AN AGENT-BASED STREET SIMULATOR

CHIUNG-HUI CHEN
Department of Digital Media Design, Asia University, Taiwan

ABSTRACT: This paper aims to study interactions between a behavioral model of pedestrians and urban spaces, and regards micro-scale urban spaces as its target. This paper suggests constructing and analyzing a pedestrian behavioral model using the “Attention Theory”, and introducing the rules and attributes of agent behavior oriented simulation. Based on the validation of actual street cases, the findings show that the pedestrians can be represented by an agent program, and behavioral reactions of walking agents under different stimulus can be further simulated.

KEYWORDS: Agent, attention, behavior, simulation

RÉSUMÉ: L’objectif de cet article est d’étudier les interactions existant entre les types de comportements des piétons et l’espace urbain. L’étude porte sur les micro-espaces. Nous proposons la construction et l’analyse de modèles de comportements en utilisant le « Attention Theory », et en introduisant des règles et attributs aux agents de comportement. En nous basant sur la validation d’études de cas réelles, nous démontrons que les piétons peuvent être représentés par des agents et que leurs comportements sous différents stimuli peuvent être simulés.

MOTS-CLÉS: Agent, attention, comportement, simulation

T. Tidafi and T. Dorta (eds)
Joining Languages, Cultures and Visions: CAADFutures 2009
© PUM, 2009
1. INTRODUCTION

Spatial cognition and pedestrian movements in cities are important issues for urban designers in spatial planning and analysis. Generally speaking, a pedestrian’s behavior and spatial selection are influenced by current environmental information and past spatial experiences. Present studies on individual models of pedestrians can be divided into three categories: 1) the first category concerns the geometric attributes of movement; 2) the second category aims to explore the correlation between the itinerary and destinations of a pedestrian’s movements; 3) the third category treats spatial cognition as the research orientation method. However, there are few models integrating the issues of these three aspects (Batty 2001). The construction of a pedestrian model is associated with spatial structures, important locations, and spatial cognition. These factors also reflect the issues of urban design. Spatial structure involves the characteristics and limitations of the present space. For example, geometric features of streets tend to be the base of urban spatial limitations and developments. Important locations are the centers of urban activities and spatial cognition is related to the users and their spatial experience. By integrating the three aspects, the simulation of design projects can be more complete. According to the spatial scale, the study of pedestrian movement models, include both macro and micro levels and the factors and research directions of the models differ. For instance, Helbing et al. (2001) targeted on physical model of particle flow and lead the agents to have rich behavior by simple rules. “STREETS” model of Schelhorn et al. (1999) assumed that the pedestrians’ movement is influenced by both spatial structure and local attractiveness. They apply social and economic data as quantitative base of the pedestrians’ movement in the cities to construct different agents’ possible itineraries. “SimPed” model of Jiang (1999) constructs the basic framework of the model by environmental psychology and spatial syntactic principles and analyze the visions as the base to construct sight scope and sight distance. The said researcher assumes that the vision represents all possibilities of walking, leads the pedestrians’ selection of the next walking and further establishes the relationship between the pedestrians’ movement and spatial structure. However, the above-mentioned studies only targeted on different pedestrian movements, according to different destinations, which further influences overall flow, and did not explore the design-oriented spatial meaning.

In addition, the study of individual behavior simulation in the computer animation field is common and the one most representative is Reynolds’ (1987) Boids Model simulation, which is based on three types of virtual forces: separation, cohesion, and alignment, thus, Boids Model can maintain speed, distance, and show group movement. Reynolds (1999) extended the original model by adding features, such as seek, and flee, pursuit, wander, and obstacle avoid-
When these behaviors are integrated, they become a complicated system. Helbing and Molnar (1995) established a Pedestrian Dynamics model, which proposes the concept of social force. The agent’s movement relies on the interaction of four types of force; 1) self-driven to destinations; 2) separation to avoid others; 3) separation to avoid walls; 4) and attractiveness to exits. Helbing et al. (2000) simulated panic escape by social force and the result shows that the people block the door in an arc, which matches reality. These researchers suggested that, an increase of exits does not significantly improve panic escape. Borgers and Timmermans (1986) predicted pedestrian movement through gravity models in Markov chains. Saunders (2004) extended Helbing’s social force with the addition of the curiosity theory (Berlyne 1960). After each interaction, agents will accumulate their curiosity to others. The figures influence the agent’s group movements, and lead to complicated behaviors. We thus apply this model in the design evaluation of exhibit space.

As discussed, past studies on pedestrian's spatial movements selection were in the scope of an individual’s serial spatial selection. The conditions of this kind of model refer to an individual’s space with complete information. However, in reality, an individual’s understanding of the environment differs due to their degree of cognition, and thus, the research findings tend to be extremely different from reality. This misdirection leads to researchers looking for an individual’s decision-making process through cognitive behaviors. Therefore, this paper intends to study the influence of a pedestrian’s spatial cognition on spatial selection. From the perspective of the pedestrians, we applied the 'attention' theory and integrated street space design knowledge and an agent model. The concept of the theoretical model includes three dimensions; urban street design, agent behavior, and attention theory. The purposes of construction of the model are exploring the correlation between the pedestrian's movement, the behavior model, and design of spatial locations. The order of this paper is as below: Section 2 describes related theories, and defines agent behavior and attention; Section 3 elaborates on the module interface of the system; Section 4 is case study and the results of simulation; Section 5 offers the conclusion.

2. DEFINITION OF AGENT BEHAVIOR AND ATTENTION

The pedestrian design in this paper is based on the individual design. The characteristics of agent behaviors and guidance of attention in the space are described below.

2.1. Guidance of attention in a space

Attention studies have targeted internal processes to examine a human's ability to select and distribute cognitive resources. On the contrary, they rarely
explore how attention influences the output of the behavior system or reaction proposed in this study. In short, attention is based on spatial selection, which is referred to as space-based attention. However, according to the experience of daily life, occasionally the targets we give attention to or select are objects instead of simple spatial location, and are thus called object-based attentions. In the early 80s, studies that explored the characteristics of attention by spatial orientation tended to define attention as a kind of spotlight model. Thus, many researches have proposed the orientation characteristics of attention, particularly the methods to activate attention; “endogenous orienting” and “exogenous cuing attention”. Scholars have proposed extremely different views on the influence of the two orientations regarding movements of attention. For instance, Egly et al. (1994) suggested that endogenous orienting tends to result in space-based attention selections. However, Goldsmith and Yeari (2003) offered new suggestions, one of which was their conclusion based on exogenous cuing attentions (attention focusing hypothesis). Based on this hypothesis, in experimentation of exogenous cuing attentions, prior to the cue, participants must maintain a large scope of attention because they could not predict targets in advance. Attention distribution certainly includes the targets that lead to object based selections.

According to physical limitations of humans (Sanders et al. 1993), this paper set the agent’s visual field at 90–120 degrees. The definition of visual field is as shown in Figure 1. For example, in Figure 2, No.1 is the moving agent with one solid line vector, which refers to the agent’s speed and direction. In the visual field, No. 1 agent can see No.2, and thus, there is drive between them. No. 3, 4, and 5 agents are out of the visual field, and are therefore, less likely to draw the attention of No. 1 agent.

2.2. Characteristics of Pedestrian-Agent Behavior Mode

Arthur and Passini (1992) indicated that studies on the relationship between human activities and space information can provide a general principle for design in environmental planning. However, these types of study must collect sufficient data, which is not easy. Since in a real environment, observation of human behav-
ior requires a lot of time and energy; it is also quite difficult to accurately identify the main factors of human behavior. Business activities in different natures are gathered on streets; hence, the behaviors of crowd activities are reflected in a wide difference. Business types determine the nature of activity; whether business type in the same or similar nature gathers on the same street also determines the characteristics of the street itself. This study adopted the famous business and recreational streets in Taiwan as the simulated environment to observe the behaviors of pedestrians in the street space. By employing the surface atlas recording and analysis to record the behavioral modes of the subjects, this studied conducted indirect observations, such as illustration, photographing, and video-recording. Two methods were adopted for observation: (1) follow the pedestrians, photograph and record the important tracking observations; (2) conduct important fixed-point observation on a certain pedestrian in a surveyed area street space in order to obtain the tracking atlas of the moving process. The main purpose is to observe the interactive behavior between pedestrians and street environment, and survey the types of information produced by the environment that the pedestrians would notice when walking on the streets. Based on the above, we include behavioral rules and attributes to these three types of agents, and construct virtual forces to determine their preference of actions, as shown in Table 1. This paper studies the influence of stimulus, as found on urban streets, on a pedestrian’s behavior.

**Table 1. Characteristics of Pedestrian-Agent Behavior Mode.**

<table>
<thead>
<tr>
<th>Type</th>
<th>Characteristic</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive-Agent</td>
<td>The first is the wandering reactive-agent, who will move without any stops and motivations and destinations are unclear. The agent moves randomly, without intentional direction or itinerary.</td>
<td>Random Movement: Motives and target activity points are vague, and random moving tracks have no particular direction or route.</td>
</tr>
<tr>
<td>Proactive-Agent</td>
<td>The second is a proactive-agent, who has the capacity to recognize and select a space, including stops and movements. During movement, the said agent determines and selects attractive locations. In other words, during the process, the agent continues determining the next destination.</td>
<td>Scattered Destinations: Scattering of target activity points; the moving process is essential in selection and determination for the attractive activity point.</td>
</tr>
<tr>
<td>Motivate-Agent</td>
<td>The third is a motivated-agent, who intentionally explores the environment. This agent will observe interesting things from far away and move quickly toward the target. Motivation is simple and clear with definite purpose. Thus, movement will lead directly to the destination.</td>
<td>Single Destination: Single and specific motive with clear behavioral objectives; the moving mode will directly reach the target activity point.</td>
</tr>
</tbody>
</table>
3. SYSTEM ARCHITECTURE AND INTERFACE

The significance and relationship of the system component is shown below, in Figure 3. The concept of the architecture is based on behavior selection in an environment, where perception and preference lead to decisions. We emphasize the pedestrian’s attention, recognition, and selection process of spatial cognition to obtain the differences of their spatial cognition in an environment. Each pedestrian was regarded as one computer agent, who has different behavioral reactions of cognition and attention toward urban streets. We can adjust the agent’s parameters, including distance, vision, and speed in order to result in a virtual force influencing the agent’s movements. The virtual platform system of this paper is developed by Java language upon Applet. The overall design framework is as below: 1. Basic Settings 2. Time 3. Scene Settings 4. Entry Settings 5. Agent-Quantity Settings 6. Simulation Settings. The module functions of the systems and the operational processes of the interface are as below, as shown in Figure 4.

- “Basic Settings”: For each type of agent we set the walking distance, horizontal visual distance, visual angles, moving processes, and radius of the proper distance to other agents.
- “Time”: The simulated system time is equal to the real time. The time ratio in execution and the setting of “delay” is explained as follows: Assuming that the delay is 10 milliseconds, the time ratio is 100:1 (one second=1000 milliseconds). For instance, 30 minutes in real time equals to 18 seconds (30*60sec/100=18) of simulation time. The time displayed in the simulation process is the real time. In the setting of “centimetres per pixel”, since the system uses full scales when generating scenario element block, to reduce the full scale onto the system screen, the parameter settings of centimetres per pixel are provided. In other words, 1 pixel on the screen equals to 1 cm in the full scale.
- “Scene Settings”: We constructed the stimulus on actual streets, including solid and virtual elements, such as east, west, south, and north of the shops, positions of the furniture of the street, rest areas, fountains, markets and squares, food stands, and activities. We set the scale of each element, geometric forms, and the scope for walking and traversing. In addition, “attractions” includes three intensities: low, medium, and high. For instance, the ones with high attraction will easily attract more agents.
- “Entry Settings”: Designers may arrange entrance position of the street space. If more than two entrances are established, the system will calculate the flow of pedestrians, based on the level of each entrance, assign to different entrances according to the number of pedestrians set up by the designers.
- “Agent-Quantity Settings”: We set three types of agents: Reactive-Agent with a green moving path, Proactive-Agent with a blue moving path, and Moti-
vated-Agent with a red moving path. For each kind of agent, we respectively set the number and the walking speed of every minute.

6. “Simulation”: Within the settings, we have districts and simulation results.

**FIGURE 3. SYSTEM ARCHITECTURE.**

**FIGURE 4. PROCESSES OF SYSTEM INTERFACE.**
4. CASE STUDY - SHOPPING STREET

Shopping street has unique characteristics. “Jingming 1st Street”, the target of this paper, is located in the 5th rezoning area of Taichung City, Taiwan, as seen in Figure 5. In terms of urban structures, the east side is the old downtown, and the west side is the administrative center of the new city. The location becomes critical for connecting different areas. Jingming 1st Street runs in a south-north direction, and the businesses involved tend towards food (22.5%) and clothing industries (55%). There are 42 shops within the surrounding buildings. Thus, Jingming 1st Street, which is mainly based on open-air walking space, has positive climatic conditions for pedestrians. The width of the street is 8 m. Since there are 4 m for the porches of the surrounding buildings, the actual width is 16 m, and the length is about 130 m. For the pedestrians of both sides, we installed rain shower awnings above the windows and shop signs to create a natural shopping space.

4.1. Stimulus

In the environment, the people’s behaviors are maintained and operated by fixed, semi-fixed, and non-fixed objects, which can be treated as the information in the environment. People thus recognize the information, and furthermore have interactions, behaviors, and action matching the scenarios. Thus, the information of the street design is critical with respect to the meaning of a communicative environment and behavioral rules. This paper follows the concept of Rapoport (1982, 1987) and reorganizes the stimulus of Jingming 1st Street, as shown below, according to the characteristics:

- Fixed-feature elements: They are fixed, such as the façade of the shops, furniture on the street, street lamps, etc. The organization of these elements
defines the size and scale of the space. In addition, on streets in Taiwan, ads are placed on the pillars of the porches to draw the attention of the pedestrians.

- **Semifixed-feature elements:** These are varied, such as shop signs, plants, displays, outdoor cafes, food stands, etc. Semifixed-feature elements include movable objects. We find the meanings of semifixed-feature elements on the streets of Taiwan. They reveal personalized aspects and imply potential function. Semifixed-feature elements no longer function superficially in cultural systems. Because of information complexity, semifixed-feature elements have more hidden environmental meanings, which will further draw the pedestrian’s attention.

- **Nonfixed-feature elements:** They are the pedestrian's non-verbal behaviors, such as changeable poses, facial expressions, and unconscious visual exchanges, etc.

The above stimulus draws the pedestrian’s attention to environmental factors. Those with new, and special content will satisfy the pedestrian’s psychological need to pursue new things. Though some of them are useless, they trigger other activities for the pedestrians. For instance, the crowd on the streets might imply activities. The elements will lead to the pedestrian's behavior during the process of satisfying activities and their adjustment to the next destination. Their ultimate intentional activities or moving to other locations will be affected.

### 4.2. Simulation

In order to validate the propriety of the model and system in this paper for accurate simulation of pedestrian’s street behaviors, and the feasibility of moving models of the windows, we conduct the following simulation, targeting on the space of Jingming 1st Street (see Table 2). In the case of this street, four different colors are used to differentiate the four main types of businesses of the stores. Food stands are in the pink zone, and the clothing industry is in the blue zone. Crafts and jewelry are in a yellow zone, and other industries are in gray zones. In this system, designers may choose colors after classifying the type of business based on the nature of business. In addition, intensity setting of attractiveness through the system on every store block also gives different implication. We thus discuss, and compare, the influences of different spatial structures and stimulus on a pedestrian’s behavior, according to simulation results.
**TABLE 2. SETTING OF SPATIAL SCENARIOS ON JINGMING 1ST STREET.**

<table>
<thead>
<tr>
<th>Shops on the east side</th>
<th>Shops on the west side</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td><strong>Attraction</strong></td>
</tr>
<tr>
<td>Food stands</td>
<td>H</td>
</tr>
<tr>
<td>Clothing</td>
<td>M</td>
</tr>
<tr>
<td>Clothing</td>
<td>M</td>
</tr>
<tr>
<td>Food stands</td>
<td>H</td>
</tr>
<tr>
<td>Food stands</td>
<td>H</td>
</tr>
<tr>
<td>Clothing</td>
<td>M</td>
</tr>
<tr>
<td>Clothing</td>
<td>M</td>
</tr>
<tr>
<td>Clothing</td>
<td>L</td>
</tr>
<tr>
<td>Clothing</td>
<td>L</td>
</tr>
<tr>
<td>Food stands</td>
<td>M</td>
</tr>
<tr>
<td>Food stands</td>
<td>M</td>
</tr>
<tr>
<td>Clothing</td>
<td>M</td>
</tr>
<tr>
<td>Crafts and jewelry</td>
<td>L</td>
</tr>
<tr>
<td>Clothing</td>
<td>M</td>
</tr>
<tr>
<td>Clothing</td>
<td>M</td>
</tr>
<tr>
<td>Clothing</td>
<td>M</td>
</tr>
<tr>
<td>Food stands</td>
<td>H</td>
</tr>
<tr>
<td>Others</td>
<td>M</td>
</tr>
<tr>
<td>Clothing</td>
<td>M</td>
</tr>
<tr>
<td>Others</td>
<td>L</td>
</tr>
<tr>
<td>Crafts and jewelry</td>
<td>L</td>
</tr>
</tbody>
</table>

4.2.1. Scenario: café and foundation on outdoor pavement of shopping street

We increased attraction objects (facilities) on the street: we placed the café and foundation on the outdoor pavement and, respectively, changed the proactive-agents’ horizontal visual distance and visual angle, as shown in Table 3. The simulation time refers to 10, 30, 60, and 90 minutes. The simulation results are shown in Figure 6.

**TABLE 3. PARAMETER SETTING OF SCENARIO.**

<table>
<thead>
<tr>
<th>Scenario: Café and foundation on outdoor pavement of shopping street</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) We set the horizontal visual distance as 10m and visual angle as 90°</td>
</tr>
<tr>
<td>(b) We set the horizontal visual distance as 30m and visual angle as 120°</td>
</tr>
</tbody>
</table>

There are 40 proactive-agents and each step is set as 30 cm. The radius of the proper distance from other walking pedestrians is 100 cm.
4.3. Analysis

Through the above simulation results, we reorganize three subjects, as below: the orientation of the pedestrian’s attention in the space, the relationship between the pedestrian’s spatial movements and visual distance, and the interactions between attention and street spatial design elements.

4.3.1. The orientation of the pedestrian’s attention in the space

According to the simulation results in Figure 7, we found that, a pedestrian’s attention was oriented, and movement in the space was acted upon non-sequential and discrete methods. The agents changed their directions because of detecting new attractive objects, they move from the shops at the west side to the opposite shops. Thus, there are “diagonal” paths. Therefore, the placement of the attractive objects will affect the agents’ behavior in a simulated environment, suggesting that sufficient attractive facilities on a street, the facilities can be the foundations, fountains, entrance signs, outdoor seats, plants, etc. will attract a pedestrian’s attention.
4.3.2. The relationship between the pedestrian’s spatial movements and visual distance

We compare the simulation results and treat the horizontal visual distance and visual angle as the variables to draw the pedestrian’s attention. During the simulation processes, when there are attractive activities, the agents tend to approach. When there are more attractive visual objects on the street, such as new landmarks or shop signs, the agents’ walking speed will be slower, which changes the agents’ moving angle since selecting the next object determines their moving direction. If they do not find attractive activities or other stimulus, they will continue walking and look for shops or other interesting facilities, as shown in Figure 7 (check the rectangular box). Thus, we conclude that attention moves as serial analogy in the space. While walking, the pedestrians first decide the activity location, determine the direction and distance, and then follow the paths.

4.3.3. The interactions between attention and street spatial design elements

After comparing the simulation results, we find that the walking agents tend to stay and watch attractive facilities in some areas on the street. In other words, because of different destinations and motives, larger visual angles and longer visual distances, the agents will have different attentions on the information of spatial structures. Thus, they will first select their priority destinations, and
then determine the secondary locations. Thus, when there are important business activities or artistic performances in front of the shops, the agents tend to be attracted, which results in surface distribution, as shown in Figure 7 (circle here), demonstrating the space for the use of the crowd. In other words, visual attention in the space is the implication of spatial structures. When there are more clues, the pedestrians will have stronger intentions to use the space.

5. CONCLUSIONS

The simulation results in this study showed that, the behavior of pedestrian groups not only concerns simple grouping, individual movement in the group often changes due to implication in the environment and gradually affect neighboring individuals, similar to an infection. The case simulation aimed to establish an object of attention with attractive nature in the outdoor street environment, assigned it with implication for attention-gathering. When the pedestrians walk on the street before the clues appear, a larger area of attention must be maintained mainly because there is no way to predict where an interesting target would appear. This wider range of attention will also cover the simulated establishment of attention, and therefore, improve the opportunity for selection based on the object. The farther pedestrians would gradually move towards the direction when they see the crowd gathering ahead. Thus, when designers use this system, objects of attention in different natures are established according to the needs of space activity, in order to spread influence to simulate the agent presentation in the environment.

In addition, the defined visible area of attention in this paper refers to activity point where can be reached within urban open space for pedestrians. Visible area of attention is defined as a two-dimensional substantial architecture, street furniture and obstacles; since pedestrians basically move on the ground level, street walking space does not have too much height changes. Hence, this study only discussed two-dimensional surface. It is suggested that future studies may incorporate three-dimensional space to examine the effect on visible area of attention.

ACKNOWLEDGEMENTS

This study is supported by the Taiwan National Science Council, grant-NSC-97-2511-S-468-001. The author is grateful to Prof. Mao-Lin Chiu for discussing and contributing to this work.
REFERENCES


