# A Multi-Agent Cellular Automata System for Visualising Simulated Pedestrian Activity

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Abstract

This paper describes the first impressions of the development of a multi-agent system that can be used for visualising simulated pedestrian activity and behaviour to support the assessment of design performance. This system is based on cellular automata and agent technology. Agents represent objects or people with their own behaviour, moving over a pedestrian network. Each agent is 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 conforming local rules. Agents positioned within an environment have sensors to perceive their local neighbourhood and affect their environment. In this manner, autonomous individuals and the interaction between them can be simulated by the system.

## 1 Introduction

Architects and urban planners are often faced with the problem to assess how their design or planning decisions will affect the behaviour of individuals. Various performance indicators are related to the behaviour of individuals in particular environments. One way of addressing this problem is to develop models which relate user behaviour to design parameters. For example, models of pedestrian behaviour have been developed to support planning decisions related to the location of facilities, parking policies, etc.

Graphical representations and 3D simulations might be a powerful tool of assessing design performance in terms of such user behaviour. 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 behaviour 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 more the 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 neighbours 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 neighbourhood 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 [1]. 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 behaviour.

Point of departure is a pedestrian movement within a shopping mall where pedestrians are walking. The focus is on simulating pedestrian behaviour in a shopping mall and the choice mechanisms that are involved where to stop, in what order, and which route to take. Suppose that a pedestrian visits this mall. We assume this visit is motivated by the desire to realise particular goals by conducting particular activities, in what sequence, and which route to take. In our simulation model, we will get insight in this pedestrian behaviour and pedestrian flows in shopping malls, not yet existing.

As a first step in realising such a multi-agent CA system this paper explores the use of CA for modelling pedestrian movement.

## 2 Background

CA are discrete dynamical systems whose behaviour is completely specified in terms of a local relation [2]. 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 [3] 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 synchronised traffic [4]. 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 [5].

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 [6] 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 channelised lanes, pedestrian movement is a complex and chaotic process. CA presents the possibility of using individual behavioural rules to model the behaviour of pedestrians.

In ‘modeling and simulation of pedestrian traffic flow’ [7] a simulation tool is presented to estimate the relevant performance measures of the pedestrian traffic system. Also, a stochastic model is presented based on the assumptions that (i) any pedestrian facility can be modeled as a network of walkway sections, and (ii) pedestrian flow in this network can be modeled as a queuing network process, where each pedestrian is treated as a separate flow object, interacting with other objects.

We think, that the principles of CA for traffic flows and to simulate the pedestrian movement and the pedestrian activity 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.

# 3 Motivation

Cellar automata and multi-agent technology can be combined to develop a model of how pedestrians move in a particular 3D (or 2D) environment. Pedestrians are represented by agents, and the CA model is used to simulate their behaviour 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 CA implies the possibility to simulate how an ‘agent’-user moves in a given environment, dependent of the behaviour of other agents in the system.

An example of an application is the design of a shopping centre. Critical performance indicators related to user behaviour include the distribution of visitors across the centre, easy of navigation, pedestrian expenditures as a function of layout, and functional characteristics of the centre 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 conceptualise this problem, on might assume that pedestrians have a list of activities they want to do while visiting the shopping centre. They will try to realise these goals by navigating through the centre. In terms of a CA model, this means that they will move one or more cells forward in the network (grid of cells), dependent of the speed of the pedestrian flow. Their behaviour can also be affected by avoiding activity or by unplanned circumstances such as signage and window-shopping.

In developing this system, it is useful to differentiate between the CA part and the distributed artificial intelligence agent’s structure. The agents structure part involves the different agents with their respective roles. We will distinguish various agent types in the model. There are user-agents that represent people in the simulation. The one, who is part of the simulation, is called the subject-agent.

Actor-agents can simulate pedestrians. Thus, subject-agent and actor-agents are user-agents that navigate in the virtual environment network, each with their own behaviour, 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 behaviour as the interaction between the user-agent and the environment. For the subject-agent, this behaviour 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 behaviour, which is draw up by a behaviour-agent. We could consider styles of behaviour like anticipated behaviour and unplanned behaviour. Besides a behaviour-agent, we also distinguish an intra-task-agent. An intra-task-agent fulfils the intentions of a user-agent to reach a destination (goal) and/or to carry out a list of activities (plan).

We define a user-agent as tuple: $U = < R, A, F >$, where

- $R$ is a finite set of role identifiers. It represents the enumeration of all possible roles that can be played by user agents.
- $A$ represent the activity agenda of user-agent $i$ to perform the goals and desires ( $\{Ai\}$ ).
- $F$ represent the knowledge or information about their environment which an user agent possesses ( $\{Fi\}$ ), 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.

A framework for the agents structure is given by Dijkstra and Timmermans [8], which focuses on the interaction with a virtual environment.

# 4 CA Model of Pedestrian Movement

A CA model is used to simulate pedestrian movement along the network of the system. The network is the three-dimensional CA 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.

A user-agent can occupy a number of cells. The navigation speed $v$ is the number of cells that are crossed during an update time-step $\Delta t$. 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.

We define a regular lattice of some width $W$ and length $L$, and density that represents the mesh of the network. Cells within the lattice are given the notation $c_{t,i,j}$ , where $1 \le i \le W$ and $1 \le j \le L$, and $t$ indicates the celltype where $t \in \{empty, decision, wall\}$. *Empty* means the cell belongs to the walkway. *Decision* means the cell belongs to the decision-point area (e.g. a T-junction) where the pedestrian takes the decision where to go. *Wall* means that the cell is part of a wall, shop etc.

We define a cell $x$ (actually $c_{t,i,j}$) in the pedestrian walkway to be *on* ($s(x)=1$) if it is occupied by pedestrian $p_n$, otherwise it is *off* ($s(x)=0$). Also we define a density size $\delta_r$ ($x$) which shows the activity around cell $x$; it shows the number of neighbours in an *on* state in relation to the total number of neighbours in the Moore neighbourhood of cell $x$ with radius $r$. In a $d$-dimensional grid with a Moore radius $r$, the number of cells $n$ in the neighbourhood of cell $x$ ($x$ included) = $(2r+1)^d$. The updated cell $x$ depends on the *on* states of all cells in the neighbourhood $N$ of $x$ ($N(x)$). To summarise the transition of a state of a cell,

$$s^t(x) = 0 \rightarrow s^{t+1}(x) = 1 \text{ ,if hit by an object or an user-agent;}$$

$$s^t(x) = 1 \rightarrow s^{t+1}(x) = \begin{cases} 1, if\ cell\ activity\ remains \\ 0, if\ a\ useragent\ left\ the\ cell\ behind \end{cases}$$

$$\delta_r(s^{t+1}(x)) = (\sum_{i=0}^{n}((s^{t+1}(x+y_i))/n); \text{ where}$$
$$y_i \in N(x), y_0 = 0, n = (2r+1)^d$$

The CA microsimulation proceeds in time steps. In each time step lane assignment and speed updates change the positions of all pedestrians according to local rules applied to each pedestrian. During a forward movement of a pedestrian based on the original Speed, for instance *2 cells/Δt*, the rule set follows:

**Rule1: check decision-point**

**If** decision-point is passed
**Then** goto Rule3
**Else** goto Rule2

**Rule2: check celltype**

**If** celltype='decision'
**Then** examine the behaviour of the pedestrian, which direction the pedestrian eventually wants followed by a turn in that direction; decision-point will be passed
**Else** goto Rule3

**Rule3: check cell**

**If** cell isn't occupied by a pedestrian **and** celltype='empty' **or** celltype='decision'
**Then** Walk
**Else** goto Rule4

**Rule4**: **check adjacent cells**

**If** the cell over to the left (right) isn't occupied by a pedestrian
**Then** Move to the left (right) cell
**Else** Wait

# 5 Simulation Model of Pedestrian Movement

Figure 1 is the graphical notation that expresses the simualtion process where pedestrians are represented by actors.

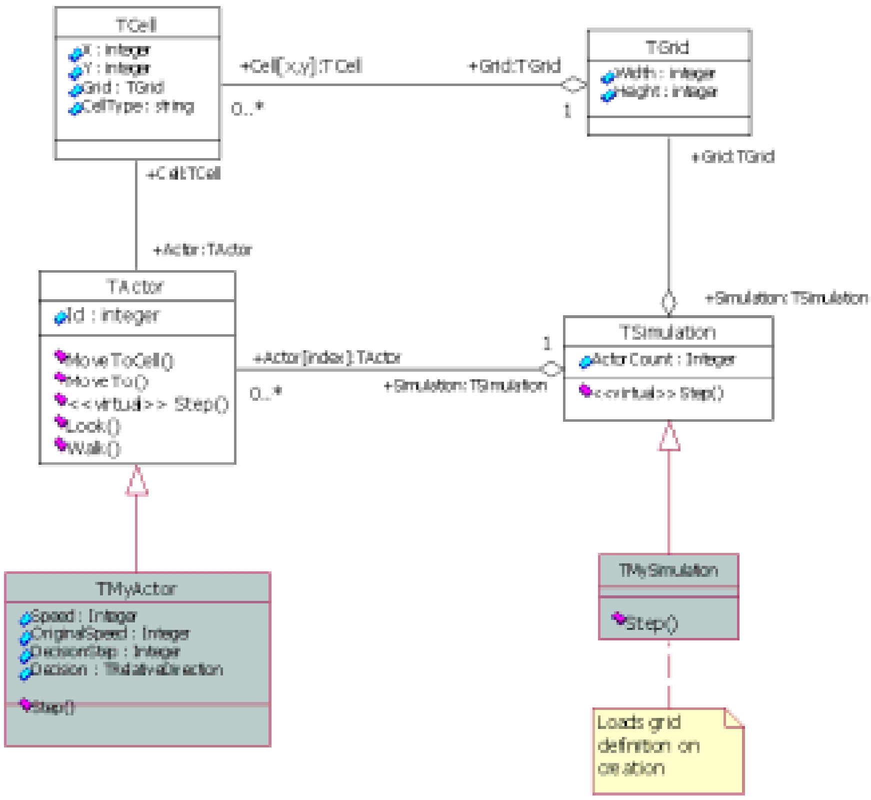


Figure 1: Graphical notation that expresses the simulation process based on UML.

In our simulation model, we will get insight in the pedestrian activity behavior 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. 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.

Initially, we will realize different graphic representations of our simulation: (i) an actor-based view to represent the pedestrians in the simulation, (ii) a network-based view to represent the density size of occupied cells in the network, and (iii) a main node-based view to represent the main decision points in the network and the decision points which are arrived.

To simplify these representations, we introduce the following definitions (partially adapted from Løvås [7]): the pedestrian environment is called building. A section of the building is called a room. The rooms {R} are divided in four subsets: stores or establishments {S}, entries or departures {E} that are rooms outside the building, walkway intersections or bends {W} and remaining walkway sections {O}. There is one decision point in each room; if the room is large, it may be modeled as several sub-rooms. A decision point is called a node in the network; the main nodes; the main decision points are situated in {E} and {W}. A line between two decision points represents a link between these points; i.e a walkway between these points. Each walkway is dived in two parts; one part belongs to each of the two remaining rooms. For example the walkway between rooms *i* and *j* has the length $d\ (i,j) = d_i(j) + d_j(i)$.

In our simulation experiment, 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 automata grid with pedestrians, represented by arrows and actor-number, moving along the network. Also, this figure gives an impression of the visualised simulated pedestrian movement.

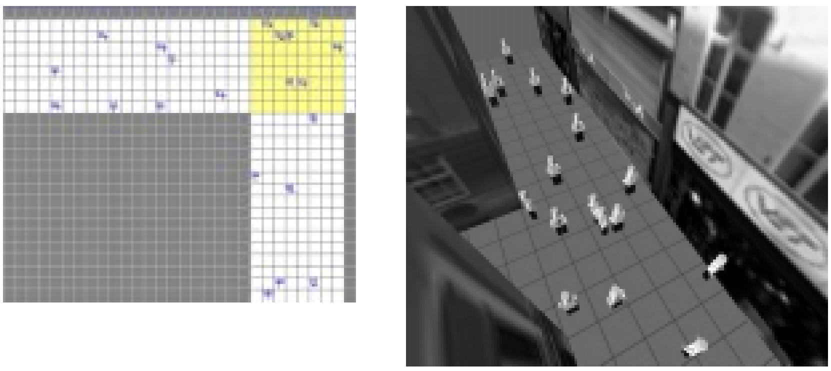

Figure 2: Cellular Automata grid and visualised pedestrian movement.

# 6 Discussion

In the present paper, we have discussed the concept of a multi-agent system for visualising pedestrian activity based on cellular automata theoretical. We have described a simulation of pedestrian movement to get a first impression of our approach. The experiment with a T-junction looks very well, especially the 3D view of the simulation.

The ultimate test of the relevancy of such a system depends on empirical evaluation. Starting from the presented model in the paper, we plan to extend the simple model with limited user-agents (pedestrians) with restricted behaviour and learn from this system to simulate user behaviour. 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 centres and passageways to get insight in passenger's flow.

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## References

1. Gilbert N, Troitzsch KG. Simulation for the social scientist. Open University, London, 1999
2. Ferber J. Multi-agent systems: an introduction to distributed artificial intelligence. Addison-Wesley, New York, 1999
3. Nagel K, Schreckenberg M. A cellular automaton model for freeway traffic. Journal de Physique I 1992; 2:2221-2229
4. Barlovic R, Schadschneider A, Schreckenberg M. Metastable states in cellular automata for traffic flow. European Physical Journal B 1998; 5:793-800
5. Esser J, Schreckenberg M. Micrsoscopic simulation of urban traffic based on cellular automata. International Journal of Modern Physics C 1997; 8:1025-1036
6. Blue VJ, Adler JL. Emergent fundamental pedestrian flows from cellular automata microsimulation. Transportation research Board 1998; Record 1644:29-36
7. Løvås GG. Modeling and simulation of pedestrian traffic flow. Transportation Research Board 1994; 28B(6):429-443
8. Dijkstra J, Timmermans HJP. Towards a multi-agent model for visualizing simulated user behavior to support the assessment of design performance. In: Ataman O, Bermúdez (eds) ACADIA99 – Media and design process. Acadia 1999: 226-237