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A Multi-Agent Systems Approach for Visualizing Simulated Behavior to Support the Assessment of Design Performance

Jan Dijkstra
Eindhoven University of Technology
Faculty of Architecture, Building & Planning
Design Systems, P.O. Box 513
5600 MB Eindhoven, The Netherlands
31 40 2472262
J.Dijkstra@bwk.tue.nl

Harry J.P. Timmermans
Eindhoven University of Technology
Faculty of Architecture, Building & Planning
Urban Planning, P.O. Box 513
5600 MB Eindhoven, The Netherlands
31 40 2473315
H.J.P.Timmermans@bwk.tue.nl

ABSTRACT
This paper describes the outline of a multi-agent system that can be used for visualizing simulated user behavior to support the assessment of design performance. This system is based on cellular automata and agent technology. The system simulates how agents move around in a particular 3D environment. Agents represent objects or people with their own behavior, moving over a pedestrian network. Each agent will be located in a simulated space, based on the cellular automata grid. Each iteration of the simulation is based on a parallel update of the agents according to local rules.

Keywords
Autonomous agents, multi-agent system, cellular automata, design evaluation, simulation.

1. INTRODUCTION
Architects and urban planners are often faced with the problem to assess how their design or planning decisions will affect the behavior of individuals. Various performance indicators are related to the behavior of individuals in particular environments. One way of addressing this problem is to develop models which relate user behavior to design parameters. For example, models of pedestrian behavior have been developed to support planning decisions related to the location of facilities, parking policies, etc. [1]. Graphical representations and 3D simulations might be powerful tools of assessing design performance in terms of such user behavior. Therefore, we formulated a research project that aims at exploring the possibilities of developing such a tool in a virtual reality environment using multi-agent simulation and cellular automata.

In a cellular automata (CA) model, space is represented as a uniform lattice of cells with local states, subject to a uniform set of rules, which drives the behavior of the system. These 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 the basic CA model allows the state of any particular cell to be influenced by states not only of the contingent cells, but also the by the states of more remote cells. State changes may depend on the aggregate effect of the states of all other cells, or some subset of these. Another extension is to build models in which cells preserve state information and calculate their next state on the basis of their neighbors and their own history of state changes. Agent technology is implemented to build a framework for multi-agent simulation. Objects or people moving across the network are represented in terms of autonomous agents. Each agent will be located in a simulated space, based on the CA grid. Agents positioned within an environment need sensors to perceive their local neighborhood and affect their environment. The choice of a multi-agent system is motivated by their promise to simulate autonomous individuals and the interaction between them [2]. Agent technology is also used to simulate the outcome of the model and the simulation. Designers can use the system to assess the likely consequences of their design decisions on user behavior.

2. CELLULAR AUTOMATA BACKGROUND
CA are discrete dynamical systems whose behavior is completely specified in terms of a local relation [3]. They are mathematical models of spatially distributed processes. The purpose of the model is to simulate dynamic processes. CA models have been used to model transportation systems. For instance, CA models for road traffic have received a great deal of interest during the 1990s. A road traffic CA model seemed suitable to an urban environment. Nagel and Schreckenberg [4] have analysed vehicular movements with a CA car-following model. Based on the Nagel-Schreckenberg model the dynamics of CA 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 [5]. 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 [6].

In recent years there has been a growing interest in understanding traveler behavior, including that of pedestrians. Pedestrians are an integral part of the transportation system. Blue and Adler [7] have applied CA microsimulation 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 channelized lanes, pedestrian movement is a complex and chaotic process. CA presents the possibility of using individual behavioral rules to model the behavior of pedestrians.

We think, that the principles of CA for traffic flows are applicable as well to the modeling and simulation of user behavior in buildings and public spaces, although the specific mechanisms need to be changed. For example, the behavior 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.

3. MULTI AGENT SIMULATION SYSTEMS

The development of multi-agent systems offers the promise of simulating autonomous agents and the interaction between them. Simulations with complex behavior 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. Therefore, in our opinion, cellular automata form a useful framework for a multi-agent simulation model that can be used for network decision analysis.

We will use simulation as a particular type of modeling; building a model is a well-recognized way of understanding the world. The uses of simulation are (i) to obtain a better understanding of some features of the world, and (ii) we can develop a model that truly reproduces the dynamics of some behavior. With the development of a multi-agent system is it 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 (complex) system is that behaviors evolve dynamically during the simulation. Evolution capabilities should then be given to behavior-agents when designing the system, such as:

- Evolution of the agent's environment (neighborhood); reflects the emergence of structures (also called self-organization).
- Evolution of the agent's behavior during the simulation, decomposed in:
  - Adaptation of the behavior according to knowledge and environment evolution, i.e. improvement and adjustment to the environment (self-adaptation or anticipated behavior).
  - Description of non-predictable behaviors (unplanned behavior). Sometimes, from the analysis of the best actions of the system, some rules can be generalized that lead to prediction of behavior.

4. TOWARDS A MULTI AGENT MODEL FOR VISUALIZING SIMULATED USER BEHAVIOR

4.1 Motivation

In this section, we describe how cellar automata and multi-agent technology can be combined to develop a model of how people move in a particular 3D (or 2D) environment. People are represented by agents, and the cellular automata model is used to simulate their behavior across the network. In this environment, agents can have particular targets such as a starting point and destination point, or a series of stops, but also the route of shortest duration or the most attractive route. Interaction between agents is also an issue: for example, more agents will decrease the speed of movement. There are also opportunities to stop for window-shopping and/or to start a conversation. Thus, the application of cellular automata implies the possibility to simulate how an 'agent'-user moves in a given environment, dependent of the behavior of other agents in the system.

An example of an application is the design of a shopping center. Critical performance indicators related to user behavior include the distribution of visitors across the center, ease of navigation, pedestrian expenditures as a function of layout, and functional characteristics of the center and its shops, etc. A simulation model would allow the designer to assess how its design decisions influence pedestrian movement, and hence these performance indicators. To conceptualize this problem, on might assume that pedestrians have a list of activities they want to do while visiting the shopping center. They will try to realize these goals by navigating through the center. In terms of a cellular automata model, this means that they will move one or more cells forward in the network, dependent of the speed of the pedestrian flow. Their behavior can also be affected by avoiding certain parts of the environment or by unplanned circumstances such as signage and window-shopping.

4.2 Agents Structure

We will distinguish various agent types in the model. There are user-agents that represent people (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 the virtual environment network, each with their own behavior, beliefs and intentions. A belief is the internal, imperfect representation of the virtual environment including the state of other user-agents, on which their decisions are based. We must view behavior as the interaction between the user-agent and the environment. For the subject-agent, this behavior is not an attribute of the agent, but rather lies in the mind of the subject alone. The researcher will determine an actor-agent's behavior, which is draw up by a behavior-agent. We will make a distinction between *inter*- and *intra*-agent. An inter-agent interacts with the environment and communicates with other agents. An intra-agent performs a task within an agent. A behavior-agent performs a task within the user-agent. We could consider styles of behavior like choice behavior, anticipated behavior and unplanned behavior. In addition to a behavior-agent, we also distinguish other intra-agents. Other intra-agents fulfill the intentions of a user-agent to reach a destination (goal) and/or to carry out a list of activities (plan). Elaborated on intelligent agents [8] and Belief, Desire, Intention (BDI) architectures [9], we will define an user-agent as: $U = < R \mid S >$, where

- *R* is a finite set of role identifiers. It represents the enumeration of all possible roles that can be played by user agents. At first, we will restrict the set of role identifiers to {actor, subject}. Later on we can differentiate the role of an actor-agent. This description is a general notification of the user-agent taking into account that these agents are pedestrians with the behavior speed and movement. Speed and movement are controlled by behavior-agents.
- Each user-agent receives a scenario *S* in the simulation, which represents the attitude and intentions of the user-agent. We will define S by: $S = < B, I, A, F, T >$, where
  - *B* represents the behavior. Each user-agent *i* has a list of behavior-aspects from $\{B_i\}$.
  - *I* represent the intentions of a user-agent *i*, which is a list of intention-aspects from $\{I_i\}$.
  - *A* represents the activity agenda of a user-agent *i* to perform the intentions ($\{A_i\}$). The activity agenda is a successive list of activities. Each activity includes a certainty factor that determines the priority of that activity. A priority hierarchy may be part of the activity agenda. Thus the activity agenda represents the activities that a pedestrian plans to conduct during the visit to a shopping mall or public space. We assume that the activity agenda is time-dependant to allow changes in the agenda during the visit.
  - *F* represents the knowledge or information about their environment which a user agent *i* possesses ($\{F_i\}$), which is called Facets. Part of these facets is amongst others beliefs, awareness, experience, preference and choice. All these facets are dynamic and may change over time in the simulation loop.
  - *T* represents the time-budget each user-agent possesses.

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 traffic flow will be affected.

Concerning inter-agents, we distinguish among others an interface-agent for assisting the user-agents in the virtual environment, a monitoring-agent for monitoring the simulation process. In the simulation process, we also distinguish system components such as a conjoint-measurement component for subject's preference measurement and a decision-support component to assist the researcher or designer in a decision process. The 'cellular automata' component will simulate the evolution of the simulation model. A framework for the agents-structure is given in Figure 1, which focuses on the interaction with a virtual environment. There is an intuitive communication between the subject-agent and the interface-agent.

We will integrate the agents' structure in our proposed system. We will incorporate features like the dynamic aspects of pedestrian choice behavior, and the relationships between individual choice process and emergent aggregate patterns. Given the activity agenda, the pedestrian is faced with the multi-faced problem of deciding where to conduct the activities, in what sequence, and which route to take.

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

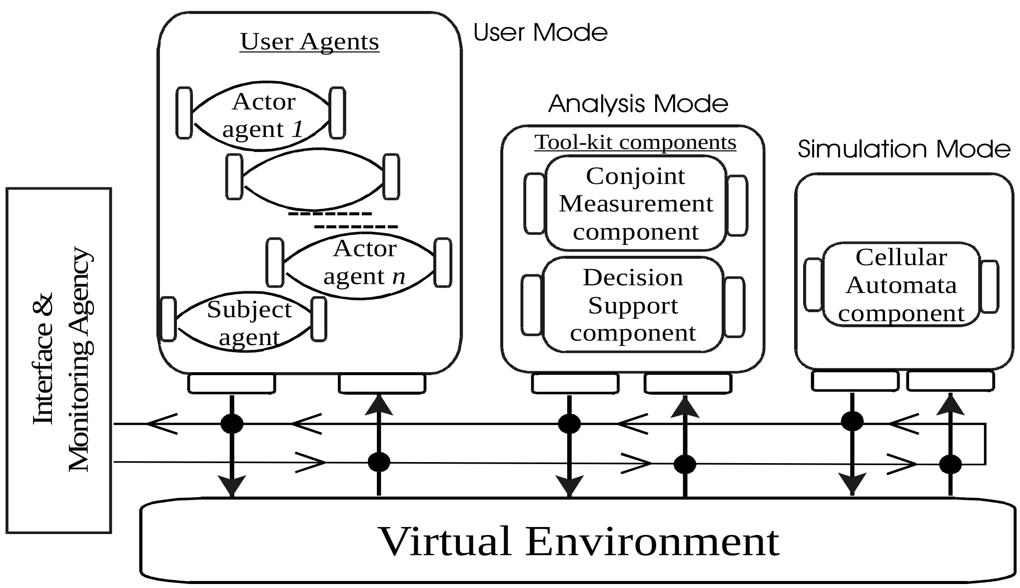

Figure 1. Framework of the agents structure

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 visualized simulated pedestrian movement.

Figure 2. Visualized pedestrian movement.

5. DISCUSSION

In this contribution, we have discussed the concept of a multi-agent system for visualizing pedestrian activity based on cellular automata theoretical. The experiment with a T-junction looks very well, especially the 3D view of the simulation. It shows how the pedestrians are moving and shows the shortcomings of the algorithms. In our simulation model, we will get insight in pedestrian behavior in shopping malls, not yet existing. This will be of great importance in the assessment of design performance.

The ultimate test of the relevancy of such a system depends on empirical evaluation. Starting from the presented model, we plan to extend the simple model with limited user-agents (pedestrians) with restricted behavior and learn from this system to simulate user behavior. Also, we will perform the effective mesh of the network and the walking speed of pedestrians. For instance, the speed of pedestrian *p* may be a function of personal factors and situational factors ($S_p = f$ (personal factors, situational factors)) and controlled by an activity agenda of pedestrian *p*. Based on the experiences with such a system, we then plan to develop, test and apply a full-blown system. We think that this approach is also applicable to public spaces as of airports like plaza shopping, visitor's centers and passageways to get insight in passenger's flow.

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7. REFERENCES

[1] Kurose, S., A. Borgers, and H. Timmermans, "Predicting Pedestrian Shopping Behavior using Heuristic Rules", Submitted for publication to *Planning and Design* (1999).

[2] Gilbert, N., and K.G. Troitzsch, *Simulation for the Social Scientist*, Open University Press, London (1999).

[3] Ferber, J., *Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence*, Addison-Wesley, New York (1999).

[4] Nagel, K., and M. Schreckenberg, "A Cellular Automaton Model for Freeway Traffic", *Journal de Physique 1*, 2, 2221-2229 (1992).

[5] Barlovic, R., L. Santen, A. Schadschneider, and M. Schreckenberg, "Metastable States in Cellular Automata for Traffic Flow", *European Physical Journal B*, 5, 793-800 (1998).

[6] Esser, J., and M. Schreckenberg, "Microscopic Simulation of Urban Traffic on Cellular Automata", *International Journal of Modern Physics C*, 8(5), 1025-1036 (1997).

[7] Blue, V.J., and J.L. Adler, "Emergent Fundamental Pedestrian Flows from Cellular Automata Microsimulation", *Transportation Research Board* 1644, 29-36 (1998).

[8] Wooldridge, M., "Intelligent Agents", in G. Weiss, ed., *Multiagent Systems – a modern approach to distributed artificial intelligence*, MIT Press, Cambridge, 36-70 (1999).

[9] Fisher, K., J.P. Müller, and M. Pischel, "A Pragmatic BDI Architetcure", in M.N. Huhns and M.P. Singh, eds.,

Readings in Agents, Morgan Kaufmann Publishers, San Francisco, 217-224 (1998).