THE VISIBLE AND INVISIBLE NETWORK OF A SELF-ORGANIZING TOWN

Agent-Based Simulation for Investigating Urban Development Process

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Abstract. This study applies self-organization as a methodology to understand the complex process of city networks caused by interactions between spatial structures and individual behaviors. The agent-based simulations have been conducted to investigate the visible and invisible networks understanding the self-organized aspects of city development processes. To develop optimal future networks providing connectivity and accessibility this study investigates spatial network configurations from internal individual behavior and movement. As results, it was found that the spatial configurations of the agent movement trails match to the current district boundaries and the similar network patterns were seen in various control values of agent behavior settings. This study contributes to searching out the hierarchy of network structures which is an important factor for re-planning of the way system.

Keywords. Agent-based simulation; network analysis; self organization; urban development process; Physarum polycephalum.

1. Introduction

Nature is a source of inspirations for solutions to adapt to environmental challenges. Biomimetics is a methodology which finds solutions applying the biological forms, processes, and systems to solve human problems in various fields (Pawlyn, 2011). Self-organization, the phenomena which a system self-organizes its structure by internal individuals with no control of external agents, is essential to understand open and complex systems (Portugali, 1997b). For a qualitative approach to environmental systems of cities, this study applies self-organization as a methodology to see the complex process of city networks caused by interactions between spatial structures and individual behaviors. Spatial configuration and connectivity in the context of the past, present, and future are investigated to search out an optimum prediction of networks for future development.

In this study, a dynamical synthetic model of Physarum Polycephalum networks is investigated to understand self-organizing aspects of urban development processes and to predict the optimized paths for the future. This research focuses on a case of a naturally grown town in Seoul and investigates to

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apply the biological principles to urban design issues. The case is a town located on the hillside of Nam mountain in Seoul, Haebangchon. Its history begins with the Korean War when the city was in absence of governmental regulations. The streets and houses were built up spontaneously by the refugees from the North. Since then, due to the development restrictions such as the height limit for the Nam mountain, Haebangchon has been under-developed being one of the oldest districts in Seoul. This town captures the characteristics of a self-organized city being open, complex, unstable and nonlinear, being intimately related to the chaotic urbanism in the early 20th century.

As of the recent moving plan of the government agencies nearby, the city is searching for a recreation plan for this area. For the future map, a new and optimized way system is to be searched. Providing connectivity and accessibility is essential to support city's growth in communicative and constructive ways which may lead them healthy and creative city planning. Like blood vessels, smooth circulation is a fundamental issue to the city system. The new network system should support effective circulation minimizing any blockage, heavy traffic and satisfy the safety in a qualitative way. The town's new plan is to develop a communicative and active network in a link to other regional centers despite moving out of the government agencies, which may cause isolation and underdevelopment due to the huge loss of population.

2. Self-organization of Physarum Polycephalum

2.1. SELF-ORGANIZATION

Self-organization has been used as a methodology quite extensively to simulate and study urban development process and for interpretations of the city systems. The city systems are open and complex as their parts are so numerous that there is no absolute way to establish causes and effects among them. Their parts and components are interconnected in nonlinear and complex networks. Self-organization is a paradigm relevant to studying such city systems which are open and complex (Batty, 2007). Self-organization explains the property of non-causality of the systems finding that external forces do not determine its behavior, but instead internal individuals spontaneously self-organize the system by independent acts and processes (Portugali, 1997a).

The attractiveness of self-organization models for the study of cities is the resemblance to the real systems. The attributes of spatial units are determined in relation to their adjacent neighbors. The self-organization models are built of discrete units, which determine the global structures in relation to their neighboring units. These resemblances make self-organization modeling tools to simulate urban processes (Batty, 1998). Some of theories and methodologies of self-organization which are applied to the cities are dissipative cities (Prigogine and Stengers, 1984; Allen and Sanglier, 1981), synergetic cities (Haken, 1996), fractal cities (Batty and Longley, 1994), cellular automata cities (Wolfman, 1984) and the others. In this study, agent-based modeling is used to simulate flows of individual behavior in connection to their environment. In agent models the individual agents determine the city networks as the outcome of their behaviors and their interconnected dynamic actions and behaviors in the city become the circular causality of city formation.

2.2. PHYSARUM POLYCEPHALUM NETWORK

P. polycephalum is an example of how simple self-organizing local interactions develop emergent transport networks, reacting to the spatial structure of changing environmental conditions. In its movement to food sources, P. polycephalum shows ranges of spatial pattern formations via its behavior for growth, movement, food foraging, nutrient transport, hazard avoidance, and shape maintenance (Jones, 2010b). The individuals are blind and do not see a global picture of the structure. They receive information only from the nearest mates yet they can solve spatial problems. In the form of network minimization, it contributes to the understanding dynamics and development processes of city networks. The networks of the P. polycephalum match the man-made transport networks (Nagasaki et al., 2000; Tero et al., 2010).

P. polycephalum presents a bottom-up approach to the modeling of emergent networks. Computationally, their networks can display desirable measures of transport efficiency in terms of minimal path length, connectivity and network resilience (Jones, 2015). The simple particle-like agents coupled with chemoattractive behavior in an environment can simulate the spontaneous emergence of the complex structure of networks. In this study, the network of P. polycephalum is explored for interpretation and prediction for a city network model using a computational simulation tool.

3. Self-organizing town, Haebangchon

When the Korean War broke out people from North Korea came to the South and settled down in a hillside under Nam mountain. Since then unlicensed houses were built forming this shanty town called Haebangchon. ‘Haebang’ means liberation and ‘chon’ means a village. As a lot of Christians migrated in this area, churches and schools were founded. Since then the town gradually developed as a dense residential area. In the 1970s, the Act on Housing Improvement was enacted, and the redevelopment project was carried out for the first time in Haebangchon. The irregular landscape conditions were formalized and road networks were expanded in the width of 4 to 6 meters. The irregular blocks and complex street networks started to be regularized and refined. However, the structure has remained and the development is still undergoing deterioration without improvement. The streets are stiff and narrow with no boundaries between pedestrians and cars. At the Ogari junction, the center place of Haebangchon, pedestrians, cars and public buses are all intertwined. In 2015, the Seoul Metropolitan Government has selected this area as one of the urban renewal project areas under a revitalized urban regeneration plan. With a recent moving plan of the government agencies nearby, developing an accessible and communicative city planning preventing isolation and supporting the growth of the town is an issue.

Figure 1. Current map of Haebangchon (left), photos of Haebangchon in 1950's (right top), current photos of Haebangchon - roads and landmarks (right middle and bottom).

4. Method

The simulation of P. polycepharum network is conducted to understand the real system of complex paths and spatial patterning of self-organized local movement which forms visible and invisible networks of the town. Grasshopper plug-in 'Physarealm' is used for agent-based modeling based on the behavior of P. polycephalum in a stigmergy algorithm (Ma, 2017). The simulation is conducted on a 3D terrain digital model to explore its implications on the real system and the 3D terrain model is developed by Rhino and Grasshopper using map and contour data downloaded from Korea National Spatial Data Infrastructure Portal OpenAIP (www.nsdi.go.kr).

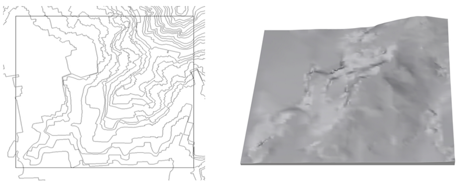

Figure 2. Topographic 3D model of Haebangchon.

4.1. PHYSARUM POLYCEPHALUM BEHAVIOR MODEL

The behavior model for P. polycephalum followed Jones' multi-agent approach (Jones, 2010b). In Jones' model, the agent follows simple stimulus-response behavior. At the start, each agent moves randomly to an unoccupied location with a random orientation. At each execution step for the food sources, every agent attempts to move forward from its current direction. If the movement is successful, the agent moves to the new position and deposits a value. If the movement is not successful, the agent remains in its current position and a new orientation is randomly selected. The agent receives sensory stimuli from its environment via only the sensors in front of the agent's current position and the agent responds to differences in the local environment trails by altering its orientation (Figure 3).

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[Motor stage]
- Attempt move forwards in current direction
- If (moved forwards successfully)
        Deposit trail in new location
- Else
        Choose random new orientation
[Sensory stage]
- Sample trail map values
- if (F > FL) && (F > FR)
        - Stay facing same direction
        - Return
- Else if (F < FL) && (F < FR)
        Rotate randomly left or right by RA
- Else if (FL < FR)
        Rotate right by RA
- Else if (FR < FL)
        Rotate left by RA
- Else
        Continue facing same direction
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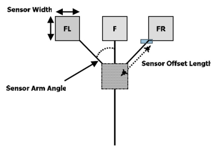

Figure 3. Sensory morphology of agent behavior model.

4.2. IMPLEMENTATION

In Grasshopper, the simulation process is set plugging in groups of the inputs and outputs into the core Physarealm component. The inputs include surface, emitters and foods as the work environments with the value setting parameters shown in Table 1. The outputs are population positions and trails of agents. A boolean toggle and a timer component control a start and a loop, and the iterations are counted.

The value setting parameters in Table 1 explains the behavior algorithm which agents follow and the values can govern the framework of urban development processes and network configurations. The value setting parameters for population size (%p), sensor angle (SA), sensor offset distance (SO), and the agent's rotation angle (RA) are the main parameters affecting agents' behavior in forming spatial patterns. Adjusting those parameters, different emergent network patterns can be generated. On the terrain model, the environment core is set establishing the surface, the emitters and the foods (Figure 4).

Table 1. Parameter values for agent behavior model.

Parameter	Typical Value	Description
Image	500 x 500	Grid size
IP	300	Initial population size
SA	22.5	Sensor angle to forward position
RA	45	Agent rotation angle
SO	10	Sensor offset distance
MS	5	Max speed
PCD	0.1	Possible change direction
DDis	100	Death distance
TrR	5	Agent-food trail ratio
OGF	10	Orient guide factor
DvR	2	Division Detect Radius
DvMin	0	Divide if neighborhood agents count above or equal
DvMax	10	Divide if neighborhood agents count below, As integer $(DvR \times 2 + 1)^2$
DeR	3	Death detect radius
DeMin	0	Die if neighborhood agents count below or equal
DeMax	10	Die if neighborhood agents count above, As integer $(DeR \times 2 + 1)^2$

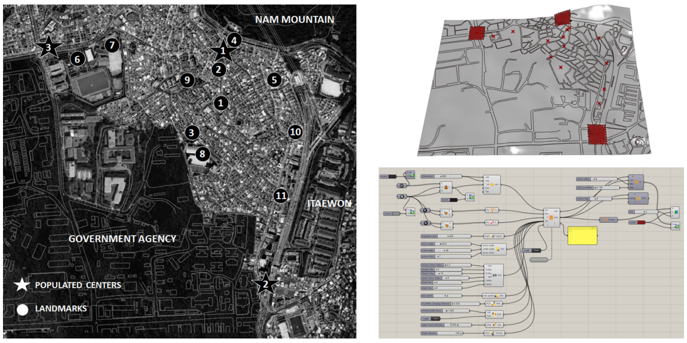

Figure 4. Setting the simulation environment. 1) landmarks and populated junctions marked on map (left), 2) setting environment on the 3D terrain digital model - 3D terrain model as surface, 3 red spots as emitters and 11 points of landmarks as foods (right top), 3) setting parameter values of agent behavior in Grasshopper (right bottom).

In Figure 4, the emitters are the most populated center places, which are (1) Haebangchon 5-geory junction, (2) Haebangchon entryway, (3) Yongsan high school junction. The foods are set with the landmarks and the historical buildings from 1945 to present including churches, schools, community centers and market areas of Haebangchon, which are (1) Haebangchon Presbyterian church, (2) Shinheung market, (3) Haebangchon Catholic church, (4) Yongsan 2-ga community center, (5) Namsan Presbyterian church, (6) Yongsan high school, (7) Yongsan middle school (8) Bosung girls high school, (9) Centennial Christian school, (10) Jongjum pharmacy and (11) Haebanchon gourmet street.

5. Network Analysis

5.1. UNDERSTANDING URBAN DEVELOPMENT PROCESSES

The emergent networks of P. polycephalum is experimented as a means of constructing synthetic biological spatial configurations. The modeling of the agent movements from the center places where expansions occur show how the urban centers emerge, grow, and form the whole regional system indicating where it produces symmetry breakings and where it joins (Allen and Sanglier, 1981). By setting the three center places as emitters at an initial population of 300, the urban development processes are simulated in emergence and growth of the agents.

Based on the parameter value settings for the agent behavior shown in Table 1, the nonlinear pattern formations of the agent trails are captured. The model contains a number of parameters and there are three main agent parameters (SA, RA and SO) which significantly affect patterning. When RA is larger than SA, the dynamic emergence of agents' movements from the populated center places occurs. Figure 5 shows agent trail maps when SA is 22.5, RA is 45 and SO is 10. The trail maps contain food source stimuli and agent locations. The initial random distribution and movement of agent particles go through phases of transition and self-organizes its structures as growing, forming certain spatial boundaries. The agents move to forage food stimuli and emerge in the spatial territories. The emergence of populations constructs nonlinear structures, streaming and joining with distant parts. The small circular gaps appear and disappear as the agents branch out to the distant parts. As a result, it is shown that the spatial territories of the agent trails match to the current map. The nonlinear spatial patterns formed by the self-organized movements of the agents show that the spatial configurations are formed in similarity to the current district boundaries of Haebangchon in the development processes.

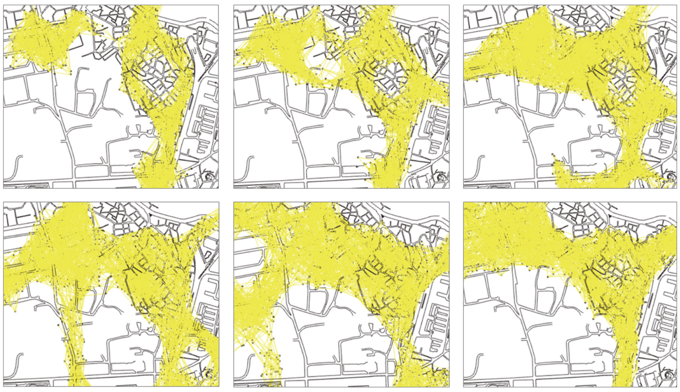

Figure 5. The emergence of agent particles on 3D terrain model (top view). Yellow indicates agent trails. Sensor values at SA 22.5, RA 45 and SO 10. Simulation result snapshots are taken at t=50, 75, 150, 300, 500 and 1000.

5.2. FINDING OPTIMAL NETWORKS FOR FUTURE DEVELOPMENT

Experimenting spontaneous pattern formations of the agent trails, dynamic bottom-up patterns of networks are explored. Controlling the division and death detect value settings in the agents' movement behaviors, the optimized networks are searched. It is investigated where the strong networks are initially formed and how those grow. The three center places are set as the emitters and the historical landmarks are set as food sources in the simulation model.

Figure 6 shows how the initial random movements of the agent particles form network patterns in changes of the division and death detect value settings. In the simulation, the network structures transform as the agents emerge and die in the movement to forage food stimuli. In the process, branching and joining with distant parts have formed closed circular network structures. The pores of circular structures become large or small as time step runs. Occasionally, a bifurcation appears in one of the network edges and agents branch out dividing space of a single pore. As the smaller pores shrink and disappear, larger lacunae dominate and grow. In the result, it is seen that the circular network between center place 1 and 2 and the linear path from center place 1 and 3 remain from the initial trail maps to the most developed one in the simulation process. These paths are interpreted as the highly influential network circulation paths, and evidently, these are the public transport paths in the current system.

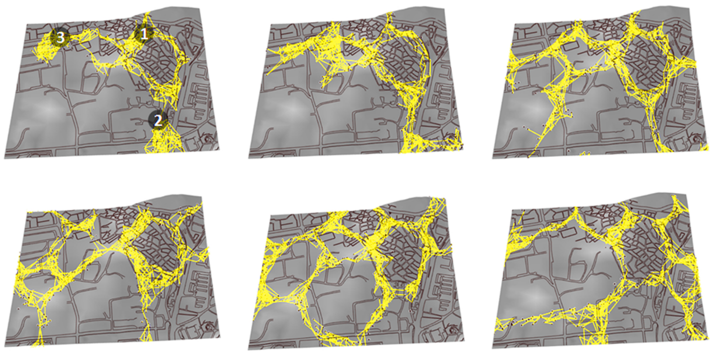

Figure 6. The emergence of agent particle networks on the 3D terrain model (perspective view). Three center places set as emitters. Trail map patterns indicate agent trails. 1) sensor values at SA 22.5, RA 45 and SO 10. 2) division detect values at DvR 2, DvMin 0 and DvMax 10, 3) death detect values at DeR 3, DvMin 0 and DvMax 5. Simulation result snapshots are taken at t=50, 75, 150, 300, 500 and 1000.

It is further investigated how the agents adapt its network system formations to the parameter value changes of SA, RA and SO. The parameter values tested are in Table 2 and Figure 7 shows the results. When the SA and RA are larger angles, the agents correspond to remote sensing behaviors to the distant parts forming bigger pores. When SO is smaller, joining behaviors to the adjacent parts gets stronger. Thus, the three main values are to be set in terms of the city scale and density of populations. In Figure 7, the circular networks around the center place 1 and 2 and the linear network between the center place 1 and 3 are shown from trial 1 to trial 4. These road networks are interpreted as the center stream of the town flow, which need to be maintained and widened for the smooth and effective circulation of the town in development processes.

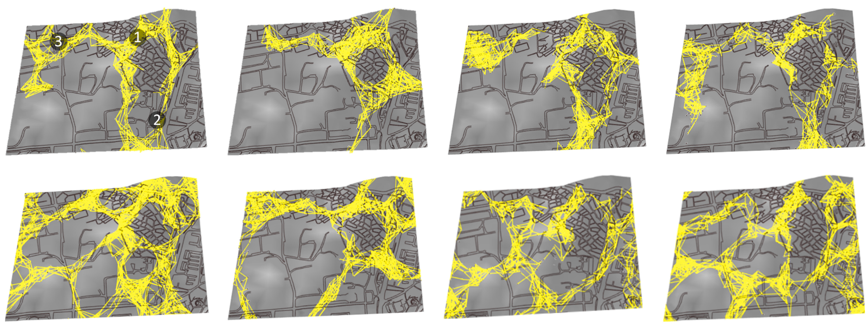

Figure 7. Example of the emergence of agent particles on the 3D terrain model. Trial 1 to 4 from left to right. Three center places set as emitters. Trail map patterns are indicated by agent trails. 1) sensor values at SA 22.5, RA 45 and SO 10. 2) division detect values at DvR 2, DvMin 0 and DvMax 10, 3) death detect values at DeR 3, DvMin 0 and DvMax 5. Simulation result snapshots are taken at t=100 and 1000.

Table 2. Parameter values for agent behavior simulations.

Parameter	Trial 1	Trial 2	Trial 3	Trial 4
SA	22.5	22.5	45	45
RA	45	45	90	90
SO	5	10	5	10

6. Conclusions

The agent-based simulations have been conducted to investigate the visible and invisible networks of a town through understanding the self-organized aspects of city development processes exploring the road network formations of the agent movements. These are to find optimal future networks which provide connectivity and accessibility to the cities through spatial network configurations of internal individual behavior and movement in the context of the past, present and future of the town.

Experimenting spontaneous pattern formations of the agent trails, dynamic bottom-up patterns of networks are explored. First, setting the agent behavior model in emerging mode by controlling the division detect values higher than death detect values, and RA larger than SA, the spatial territories of which agents' movements form is observed. From the simulation, it is found the spatial pattern formations of the agent trails match to the current district boundaries and the transformations of spatial configurations display the development processes. The modeling of the agent movements from the center places where expansions occur show how the urban centers emerge, grow, and form the whole regional system.

Second, the network paths were investigated through simulations of various control values of agent behavior settings, aiming at finding the optimal urban networks for future applications through organizing the best hierarchy of network structures. Like blood vessels, the width of roads needs to be large or small in terms of a necessary amount of traffic. However, in the current way system of Haebangchon, the roads are narrow with similar width and the hierarchy of the paths is invisible. In the simulation results, some road networks were seen consistently in changes of the control values, which indicate these are to be planned as the main roads for smooth and effective circulation of the town in changing circumstances. As of the recent moving plan of the government agencies in Haebangchon, these understandings and findings may support to search out a constructive recreation plan preventing the area being isolated or under-developed with a big loss of population.

This study contributes to understanding complex city systems through investigating the visible and invisible hierarchy of network structures, which is an important factor for re-planning of a way system. In city's changing circumstances under various scenarios which may impact a huge population gain or loss, the road networks need to be re-planned. The application of the agent-based simulations can be a tool for finding solutions. For future study, other cases will be further investigated to apply the agent-based simulations as a means of finding the effective links and nodes for restructuring way systems which support the communicative and smooth circulation for an optimized urban system.

Acknowledgement

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