DEFINING SPATIAL NEIGHBORHOODS FOR 3D TOPOLOGICAL ANALYSIS IN INDOOR SPACE

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ABSTRACT:

Since September 11, 2001, geospatial researchers have been interested in utilizing GIScience technologies to solve geographical questions in micro-scale space in built-environments such as indoor space within a building. The indoor space should be dealt with differently from outdoor space in order to provide integrated and seamless location-based services (Li, 2009). The indoor LBS applications provided in multi-level structures such as buildings require a fundamental geo-spatial functionality to define spatial relationships among 3D entities to describe how individual spatial units interact. Because the 3D query operations are much complex geometric computational problems, this study proposes an alternative method to define the spatial neighborhoods among the 3D objects based on network-based topological representations for analyzing spatial relationships in indoor space.

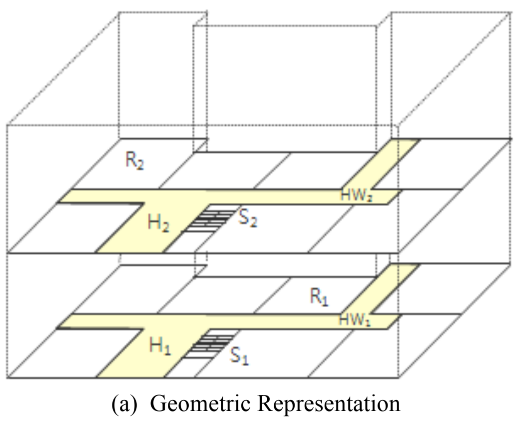
1. INTRODUCTION

Since September 11, 2001, geospatial researchers have been interested in utilizing GIScience technologies to solve geographical questions in micro-scale space in built-environments such as indoor space within a building. The indoor space should be dealt with differently from outdoor space in order to provide integrated and seamless location-based services (Li, 2009). The indoor LBS applications provided in multi-level structures such as buildings require a fundamental geo-spatial functionality to define spatial relationships among 3D entities to describe how individual spatial units interact. The spatial region surrounding each target feature is called “spatial neighborhood”, which is 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 neighboring properties. In general, these spatial relationships in most current analyses have been represented in terms of adjacency-based neighborhoods or distance-based neighborhoods in 2D space.

With comparing to 2D analysis, the 3D query operations are much complex geometric computational problems involved in defining spatial neighborhoods between the 3D target object (for example, a explored lab) and well-formed 3D objects in indoor space (such as spatial units in a building). This study is motivated by the need of an alternative method to define the spatial neighborhoods among the 3D objects for analyzing spatial relationships in indoor space, in order to analyze a relative accessibility measurement for people with different abilities, an evaluation of neighborhood pedestrian accessibility, or location interoperability services for emergency operations within a medical center. Therefore, this study proposes an algorithm to define spatial neighborhoods based on network-based topological representations for 3D topological analyses in indoor space.

2. NETWORK-BASED TOPOLOGICAL DATA 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 in geometric and topological aspects (Oosterom et al. 2002; Arens et al. 2005), instead of 3D topological models based on b-rep representations. In order to represent topological relationships among 3D spatial objects in built environments (such as buildings), this study utilizes the 3D network-based topological model (Lee 2004), which was developed to abstract and represent the spatial relationships of the internal structure of buildings. It is derived through 3D Poincaré Duality using a graph-theoretic framework and a Straight-Medial Axis Transformation (S-MAT) modeling. The 3D Poincaré Duality is utilized to abstract the topological relations among a set of 3D objects and to transform ‘3D to 2D relations’ in primal space to ‘0D to 1D relations’ in dual space (Lee and Kwan 2005).



(a) Geometric Representation

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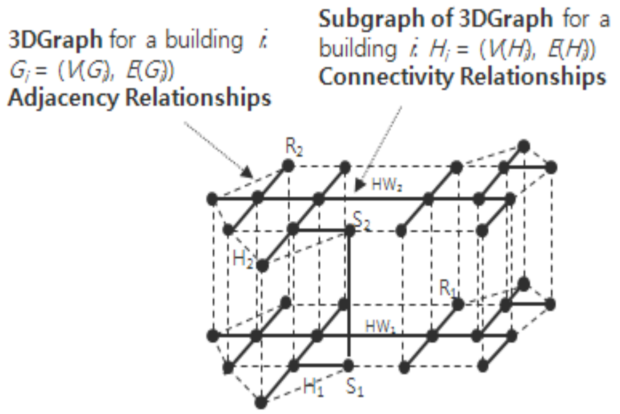


(b) Topological Representation

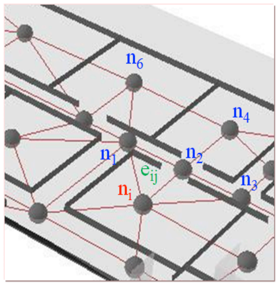
Figure 1. A Building Representation

As shown in figure 1(b), one node set and two edge sets are defined in this example, which is formalized as graph $G = (V(G), E(G))$, and graph $H = (V(H), E(H))$. Graph G represents the adjacency relations among the 3D objects in the building, and graph H represents the connectivity relations among the 3D spatial units. Node set $N = \{n_1, n_2, n_3, \ldots\ldots, n_{12}\}$ is an abstraction of the 3D features or spatial units in the building. One edge set represents the adjacency relationships, $EA = \{ea_1, ea_2, \ldots\ldots, ea_n\}$, between the 3D units, and the other set represents the connectivity relations, $EC = \{ec_1, ec_2, \ldots.., ec_m\}$. In the node set, the node n_1 in the 3D network-based topological model corresponds to the 3D unit s_1 of the building; node n_2 to s_2, node n_3 to s_3, and so on.

3. SPATIAL NEIGHBORHOOD QUERY ALGORITHMS

As mentioned in the above, the purpose of this study is to present an algorithm to define spatial neighborhoods based on network-based topological representations for 3D topological analyses in indoor space. For example, in order to identify spatial distribution patterns created by geographic objects, we need a method to measure the similarity or dissimilarity of any pair of neighboring features within a given spatial neighborhood, which may be defined by a distance or neighbor orders. Spatial neighborhoods in 3D space can be defined as adjacency-based neighborhoods and connectivity-based neighborhoods in different applications. The adjacency-based spatial neighborhoods can be used in environmentally oriented analyses including noise impacts, air pollutions, and emergency events such as bombing in indoor space, while the connectivity-based neighborhoods would be defined for analyzing human behaviors including pedestrian accessibility measurements, pathfinding, allocation and tracing analyses within indoor space. Therefore, this study will present two algorithms to define spatial neighborhoods in 3D space: one is an algorithm to define adjacency-based neighborhoods based on higher-orders, and the other is an algorithm to define connectivity-based neighborhoods based on a distance.

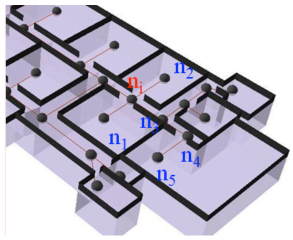
The adjacency-based higher-order neighborhoods can be defined as follows:



- Adjacency Link Indicator (ALI):
  - $e_{ij} = 1$ (if n_i and n_j are linked directly)

- AN between n_i and n_j;
  - when MIN (Total_ALI$_{ij}$) = 1,
  - All n_j are First-order Neighbors of n_i
  - when MIN (Total_ALI$_{ij}$) = 2,
  - All n_j are Second-order Neighbors of n_i
  - …..
  - when MIN (Total_ALI$_{ij}$) = k,
  - All n_j are k^{th}-order Neighbors of n_i

The distance-based neighborhoods having connectivity relationships can be defined as follows:



- Connectivity Link Indicator (CLI):
  - e_{ij} = distance b/t n_i and n_j

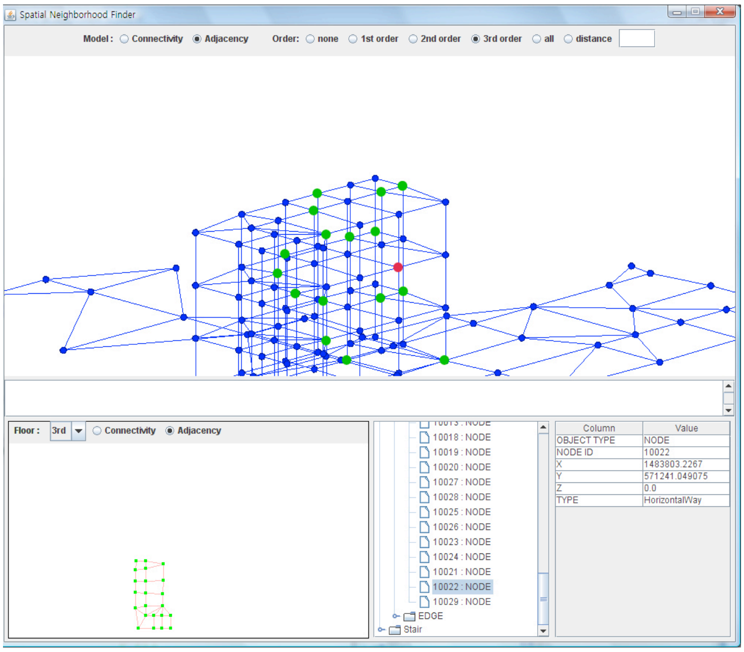
- CN between n_i and n_k;
  - cut-off distance = d_c
  - when Total_ALI$_{ik}$ <= d_c,
  - All n_k are connectivity Neighbors of n_i within distance d_c;

The approach utilizes the algorithm to find a shortest path in a connected and undirected graph (Dijkstra 1959). Because the dual graph topological model G is a network representation having geometric properties (lengths and directions) or a adjacency link indicator (neighboring orders), well-known algorithms for finding shortest paths in graphs can be applied to defining 3D spatial neighborhoods. In other word, the algorithm can generate a shortest path from a node n_i of the network G, and then the network segments within a specific distance (a threshold or cutoff distance) or ALIs from the node n_i can be identified from the shortest path. Each node in the shortest path contains the total distance (or cost) from the rooted node n_i. From the identified network segment, the set of nodes within the neighborhoods can be determined. The nodes in the network segments represent the spatial units within the specific distance or orders from the node n_i. The Dijkstra's algorithm (1959) is implemented for this purpose. Since the Dijkstra's algorithm identifies shortest paths 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 or to define nodes by neighboring orders.

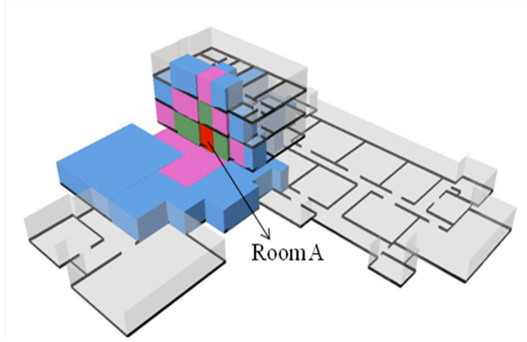
4. IMPLEMENTATION

To evaluate the proposed spatial neighborhood query algorithms, an experimental implementation of the Spatial Neighborhood Query system was undertaken. The components of systems were embodied in a Java development environment. The study area used to test the proposed algorithms is McEniry Building, located on the campus of the University of North Carolina at Charlotte, USA. The geometry data for representing the internal structure of a building was ArcGIS shapefile data. And to represent the topological relationships among rooms within the building, an network-based data model was used. The nodes in the model represent a room inside a building. Each node and edge has geometrical properties and thematic attribute data.

The adjacency-based higher-order neighborhoods from room A are defined as seen in the below figure:



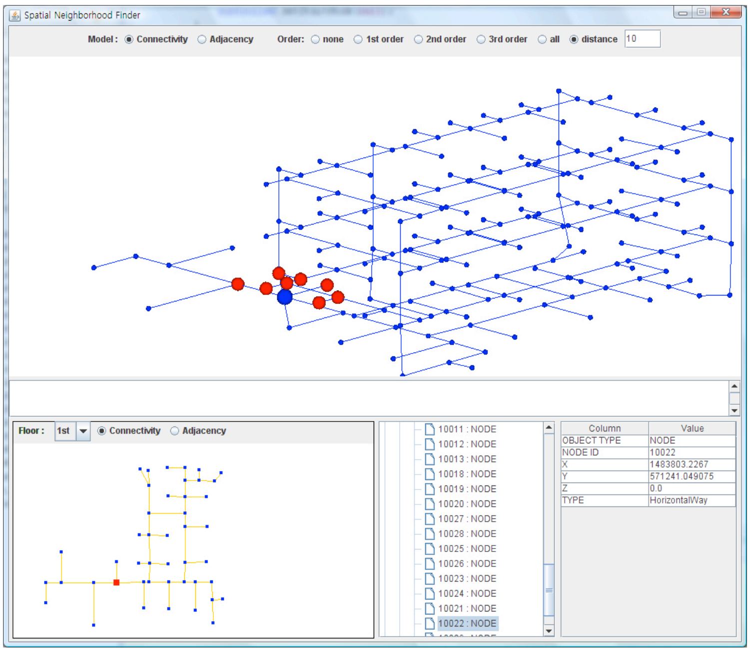
a) Results by Spatial Queries



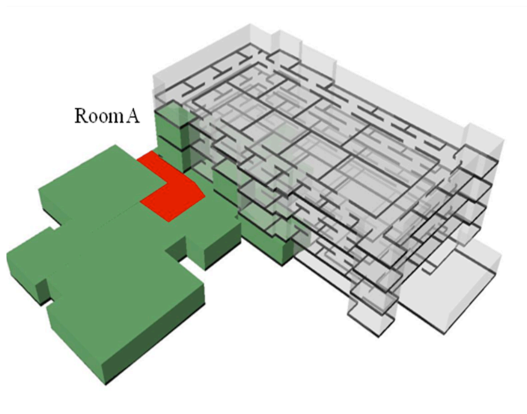
(b) First-, second-, and third-order neighborhoods

Figure 2. Adjacency-based higher-order Neighborhoods

The result of the implementation to define the distance-based neighborboods having connectivity relationships among 3D objects inside building is illustrated in Fig. 3. The cut-off distance from room A is 15 meters.



(a) Results by Spatial Queries



(b) Spatial Neighborhoods within 15 meters from Room A

Figure 3. Distance-based Neighborhoods

5. CONCLUSION

The proposed algorithm is to define the distance-based neighborhoods among 3D objects. Using the network-based topological data model, we also define the spatial neighborhoods based on first-order features or higher-order features. This spatial neighborhood information can be used in environmentally oriented analyses or in analyzing pedestrian movement patterns in indoor space. 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, toxicity status, bottleneck locations, etc.

ACKNOWLEDGEMENT

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