Conformance Checking by Capturing and Simulating Human Behaviour in the Built Environment

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ABSTRACT

In order to model natural human behaviour, it is necessary to capture this behaviour. First, we will start out by modelling behaviour for specific situations, such as taking a seat in a theatre. To capture human behaviour, the following experiment is performed: Given a virtual environment, a sufficient number of subjects (real humans) are asked to execute a human task in this virtual environment (e.g. take a seat in the theatre). Whenever the subject deviates from the shortest path, the system will ask for a clue why this is done. The hypothesis is that the combination of the motion paths and the clues for making/changing decisions will provide decision rules to make reliable predictions about human behaviour under the same conditions when using virtual persons. To test the hypothesis, we propose to use the university's main conference and presentation hall as a test case. A 3D model and a motion path graph are constructed that enables a virtual person to find its way to a selected chair. The clues from the experiment are implemented as decision rules that determine a virtual person's behaviour. Running the simulation will result in the following data: Time per person to find a chair, Deviation from the shortest path, Distance covered per person to find a chair, Distribution of seated persons over time and Relocation of persons. To validate the test case, the process of people entering the hall and finding a chair is recorded on videotape. The walking behaviour of the people observed on the video is analysed and compared with the data from the simulation.

1 INTRODUCTION

To date 3D models of the built environment are predominantly used for presentation of the design to non-professionals and for design evaluation amongst professionals (Whyte 2001). Increasingly, such presentations are done in an interactive and real-time manner, using VR-based techniques. Although images of humans do occur in such presentations, these are hardly ever interactive, nor do they display human behaviour. This is all the more striking, as in architectural and urban design human behaviour is the starting point. Why not test (intermediate) design performances by simulating human behaviour? Therefore, we need virtual persons that show representative behaviour and that allow us to analyse the performances of the design.

The most obvious, but scientifically the least interesting, application is populating 3D models with virtual humans. Scientifically more challenging and more related to the design process is the use of virtual humans as substitutes for testing and evaluation purposes, such as:

- Hazard situations: How much time does it take to find a way out

- Crowding and queuing: How long does is take to reach your location and is there enough space
- Way finding: Can people find the location they are looking for
- Perception: How do people perceive the climate conditions (lighting, heating, cooling, air flow, acoustic) over time
- Efficiency: How efficient is the building being used (walking distances, floor occupation, shared floor area use)
- Training: Instructions for the workers on the building site (how to construct this window pane, steel frame, etc)

By allowing virtual humans to populate a design in a specific situation, behaviour of groups as it occurs in 3D space can be studied in real-time. Such simulation can give valuable feedback on the performance of the design.

The outline of the paper is as follows: At first we will give an overview of on-going related research. Therefore we will discuss research topics and present a list of the relevant methods and technologies. Next we explain our own approach, the system set-up and the data collection. Finally, preliminary conclusions are drawn and how we will continue the research project.

2 RELATED WORK

Simulation of human behaviour has attracted researchers from different disciplines. An overview is given by discussing the following research topics: (1) Virtual Environment, (2) Virtual Human Behaviour and (3) Way-finding. In advance, commercial available tools are touched upon very briefly.

2.1 Commercial software

Lately, many applications come to the market for creating virtual humans. This development is especially driven by the growth of Internet utilization. Game engines often also include 'characters' that can move quite smoothly. However adding human behaviour is less obvious. VR environments offer procedural languages to implement human behaviour including movement.

2.2 Research

Virtual Environments provide ideally three elements to immerse a participant: visual, auditory and haptics (Capin et. al. 1999). The graphical representation of a person is indicated as Avatar. In many cases Avatars do not perform real human behaviour but only show human characteristics for a specific purpose. For example, an Avatar can help you, guiding you through a virtual world while giving instructions (Shaw et. al. 1999). In games Avatars are usually called Non Playing Characters or Bots. The reason for their existence is the game-play, not real human interaction, because this would be rather boring probably.

With the increasing bandwidth of the Internet, Virtual Environments become accessible through web technology. Communication through dialogue boxes will be replaced partly by communication through embodiments like avatars. The next step is interlinking Virtual Environments, allowing for interaction between humans that are physically at different locations (Staadt et. al. 2001).

Virtual Human behaviour is the technology that mimics real human behaviour. Human behaviour research can be approached from cognition and from body actions. In research on implementation of cognition in computer applications, Artificial Intelligence is the commonly used description for a range of technologies such as expert systems and neural networks that can mimic parts of the human reasoning process. The research on implementation of body actions encompass many aspects such as seeing and animation of body parts and face. However, most studies on virtual human behaviour focus on a specific aspect such as motion control, which includes both cognition and body actions. A reduced implementation of virtual human behaviour is often indicated as Autonomous Characters. Here the fact is stressed that a human or non-human character can operate in an improvisational manner. The so-called Non Playing Characters in games belong to this type of reduced behaviour implementation. Virtual social behaviour simulation is the behaviour of groups of people that are mostly based on Flocking (Reynolds, C. W. 1987, Musse et.al. 1999).

Way finding concerns the spatial organization of a setting, the circulation system and architectural as well as graphic communication (Passini 1996). In the urban context researchers have studied existing situations and have derived guidelines for designers that help humans with orienting themselves (Lynch 1989). More recently research is performed to predict the behaviour of pedestrians (Blue and Adler 1998, Dijkstra et.al. 2000). Way finding in buildings does not receive much attention with the exception of research on people's behaviour when there is panic in the building (Helbing et. al. 2000, Schreckenberg and Sharma 2002.). Hazard situations are extreme circumstances, but also under normal conditions way finding technology can give insight about potential problems because of the architectural layout of a plan. Few examples can be found of analytic studies on the actual use of buildings including movement patterns (Leusen and Metossi 1998).

3 PERCEPTION SIMULATION

For perception simulation, three predominant methods are found in literature, namely: (1) object map, (2) ray casting and (3) discrete space.

An *object map* is the 2D plan of the 3D environment, assuming that we will move over a ground plane. In each location we can ask the geometric engine what our position is on the map. On the maps, regions are specified where it is allowed to navigate. Thus, we cannot inspect the environment, unless we add properties to the regions describing the environment.

The most well known model for *discrete space* simulation is Cellular Automata (CA) (Zeigler et. al. 2000). In CA, each Cell executes specific rules in each simulation step. Before rule execution a cell can check the state of all other cells in the grid. Thus the outcome of a simulation step is for each cell dependent on the states of all other cells. CA can be used to implement perception by checking cells of the grid from a certain position in the grid. For example if a cell can have the property Wall or Person, then a cell with property Person can inspect the neighbouring cells to find out if it will hit a wall when it moves in that direction. Another example is that a Person can 'look' in a certain direction to check whether it will cross a cell with e.g. the property Exit.

Ray casting determines the visibility of surfaces by tracing imaginary rays of length from the viewer's eye to objects in the scene (Foley et. al. 1990). Consequently the geometric engine of the system can tell which object is hit and at what distance. For example we can 'see' at what distance on object of type Wall is located. This method is also commonly used for collision detection.

4 INDIVIDUAL BEHAVIOR SIMULATION

For the elaboration on individual human behaviour simulation we will use Reynolds hierarchy of behaviours, namely (1) action selection: strategy, goals, planning, (2) steering: path determination and (3) locomotion: animation, articulation.

In this paper we will not include low-level behaviour simulation such as motor skills and facial expressions, because our focus is on predicting behaviour instead of a highly realistic simulation.

4.1 Action selection

Activity-based modelling is a method for prediction people's behaviour using their activity schedule as input (Tan et. al. 2000). To create such an activity model people are asked to fill in a questionnaire stating their activities such, shopping, travelling etc., together with a time spent for each activity. The data are analysed to identify the rules that people make when making decisions. Action selection is represented as scheduling and rescheduling daily activities. This method has been applied successfully especially in the research of traffic patterns.

Decision tables are a method to implement decision-making especial suitable for those circumstances where it is very difficult to deduce decision rules (after Wets 1998). If the data collected from surveys are categorized in discrete values or in ranges, then decision tables can be constructed. In the decision tables, even with dependent attributes, all possible outcomes can be represented together with the measured value among the respondents. With many interrelated actions, decision tables become very large and difficult to maintain.

Constraint satisfaction is a general term for a method that makes use of numerical equations to search for values in the domains and check them against the constraints (after

Kelleners 1999). Usually there is an infinite set of solutions and therefore to speed up the process, search algorithms are used to find the solutions in the search space. Evidently all human decisions must be expressed as (linear) equations.

Logical reasoning methods can be divided in two groups, namely without learning and with learning. A representative of the first group are Rule-Based-Systems. Human decision rules in this case are basically expressed as If-Then-Else structures. With these rules the system can reason about new conditions using techniques like induction and deduction. The second group is represented by neural networks. In neural networks a pool of simple processing units communicate by sending to each other signals over a large number of weighted connections. Knowledge is constructed by feeding the system with relevant human decision cases and letting it change its weights according to some learning rule.

Petri-nets are formal descriptions of (logistically complex) processes. In Petri-nets we have places in which complex tokens may reside and transitions that may consume and produce complex tokens from specific places (Hee 1994). In case of human decision-making, transitions are activities and places are the holders of the messages that are exchanges between humans but also within a human. In the latter case, decision-making must be modelled as a network of activities with input- and output-data.

4.2 Steering

For *Shortest path* finding, methods are ready available, like Dijkstra's algoritm and the A* algorithm (Nilsson 1980). Shortest path calculation requires a (directional) graph and for each node of the graph the corresponding location in the 2D or 3D environment. When using graphs as mental map of virtual humans, the graph can be part of the virtual environment and thus identical for all its inhabitants or it can be constructed by each virtual human individually. In the last case nodes as possible location to go, must be generated by the system, for instance as grid points that are flooded over the environment.

Grid maps divide the 2D or 3D environment in cells (Bandi and Thalmann 1998). Each cell has one or more attributes to express physical conditions (e.g. wall) or a state (e.g. occupied). Steering is implemented by moving through the grid and meanwhile inspecting the neighbourhood cells. Dependent on the physical condition and the state of cell the decision is made whether or not moving on in that direction is possible. Evidently the environment and its occupying objects must neatly be fitted in the grid, which is not always trivial (e.g. curved objects).

In *Particle systems*, objects have a specific shape, speed, direction and lifetime (Watt and Watt 1992). Adaptation of one or more of these attributes is controlled by stochastic processes (e.g. clouds), kinematical processes (e.g. collision) or dynamic process (e.g. aging). Process control can be divided into physical processes (e.g. action-reaction of forces) and non-physical processes (e.g. flocking of birds). Particles can mimic humans' autonomous and social behaviour. No artificial conditions like graphs or cells are needed to navigate, however more intelligence implemented with one of the techniques mentioned in section 4.1 is necessary to arrive at predictable behaviour.

4.3 Locomotion

Kinematic animation falls into two categories: forward kinematics and reverse kinematics. For simulation of human motion, forward kinematics is most common. Motion of the body parts is determined as the accumulation of all transformations of the connecting nodes. In case of the human body the model consists in fact of two parts (1) the geometry of the body parts and (2) the skeleton that connects them. An adequate visualization of a human requires many polygons. Kinematic animation is very flexible but also very computer capacity demanding.

In *key-framing* an animation rendering system will interpolate between two key frames and generate the in-between frames. The animation sequence of a moving virtual human is replayed in the 3D virtual environment. As a consequence all possible body parts displacements must be pre-animated before use in the virtual environment.

5 SYSTEM ARCHITECTURE

The predominant system architectures that can be found in literature on Virtual Human behaviour research are (1) agent-based system and (2) rule-based systems.

Agent-based systems are probably most widely spread for this kind of simulation system, such as Swarm (www.swarm.org) and Desire (Brazier et. al. 1997). This is not so surprising because autonomous behaviour of virtual humans concerts very well with agent concepts. The paradigm of agents is still quite young and agent-based systems are maturing but do not yet have as a sound scientific foundation as for instance the object oriented paradigm. The notion however that a virtual human behaviour simulation system must implement virtual human as self-contained objects is well-accepted. In agents systems each agent creates its own thread in order to control it by the agents controller. Agents communicate by message passing and have a shared memory in the agents controller.

Rule-base systems are especially suitable in the context of virtual human behaviour for expressing human decision making in pseudo natural language (Schweiss at. al. 1999). The reasoning process makes use of well-known methods such as forward- and back-tracking. RBS's require clear-cut conditions (e.g. chair not occupied) and actions (e.g. sit down). Major problem is how to derive these clear-cut rules from human decision-making. In reality many conditions are considered and weighted in one process step. Disentangling these considerations into independent decisions is not trivial.

6 RESEARCH METHOD

The long-term goal of the research project is to develop a system for the simulation of human behaviour in the built environment. The critical issue is the capturing of human behaviour or more precisely of human decision-making. To support the implementation of the simulation system we make use of camera observation and of a so-called Desk-Cave for data collection and validation.

Camera observation in a building as a method for data collection is rather straightforward. The only problem is that enough camera's are available to cover the whole area of study (e.g. a theatre) and that a camera position must be found in which persons will not be completely covered by other persons. Replaying the videotapes synchronously with a time counter and with a floor map of the room, the motions, the routes, the speed and the destination can be reconstructed for each person. Although camera observations are as realistic as possible, the limitation is that you cannot learn about the person's decision-making.

Figure 1: **Desk-Cave**

The Desk-Cave consists of a table with a projection at both sides and one screen at the back. Via a mirror above the table the forth image is projected on the desktop. Sitting behind the table the subject is surrounded by projections with the exception of the front/entry side and the ceiling. The Desk-Cave creates immersive virtual environments of rooms and spaces. In the Desk-Cave real humans can navigate through the virtual environment. While doing so, we can track their route, viewing direction, motion speed and moreover, ask them what their considerations are and to what decisions they lead.

7 IMPLEMENTATION

As a first outset in the research project, three systems are developed to support the test case: a simulation of people finding their way to a chair in a theatre. Perception is implemented making use of cellular automata. The 3D model of the theatre is fitted in a grid in such a way that a person and a chair occupy one grid cell and the spaces between the chairs and the corridors are bands of cells. While moving through the grid, a virtual person can inspect the cell around him to find out if another person occupies it. Though the CA system is capable of handling 3D grid cell structures, in this case we use it in a 2D manner, thus only one level of cells.

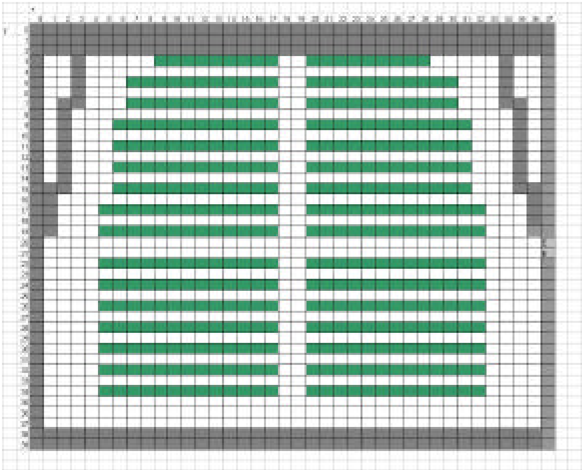

Figure 2: **Cellular Automata grid**

The current system is build up from a rather primitive action-selection-system that is simply implemented using If-Then-Else statements. The only action that can be selected is 'look for a free chair and walk to it'.

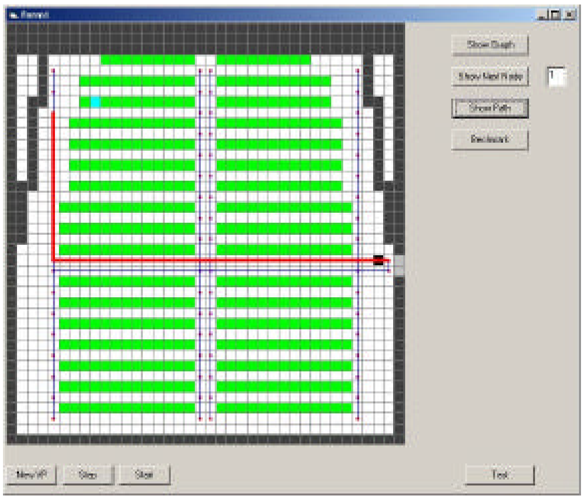

Figure 3: **Shortest path**

The initial action selection can be reset if the chair becomes occupied by another person while walking to it. Steering is driven by the shortest path calculation from the entry of the theatre to the chosen chair. For convenience the nodes of the route coincide with the centres of the grids cells.

Figure 4: **Theatre population simulation**

Locomotion was in this test case technically speaking the biggest challenge since we wanted a real-time simulation of at least a few hundred virtual humans. We started with kinematical animation of human figures, but even with a low number of polygons and thus rather crude looking figures we reached the limits of our hardware with only tenths of them. A solution was found by creating bill-board figures and animating the walking motion using a sequence of frames.

In the Class diagram the Grid class and the Cell class belong to the Cellular Automata system. The behavioural knowledge is included in the Virtual Person class. For the interaction between the 3D environment and the CA grid it was decided to implement two methods that will signal as soon as a Virtual Person crosses a (invisible) grid line. An alternative approach is to calculate the position of a VP by interpolation between two cell locations. The problem here is that a VP cannot move through the environment in a non-orthogonal direction. Secondly, the CA cells have to match exactly with the grid cells of the 3D environment. In the case at hand, this would mean that the space between two rows is equal to the chair dimension, which is obviously far from reality.

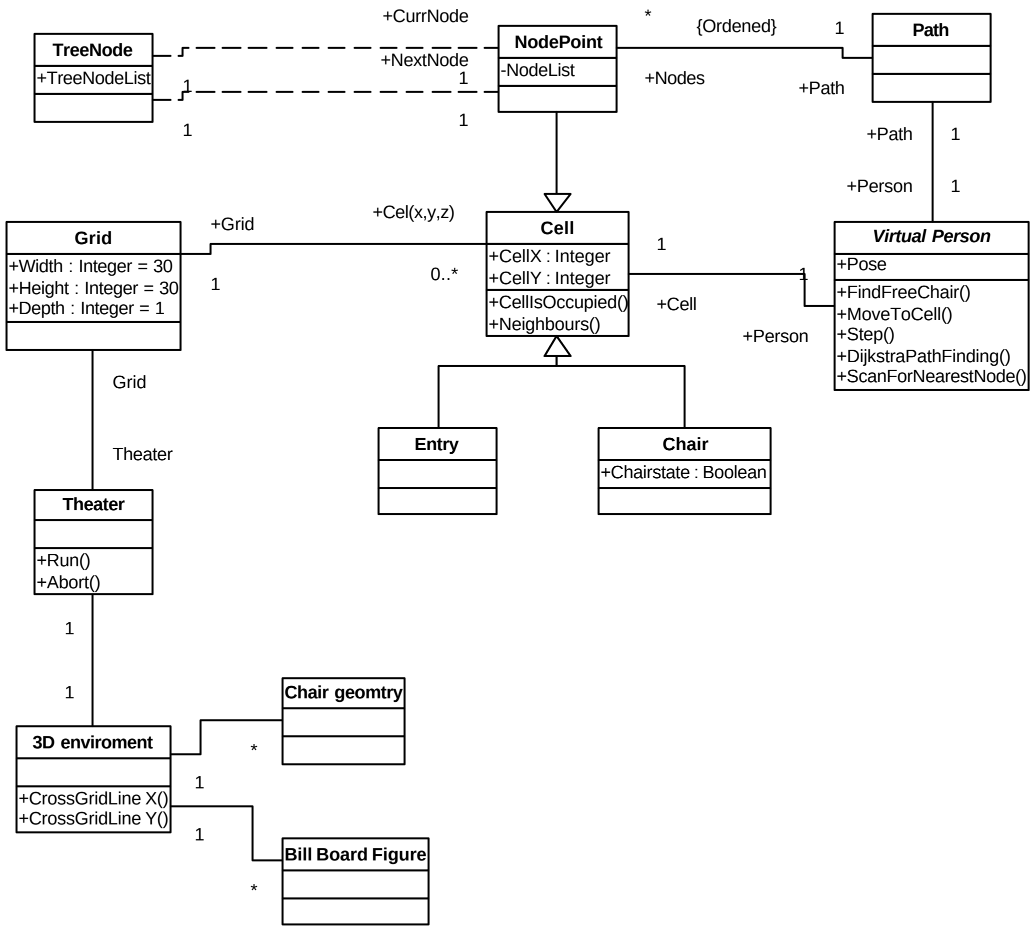

Figure 5: **Class diagram simulation system**

8 DATA COLLECTION AND VALIDATION

The data collection in the Desk-Cave will focus on the *path* that is followed by a person and the *chair* that is selected dependent on the *company* of a person, whether he/she has a friend in the *audience* and the *population* of the theatre.

Table 1: **Conditions**

Company	Alone, Together with acquaintance
Audience	No one familiar, Friend in the audience: Front, Aisle, Middle, Rest
Population	5 %, 50 %, 90 % full

Table 2: **Output data**

Path	Shortest path, Other path + motivation
Chair	Front, Aisle, Middle, Rest

The condition that the subject is accompanied with an acquaintance, is symbolized by colouring the accompanying virtual person red. The condition that the subject has a friend in the audience, is symbolized by colouring a virtual person in the audience red. The population condition is set by repeating the experiment with respectively 5%, 50% and 90% occupation of the theatre.

The path output data are registered by drawing the route on a map and making notes about the motivations for the preferred chair. The chair output data are marked on a map of the theatre with all the chairs. The population output data is noted by explicitly asking about the influence of already seated persons on the selection of a chair and on the route that is followed.

Total number of condition combinations is 2 * 5 * 3 = 30. In this set of combinations we can discriminate between experiments needed to deduced parameters and rules for individual behaviour and for social behaviour. The individual behaviour experiment consist of only 3 conditions, namely a single person finding his/her way to a chair when the theatre is 5%, 50% and 90% full.

At first we will analyse the results of the individual behaviour experiment to calibrate our simulation parameters and to adjust the decision rules of the virtual person. Then we will see how well the simulation matches with the recorded situation and decide if additional social behaviour experiments are relevant.

Parameters respectively Rules that are deduced from Desk-Cave experiment:

- Preference for chair in Front, Aisle, Middle, Rest (Parameter)
- Walking speed / Number of persons that enter the theatre per second as a function of time (Parameter)
- Motivations for an alternative Path (Rules)

Additional input parameters for the simulation experiment:

- Percentage of persons with a friend in the audience on entry (Parameter)
- Percentage of persons together with acquaintance on entry (Parameter)

Validation of the simulation is established by comparing the following data from the simulation with the same data derived from the recorded observation:

- Time per person to find a chair,
- Deviation from the shortest path,
- Distance covered per person to find a chair,

- Distribution of seated persons over time,
- Distribution of standing persons over time,
- Relocation of persons.

9 PRELIMINARY CONCLUSIONS AND FUTURE RESEARCH

Visually the simulation system is quite satisfactory. The title of this paper suggests conformance checking as the prime motivation to turn the simulation system into a design support tool. Regrettably, therefore the system is far too inflexible. Changing the design of the theatre to analyse the consequence of different widths of the corridors for instance, means refitting the 3D model into the grid structure. One way to proceed is automating this process, another way is not to use grids or some hybrid solution. Another consequence of grid cells is that the maximal density of a crowd is determined by the minimal cell dimension, in our case 60*60 cm.

A potential problem arises when virtual persons walk back and then bump into a virtual person walking into the opposite direction. Pass-by rules overcome this problem under most circumstances.

Fundamental problem for an accurate simulation is that we usually do not know the social behaviour input parameters (percentage of persons together with acquaintance, percentage of persons with a friend in the audience). Additional research is required to determine the influence factor and whether it is possible to deduce general rules for human behaviour within the built environment.

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