DEFINING 3D SPATIAL NEIGHBORHOODS FOR TOPOLOGICAL ANALYSES USING A 3D NETWORK-BASED TOPOLOGICAL DATA MODEL
- CA-BASED BUILDING EVACUATION SIMULATION -

Inhye Park [a] , Jiyeong Lee [a, 1]

[a] Dept. Of Geoinformatics, the University of Seoul, South Korea – {ihpsm, jlee}@uos.ac.kr

Commission WG II/2

KEY WORDS: GIS, 3D GIS, Evacuation, Spatial Data Analysis, Topological Analysis, Dynamic Model

ABSTRACT:

After 9/11 there has been special interests in 3D models to represent internal structures of micro-scale environment (built-in urban areas), in order to understand and analyze human movements under such emergency situations in micro-scale environment. With comparing to 2D analysis, the 3D searching operation should deal with complex geometric computational problems involves with defining spatial neighbourhoods between the 3D target object and well-formed 3D objects in a micro-scale urban area such as spatial units in a building. Therefore, this study is motivated by need of a new method to analyze human behaviours in micro-space urban environments, such as a relative accessibility, or location interoperability services for emergency operations within a medical centre. In this study, we considered about the application method of three dimensional models and indoor positioning techniques. We presented an algorithm to define spatial relationships based on network-based neighbourhoods for 3D topological analyses in micro-scale urban area. We utilize Cellular Automata model to connect with indoor positioning techniques and present movement of individual evacuees for the 3D topological analysis.

1. INTRODUCTION

1.1 Background and object

After 9/11 there has been special interests in 3D models to represent internal structures of micro-scale environments, in order to understand and analyze human movements under such emergency situations in micro-scale environments. In addition, large complex buildings In urban built environment, are increasing in number and efficiency gradually. With the increase of large complex buildings, requirements of users for the services which relate with internal space are getting increase. Geospatial researchers have attempted to utilize GIScience technologies in emergency situations (Cahan and Ball, 2002; Cutter, Richardson, and Wilbanks, 2003; Kwan, 2003; Kwan and Lee, 2005; Pu and Zlatanova, 2005; Winter et al. 2005; Lee, 2007).

Suppose that an emergency situation has occurred on the tenth floor of building, for instance a fire or chemical material explosion at a room. Spatial analyses in emergency response such as optimal evacuation route or fire spread analyse within the building need to define spatial relationships among rooms to describe how individual spatial units interact. These analyses require defining the area surrounding each target feature within which feature values are compared – termed "spatial neighbourhood." The neighbourhoods are defined in terms of the interaction or movement between features. For example, the value of a property is often strongly influenced by the values of neighbouring properties. In most current analyses, these spatial relationships are represented using adjacency-based neighbourhoods or distance-based neighbourhoods in 2D space.

However such emergency response applications require three-dimensional data models to represent the internal structures of urban built-environments and three-dimensional analytical functions to conduct 3D geographic information systems (GIS)-based spatial analyses such as calculations of optimal routes inside urban entities(Lee, 2007). In addition, most currently studies about emergency situation are based on hypothetical data or static in scientific research. With the recent progress of indoor positioning systems, the simulators can be enhanced to real-time service systems. Especially, evacuation simulators can be enhanced to real-time evacuation systems with the application of three-dimensional models to represent internal structures, three-dimensional analytical functions and indoor positioning technologies. So, in this paper we consider the application method of three dimensional models and indoor positioning techniques. With comparing to 2D analysis the 3D searching operation should deal with complex geometric computational problems involved with defining spatial neighbourhoods between the 3D target object (for example, a explored lab) and well-formed 3D objects in a micro-scale urban area (such as a spatial units in a building). Therefore this study is motivated by the need of a new method to define the spatial neighbourhoods among the 3D objects for analyzing human behaviours in micro-space urban environments, such as a relative accessibility, or location interoperability services for emergency operations within a medical centre.

The purpose of the paper is to present an algorithm to define spatial relationships based on network-based neighbourhoods for 3D topological analyses in micro-scale urban area. Through the application of Cellular Automata model it is possible to connect with indoor positioning techniques and present movement of individual evacuees.

[1] Corresponding author

1.2 Literature Review

Recently, many studies have been conducted to deal with complex phenomena such as behaviours of pedestrian in view. Some instances of evacuation simulation system applied molecular dynamics, lattice gas, or Cellular Automata (CA) model. Specially, CA model is used plentifully in simulation because its operation process is very simple and it can display individual movements.

Ioakeim G. Goergoudas (2006) applied CA model to tracking movement of crowd in emergency situation, and Yuan Weifeng (2007) applied CA model to computing movement of evacuees with various velocities. B. Toledo (2007) set virtual cellular spaces and compared the difference of evacuation time which follows in presence of the exit (Figure 1).

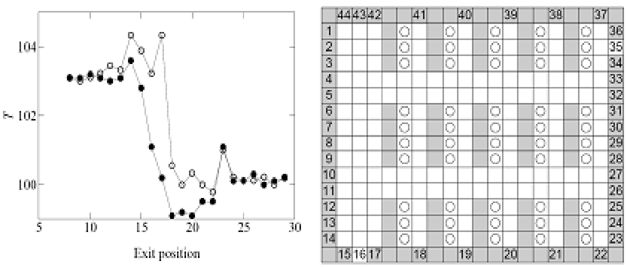


Figure 1. Evacuation time followed positioning of exits (B. Toledo, 2007)

The CA model divided continuous time and space to discrete timestep and regular grid cell and then computed distance of each cell from exits (Figure 2). After then they simulated with changes positioning of obstacles and exits.

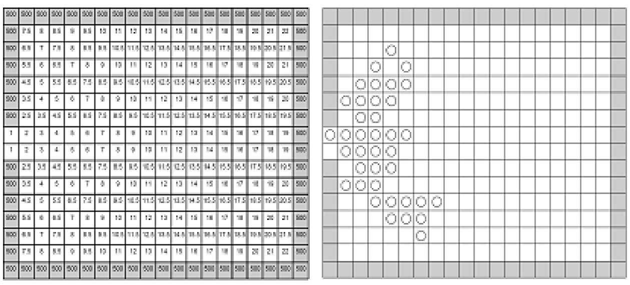


Figure 2. Cell value and simulation (B. Toledo, 2007)

In this study we reference the application method used in the study of B.Toledo.

2. DATA MODELS FOR TOPOLOGICAL ANALYSIS

This study is divided in two parts. One is 3D network-based topological data model and the other is dynamic model. The former is for representing building structure and analytical functions. And the other is for applying data from indoor sensors or positioning systems.

2.1 3D Network-based Topological Model

3D geo-information has been always challenged due to a variety of data models, resolution and details, and ways of geometric and topological representations (Zlatanova et al. 2004). In order to maximize efficiency and effectiveness in the provision of operations, hybrid data models are proposed to be maintained in one database by describing the objects, rules and constraints of each model in a metadata table. Metric and position operations such as area or volume computations are presented on the geometric model, while spatial relationship operations such as “meet” and overlap” are performed on the topological model (Oosterom et al. 2002; Arens et al. 2005). In order to represent topological relationships among 3D spatial objects in built environment (such as buildings), this study utilize the 3D network-based topological model (Figure 3) (Lee, 2004), which was developed to abstract and represent the connectivity spatial relationships of the internal structure of buildings It is derived through 3D Poincaré Duality using a graph-theoretic framework and a hierarchical representation schema, and a Straight-Medial Axis Transformation (S-MAT) modelling. The 3D Poincaré Duality is utilized to abstract the topological relations among a set of 3D object and to transform ‘3D to 2D relations’ in primal space to ‘0D to 1D relations’ in dual space (Lee and Kwan, 2005).

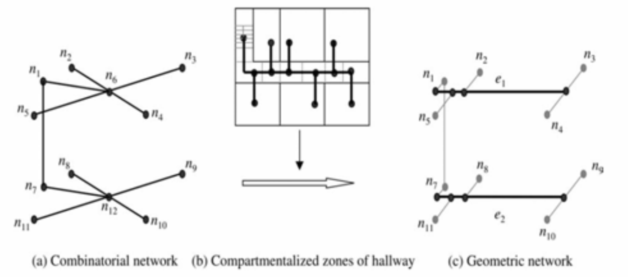


Figure 3. Node-Relationship Structure for representing topological relations within 3D objects (Lee, 2004)

This study presents an algorithm to define spatial relationships based on network-based neighbourhoods for 3D topological analyses in micro-scale urban areas. The approach utilize the algorithm to find a minimum spanning tree (MST) in a connected and undirected graph (Kruskal ,1956) Because the dual graph topological model G is a network representation having geometric properties (lengths and directions), well-known algorithms for finding minimum spanning trees in graphs can be applied to defining 3D spatial neighbourhoods. In other word, the algorithm can generate a minimum spanning tree from a node n_i of the network G, and then the network segments within a specific distance (a threshold or cutoff distance) from the node n_i can be identified from the MST. Each node in the MST contains the total distance (or cost) from the rooted node n_i . From the identified network segments, the set of nodes within the specific distance from the node n_i. The Prim’s algorithm (1957) is implemented for this purpose. Since the Prim’s algorithm identified minimum spanning tree from a source node to all other nodes, the algorithm needs to be modified in order to implement spatial queries from a rooted node to define nodes within a specific distance, a threshold. In order to define the neighbourhoods from a rooted node using a cutoff distance, the input data are a weighted 3D graph G = (V(G), E(G)) for each edge e, having a distance value d_e for the edge. Other are the cutoff distance, *d-bis*, and the rooted node *r*. The output file is a N[ ], a set of nodes, which represent 3D objects (such as rooms within a building) in a primal space.

2.2 Applying the CA-based Evacuation Simulation

The output data of dynamic model would be input data of spatial analysis in the 3D network-based topological model. For example, existences and locations of evacuees are outputs of dynamic model. Dynamic model computes such variables from data which measured by indoor positioning systems. Dynamic model is connected with network model by a node which involved in network model (Figure 7(b)). The node symbolizes a space (for example, room or divided corridor). This is detailed in the next section.

We simulated the movement of evacuees which applied Cellular Automata (CA) (Figure 4) model. CA is a discrete model which consists of regular grid cells. In this model time and space is represented discretely. So, indoor positioning system data (raster type) can be applied to CA model.

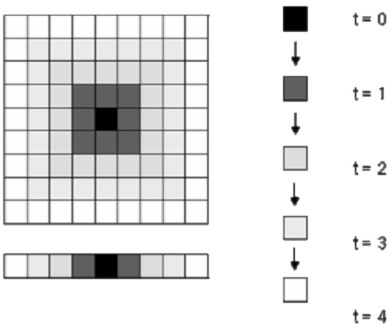


Figure 4. Information exchange in Cellular Automata (Itzhak, 2004)

We divided shape file in regular grid cells, and constructed a test system to represent CA model and to shape file in same interface.

In this simulation indoor space is represented in 2D grid. Considering the characteristics of CA model (simple operation process), we applied some rules to simulation. Table 1 shows parameters which used in simulation.

Paramter	Description
cell size	$0.4 * 0.4\ m^2$
timestep	$\Delta t \approx 0.3$ s
distance value	$N + \lambda$ ($\lambda>1$)
velocity	1.56 m/s

Table 1 Parameters

Each cell has a distance value which is calculated from exit. Cell which is corresponded wall is regarded as obstacle that bounds nonmovable space. Cells belonging to walls are given very high distance value. Figure 5 is computation process of distance value. The distance value of cells belonging to exit is assigned 1. Then all adjacent cells to the previous one are assigned value, according to the following rules

If a cell has value *N*, then adjacent cells in the vertical or horizontal directions are assigned a value *N+1*. And cells in the diagonal direction are assigned *N+1.5*.

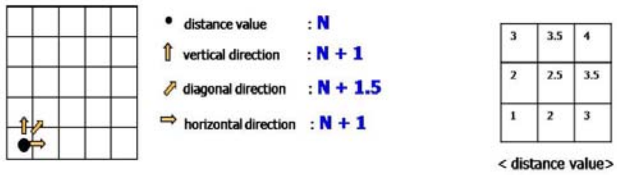


Figure 5. Computation process of Distance Value

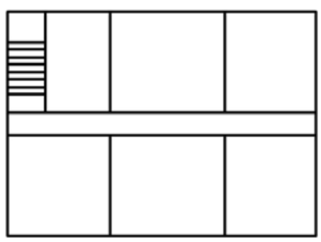
Distance values of all cells are calculated and then evacuees move with the distance value. One moves toward smaller value. There can occur conflicts in the movement process because a cell adjacent with more than 3 cells. Therefore the minimum possible value is assigned to the cell having conflicts. In this case, the minimum cell is selected randomly (Figure 6).

Figure 6. Rule of Movement

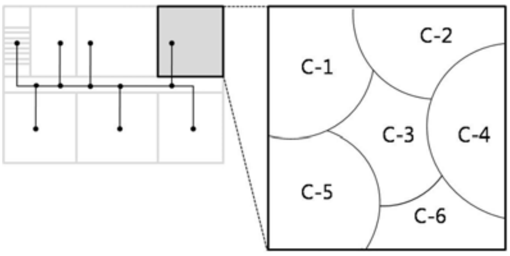
2.3 Method of Connection between CA model and Network model

Figure 7 illustrates the relationships among the geometry model, network model, indoor positioning system data and CA model. We formed network model through replacing spaces to nodes. These nodes are connected by links. Network model is to express relationships between spatial objects (Figure 7(b)). In order to apply network model to evacuation system, they are necessary information about evacuees' number and location which can be obtained from indoor positioning system data such as RFID tag data. RFID systems collect data like Figure 7(b).

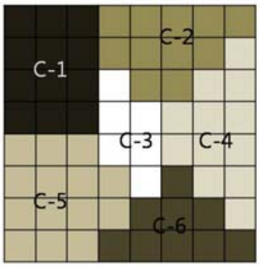
Suppose that RFID receivers are set up enough to cover the whole space with RFID coverage. We can know just the number of people (Table 2) involved in corresponding cell through the RFID data. But we cannot obtain information of individual locations. Therefore, we need to estimate locations of each people through the CA-based simulation. That simulation has some rules associated with movement of people. So we need a method to estimate individual locations from RFID data. In this study we use random distribution (Figure 8).



(a) Geometry Model



(b) Network model and RFID coverage



(c) CA-model

Figure 7. Relationship among the geometry model, network model, indoor positioning system data and CA model

Coverage	Number of People
C-1	6
C-2	4
C-3	2
C-4	0
C-5	3
C-6	4

Table 2. RFID initial information

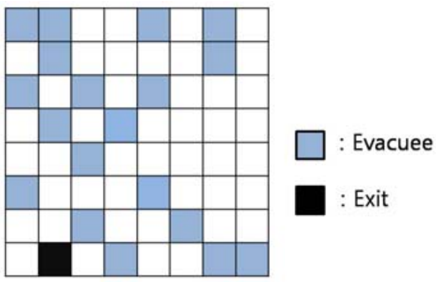


Figure 8. CA-mode assigned evacuees

We can obtain location and number of evacuees in the room through the simulation with pedestrian behaviours in emergency situation. And we can apply these values to evacuation system.

3. CONCLUSIONS

The proposed algorithm is to define distance-based neighbourhoods among 3D objects. And CA model was used to connect with indoor positioning techniques and present movement of individual evacuees. Using the network-based topological data model, we could also define the spatial neighbourhoods based on adjacency, based on first-order features or higher-order features. This spatial neighbourhood information can be used in environmentally oriented analyses including noise, air pollution, and emergency situations in urban environment. Because the 3D network was developed to represent connectivity relationships among the 3D objects based on graph model, the network model can be used for analyzing human behaviours including pedestrian accessibility measurements, pathfinding, allocation and tracing analyses within 3D micro-spatial environment. Such applications require a 3D Navigable Data Model (3D NDM) (Lee, 2007) to represent the internal structures of urban-built environments and environmental factors to model pedestrian-based indoor movement, such as traffic flows, damage status, bottleneck location, etc.

In this study, we just represent conceptual model. In the further studies we will evaluate this model through test bed systems. This study is expected to be useful in studying building evacuation.

ACKNOWLEDGEMENTS

This project has been supported by Seoul R&BD Program.

REFERENCES

Arens, C., J.E. Stoter, and P.J.M. van Oosterom(2005). " Modelling 3D spatial objects in a geo_DBMS using a 3D primitive." Computer & Geosciences, 2 : 165-167

B.Toledo, 2007, Cellular automata model for evacuation process with obstacles, Physica. A (2007) 10602.

Chou, Y-H.(1997). Exploring Spatial Analysis in Geographic Information Systems. New York, OnWord Press.

Dietrich E. Wolf, 1999, Cellular automata for traffic simulations, Physica A, 1999, 263: 438-451.

Jian-ping Meng, Shi-qiang Dai, Li-yun dong, Jie-fang Zhang, 2007, Cellular automaton model for mixed traffic flow with motorcycles, Physica A.

Kruskal, J.B.(1956). "On the shortest spanning subtree of a graph and the travelling salesman problem." Proc. Am. Math. Soc. 7(1):48-50

Lee, J. (2004) "A Spatial Access Orented Implementation of a Topological Data Model for 3D Urban Entities." Geoinformatica 8(3): 235-262.

Lee, J. (2007). "A 3D Navigable Data Model to Support Emergency Responses in Micro-Spatial Built-Environments." Annals of the Association of American Geographers, 97(3): 512-529.

Lee, J. and M-P. Kwan (2005). "A Combinatorial Data Model for Representing Toplogical Relationships between 3-D Geographic Entities." International Journal of Geographical Information Sciences, 19(10): 1039-1056.

M. Meijers, S. Zlatanova, N. Pfeifer, 2005, 3D Geo-information indoors: Structure for evacuation, In Proceedings of Next generation 3D city models 21-22 June, Bonn, Germany, 6.

Oosterom, P. v., J. Stoter, W. Quak and S. Zlatanova (2002). "The balance between geometry and topology". In D. Richardson & P. Oosterom (eds), Advances in Spatial Data Handling, 10th International Symposium on Spatial Data Handling: 209-224. Berlin: Springer-Verlag.

Sven Maerivoet, Bart De Moor, 2005, Cellular automata models of road traffic, Science Direct, Physics Reports, 2005, 419, pp.1-64.

S.L. Cutter, 2003, GI Science, Disasters, and Emergency Management, Transaction in GIS, 2003, 7(4): 439-445.

Takashi Nagatani, 1994, Dynamical jamming transition induced by a car accident in traffic-flow model of a two-lane roadway, Physica A, 1994, 202: 449-458.

Yuan Weifeng, Tan Kang Hai, 2007, A novel algorithm of simulating multi-velocity evacuation based on cellular automata modeling and tenability condition, Physica A, 2007, 379: 250-262.

Zlatanova, S., A. Rahman and W. Shi(2004). "Topological models and frameworks for 3D spatial objects." Journal of Computers & Geosciences, 30(4): 419-428.

Smith, J., 1989. *Space Data from Earth Sciences*. Elsevier, Amsterdam, pp. 321-332.

Allan Brimicombe, 2003, *GIS, Environmental modeling and engineering*, Taylor & Francis.

Itzhak Beneson, Paul M. Torrens, 2004, *Geosimulation - Automata-based Modeling of Utban Phenomena*, JHON WILEY & SONS, LTD.

Nathalie Waldau, Peter Gattermann, 2005, *Pedestrian and Evacuation Dynamic 2005*, Springer.