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ABSTRACT

The paper discusses an agent architecture for investigating visualized simulated pedestrian activity and behavior affecting pedestrian flows within the built environment. The approach will lead to a system that may serve as a decision support tool in the design process for predicting the likely impact of design parameters on pedestrian flows. UML diagrams are used to communicate about the interpretation of the agent architecture.

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 [35]. 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 behavior. This is all the more striking, as in architectural and urban design human behavior is the starting point. Why not test (intermediate) design performances by simulating human behavior? Therefore, we need virtual persons that show representative behavior and that allow us to analyze the performances of the design.

Scientifically, a lot of research is related to the design process by using virtual humans as substitutes for testing and evaluation purposes, such as hazard situations, crowding and queuing, wayfinding, perception, building efficiency, and training.

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

More seriously, we want to take this one step further by developing a system that relates human behavior to design parameters. For example, consider the design of a shopping center. Critical performance indicators related to human behavior include the distribution of visitors across the center as a function of layout, and the functional characteristics of the center and its shops.

The conceptual underpinnings of the system approach are based on a hybrid approach including cellular automata and agent technology. The system simulates how agents move around in a particular 3D environment, in which space is represented as a lattice of cells with local states, subject to a uniform set of rules, which drives the behavior of the system. Agents represent whether virtual humans or more specifically pedestrians with their own behavior, moving over the network. First, the approach in a 2D environment will be worked out for verifying the underpinnings.

The paper is organized as follows. First, we will give some background of the motive of developing a multiagent system for simulation pedestrian behavior. Next, we discuss some related research. Than, we will discuss the pedestrian model and agent structure. Next, we will discuss the simulation of pedestrian behavior. We will conclude with a brief discussion.

2. BACKGROUND

Since the 1990s, several models of pedestrian movement and pedestrian traffic flows have been developed. Noticeable is the success of cellular automata models in various disciplines, including transportation (e.g. [7,23,29]). Most models are concerned with pedestrian movement in hazardous situations, such as evacuation and escape situations (e.g. [19,21,24]). After the September 11 disaster, great importance has been attached to these models because the prediction of such behavior is of great public interest.

In line with this tradition, several years ago we started a research project that has received the acronym *AMANDA*, which stands for A Multi-Agent model for Network Decision Analyses. The purpose of this research project is to develop a multi-agent system for network decision analyses [12]. The term network decision analysis is used to encompass all design and decision problems that involve predicting how individuals make choices when moving along a network such as streets and corridors in a building.

The popularity of cellular automata models is possibly based on its property that simple principles can be used to successfully simulate complex traffic flows. A cellular automata model therefore seemed suitable to simulate other types of movement in an urban environment. Based on the Nagel-Schreckenberg model the dynamics of cellular automata models have been investigated [25,17,5]. The generalization of cellular automata models from simulated traffic flows to pedestrian movement is considerably more complicated. While car movements are restricted to lanes, pedestrian movement is a complex and chaotic process. Nevertheless, available evidence [6] indicates that cellular automata models are powerful tools to simulate pedestrian movement. Road traffic simulation and generation [11,28] as well as intelligent traveler information systems, traffic management [20,32,22] and driving agent [16,33,18] systems are subjects in the context of traffic analysis and finding efficient ways to model and predict traffic flow.

Previous models of pedestrian behavior have focused primarily on movement rules, lane forming and crowd dynamics. We want to extend these models with destination and route choice, and activity scheduling. To that effect, we started with the basics of other approaches that have focused on destination and route choice [8,9]. In these approaches, it was not so much the actual detailed movement itself, but rather the outcomes of such movements in terms of destination and route choice that were the purpose of the modeling process.

We assume that in turn destination and route choice decisions are influenced by factors such as motivation, activity scheduling, store awareness, signaling intensity of stores, and store characteristics.

3. RELATED WORK

Agent-based modeling of pedestrian movement in urban spaces, especially the implications for the design and modeling of effective pedestrian environments has been discussed in the research of Willis *et al.* [34]. Microscopic movement trajectories of involved pedestrians were investigated in a video-based observational study. The results of this study led to a clear insight into individuals' movement preferences within uncluttered environments, desired walking speed, microscopic position preferences, etc. In other words, insight into movement principles that are of interest in steering mechanism approach.

Research on multilayered multi-agent situated systems provides a framework that explicitly defines the spatial structure of the environment in which a system of situated agents act and interact [3,4]. With respect to agent behavior, both agent state and position can be changed by the agent itself according to a perception-deliberation-action mechanism. In the perception view, an agent state determines receptiveness and sensitivity. Receptiveness modulates field intensity and sensitivity filters not perceivable signals; where field diffusion emits signals that spread throughout the spatial structure of the environment. At this, we perceive some correspondence with the *AMANDA* environment; signaling intensities of objects can spread throughout the cellular grid that contains information about agents and their occupation. Agents can perceive their environment and sense the information the environment contains.

Nagel [26] pointed out that traffic simulations need to include other modes of transportation besides car. In a multi-modal approach a conceptual representation of network layers provisions for multi-modal trips is explained. Balmer *et al*. [2] distinguish two layers of a mobility simulation system: the physical layer and the mental layer. The physical layer simulates the physical world where agents move, avoid each other, go around obstacles, etc. In the mental layer, agents generate strategies, such as routes, mode choice, daily activity plans, etc. In addition, a feedback is used for adapting mobility simulation results to the initial mental condition. Hereby, simulation results are the outcomes of computing strategies by running the mental module. Starting from our ideas about activity behavior and movement, we notice some similarities. An agents' activity agenda will be updated after an action selection that influences the movement pattern.

4. PEDESTRIAN MODEL

We want to extend the virtual human behavior approach to a more generic approach by introducing more behavioral concepts. To populate an environment with agents representing pedestrians, we will consider a shopping mall or shopping environment with shopping pedestrians. Consider a shopping mall or shopping environment with shopping pedestrians. This environment consists of streets, which can be represented by a network consisting of N nodes and L links, and a set of establishments, consisting of J stores, restaurants, etc. A subset E of these N nodes represents the entry/departure points of the system. Let us assume that the pedestrians can be represented by a multiagent system approach with I agents. Each agent i is supposed to carry out a set of activities A_i. That is, agents are supposed to purchase a set of goods, become involved in window-shopping, and possibly conduct other activities such as having lunch, going to a movie, etc. We assume that the activity agenda is time-dependent to allow for changes in the agenda during the trip. The need to actually realize the various planned activities may differ, partly in relation to the nature of the trip. If the reason for the trip is primarily leisure-oriented, the goals and activity agenda may be relatively fuzzy. In contrast, if the trip is initiated because of some urgent goal, the need to realize the activity that serves this goal would be high.

We assume that the completion of an activity is a key decision point, where agents will adjust, if necessary, their activity agenda and anticipated time allocation to the activities not yet completed. Another decision point is every node of the network where agents may decide to take another route, changing the anticipated duration of the overall visit in the shopping center.

Agents can perform the activities in a set of J stores or establishments. Over time, agents form and update beliefs about these stores. We assume that that these beliefs are a function of the degree to which the beliefs of the store, driven by their actual attributes, match the agent's ideals.

In order to implement the activity agenda, the agents need to successfully visit a set of stores and move over the network. We assume that the agents' behavior is driven by a series of decision heuristics. Agents need to decide which stores to choose, in what order, and which route to take, subject to time and institutional constraints. We also assume that agents are in different *motivational states*. They may at every point during the trip have general interests in conducting particular activities, without having decided on the specific store or establishment to visit, but they may also be in a more goal-directed motivational state in which case they have already decided which store to visit.

When moving over the network, we assume that agents have *perceptual* fields. *Perceptual fields* may vary according to the agent's *awareness threshold*, which in turn may depend on his motivational state, age, travel party, eye-sight, and the like, and the *signaling intensity* of the store, which is assumed a function of distance, appealing architecture, and whether or not the view is interrupted by other agents [13].

5. AGENT ARCHITECTURE

5.1 General description

To better communicate our interpretation of agent architecture, we use UML (Unified Modeling Language) diagrams to guide an implementation design

Vidal et al. [31] point out that is not trivial to implement common agent architectures using object-oriented techniques. They make a UML agent description by figuring out agent features that are relevant to implementation: unique identity, proactivity, autonomy, and sociability, inherits its unique identity by being an object but an agent is more than just a single object. The mentioned features proactivity, autonomy and sociability have to do with the common agent notion that an agent perceives its environment, uses what it perceives to choose an action and then perform the action.

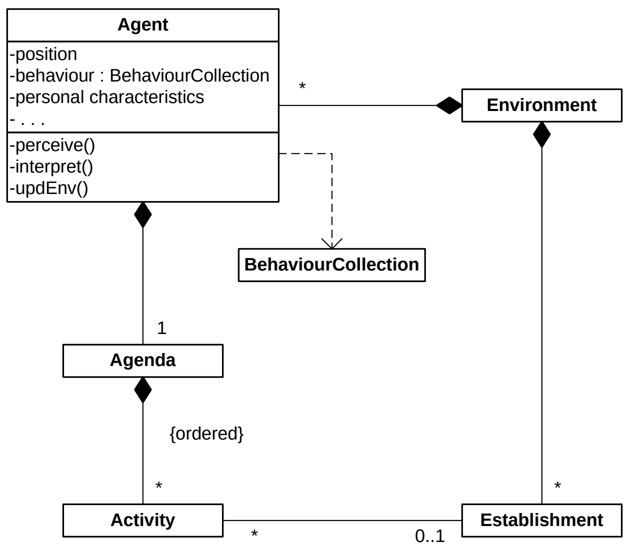

Figure 1. UML diagram of a pedestrian agent

Figure 1 shows the initial concept of a pedestrian agent description as basis a generic agent structure that can be applied. By declaring the methods *perceive, interpret* and *updEnv* private, the agent has its own control of the methods. The declaration of *behaviour* represents the set of possible attitudes. In this diagram it is not worked out.

The environment consists of streets, a set of establishments and pedestrians represented by agents. Streets are presented as a cellular grid, which is used to simulate agent movement. An agent moves with his own behavior and personal characteristics. Every time step, there is an update about agent's positions. In fact, each cell in the cellular grid can be considered as an information-container object. It contains information about the signaling intensity of an establishment and information about agent's positions. We regard a restricted environment *E* of an agent in the cellular grid. The cellular grid provides percepts to the agent and the agent performs actions in them. Therefore, we distinguish the functions perceive and interpret:

$$Perceive: E \rightarrow P^*$$

The function *perceive* represents the perception process of the agent. It maps the environment *E* to a set of percepts. The function *interpret* represents the decision making process of the agent and has a more complex form because an agent has an internal state, which includes the built-in knowledge. The function *interpret* is of the following *type*:

$$Interpret: P^* \times I \times G \rightarrow A^*$$

The *interpret* function maps the perception (*P*) of the environment, the current internal sate (*I*) and the current activity agenda (*G*) into a list of one or more actions *A*, for instance The interpret function updates the internal state based on its percepts and the activity agenda; select actions (*act*) based on the updated activity agenda and the *updated* internal state.

$$UpdStatePandG: P^* \times I \times G \rightarrow I \times G$$
$$act: I \times G \rightarrow A^*$$

The function updEnv represents the reaction of the environment to the agents' actions.

$$UpdEnv: E \times A^* \rightarrow E$$

A new state of the environment is realized.

5.2 Basic Agent

Figure 2 represents a UML diagram of the suggested agent architecture. In particular, the upper part of the diagram provides the agent description. The Agent class is of the type BasicAgent, which consists of a Body and a Sensor. This corresponds with Brooks' notions about thought and reason [10]. In the discussion about behavior-based robots, he characterizes among others the key aspects situatedness and embodiment. In our case, the Body embodies the object in question in the urban environment, and the Sensor is needed to observe the visual area. The Body class has attributes that specify an agent's position, direction, speed and other object specific attributes that define its movement in the regarded environment. The Body class is of the type Vehicle with basic attributes of its movement through the environment. For its part, the Vehicle is of the type Movable with a position and bounding box. In other words, the Body has dimensions and is movable with a certain speed and direction. The Body implies the characteristics *Situatedness* and *Embodiment* [10]. In our case, the Body represents a pedestrian, is situated in the world and experience the world directly.. The suggested description involves other approaches of body, for instance driver.

Furthermore, the Agent will be driven by the Brain. It reflects the relationship between the mind and the brain. What is perception and how is it related to the object perceived. While the mind remains a mysterious and inaccessible phenomenon, many components of the mind, such as perception, behavior generation, knowledge representation, value judgment, reason, intention, emotion, memory, imagination, recognition, learning, attention, and intelligence are becoming well defined and amenable to analysis.[1].

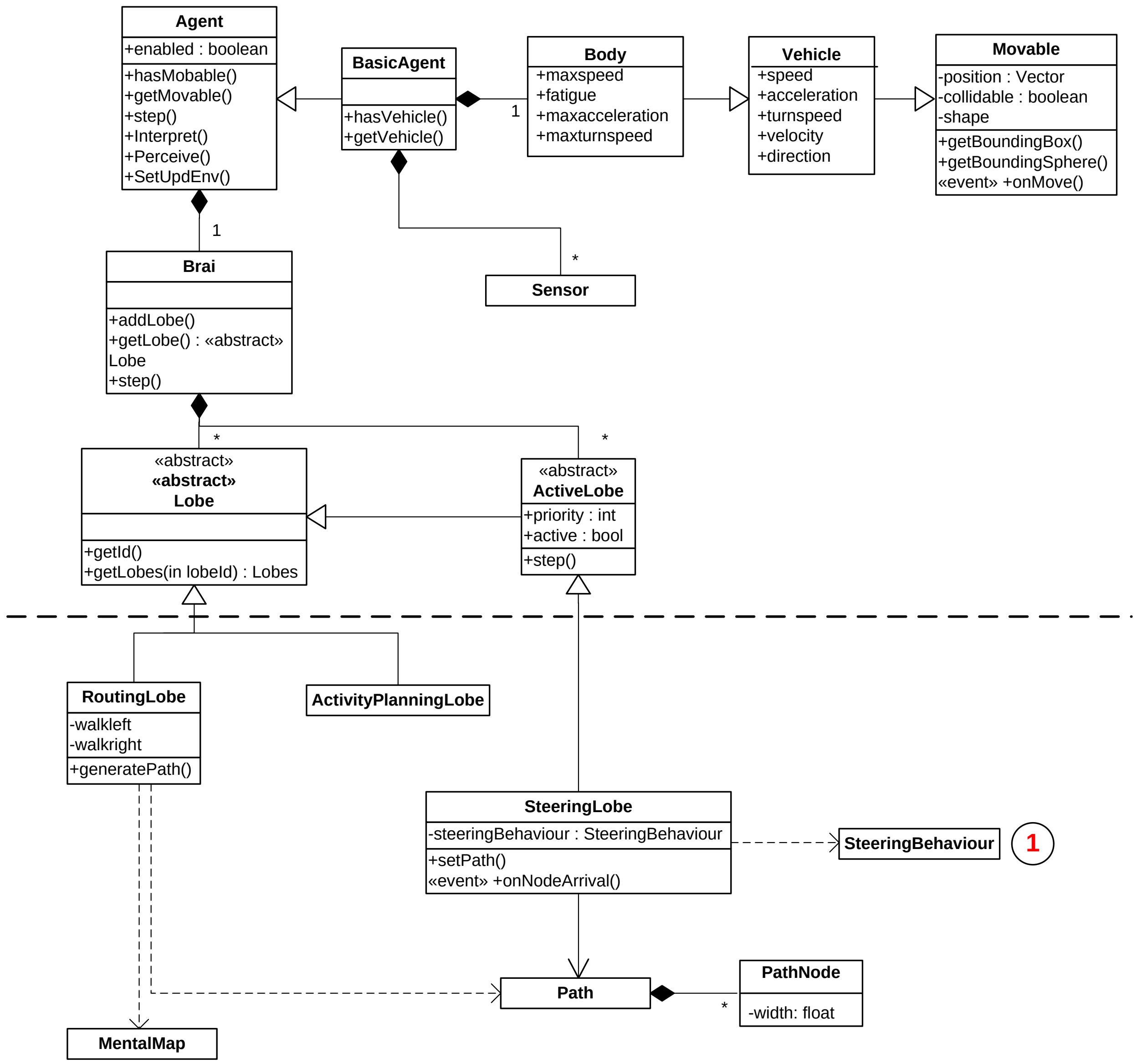

Figure 2. Agent Diagram

In this way, the Brain consists of functional elements. On the one hand, behavior generation such as the planning and control of action designed to achieve behavioral goals, on the other hand sensory perception for the transformation of data into meaningful and useful representations of the world. We assume the Brain class consists of active and passive lobes that can be extended with other lobe such as ShoppingLobe that is not included in the diagram. Active lobes are lobes for which the step function will be called regularly; they are continuously active. On the other hand, Passive lobes must be triggered before its specific functionality getting active. Subtypes of the ActiveLobe class are among others the SteeringLobe class which drives steering behavior; which differs from agent to agent. The SteeringBehaviour class is connected with the SteeringLobe class (quoted as 1. in figure 2.). Herein, the SteeringActuator class executes a behavior and let an assigned vehicle move according to that behavior.

Other subtypes of the ActiveLobe class are the PlanCheckerLobe, the SensingLobe class, and the ConductActivityLobe class. PlanCheckerLobe checks if the activity schedule needs to be updated because the current plan is not accurate or viable anymore. SensingLobe will be a special event generation system. ConductActivityLobe simulates doing an activity. Subtypes of the passive Lobe class are the RoutingLobe class and the ActivityPlanningLobe class. RoutingLobe uses visible data from the neighborhood and data in memory for parts of the environment that are not visible to plan routes. The ActivityPlanningLobe makes up an activity schedule.

5.3 Steering Behavior

Graphs are used for path finding to a specific location in the environment; each node of the graph has a corresponding location in the 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.

The cellular grid divides the environment in cells. 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 neighborhood 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).

Figure 3 shows the steering behavior diagram; the SteeringBehaviour class determines the existence of the vehicle and how behavior is assigned to that vehicle. SteeringActuator executes a behavior and an assigned vehicle moves according to that behavior which includes all checks and the movement itself. The composite design pattern SteeringComposition indicates how the different SteeringBehaviours are coordinated. The steering behavior diagram is the base of the steering algorithm and contains different methods of combining steering behaviors and is extendable. The steering algorithm will make use of the properties to determine its behavior but also the composition of steering behaviors will influence the way the steering will work. Vehicles use steering behavior including (i) path following to follow paths generated by path generation algorithms, (ii) unaligned collision avoidance to avoid collisions with moving objects or agents, (iii) obstacle avoidance or containment to avoid bumping into static obstacles and buildings, and (iv) non penetration constraint to avoid vehicles to overlap with each other or obstacles. The steering module will complete integrate with the environment. Figure 4 shows a simplified steering object diagram.

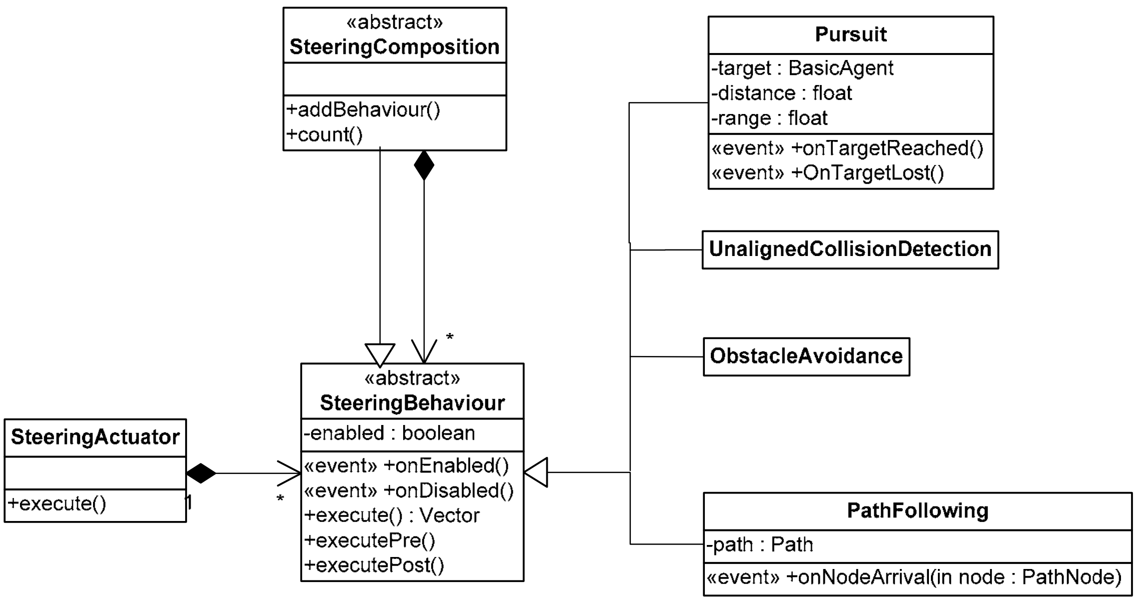

Figure 3. Steering Diagram

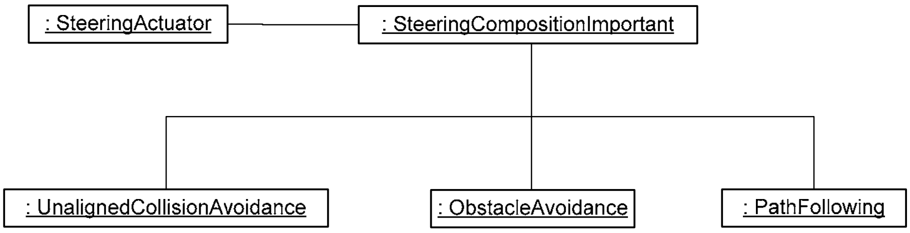

Figure 4. Steering Object Diagram

5.4 Environment model

In the *AMANDA* model system, we populate an environment representing pedestrians. Polygons are used to indicate borders and functional areas like walkways. Discretisation of these polygons generates a grid of cells, which is called a cellular grid. Therefore, a cellular grid together with the polygons represents the environment. Each cell in the cellular grid can be considered as an information container object. It has information about which agents and polygons occupy it. Also, it contains information about other features such as appearance characteristics or establishments that are observable from that cell.

Figure 5 shows the environment diagram. The environment class consists of a cellular grid and a Layer class. Movables can be positioned in cells of the grid. The environment will use layers to classify the meaning of the containing polygons.

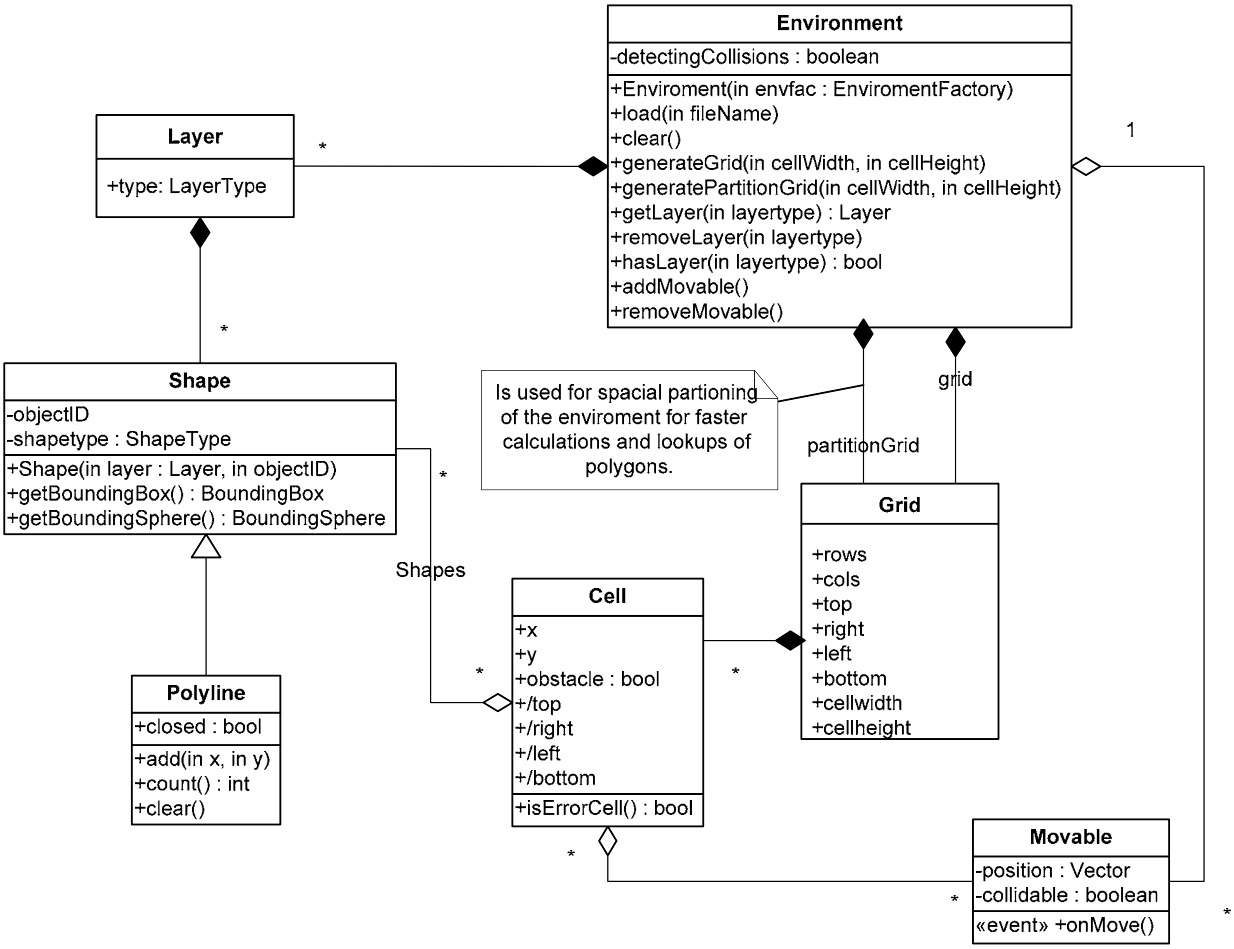

Figure 5. Environment Diagram

We suggest a dual definition of the environment. The environment is defined using polygons with a reference to one information object for each polygon. Otherwise, the environment is described as a lattice of cells. Each cell references to an information object. Often, a lot of cells will reference to the same information object, simply because for example a stroe will be made up of multiple cells. Also a cell could involve information about the attraction of a store, smell, noise, etc. Cells nearby the store have a more noticeable perception than cells farther away.

6. PEDESTRIAN SIMULATION

Two aspects are relevant for understanding the simulation of individual pedestrian behavior: steering including path determination, and action selection including strategy, goal formulation and planning.

Action selection ➔ *Steering* ➔ *Movement*

6.1 Action selection

We assume that pedestrian movement is embedded in the larger problem of activity scheduling [30]. It is assumed that individuals made decisions regarding their activity agenda, destination and route choice when moving over the network. We assume that the completion of an activity results in adjustments, if necessary, of a pedestrian's activity agenda.

In other words, action selection can be viewed as scheduling and rescheduling activities. Such scheduling decisions involve decisions about which activities to conduct, where, in what order, when and for how long. Pedestrians can perform the activities within the shopping environment in a set of stores or establishments.

Action selection may depend on personal characteristics, motivation, goals, time pressure/available time budget and familiarity with environment respectively stores and establishments. In addition, store and establishment characteristics, duration, and awareness also influence the scheduling of a pedestrian's activity agenda [13].

The visible action of the agents is movement, which realizes a new agent's position on the cellular grid. A behavior can be distinguished into a hierarchy of three layers: action selection, steering and movement [27].

6.2 Steering

Steering reacts to continuous changes in the environment. With respect to navigation, an agent may decide for a faster or slower lane, window-shopping is done at the outer lanes; there is tendency to keep right (left), etc. Speed may be influenced by socio-economic variables (gender, age, etc.), physical features such as obstacles, passages, crossings, and width of the corridor or street. All these facets influence agent movement and are part of the simulation process.

6.3 Illustration

The simulation of pedestrian behavior will be applied to the city center of Eindhoven as an illustration. Behavioral principles towards perceptual field and activity agenda of agents in particular environments are described elsewhere [13].

As a consequence, data requirements are formulated and empirical data were collected by interviewing pedestrians at several points along the main shopping street. Pedestrians were asked to list the stores they perceived immediately after crossing some point on the network. One group of pedestrians was asked to list the stores they perceived in front of them. In an attempt to obtain as reliable data as possible, respondents were first unobtrusively triggered to change their position such their back was turned to the shopping street in their walking direction. A second group of pedestrians was asked to list the stores they were aware in the section of the shopping street they had just passed. These collected empirical data were used to estimate the parameters of the equations that drive the behavior principles of the simulation [14]. First empirical results of a model predicting the perceptual field of agents moving over a network has been reported in Dijkstra *et al.* [15]. Herein, it was hypothesized that the probability of spotting a store is a function of the signaling intensity of the store and awareness threshold, which in turn is a function of distance and some other factors.

7. DISCUSSION

In this paper, we have set out the agent architecture for simulating pedestrian behavior. In a way, it is hybrid approach; on the one hand the actual movement of pedestrians is based on steering. On the other hand, an extension of the cellular grid is proposed by preserving information about objects like establishments etc. and the state changes in cells besides the agent's position.

As opposed to other existing traffic behavior models, we show an agent diagram for a better understanding of the mechanisms of the model system. Besides the basic agent diagram, also the mechanism of steering behavior is

The *AMANDA* model system where the above discussion proceeds, is currently under development to allow designers, and urban and transportation planners to assess the effects of their policies on pedestrian movement. At this, the main part of the agent diagram and the environment diagram are already implemented.

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