The Integration of Mobile GIS and Spatio-temporal Database for Evaluating Space-time Accessibility of an Individual: An Approach Based on Time Geography Model

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Abstract: This study attempts at building an integrated GIS computing framework for evaluating space-time accessibility of an individual with the approach of time geography model. The proposed method is based on the integration of mobile GIS and object-relational spatio-temporal database. Three components are central to our system: (i) mobile GIS application that transmits spatio-temporal trajectory data of an individual; (ii) spatio-temporal database server that incorporates the time geography model; and (iii) geovisualization client that provides time geographic queries to the spatio-temporal database. As for the mobile GIS application, spatio-temporal trajectory data collected by GPS-PDA client is automatically transmitted to the database server through mobile data management middleware. The spatio-temporal database server implemented by extending a generic DBMS provides spatio-temporal objects, functions and query languages. The geovisualization client illustrates 3D visual results of the queries about space-time path, space-time prism and space-time accessibility. This study shows a method of integrating mobile GIS and DBMS for time geography application, and presents an appropriate spatio-temporal data model for evaluating space-time accessibility of an individual.

Keywords: Spatio-temporal Database, Mobile GIS, Time Geography Model, Space-time Accessibility

1. Introduction

The "time geography" study originated from Hägerstrand (1970) has focused on spatio-temporal characteristics of an individual's day-trip, using space-time cube with X, Y and T axes. The researches after 1990s powered by GIS and computer graphics lifted up the time geography model from theory to implementation. Recently, three-dimensional visualization (Kraak, 2003), computational model (Miller, 2005) and space-time accessibility (Kim and Kwan, 2003) for the time geography model have been explored systematically.

Handy acquisition of spatio-temporal data using location technologies like GPS may bring about the necessity of the integration of time geography model and spatio-temporal database for large data processing. In fact, many researches on database have dealt with the issue of spatio-temporal data management such as spatio-temporal data modeling (Worboys, 1994), moving object data modeling (Sistla et al., 1997) and spatio-temporal database query (Güting et al., 2003). However, the efforts for combining time geography model with spatio-temporal database have not been sufficiently conducted yet.

Based on the existing research results of time geography and spatio-temporal database respectively, we aim to build an integrated GIS computing framework for evaluating space-time accessibility of an individual with the approach of time geography model. The proposed method is based on the integration of mobile GIS and object-relational spatio-temporal database. Three components are central to our system (Figure 1): (i) mobile GIS application that transmits spatio-temporal trajectory data of an individual; (ii) spatio-temporal database server that incorporates the time geography model; and (iii) geovisualization client that provides time geographic queries to the spatio-temporal database. As for the mobile GIS application, spatio-temporal trajectory data collected by GPS-PDA client is automatically transmitted to the database server through mobile data management middleware. The spatio-temporal database server implemented by extending a generic DBMS provides spatio-temporal objects, functions and query languages. The geovisualization client illustrates 3D visual results of the queries about space-time path, space-time prism and space-time accessibility.

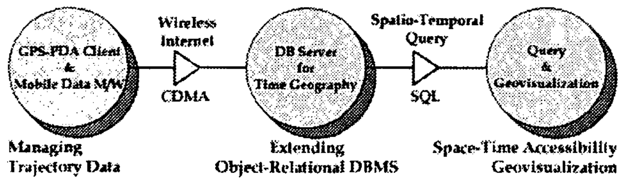


Figure 1. Framework of the Proposed Method

2. Space-time Accessibility in Time Geography Model

Two entities are central to time geography model for evaluating space-time accessibility of an individual (Miller, 2005): namely, space-time path (Figure 2a) and space-time prism (Figure 2b). The space-time path traces the movement of an individual in space and time. Individual paths convey information about the individual's activity space (the limited extent of the environment used by the individual) and the influence of fixed activities that comprise the anchor points of day-to-day existence (Golledge and Stimson, 1997). The space-time prism is an extension of the space-time path: this measures the ability to reach locations in space and time given the location and durations of fixed activities. Potential Path Space (PPS) is the interior of the prism. Projecting the PPS to the two-dimensional geographic plane delimits the Potential Path Area (PPA).

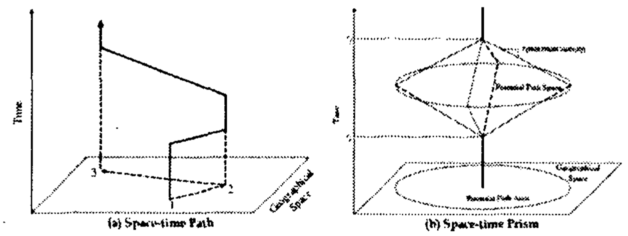


Figure 2. Space-time Path and Prism

A space-time path consists of two major components: a sequence of control points and a corresponding sequence of path segments connecting these points (Miller, 2005). Control points are measured locations in space and time (Formula 1). Path segments are the unobserved locations in space that connect temporally adjacent control points. The simplest representation of the unknown observations is a straight-line segment between two observed points (Formula 2). Combining the segment definition with the list of control points provides a time parametric equation for the space-time path (Formula 3). Temporally adjacent control points imply travel velocities (Formula 4).

$$c_i \equiv c(t_i) = x_i \quad (1)$$

$$S_{ij}(t) = (1 - \frac{t - t_i}{t_j - t_i})x_i + \frac{t - t_i}{t_j - t_i}x_j \quad (2)$$

$$P(t) = \begin{cases} c_i, t \in (t_S, \ldots, t_i, t_j, \ldots, t_E) \\ S_{ij}(t), t_i < t < t_j \end{cases} \quad (3)$$

$$v_{ij} = \|x_j - x_i\| / (t_j - t_i) \quad (4)$$

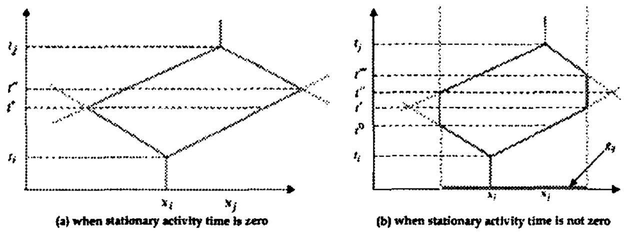


Figure 3. Temporal Boundaries of Space-time Prism

Similar to path segments, the space-time prism can be stated as a parametric function of time (Miller, 2005). When stationary activity time is zero (Figure 3a), the prism at time t is the intersection of two sets of cone (Formula 5). $f_i(t)$ is the set of locations that can be reached from x_i by the elapsed time t-t_i (Formula 6), and $p_j(t)$ is the set of locations that can reach x_j given the remaining time t_j-t (Formula 7). $f_i(t)$ is the possible futures of c_i, and $p_j(t)$ is the possible pasts of c_j at time t (Hawking and Penrose, 1996). The upper and lower bounds of the temporal zone Z_{ij} are t' (Formula 8) and t'' (Formula 9) respectively, where t^*_{ij} is the minimum travel time between c_i and c_j (Formula 10).

$$Z_{ij}(t) = f_i(t) \cap p_j(t) \quad (5)$$

$$f_i(t) = \{x \mid \|x - x_i\| \le (t - t_i)v_{ij}\} \quad (6)$$

$$p_j(t) = \{x \mid \|x_j - x\| \le (t_j - t)v_{ij}\} \quad (7)$$

$$t' = (t_i + t_j - t^*_{ij})/2 \quad (8)$$

$$t'' = (t_i + t_j + t^*_{ij})/2 \quad (9)$$

$$t^*_{ij} = \|x_j - x_i\| v_{ij}^{-1} \quad (10)$$

In more general cases when the stationary activity time (a_{ij}) is positive (Figure 3b), a cylinder of length a_{ij} separates the two cones comprising the prism (Miller, 2005). This prism at time t is the intersection of three sets (Formula 11), where the two-dimensional projection of g_{ij} delimits PPA (Formula 12). The temporal bounds of g_{ij} are t^0 (Formula 13) and t''' (Formula 14) respectively.

$$Z_{ij}(t) = \{f_i(t) \cap p_j(t) \cap g_{ij}\} \quad (11)$$

$$g_{ij} = \{x \mid \|x - x_i\| + \|x_j - x\| \le (t_j - t_i - a_{ij})v_{ij}\} \quad (12)$$

$$t^0 = (t_i + t_j - t^*_{ij} - a_{ij})/2 \quad (13)$$

$$t''' = (t_i + t_j + t^*_{ij} + a_{ij})/2 \quad (14)$$

3. Mobile Application for Data Transmission

The spatio-temporal trajectory data of an individual as the source of spatio-temporal database can be acquired by GPS receiver connected with PDA. We developed GPS-PDA client (Figure 4) and mobile data middleware (Figure 5) for the trajectory data transmission to server. The GPS-PDA client receives GPS data through RS-232C serial communication and transmits them to the mobile data middleware at intervals of n seconds. The mobile data middleware receives the trajectory data from GPS-PDA client through wireless internet; performs WGS84 to TM transformation; and transmits the converted data to server for the creation of server-side spatio-temporal objects by invoking PL/SQL procedure.

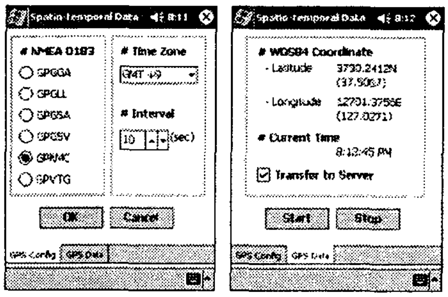


Figure 4. GPS-PDA Client for Data Transmission

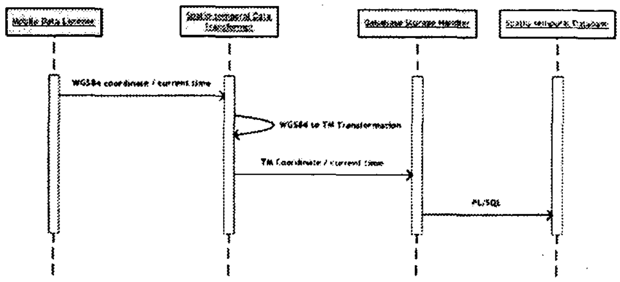


Figure 5. Mobile Data Middleware for Client/Server Brokerage

4. Implementation of Spatio-temporal Database

Our implementation of spatio-temporal database may be unique in that it focuses on the application of space-time accessibility based on time geography model. Using the Oracle 10g DBMS that provides spatial functionalities, we developed plug-in objects such as TIMESPAN, SPACE_TIME_PATH and SPACE_TIME_PRISM for temporal and spatio-temporal functionalities in accordance with the time geography model. The TIMESPAN object for temporal intervals and several operators for the object (Figure 6) were implemented by applying the temporal relation model of Allen (1983).

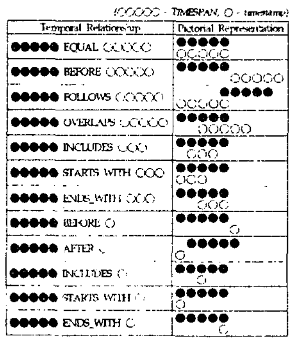


Figure 6. Temporal Operators for TIMESPAN object

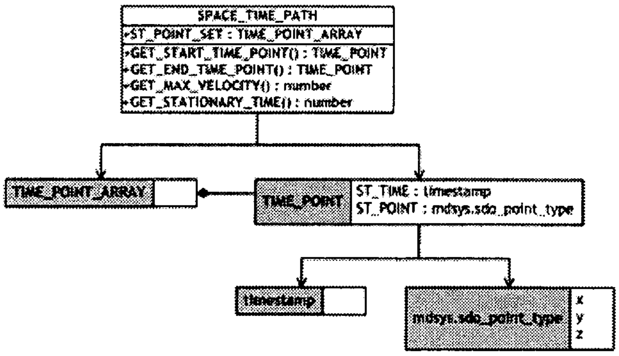
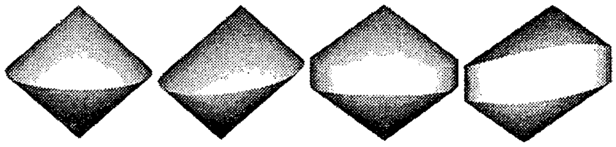


Figure 7. Structure of Space-time Path Object in Database



(a) $aij=0, xi=xj$ (b) $aij=0, xi \neq xj$ (c) $aij>0, xi=xj$ (d) $aij>0, xi \neq xj$

Figure 8. Four Types of Space-time Prism Object

The space-time path object is composed of a set of control points and several functions that provide necessary information for visualizing a space-time path in the query client (Figure 7). The space-time prism object is categorized into four types (Figure 8) according to the stationary activity time and the geographic locations of starting and ending points. The minimal requirements to represent the four types of space-time prism are starting point (c_i), ending point (c_j), maximum travel velocity (v_{ij}) and stationary activity time (a_{ij}). The upper/lower cones and a cylinder composed of a space-time prism can be derived from this information (Figure 9).

The notion of DUR (possible activity duration within facility opening hours) may be useful for evaluating space-time accessibility of an individual (Kim and Kwan, 2003), because it can differentiate between accessible and inaccessible urban facilities by comparing the opening hours of each facility and the available temporal zone of a space-time prism. The urban facility is a kind of POI (Point of Interest) from the day-tripper's viewpoint. We implemented the POI type that includes geographic location and opening hours (Figure 10) so that it can be used for evaluating space-time accessibility based on the DUR concept. In order to distinguish the POI's included in a PPA, the space-time prism object provides GET_POI_ARRAY function using point-in-circle and point-in-ellipse relations.

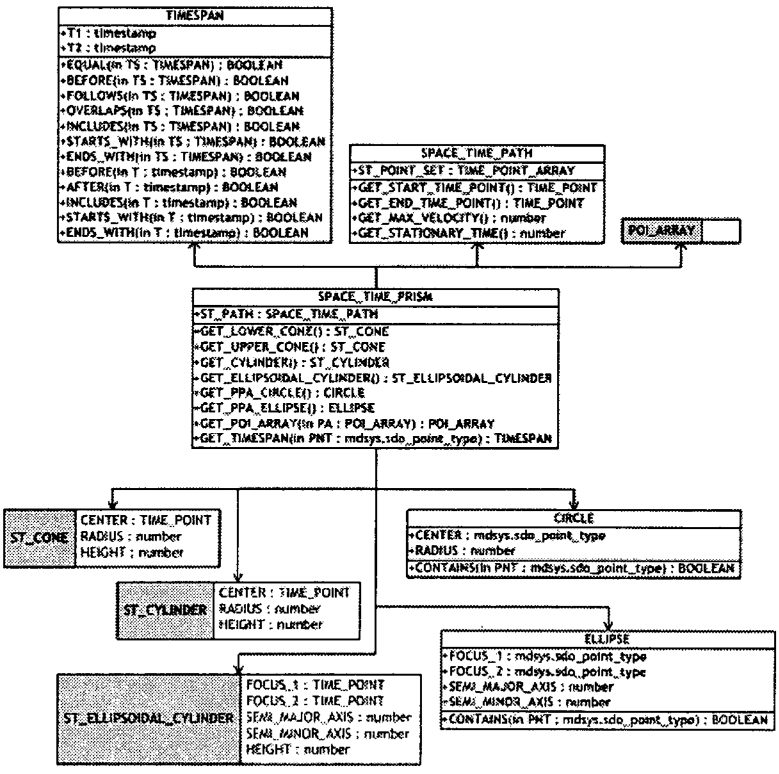


Figure 9. Structure of Space-time Prism Object in Database

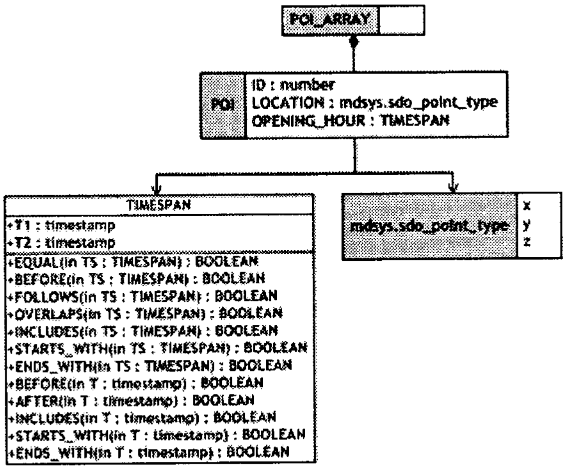


Figure 10. Structure of POI Type in Database

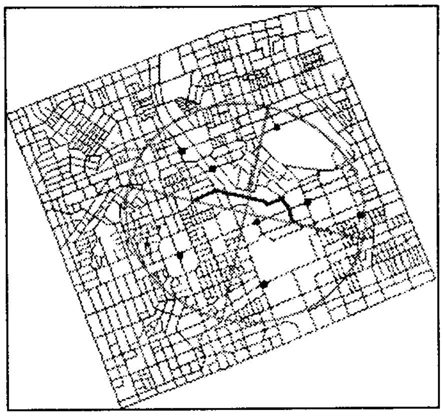


Figure 11. Query Result of Space-time Path, PPA and POI

5. Query and Visualization of Space-time Accessibility

The spatio-temporal objects stored in database server can be inquired by time geographic queries. We developed the query and geovisualization client that allows spatio-temporal SQL for space-time path, space-time prism and space-time accessibility. For an experiment, an individual's trajectory data around Kangnam Station in Seoul were stored in database server by the automatic transmission of our GPS-PDA application. POI data was created in a few virtual locations. The DDL (Data Definition Language) for the individual trajectory and urban POI is as follows.

```
• create table INDIVIDUAL_TRAJECTORY (person_id number(8), st_prism SPACE_TIME_PRISM);
• create table URBAN_POI (poi_set POI_ARRAY);
```

The query about space-time path, PPA and POI (Figure 11) uses a member field named ST_PATH and a member function named GET_PPA_ELLIPSE of the SPACE_TIME_PRISM object. To get the POI's included in a PPA, a member function named GET_POI_ARRAY is used as in the following SQL.

```
select a.st_prism.st_path, get_ppa_ellipse(a.st_prism),
get_poi_array(a.st_prism, b.poi_set)
from individual_trajectory a, urban_poi b
where a.person_id = 1;
```

In addition to the space-time path, PPA and POI, the query about space-time prism (Figure 12) needs the upper/lower cones and an ellipsoidal cylinder consisting of a space-time prism. The member functions named GET_UPPER_CONE, GET_LOWER_CONE and GET_ELLIPSOIDAL_CYLINDER are used as in the following SQL.

```
select a.st_prism.st_path, get_ppa_ellipse(a.st_prism),
get_poi_array(a.st_prism, b.poi_set),
get_lower_cone(a.st_prism), get_upper_cone(a.st_prism),
get_ellipsoidal_cylinder(a.st_prism)
from individual_trajectory a, urban_poi b
where a.person_id = 1;
```

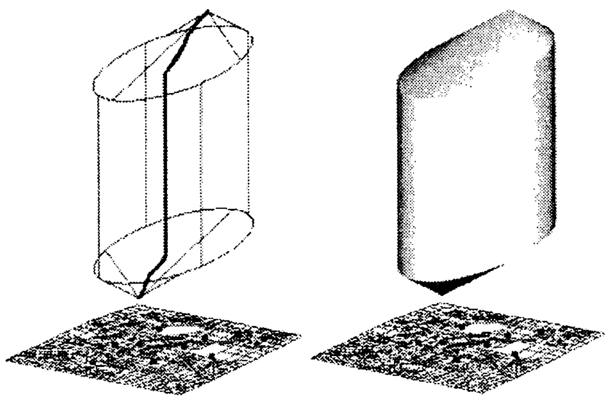


Figure 12. Query Results of Space-time Path, PPA, POI and Space-time Prism

For the query about DUR-based space-time accessibility (Figure 13) combined with space-time path, PPA, POI and space-time prism, the SQL statement is the same as previous. The visualization of opening hours of the urban facilities can be processed in the client-side using the information of POI elements included in the query result. In addition to the opening hours, other criteria for evaluating accessibility such as attractiveness could be derived from AHP (Analytic Hierarchy Process) method, for instance. The weighted average of space-time accessibility for n criteria of m facilities is like $\sum_{i=1}^{n}\sum_{j=1}^{m} w_i s_{ij}$, where w is the weight for each criterion and s is the score for each facility.

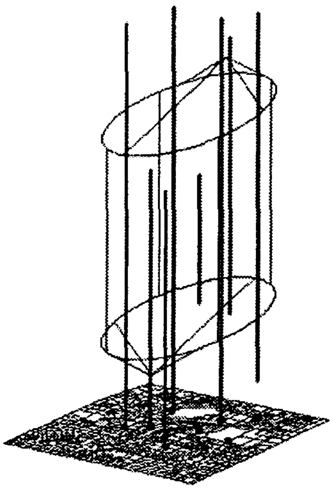


Figure 13. Query Result of DUR-based Space-time Accessibility

6. Conclusion

This study presented a method of building GIS computing framework for evaluating space-time accessibility of an individual with the approach of time geography model. The proposed method is based on the integration of mobile GIS and object-relational spatio-temporal database. The mobile GIS application composed of GPS-PDA client and mobile data management middleware allows the automatic transmission of trajectory data. The spatio-temporal database server provides spatio-temporal objects, functions and query languages in accordance with time geography model. The geovisualization client illustrates 3D visual results of the queries about space-time path, PPA, POI and space-time prism for evaluating space-time accessibility of an individual. The DUR-based evaluation method may be able to incorporate necessary criteria for space-time accessibility. System improvements for more various evaluation methods are under way.

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