A STUDY ON BEHAVIOR MODELING OF PEDESTRIAN

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ABSTRACT:

It is important to understand how people act in urban areas in order to design any social and economic systems. In this paper we focus on the spatial phase of peoples act, in other word, how they move around. The need to comprehend the way in which people move through urban areas leads to the desire to predict their movement, such as an assessment of impacts of new policy or an identification of the optimum location for a new shop. This paper describes a structure of agent-based behavior model, which is intended as the rough framework of such predictive models. The model suggested here is based on some analysis of survey data sets, including real trajectories, mental process and viewing fields of pedestrians. It is because of the assumption that pedestrian movement should be influenced by many factors such as configuration and the location of attractions, previous knowledge of the place, quality and quantity of the information they acquire and so on. So as the first step of making a multi-agent based model, some ideas of current human behavioral models in other different fields such as social psychology and cognitive sciences were reviewed and introduced to decide what kind of factors should be included in the model to cover most of the possible influence on pedestrian movement. In addition to these, demographic profiles of the pedestrians, the attributes or preferences of guests, are included in our model framework. We will develop a series of Multi-agent simulation systems and their applications, some of which are currently still under development but will be finalized in near future to examine these possible factors. The results from these simulations will show which factor(s) really have major influence on spatial movement and will help us with setting the best combination of factors and appropriate values of parameters in our final model.

1 TRANS-DISCIPLINARY REVIEW OF PEDESTRIAN BEHAVIOR MODELING

1.1 Outline of Previous Pedestrian Behavior Models

There have been growing needs for certain pedestrian behavior models in order to predict how people move around in urban areas. Since it is important to understand the way of spatial movement of pedestrian for any design processes of facilities in various fields, not only urban planners or government officials but also retailers and advertising agencies, have gradually been interested in how their customers behave in their shops and, broadly speaking, commercial districts.

Although there have already been several spatial behavior models, which intend to predict each person's behavior, they did not and have not been able to deal with each pedestrian movement in micro-scale environment such as inside of shopping malls or a railroad stations. This is just because most of those models were based on the same assumption that

every spatial behavior has rigid structure that consists of 3 parts: setting destination or final aim of the behavior, collecting all necessary information for making a decision to meet requirements to reach the destination point or to achieve the aim, choosing the best alternatives among many possible options by comparison of them. Apparently, these assumptions are in accordance with general process of decision-making. In fact, some models of this sort have been showed their effectiveness to estimate a potential attraction of a new shop, or to predict the approximate number of visitors or probability that a certain place will be chosen as someone's destination. Pedestrian movements in micro-scale, however, always accompany seemingly arbitrary behavior, which might be overlooked in such analysis. What brings this unpredictability may be that each pedestrian are apt to change their original destination or criterion by the information he/she newly get whilst they are walking around. To explain this kind of changeability of pedestrian movement, new models should include human mental structure such as the mechanism of information processing, whole process of cognition and leaning, from obtaining information through physical sensors, sorting necessary tips out from these miscellaneous external stimulation, to linking some tips according to an experience and background of each person.

Thus, it is useful to examine various works of research in many study fields concerning human behavior; the field of traffic management, urban design, town planning, architecture, cognitive science, environmental psychology, geography, economics, robotics, artificial intelligence and so on. In addition to previous models, empirical knowledge from observation or many dataset from survey using inquiries about the attributes or preferences of visitors, which are already available in marketing fields, also deserve to be studied closely. Because they show us some behavioral tendencies, which must be a great help for identification of common sources of contingencies to develop an overall framework to analyze behavior. The concept of agent-based modeling enables us to take account of many variables. These works and fields can be classified broadly into 3 categories according to main targets of each analysis and level of scale at which it focuses on. (Table 1) Details of major behavior models in each field are described in following session.

<table>
<tr><td>Main target
Level of scale</td><td>① Trajectory, Footpath,
Trip data, Route of travels</td><td>②Combination and correlation of ①③</td><td>③Information processing,
Mental mechanism</td></tr>
<tr><td rowspan="2">Macro
↕
Micro</td><td>Urban planning</td><td rowspan="2">DSM analysis
Route choice survey</td><td rowspan="2"></td></tr>
<tr><td>Traffic management</td></tr>
<tr><td>Architecture
Disaster prevention
Ergonomics</td><td>Environmental psychology
Social psychology</td><td>Cognitive science,
AI, Robotics
Economics, Marketing</td></tr>
</table>

Table 1. Current Research Fields Related to Pedestrian Modeling

1.2 Models in the Traffic Research & Urban Planning Field

Either of traffic management and urban planning is one of the study areas in which various behavior models have been suggested. Among various current models, the Disaggregate Logit model and Huff model respectively has been most widely used and effective to predict approximate tendency of human spatial behavior. They describe each person's spatial behavior as a series of making a choice. Possibility of a certain place being chosen as the next destination explains one trip, a movements from point A to point B in the space. Sequentially-organized set of these possibilities amounts to whole route that each pedestrian go through during his/her journey. These models are characterized by the concept of *utility optimization*. The essential point of his concept is that it regards each pedestrian as an actor who always makes the best

choice. Only one option will be chosen among all possible options after comparison between each other under a certain criteria. Every necessary information is supposed be collected and used for guessing the result which will be brought by each option and its likelihood as well. Most models provide importance or desirability of each result as a value of *utility* in order to make several options standardized for comparison. The best choice can be interpreted as one that has the highest value of utility. Therefore, it is apparent that the way in which calculation and standardization of utility has strong influence on the accuracy of prediction. Most prevailing way is based on the attractiveness of the destination, such as its area, wideness of its assortment of materials. At the same time, they include negative attractiveness, in other word constraint of the behavior, such as cost and time for transportation and for journey itself. By introducing the idea that this calculated utility can fluctuates in accordance with random variables, these models try to incorporate common sources of uncertainty of human behavior. It is, however, still black-box, how people change their behavior. New schemes of behavior should not leave this mechanism as unpredictable measurement errors.

1.3 Models in the Field of Architecture

In the process of architectural design, observation and survey on uses of the space has been established as one of major parts of design methodology. Behavior mapping and follow-up survey is as a whole widely used technique in order to get detailed information on how people walk around in a space. These information or knowledge of the space and behavioral patterns, however, has not been developed into systematic behavioral models, not taking one step further from tips for immediate design tasks. Therefore, huge accumulation of know-how, empirical rules and ideas of each designers, which must suggest important factors with much influence on arbitrary phase of human movements, exist only in fragments that is hard to abstract. The way in which we utilize this information is strongly needed.

The simulation of escape behavior is another major theme in this field, making use of behavioral patterns. Models in this area have the same structure as those in traffic management studies. Distribution of utility value of each unit of the space is calculated from degree of risk and checking location of some obstacles, and indicated as potential map of the space. Evacuation of people can be described as an interaction of each evacuee's decision and movement, which is derived from some parameters, such as his/her walking pace, sense of judgment, and susceptibility by others. This offers valuable insight for combination of utility optimization approach and of knowledge from observation. Since the former is effective only in the case with only one definite aim or stable objective of journey and with high ability to collect every necessary information and to make rational decision without fail. If we call this case a Single-task situation, introducing the latter approach will make it possible to develop a new model, which can also deal with a Multi-task situation seemingly providing changeability to pedestrian movements. In addition to that, it must be useful to look up some models, which focus on human internal mechanism, how each person interact environment.

1.4 Models in the Cognitive Science & Environmental Psychology

Much research has been made on the theme of influence of human cognitive process on movements. Several works about Way Finding such as Abu-Obeid, N (1998) showed that degree of perception of one's environment, in other word Cognitive map, strongly determine each pedestrian's random walk and the number of times of getting lost. It also suggested that abstract information such as diagrammatic illustrations would enhance the Cognitive map, compared to pictures, which include much detailed information. Appleyard, D(1970) verified that the degree of perception of a certain place is in proportion to the number of times of visit. It's notable that Lee, T.R. (1970) identified that people tend to choose the facility, which is located in central area of a city as a destination. It occurs even when there is another facility, on the fringe of a city, of which equipment is totally same as that in core city and when it is apparent that the latter is closer. It is likely that people are apt to overestimate or underestimate utility according to some images they have for the place. The word "center" or " edge" must evoke respectively a certain image. Another study showed similar tendency that route in

which pedestrians have to make many turns brings the image of "long" or "far". Introducing cognition as weight in calculation of utility will help a new model with explain changeability of pedestrian behavior.

1.5 Models in the Field of Field of Economics & Marketing

In Economic field, most of previous and current models are based on the basic idea of *Economic man*. While this means that all people always follow rational process of decision-making like calculation, some models suggest that the result and its desirability should have some influence on the way of the calculation itself. Since it is understandable that an action taken by each pedestrian is usually accompanied by some reaction from others or environment as a certain feedback, his/her cognition or knowledge of external world may well updated by the next time to make a choice. Thus the criteria and estimated utility of each option may be changed. This dynamism is called *learning and adaptation*. There have been several models, such as Howard-Sheth model and Engel-kollat-Blackwell model, which explain the process of how people form cognition or an image of brands and shops through experiences, by the learning and adaptation mechanism. Whether each customer chooses the same shop as destination again depends on whether the result from the behavior meets with his/ her expectation enough to give good impression. These models consist of 5 parts; options of behavior, each of which is independent and mutually exclusive, possibility of each option being chosen, list of possible result from each option, likelihood of each result being brought, combination of options and result. If there is an option that brought the actor much benefit, the possibility that the same option will be chosen next time should increase. The increasing rate (decreasing rate in case the option just provided negative reward) is described as *learning-rate-coefficient*, which varied from 0 to 1 and can be changed according to one's values and situation.

1.6 Models in the Field of Robotics & Artificial Intelligence

There has been increasing interests to make robot behave as human beings do. The most difficult problem to solve is complicity of rules to control robot, as it must includes a great deal of factors such as task and external stimuli and interactions between them. Arkin,R.C(1990) suggested the concept of autonomous robot architecture, which made use of combination of stimulation-response mechanism and knowledge-based behavioral schema. Balch,T(1997) developed this architecture and represented coordination of behavior of several robots, which proved to be derived from each robot's learning process. . It is suggested that when analyzing any human behavior with arbitrary movements, the following 3 sources of contingencies need to be taken into consideration. 1: Physical contingencies that influence human behavior .2:interaction and mutual effect between contingencies. 3: impact on other people of discriminative stimuli. Both Multi-agent-based-modeling and Genetic Algorism are important measures to integrate information processing and learning and adaptation process. The former technique makes it possible to handle variation of attributes, to control values of parameters and behavioral rules independently and to represent interactions between agents, subjects of behavior as well. The latter algorism autonomously develops a certain schema by taking all the controlling variables and all the possible extraneous influences into account, in order to find desirable options and to let them change their possibility to occur by themselves. When attempting modeling of pedestrian movements we need to utilize these ways of representation of interaction and feedback structure between pedestrians and environment..

2. A FRAMEWORK FOR NEW BEHAVIOR MODELS

2.1 Required Conditions for a New Model

In section 1, we sorted out previous models and specified the required condition for new behavior model of pedestrian. A framework to guide future analyses on behavior modeling should meet following conditions:

1. Micro-scale arbitrary movements should be explained
2. Mental or cognitive process should be introduced to represent interaction between each pedestrian and environment.
3. The structure of the new framework must be flexible in order to represent dynamics of behavior.
4. The concept of Learning and adaptation need to be included.
5. It is necessary to include knowledge from observation and experience as a quantitative data.
6. All behavioral patterns or rules should be converted into mathematical model.
7. The new model needs to be based on the concept of Multi-agent.

2.2 A Framework of New Pedestrian Models

In this part, we propose a new framework of pedestrian modeling. As mentioned in section 2.1, it is necessary that this framework should explain changeability of pedestrian movement not by the concept of errors but by dynamic shift of multiple tasks. It is indispensable to specify these tasks which are relevant to spatial behavior as many and detailed as possible. A preliminary observation study of pedestrian movements, especially on shopping around behavior in huge malls, was undertaken to get both quantitative and qualitative evidence of plural tasks rising toward consciousness during a trip for shopping. Identification of the route of shopping around, field of vision which is taken be eye-motion-tracking camera and inquiry on personal demographic data and preferences suggested that there can be found some patterns in seemingly arbitrary movements of shoppers. A tentative theory can be set on the basis of these patterns; it includes transition of tasks and aims of journey and Information processing and feedback-loop for cognitive process as shown in Figure. 1.

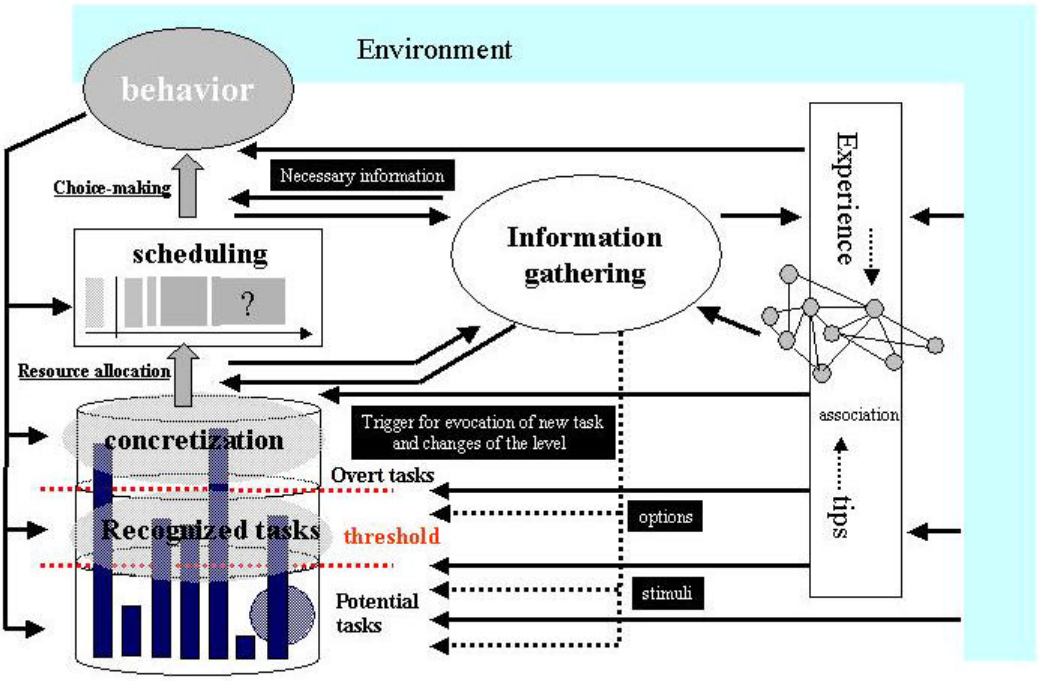

Figure 1. A Framework of Pedestrian Behavior Model

Each pedestrian has one or more tasks or motivations, some of which he/she is already aware and others remain unconscious. Stimuli from environment, perceived by physical sensors can be a trigger for some of these tasks to be realized. It means that there are 4 levels of tasks in proportion to the degree of consciousness; not existing, potential tasks

(needs), overt tasks and concrete tasks. Although each pedestrian try to solve all of the concrete tasks, there should be some constraints, such as cost and time required for achievement of the task. A sort of resource allocation process will provide a tentative schedule, which loosely defines behavior in future. Not only importance and priority of the task, but also cognition and knowledge of the place have and influence on this scheduling. Since this schedule is tentative, it can be dynamically altered as the changes of tasks and as occasion may demand. Stimuli from environment are stored in a database, which is called experience, as information or cognitive schema of the environment. This information or schema controls resource allocation process by providing necessary information for making decision. It can also provide a new idea, which evoke new tasks. Leaning and adaptation mechanism is used to represent dynamic relationship between behavior, experience and environment. At the step of each movement, choice-making model based on utility optimization theory can be applied. Once a certain task get clear priorities among several tasks, pedestrians try to collect necessary information to achieve it. If information provided by empirical database is not enough to meet requirement, they will start to fill the gap by information collecting behavior. The best option is to be chosen among all possible alternatives to be carried out as a certain spatial behavior. Distribution of the utility value is defined by cost and attractiveness of each space (shops), approximated by assortment of materials, impression, and uncertainty. This utiity distribution map itself is to be revised at the timing that pedestrian make another step of behavior.

3. FUTURE WORKS

This paper proposed a preliminary framework of modeling movements of pedestrian. Although it includes what we have found useful for analyzing the different complexities of human behavior, there might be other influential factors and a wider range of possible variables for experimentally controlling human behavior. This framework should be improved by much detail of the movement of each pedestrian. We have already developed the measurement system in order to obtain the data of fine-scale movement of pedestrian. It consists of 3 parts; a gyro sensor, radio frequency identification (RFID) tag systems, and a process of map matching proposed by Kitazawa (2000). This measurement system will give us continuously detected position of each pedestrian, which will help finding another behavioral patterns together with elaborate analysis of profiles and preferences of pedestrians. Some experiments using this measurement and surveys are to be carried out in order to identify effectiveness of any possible factors.

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