INTEGRATION OF SPACE SYNTAX INTO AGENT-BASED PEDESTRIAN SIMULATION IN URBAN OPEN SPACE

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Abstract. MAS can be utilized to analyse macro rules of whole system by simulating a number of active agents. However, simply based on the parameter of specific environment quality and incomplete statistical setting of individual, models of pedestrian traffic in realistic open space have often been imperfect, because the behaviour of people cannot be rationally reflected to the complex characteristic of space. Space Syntax Theory breaks down the space into components and measures each with the straight sight-line of individuals, which can help analyse and quantify pedestrian flow in complicated real-life environment. In this situation, we make an attempt to combine these two in our research, in order to simulate the moving of pedestrian closer to reality. In this paper, Gulou Square, an urban open space close to centre of the city with a large flow of people, is selected as the study site. The results after plenty of simulations and contrast tests can be concluded that with the assistance of Space Syntax Theory, MAS can be more functional solving the problems in sophisticated real-life environment.

Keywords. Multi-agent system; Space Syntax; Open space; Visibility.

1. Introduction

Urban open space facilitates public activities and plays a significant role in urban environment. When designing urban open space, pedestrian simulation is always considered as a potent tool that can be used to lead the initial design of a project. This simulation method is now believed as an integral digital asset to play an increasingly important role in the analysis tool chains.

From the perspective of monitoring pedestrian activities, multiple-agent system has gradually become prevalent among the researchers (Batty & Jiang 1998).
In the very beginning of the study, Center for Advanced Spatial Analysis conducted a significant number of simulations to pedestrians and further explored the reactions and behaviors of pedestrians among a variety of obstacles, which laid a firm foundation for activity simulation of pedestrians in real space (Popov 2007). With the development of pedestrian simulation model, David Schaumann studied computational framework for simulating human spatial behavior in built environment (Schaumann 2016). In addition, Michael Schyndel’s crowd modeling in the Sun Life building was able to simulate passenger flow through the design of pedestrian route in large-sized building of multiple-agent system simulation (Schyndel 2016).

However, computer simulation of urban open space is commonly focusing on larger-scaled environment or theoretical analysis. For instances, based on Netlogo platform, the Citybuilder developed by Martin Felsen and Thomas Lechner focused on the simulation of the growth process of cities (Lechner 2004). And the MAGS (Multi-Agent Geo-Simulation) developed by Moulin, which now is used in the study of pedestrian behaviors in the urban environment, was able to facilitate thousands of units possessing the ability of space recognition to interact with each other in 2D and 3D virtual geographical environment (Moulin 2003). It can be inferred, therefore, that how to focus MAS on the specific individuals’ route simulation in large-sized environment still lacks of research. The real factors such as height differences, surrounding traffic, visual obstructions, weather conditions and so forth indicate that the simulation model has to contain equal complicated parameters (Johansson 2011). Besides, these factors may also lead to the greater uncertainties. When facing with such situation, MAS’s models of pedestrian flow in realistic open space have often been imperfect because there is no appropriate way to rationally reflect the behavior of people to the complex characteristic of open space. Therefore, there should be some other method to cooperate with MAS to conduct more accurate pedestrian simulation.

Based on the measurement of individual straight sight line, Space Syntax Theory can split the space into components, thus helping analyzing and quantifying pedestrian flow (Batty 2004). Previously there has been researches on SST, such as Mohammed Javad Koohsari attempted to depict neighborhood’s walking ability based on derivative concepts of Street Integration and Intersection Density, and their further research on impacts of built environment on walking for transport (Koohsari & Sugiyama 2016).

Considering the complementary relation of MAS and Space Syntax Theory, we combine these two in our research, trying to simulate the moving of pedestrian closer to reality. The stimulation attempts to create a feasible method, which allows iterative testing of what-if scenarios to fine-tune the building design against a wide set of requirements related to different building use scenarios, matched to the expectations of different researchers.

2. Methodology

When using program to simulate pedestrians’ activities, three key factors are required: space, pedestrian and events (Crooks & Heppenstall 2011). The behavior
of pedestrians is independent, but the occurrence of events is specific reflection of the pedestrians’ behavior in the corresponding space (Guido 2007). In this case, multiple-agent system, with its autonomous, heterogeneous and active agents triggering different events in certain spaces based on their properties and behavioral rules, meets the requirements perfectly. Netlogo is a commonly used programming platform hinged on multiple-agent simulation, which comprises three types of agents: turtles, patches and the observer. In Netlogo, two-dimensional world is divided into orthometric grids taken up by patches. Each patch is a piece of ground for turtles to move on. Observers instruct turtles and patches. The simulation process is completed by repetitively executing each procedure, making the basic logical structure a loop. Therefore, these three key factors are embodied as patches, turtles and procedures. Turtles and patches have their respective properties, called attributes, which can be static values, Boolean or even a set of patches. Attributes can be pre-distributed, called parameters, or updated during the procedure, called reporters. The above are basic factors to simulate pedestrians’ activities on any spatial area.

2.1. PATCHES
In Netlogo, the space is divided into patches. According to real-life environments, multiple attributes such as unreachable walls, accessible area, starting spots and destinations are given to patches in the form of static parameters (table 1). Meanwhile, the crowd density, which shows the number of turtles on a certain patch, would be updated by reporters.

Table 1. Pre-distributed parameters set for patches.

<table>
<thead>
<tr>
<th>category</th>
<th>parameters</th>
<th>Spots</th>
<th>Dist</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>type</td>
<td>Static</td>
<td>Static</td>
<td>Static</td>
<td>Static</td>
</tr>
<tr>
<td>description</td>
<td>Unreachable walls</td>
<td>Accessible area</td>
<td>Starting spots</td>
<td>Destinations</td>
</tr>
<tr>
<td>reporters</td>
<td>The number of turtles on a certain patch</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.1.1. Turtles
In the program, after generated randomly in each spot, turtles head for a certain destination. During the process, turtles’ activities are determined by a set of attributes. On the one hand, turtles are given different characteristics by pre-distributed parameters (table 2), all of which are set in rational ranges. These parameters can be adjusted as needed to add heterogeneity into turtles. On the other, reporters make it possible for turtles to respond instantly according to the environment. Turtles’ reporters include crowdit, dist and accessible. Crowdity reports the total number of turtles on surrounding patches. Dist calculates the distance from the turtle to the closest wall within the scope of sight. Accessible decides if the destination can be seen.
2.1.2. Procedures

The basic rules of simulation ensure the operation of multiple events. Based on the above settings of space and attributes, the following procedures might be triggered:

Set-human: The program will generate a random number. Only when a certain number was generated would this procedure be triggered, making sure the proper amount of agents in the space. Before moving to their starting spots and walk, the generated turtles will be given their own speed, sight, tolerance, direction and destination.

Walk: When turtles are walking, this procedure will inspect the following factors in every step: whether the next patch is occupied by another turtle, whether the next patch is wall and whether the amount of surrounding turtles outnumbered its own tolerance. Any factor will trigger Avoid procedure.

Avoid: When the next patch is wall or occupied by another agent, the turtle will rotate a small degree to the left or to the right, then twice the same degree to the opposite direction until the next patch is accessible.

Commonsensically, an individual who attempts to get familiar with some strange environments, such as figuring out the route to unfamiliar places, is inclined to get to nodes that provide with a greater perspective of overall situation.
In other words, an individual affected by this inclination tend to get to nodes that are easier to ‘observe’ other parts of the space, such as leaving for a square from a byway.

To simulate such an inclination in Netlogo, complex algorithm should be designed. As for space syntax, it is tractable in such situation on account of its capability of describing the topology of space. Thus, some of its analytical approaches and principles are apposite to import to the MAS, in order to ameliorate the behavior pattern of agents.

In our paper, Depthmap, has been utilized. After importing a digitized map of Gulou Square, a grid map can be converted that divides the whole space into an array of square space units (nodes). Then it can make visibility graph of the grid map as well as run visibility graph analysis. Subsequently, visibility relationships of the nodes are calculated.

Among the relationships, one concept, mean depth, is vital to our research. Alasdair Turner explained in his research that mean depth is calculated for each node much like the step depth (Turner 2004). The shortest path through the visibility graph is calculated to each other node with in the graph. These are summed and divided through by the number of nodes in the graph. Besides, integration is a normalized version of the mean death. The lower mean depth a node has, the higher integration value the node is assigned.

3. Case Study: Gulou Square

This research presents the simulation of pedestrian flows in the abstracted representation of the south part of Gulou Square in Nanjing, Jiangsu province. This square acts as an essential ingredient in the well-developed traffic system, located in the city center. The rich variety of space and height-changes brings in the possibility of view blocking.

The duration of the research was from winter of 2015 to late spring of 2016. The weather changes could be provisionally ignored as it only made a difference to visitors of recreational purposes, not the research samples who employed the square as a passing road. The research was carried out between 1 p.m. to 2 p.m. under the most situation. Data was gathered by means of over-all videoing and individual tracing, with sorting and selecting afterwards. Through data processing, people who were customarily coming for entertaining were ruled out. Moreover, the data will be compared with the model’s output to assess the optimization of the model.

Figure 1 numbers each entrance/exit for the south part of Gulou Square. Based on the research data, several regulations have been sorted out as follows:
1. Pedestrians from entrance No.1 and 3 take an almost straight route passing through the square than exit from exit No.2, 5 or 6 and vice versa. Exit No.4 is usually out of consideration.

2. Pedestrians taking exit No.1 outnumbers those who choose exit No.3. The field research shows less trees near exit No.1 so the exit is clear in sight, indicating view blocking has the power affecting pedestrians' personal choices.

3. The route choice between exit No.2 and 4 are straight-lines. Because there is a public toilet beside exit No.4, people may choose this route out of strong and clear motivation.

3.1. APPLICATION OF NETLOGO AND DEPTHMAP

The first step of computer modeling is to make a digitalized map of Gulou Square. This research utilizes CAD to delineate Gulou Square, then converts it to a grid map in which each grid is given a value to be differentiated by Arcmap, and eventually imports to Netlogo (figure 1). Through such steps, the patches in Netlogo are set as an array of square grids with different values. Subsequently, they virtually become impassable walls (white part) and accessible areas (black part) and start or destination points of agents (grey part).

The second step is to set the properties virtual crowds. Values are set to be floating in a limited range so each property is a variable that affects the behavior of an agent. Thus, agents have different behavior patterns on account of the floating properties, which contain speed, sight, tolerance, destination and starting point (two points selected randomly by patches among six points). While processing the simulation, reporters will adjust some variables, including crowdity, distance and accessible to cope with different situation.

Nonetheless, the algorithm enhancement of the sight should be paid attention to. And the result of our quantification is Visual integration, calculated by Depthmap. A VGA graph reflecting the Visual Integration of each node of the space is shown in the following (figure 2). As the legend showed, the more a node’s color approach red on the color bar, the higher value the node holds. We import the grid map carrying the value of Visual integration of nodes, as well as assign the value to patches accessible, expecting that agents are able to adjust their behavior according to the Visual Integration of the periphery.

With principles of the Space Syntax being added to, the program changes accordingly. When the accessible of an agent’s destination is judged to be false, indicating the invisible destination, the agent will move to a node with the highest value of Visual Integration among nodes around it. Of course, an agent is set to avoid sharp turning while moving.

Figure 2. The visual integration model made by Depthmap of Gulou Square.
3.2. SIMULATION RESULTS

The research focuses on two contrast experiments with variable-controlling approach. The first contrast experiment analyzes the features of crowds’ behavior patterns without the intervention of Depthmap when visual range and tolerance in Netlogo changes. In this experiment, we apply the average speed of pedestrian derived from field research, that is, 0.26 patches per period. And the speeds of many subjects are randomly set around the sub-average speed. Visual range and tolerance change the same way as in realistic field and become the major study objects since differences exist among individuals and the setting range of threshold value is large. Meanwhile, the second contrast experiment analyzes the differences in model simulations with and without visual arithmetic optimization through Depthmap, keeping all other parameters unchanged. This literature attempts to deduce the possibility of combining space syntax and multi-agent through scenario simulation.

Firstly, the research conducts the contrast experiment on visual range, 5 variables of which, 10, 30, 50, 70 and 90 are respectively chosen while other parameters remain the same. According to the basic information accumulated in the field research, the number of pedestrians is set to 50, velocity of pedestrians 0.26 and tolerance 7. Each pedestrian route is recorded in red. Below (figure 3) are the simulation results and analysis:

![Simulation experiment: visual Range 10, 30, 50, 70 and 90.](image)

It can be clearly seen that visual range has essential influence on pedestrian route. There is negative correlation between these two, which indicates that the smaller visual range is, the more pedestrian detours would take. For instance, if the visual range is set to 10, the over-dense pedestrian flow line indicates a variety of illogical detours. If the visual range is set to 30, the flow line becomes clearer while illogical detours still exist. There are more lines existing around the central white obstruction perhaps because it blocks pedestrian sight at the left-side entrance and exit. The simulation result has largely improved at visual range 50. The most logical situation emerges at 70, where pedestrian routes are clear enough and generate fewer detours. There are still more lines around the central white obstruction at visual range 90, which indicates that the parameter is inconsistent with and already beyond the actual pedestrian visual range.

Secondly, the research also conducts a contrast experiment on tolerance. This experiment applies the same approach as the previous one, keeping the population
size and speed parameters unchanged, setting visual range to the most reasonable range, 70, and picking up four values, which are 2, 4, 6 and 8 as tolerance parameters. Experiment results and analysis are displayed below (figure 4):

![Figure 4. Simulation experiment: Tolerance 2, 4, 6 and 8.](image)

It shows that the lower people’s tolerance is, the more changes in routine in avoidance of congestion are, and thus the longer distance is. In our result, pictures with parameters of 2 and 4 present relatively complex routines and there are more branches from one point to another. This is because the tolerance range is too small (Notice that overlaps of routines in pictures are generated in different time other than coincidence at the same time). When tolerance is increased to 6, the flow line improves obviously and routines become concise. If tolerance continues to increase to 8, the situation is no big differences from that of 6, which indicates that tolerance values above 6 are proper and practical.

The second experiment contrasts model’s simulation condition with and without Depthmap. In our project, we first study that whether Depthmap has effects on model’s simulation under a visual range of 50 and 70 respectively (figure 5). And it can be observed from the comparison of these two groups that the application of Depthmap simplifies crowd routines and nearly eliminates wide-angle turnaround. This experiment demonstrates that Depthmap effectively optimizes the algorithm of subjective visual range in Netlogo and makes it more realistic.

![Figure 5. Contrast experiment: Visual Range 50 and 70. Left (without space syntax). Right (with space syntax).](image)

In addition, this project provides specific analysis in terms of agent volume. In comparison of massive individual routines (figure 6), we find that space syntax makes no differences when there are no barriers between the starting and end point since pedestrians can see the terminal directly. But when there are a lot of barriers, the theoretical shortest routine is circuitous, space syntax enables pedestrians to predict the methods of avoiding barriers and move towards a more spacious direction. Furthermore, when the number of subjects gradually increases to 30, 70 and 90, model’s simulation without space syntax becomes unreasonable (figure 7).
Faced with many barriers, turtle tends to walk directly towards them and make a big turn before collision due to avoid algorithm. But if turtle still cannot see the exit within new visual space, it will repeat previous action. Therefore, even though subjects make it to the end point at last, their routines are unreasonable for the repetitive actions of walking to barriers and then avoiding them. On the contrary, there are few curves in routines under space syntax and the main routines are in high coincidence. It can be inferred that Depthmap algorithm provides an optional routine after simulating routines between two points numerously. Though avoidance still appears occasionally due to the confinement of tolerance, in general, subjects all tend to the optional routine if any possible.

Figure 6. Contrast experiment: single routine. Upper (with space syntax). Down (without space syntax).

Figure 7. Contrast Experiment: The number of agents: 30, 70 and 90. Left (without space syntax). Right (with space syntax).

4. Conclusion and Discussion

After a long-played investigation, we gradually established models and completed parameters as well as algorithm in the project. Through massive simulations, we come to the conclusion that space syntax is able to improve crowd behaviors under complex open urban space. Space syntax can optimize individual visual range and is compatible with Netlogo which contains a sufficient number of complex environmental parameters. A combined application of Depthmap and Netlogo ensures the reasonability and logicality of model operation, leading simulation results to an accordance with the basic conclusion derived from our field research.

This simulation model hinged on reality is still a work in progress. Next steps
of this research will involve optimizing algorithm and setting more constrained parameters. The framework of this model will be broadened to these fields:

1. Optimize algorithm. The parameters will be designed more accurately, such as the range of speed and the operating principles of tolerance or sight. Moreover, the unreasonable interaction of these algorithm will be corrected.

2. Introduce environment parameters such as different weather conditions or micro-climate to the model and assess to which extent they can affect the outcome.

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