discusses the role of VR as an integral component of a performance toolkit. Agent technology is derived from distributed artificial intelligence (DAI), which is also applied in the construction industry (Ugwu et al, 2000).

Our system is based on micro-simulation of pedestrian flows and multi-agent technology. In this context, pedestrians are people navigating within the built environment. The system simulates how agents move around in a particular 3D environment, in which space is represented as a network which is a lattice of cells with local states, subject to a uniform set of rules, which drives the behaviour of the system. Agents represent pedestrians with their own behaviour, moving over the network. The 3D environment is a virtual environment of the design of a new building or the revitalization of an existing building. A virtual building environment with virtual pedestrians will be constructed using multi-agent simulation. In this particular environment, a set of instances corresponding to the components of multi-agent simulations is designed. We distinguish user-agents that represent pedestrians in the simulation. We call the individual that is supposed to walk through the environment a subject-agent and all other simulated pedestrians in the system actor-agents. Thus, subject-agent and actor-agents are user-agents that navigate in this virtual environment, each with their own behaviour, beliefs and intentions.

The paper is organized as follows. First in section 2, we will discuss the motivation of our approach. Then, in section 3 and 4 we will discuss the network model part and the multi-agent simulation part of the framework. Next, we will give some attention to the simulation aspects. In section 6, the simulation model will be illustrated. We will finish with a discussion and future work.

MOTIVATION

We want to describe a model how agents move in a particular 3D (or 2D) environment. We have in mind a cellular automata model to simulate such kind of behaviour. In this environment agents can have some targets as starting point and finishing post, or a series of stops, but also the route of shortest duration or the most attractive route. Interaction of agents could be the question. Also, more agents could cause a decrease in speed. There are also opportunities to make a stop for window-shopping and/or to make a conversation mutual. The application of cellular automata involve the possibility to simulate how an agent-user moves in a given environment dependent of the behaviour of other agents.

What do we have in mind? For example, we could think about a visit to a shopping center. People could have a list of activities they want to do while visiting a shopping center. Moving (navigating) implies reaching one's goals step by step. In a cellular automata model, this means one or more cells forwards in a network (grid of cells) dependent on the speed of people. The behaviour of people can be affected by avoiding activity or by unplanned circumstances as signage and window-shopping. With regard to a shopping center, we could think about the realization of a shopping mall or the renewal of a shopping mall to perceive perceptions of observed consumer behaviour and choice behaviour a priori. The simulation model, as a decision support tool could be very useful to apply possible modifications to the design concept of this shopping mall.

Realization of a simulation model would be based on cellular automata theoretical and the distributed artificial intelligence research field. We will distinguish the network part and the multi-agent simulation part. Specific agents will represent objects or people moving over the network. The network part involves the occupation of cells by these specific agents.

THE NETWORK MODEL PART

The network is based on cellular automata theoretical. Cellular automata are discrete dynamical systems whose behaviour is completely specified in terms of a local relation (Ferber, 1999). They are mathematical models of spatially distributed processes. The purpose of the model is to simulate dynamic processes. Cellular automata models have been used to model transportation systems. For instance, cellular automata models for road traffic have received a great deal of interest during the 1990s. A road traffic cellular automata model seemed suitable to an urban environment. Nagel and Schreckenberg (1992) have analysed vehicular movements with a cellular automata car-following model. Based on the Nagel-Schreckenberg model the dynamics of cellular automata models are investigated. An example may be the so-called 'velocity dependent rules'-models, where the focus is on the occurrence of metastable states or the synchronized traffic. This simulation model can be used for large-scale networks and because of the speed capability of the model even for traffic assignment and traffic forecast purposes (Esser and Schreckenberg, 1997)

In recent years, there has been a growing interest in understanding traveller behaviour, including that of pedestrians. Pedestrians are an integral part of the transportation system. Blue and Adler (1998) have applied cellular automata micro simulation to model pedestrian flows and demonstrated that these models produce acceptable fundamental flow patterns. Although pedestrian flows are an important consideration in transportation research, there are few microscopic models for studying the movement of pedestrians.

While car movements are restricted to channelised lanes, pedestrian movement is a complex and chaotic process. Cellular automata present the possibility of using individual behavioural rules to model the behaviour of pedestrians. We think, that the principles of cellular automata for traffic flows are applicable as well to the modelling and simulation of user behaviour in buildings and public spaces, although the specific mechanisms need to be changed. For example, the behaviour in buildings such as enclosed malls and in public spaces could be evaluated or simulated to better assess whether a design meets its goals in terms of clarity, and navigation.

In our system approach, a cellular automata model is used to simulate pedestrian movement along the network of the system. The network is the three-dimensional cellular automata model represented by the graphical representation of a state at a certain time. The refinement of the network will be expressed by the format of the network, for example a cube of size one-meter. If a user-agent moves over the network, the left behind occupied cell changes into an empty cell and another cell will be occupied. The speed can be influenced by the occupation of other cells in the network. The population of crowded cells could result in emergence behaviour of the crowded neighbourhood.

THE MULTI-AGENT SIMULATION PART

The development of a multi-agent system offers the promise of simulating autonomous agents and the interaction between them. Simulations with complex behaviour and activity can be built using the ideas of cellular automata, and such simulations can model social dynamics where the focus is on the emergence of properties of local interactions. We will use simulation as a particular type of modelling; building a model is a well-recognized way of understanding the world. The uses of simulation are to obtain a better understanding of some features of the world, and we can develop a model that truly reproduces the dynamics of some behaviour and activity. With the development of a multi-agent system it is possible to simulate autonomous individuals and the interaction between them. For example to simulate people with different perspectives on their world.

One of the characteristics of the system is that behaviours evolve dynamically during the simulation, such as the evolution of the agent’s environment (neighbourhood), which reflects the emergence of structures, and the evolution of the agent’s behaviour during the simulation (i.e. adapted behaviour, unplanned behaviour).

As mentioned before, a virtual building environment with virtual pedestrians will be constructed using multi-agent simulation. The movement of pedestrians will be governed by cellular automata technology. In this particular virtual world (VW), a set of instances corresponding to the components of multi-agent simulations is designed. User-agents represent pedestrians in the simulation. Each user-agent receives a scenario in the simulation. A scenario is a sequence of actions that illustrates behaviour. It represents the attitude and intentions of the user-agent. A successive list of activities represents the activity agenda to perform the intentions. Thus the activity agenda represents the activities that a pedestrian plans to conduct during the visit to a shopping center or public space. We assume the activity agenda is time-dependant to allow changes in the agenda during the visit.

In figure 1 a framework of the agents' structure encapsulated in the virtual world is given. It indicates the appearance and behaviour of the virtual world to its users, and it presents the entire collection of agents and computing components.

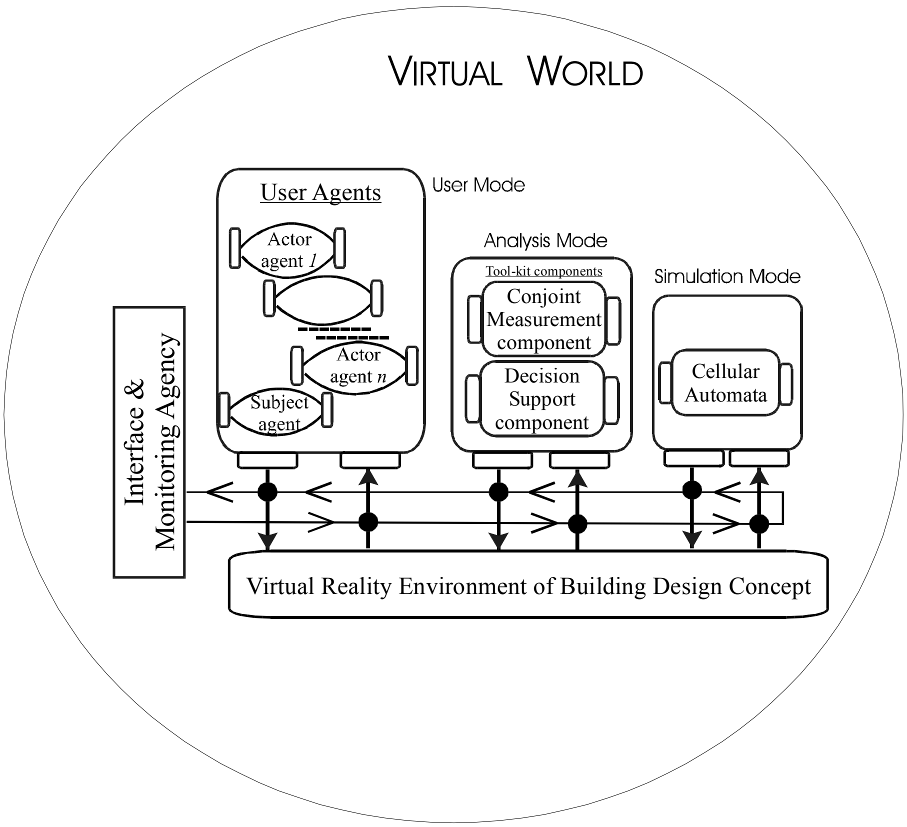

Figure 1: VW multi-agent system model

As mentioned before, the cellular automata approach is used to model pedestrian movement. Herein, space is represented as a uniform lattice of cells with local states. Rules compute the state of a particular cell as a function of its previous state and the states of the adjacent cells. An extension of this basic cellular automata model allows the state of any particular cell to be influenced by states not only of the contingent cell, but also by the states of more remote cells. State changes may depend of aggregate effect of the states of all other cells, or some subset of these.

Discrete steps govern the time evolution through the simulation. In each simulation loop, an update of the user-agent's scenario will be realized due to rescheduling of activity decisions, perceptions of the environment and adaptation of time-budget. The user-agent's scenario outcome influences the role of the user-agent. The pedestrian movement and therefore the simulation of the pedestrian flow will be affected.

SIMULATION ASPECTS

A classic use of simulation is for prediction. If we can develop a model, which reproduces the dynamics of some behaviour, we can then simulate the passing of time and thus use the model to look in the future. Also, we can build a simulation system that includes agents to simulate people with different perspectives on their worlds, different capabilities and so on. For example, we get insight in not yet realized design concepts.
The simulation can be divided in phases:

- *A model description*, that provides:
  - the virtual environment network model;
  - the architecture of (interacting) user-agents;
  - the scenario of a user-agent such as postulated goals and activities-list.
- *Model initialisation*:
  - in case of multiple alternatives (profiles) concerning design environment aspects. Selection of a profile alternative;
  - thresholds and state parameters;
  - behaviour selection and instantiation;
  - random generation of actor-agents.
- *Simulation run*:
  - control of simulation parameters (e.g. time-steps, thresholds, states);
  - navigation on the virtual environment ;
  - registration user behaviour;
  - logging of events and run time tracing.
- *model analysis* :
  - data analysis, i.e. analysis of performances of the measurements;
  - conjoint measurement in case of selection of profile alternatives;
  - decision support, i.e. decision making about design concepts

One of the characteristics of the (complex) system model is that behaviours evolve dynamically during the simulation. Evolution capabilities should then be given to behavioural principles of the user-agents when designing the system. This will be involved in the user-agent's scenario and in each simulation loop an update of this user-agent's scenario will be realized due to rescheduling of activity decisions.

SIMULATION MODEL OF PEDESTRIAN MOVEMENT

In our simulation model, we will get insight in the pedestrian activity behaviour in shopping malls, not yet existing. This will be of great importance in the assessment of design performance. Not only in the realization of new building designs but also in the revitalization of existing buildings. In the basic design cycle defined as a sequence of stages that describe the various phases of design (Roozenburg, 1996) our simulation model is very useful in the simulation of preliminary designs to see what its performance will be. As an evaluation, the simulation outcome can be compared with the design criteria. A choice can be made which alternative of a preliminary design is satisfactory. This decision results in an approved design.

The implementation of a user scenario is a complex process. It has a great impact on the rules set of the cellular automata. Shopping walkways are divided in decision areas. In these decision areas, the pedestrian (user) decides how to continue his walkway. The decision could result in the action = {forward, backward, rights, left, pause, stop and avoid}. All these actions are part of the cellular automata rules set and result in an adaptation of the walking speed in the update of the simulation step. The simulation shows the dynamics of the system. To get a first impression of our approach, we design a simulation experiment of pedestrian movement. In the simulation, pedestrians (actor-agents) possess a restricted scenario. They move through a 3D environment with a certain speed and final destination. We consider a T-junction walkway where pedestrians will be randomly created at one of the entrances. Figure 2 gives an impression of the cellular grid with pedestrians, represented by arrows and actor-number, moving along the network. The figure shows the walkway intersection as a decision area. The grid definition is loaded on creation.

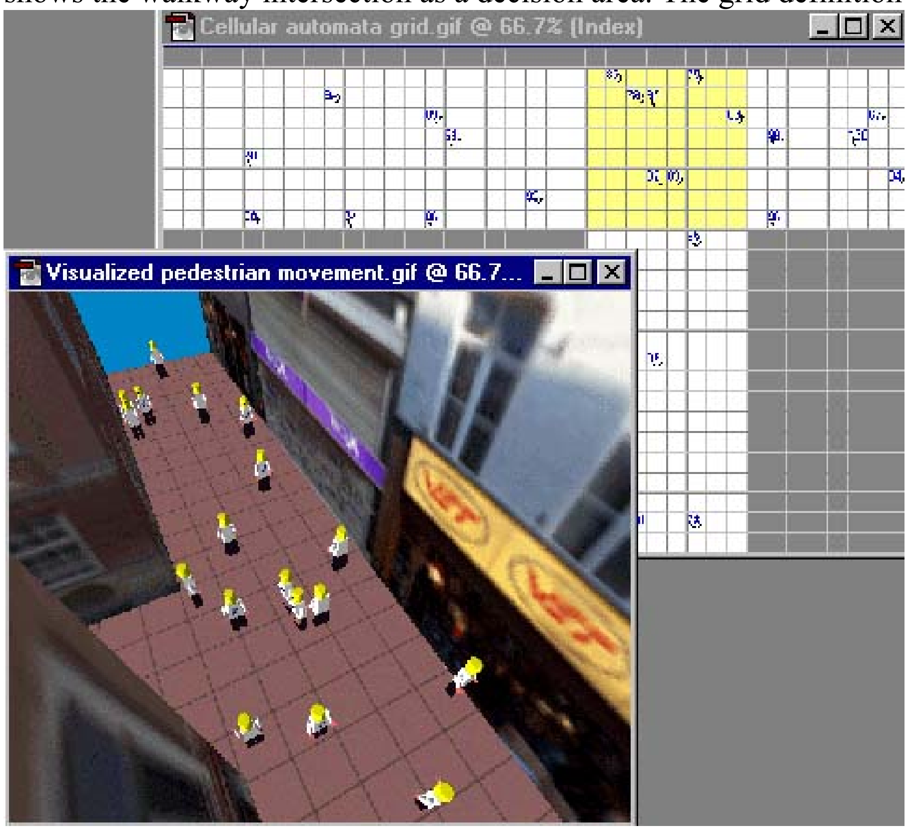

Figure 2: Cellular automata grid and visualized pedestrian movement

For visualizing the dynamics of our system, the built environment is essential. The built environment influence pedestrian’s behaviour and their activity agendas. For instance, there are activities that should be absolutely completed, whereas other activities have a lower priority. An activity agenda may change during a visit. Figure 2 also gives an impression of the visualized simulated pedestrian movement.

DISCUSSION AND FUTURE WORK

In the present paper, we have discussed the concept of a multi-agent system for VR based simulation of user behaviour within the built environment. With the simulation system, we will get more insight into the pedestrian activity behaviour and thus in the pedestrian flows in buildings, not yet existing. This will be of great importance in the assessment of design performance. For a designer or researcher, this system approach results in a decision support tool for the early stages in the design process of the construction of a building. We have described a simulation of pedestrian movement to illustrate our approach.

In the near future, aspects concerning the simulation of movement and aspects-aspects like visual range, attractors, avoidance behaviour and navigation will be drawn up. Interactions and goal-directed behaviour of user-agents within the virtual environment are influenced by evaluations during each simulation step. We will also take into account the behaviour of the network and the behaviour of facilities within a built environment such a stores in a shopping mall. For instance signalling intensity of the store, which is a function of distance, different architecture and whether or not other agents interrupt the view. The behaviour of the network has to do with the occupancy of the network with user-agents and the influence of crowded neighbourhood.

We want to realize a generalized object model by describing a user-agent, network and facilities etc. as distinct objects. Figure 3 shows the first ideas for a generalized object model. It contains a TGrid (network) and a TCell class definition.

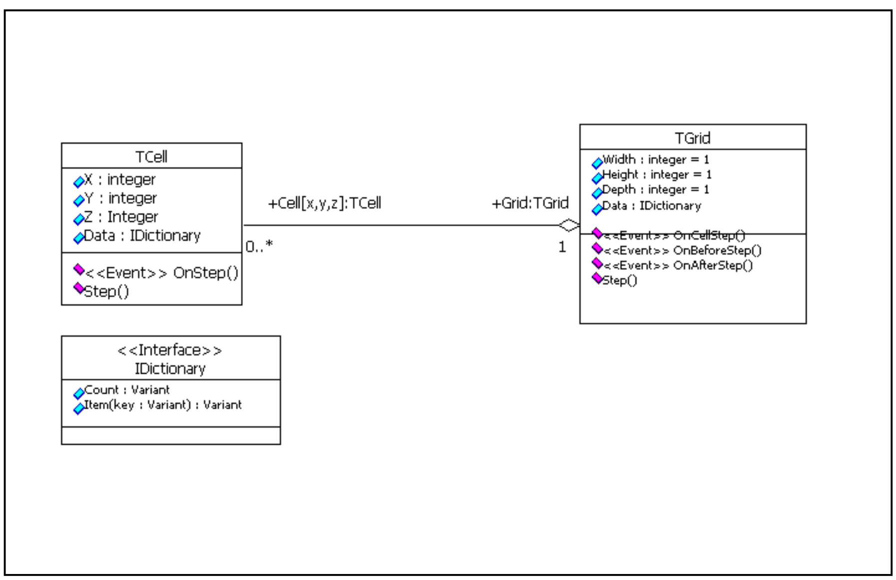

Figure 3: First object model set-up

A TGrid object can contain multiple cells. The position of a cell is expressed by a, x, y, and z coordinate. By setting the grids width, height and depth parameters, the grid object will create the accompanying cells on the correct position. Both the TGrid and Tcell classes have a data property. With this property the objects of those classes can keep track of any needed data.

The ultimate test of the relevancy of our system approach depends on empirical evaluation Starting from the presented approach in the paper, we plan to realize the generalized object model and plan to extend the simple model with limited user-agents (pedestrians) with restricted behaviour and learn from this system to simulate user (pedestrian) activity. Based on the experiences with such a system, we then plan to develop, test and apply a full-blown system.

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