

Spatio-Temporal Modeling of Dynamic Phenomena in GIS

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Abstract

Although, most of phenomena change over time, there has been an attempt to model the phenomena of real world assuming a static nature for them. Even when changes occurred in the phenomena, it is restricted to identify and assess the changes over a period of time. These static modeling can be applied when phenomena with a long change period are considered. Since late 1980s, and by increasing geospatial information systems (GISs) applications, dynamic modeling has been highlighted. It is therefore led to the development of a GIS branch called spatio-temporal GIS parallel to temporal database management systems in computer sciences. Despite, most of current GIS analyses, which are based on static modeling, a growing number of researches in temporal GIS, are being performed, which may dominate GIS market in the near future. This paper investigates the principal concepts of space-time and other relevant parameters in a temporal GIS. Focusing on different temporal GIS modeling approaches, development of a prototype temporal GIS to simulate traffic information using a cadastral map at a scale of 1:500 are discussed.

1. Introduction

Indeed, temporality is an essential trait of spatial information that has been recently considered by GIS researchers (See e.g., 10, 13, 15, 14, 4, 9). Hardware and software limitation seems to be the most important reasons that research in this field were neglected until last decade. Nowadays increasing speed and capacity of personal computers remove this limitation and there is a favorable condition for research in this area [14].

Capacity of any information system largely depends on its data model [15]. A data model is the abstract and representation of real world phenomena according to a formalized, conceptual schema, which is usually, implemented using the geographical primitives of points, lines and polygons or discretized continuous fields [2]. In the

other word, a data model should define data type, relationships, operations and rules to maintain database integrity.

Therefore, for an integrated information system, a rigorous data model is vital and to have a rigorous model for any information system, basic concepts of its domain have to be considered, which have been elaborated in this research.

2. Representation of time

Time can be considered as fourth dimension but whereas the spatial dimension usually considered as 2D (for planimetric) and 2.5D or 3D (for complete representation of spatial objects), it has been shown that a spatio-temporal object can be represented as a four dimensional vector such as (a_i, g_i, p_i, t_i) , where a_i , g_i , p_i and t_i describe attributes, geometrical positions, topological relations and temporal dimensions, respectively [8]. Major advantage of this representation is that there is a general view of all other definitions of dimension because every element in this vector can have various dimensions, such as geometrical position can have from one to three dimensions and temporal dimension can have one, two (bi-temporal) or many (multi-temporal) dimensions [11].

3. Spatio-temporal data

From temporality point of view, there are two types of information namely Static and dynamic, which must be modeled under a temporal GIS, which are discussed below.

3.1. Static information

Most of phenomena in the real world are dynamic in nature, thus the term static can only be used for objects such as cartographic maps, roads, facilities, utilities, etc, that may not change in a short period of time, however, all of these objects will change during a long period of time [1].

3.2. Dynamic information

Dynamic information refers to that information of geospatial objects that change in a short period of time. The length of this period is defined according to its usage fields.

According to working domain, one can consider the following dynamic aspects of spatial information [7]:

- Geometrical changes of features over time (such as urban expansion)
- Positional changes of features over time (such as car movement)
- Change of features attribute over time (such as traffic volume)
- Any combination of the above changes

According to the length of duration of time, one can divide dynamic information as follow [6]:

- Real time data
- Near real time data
- Time stamped data

These aspects have been considered below.

i. Real time data

Real time data and real time GIS are dual subjects. The term real time, about GIS refers to capability of management, visualization and analysis of graphical and attribute information as soon as they input to GIS and about data refers to those kinds of data such as traffic volume that are collected and imported to GIS as soon as an events occurs.

ii. Near real time data

Real time is related to momentary updating, visualization and analysis. Because of possible complex processes and analysis that may be needed for such data before they can be used in GIS, applying such data is so difficult and even in some cases is impossible. Therefore in these cases phrase near real time may be more adoptive.

iii. Time stamped data

Time stamped data refers to such data that a time represented with it in some ways (for example as an attribute). There are different components of time that can be considered about an event as follows [14, 11]:

- When an event occurred in real world (valid time)
- Occurrence duration of an event
- When information about an event imported to GIS
- When those data retrieved and manipulated (transaction time)

In addition to these aspects of time, there are some others that can be considered when special methods in modeling and representing temporal phenomenon such as picture rate for animation are used [1].

4. Components of a temporal geospatial information system

Temporal GIS components can be obtained from extension to common temporal GIS components. These components are as follows [7]:

- Temporal database
- Temporal visualization and representation
- Temporal analysis

Figure 1 illustrates existing relationships between the components, which are elaborated below.

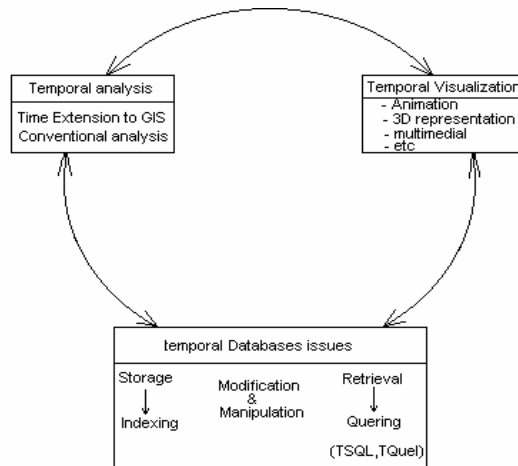


Fig.1. Relationships between temporal GIS components

4.1. Temporal databases

In some cases time can be stored as an attribute in a database. In these cases some issues such as time duration, data retrieval, updating, storing, preserving historical data etc, lead us to use special data structure for temporal databases. Object oriented and relational data structures are two major structures that increasingly used in common GIS databases in recent years. A number of researches have been undertaken in this field; representing the feasibility of conversion from these kinds of databases to new temporal extensions. These investigations led to different data models that some of them are considered in this paper.

4.2. Temporal visualization and representation

Visualization and representation are one of the most important stages in every information processing system. Because most of end users of GIS systems may not have a detailed knowledge about GIS and its analysis, systems with simple, fast, intelligent and deductive representation tools are more requested. This point must be considered in the design of spatio-temporal information systems, too. Some approaches that are offered for representation of temporal information in a temporal GIS are as follows [7]:

- Animation
- 3D representation
- Multimedia representation

Visualization of temporal information in a temporal GIS can be considered from the following aspects:

- Representation of changes in a database (changes in traffic volume)
- Representation of changes in a geometrical data (changes in roads network)
- Representation of changes in a database as well as in graphics (movement of vehicles)

In this paper a continuous representation of simulated changes in both graphics and databases using of animation method has been implemented.

4.3. Temporal analysis

Major capabilities of GIS are in its powerful analysis. Hence for a powerful temporal GIS, all of these analyses have to be extended to handling time aspects. An instance of these analysis that use both geometrical data and databases, is optimum path analysis. In order to implement this analysis, one has to consider some issues such as dynamic use of updated information from database, analysis based on the last changes in network and considering least time, in addition to other least cost parameters.

These components are connected to each other with respect to the data model designed for the system as a framework.

5. Temporal modeling in GIS

Most of conventional GIS data models are on the basis of static representation of reality. In these data models, spatio-temporal objects of an interested area will be decomposed into a collection of layers or classes according to vector, raster or an integrated data structure. These layers and classes constrain GIS capabilities for representation of dynamic information.

Therefore a spatio-temporal data model is needed to represent and analysis space-time information. This data model defines the manner that spatio-temporal information has to be stored and retrieved. If a temporal GIS does not have a good data model, queries and analysis of temporal information can not be efficient.

In this section different approaches of modeling spatio-temporal information in GIS are considered.

5.1. Temporal modeling trends

Temporal modeling in GIS has grown in parallel with temporal modeling in computer sciences. Temporal modeling in computer sciences commenced with the integration of time with relational databases and then extended into object oriented modeling. Parallel to this evolutionary process, temporal modelings in GIS started with time stamping layers and then go into event or process-based modeling [15]. This trend is represented in Figure 2, schematically.

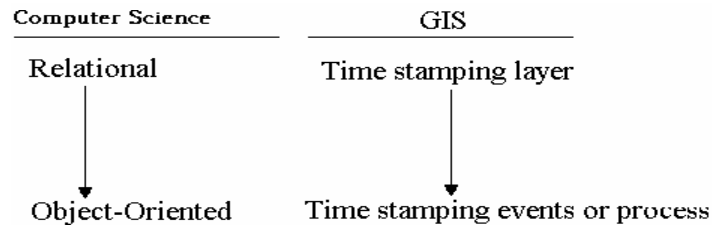


Fig. 2. Trend of evolution in temporal modeling

In this section some approaches of temporal modeling in GIS are described.

5.1.1. Time stamping spatio-temporal modeling in GIS

Some approaches of spatio-temporal modeling in GIS as follows [11, 15]:

- Snapshot model
- Space time composite
- Spatio-temporal objects

i. Snapshot model

In this model, each layer is composed of temporally homogeneous unit. In the other word, in the snapshot model, when an event occurs, new layer is constructed and occurrence time is stamped to the layer (all of the information, changed or not changed, are stored in the layer).

Inconsistency and data redundancy are major disadvantages of this approach.

ii. Space time composite model (STC)

In STC model, the real world is a collection of spatially homogeneous units in a 2D space that changes over time from one unit to another. Each STC has its unique period of change and can be obtained from temporal overlay of snapshot layers. In the other word, a STC can only represent changes in one spatial object over time. STC can model favorable properties of an object such as situation, but it can not represent changes of attributes such as movement over space. Moreover, because the geometrical, topological and relationships between STC units are changed over time, updating required re-organization of whole spatial data and databases. Also whereas STC units are constructed from overlay of snapshot layers, they may lead to a number of small polygons that can led to some problems such as indexing with databases construction.

iii. Spatio-temporal object modeling

In this model, real world is considered as a set of spatio-temporal atoms that constructed from integration of a temporal dimension orthogonal to 2D planimetric space. Each of these spatio-temporal atoms is largest homogeneous unit that can store specific properties in space and time. Thus this model can store changes in both temporal and spatial dimensions.

Whereas these spatio-temporal atoms have a discrete structure, modeling of gradual changes in space or time with this model is impossible. This model as similar to snapshot and STC models can only represent sudden changes

5.1.2. Event or process-based spatio-temporal modeling

There are two approaches that can be considered under the category of event or process-based spatio-temporal modeling [11; 15]:

- Event based spatio-temporal data model (ESTDM)
- Domain oriented spatio-temporal data model

i. Event base spatio-temporal data model (ESTDM)

ESTDM model as similar to TMS (temporal map set that is a raster base instance of the snapshot model) is a raster based model that use a collection of time stamped layer to represent temporal information from an event, however, in this model unlike snapshot model, only changes with respect to previous state are stored.

In this model, first one base map is stored and then when an event occurs, changes are discovered and stored in an event map. Relation between these event map and base map are used in a header file.

Adaptation of this model with vector base systems may be most important problem with this model. Moreover, retrieval of historical behaviors of an event requires complex processes.

ii. Domain oriented spatio-temporal modeling

This model proposed for representation, management, and maintenance identities of complex spatial objects. For instance a three-domain model for analysis of spatio-temporal information required in a fire study has been proposed [15, 16]. In this model spatial, temporal, and semantic objects are defined in three separate domains. Therefore, time is stored as an individual concept instead of consideration as an attribute of location such as in snapshot model or as an integral part of spatial objects like in STC and spatio-temporal object models. Geospatial concepts and entities can be represented with dynamic linkage of these three domain's objects from the following aspects:

- Location centered
- Attribute centered

- Time centered

Major advantage of this model is that there are no predefined patterns and to represent every concept, this three domain objects dynamically link together.

6. Practical project implementation

As seen previously, a temporal GIS has three general components (temporal database, temporal visualization and temporal analysis) that lead to three research domain in temporal GIS.

In this research, Animation as an efficient approach for representation of temporal changes is implemented and then optimum path analysis are extended as it can handle time dependent graphical and attribute information on the base of the animation representation method.

Integration of temporal path analysis with animation can be useful in many cases such as more reliable decision making and faster and better access to emergency services in critical conditions is possible if traffic volume and road network conditions imported into GIS databases, dynamically.

With this integration of animation and optimum path analysis, the system can obtain real optimum path with consideration of momentary traffic volume of road networks and other temporal parameters that affect selection of optimum path. If this system to be integrated with a GIS-GPS system, it can handle real time position of vehicle in order to evaluate real optimum path for each moving vehicle.

6.1. Implementation stages

Figure 3 represents different stages of the practical work.

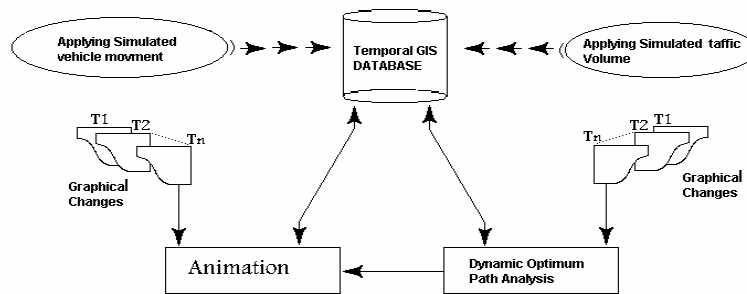


Fig. 3. The implemented system components and framework

In this section, different parts of the above mentioned process are described.

6.1.1. Roads traffic volume simulation

In practice, roads traffic volumes have to be collected and transmitted to GIS database with specific sensors [3, 12]. However as such sensors were not available in this project, traffic volume changes were simulated with an external program that developed using visual basic programming language and then applied to the database.

6.1.2. Vehicle movement simulation

Vehicle movements in a GIS can be considered as changes of planimetric position attribute in the database. This position's attributes (X, Y / Phi, Lambda coordinates) can be obtained from GPS or other positioning systems and then transmitted to the database.

In this paper similar to the traffic volume simulation, an external program has been developed that simulate vehicle movements with respect to road networks and then resulted attributes are applied to the database.

6.1.3. Graphical changes modeling

In order to represent and model graphical changes related to road networks in a cadastral map at a scale of 1:500, the snapshot model has been used. For this purpose, every change stored in a separate layer (next changes can be added to model with storage of new snapshots in the specified path on computer), then the implemented system represents these snapshots sequentially with the animation method.

6.1.4- Extended optimum path analysis

In common cases this analysis requires only one start point, one end point, some intermediate points and one attribute field such as traffic volume that includes cost information for each segment. However, in a temporal GIS, each of these elements can change over time (movement of start, end and intermediate points and change in attribute field or any combination of them). In addition to, graphical information can have structural changes (such as construction of new roads).

Therefore, optimum path analysis must be extended in order to handle these temporal changes. Moreover, representation of temporal optimum path must be coordinated with animation picture rate.

6.1.5- Animation

In graphical images such as GIF files that nowadays are frequently used to implement animation under web applications, there are some images that aligned sequentially in a file and are shown one by one. In this approach there are no tools for users to control picture rate or analysis on images. But the animation that is subjected in GIS,

must present the ability to use all GIS analysis, querying, and all other static GIS capabilities.

When animation is used in GIS, there is an important term of picture rate that returns to representation period versus real period of occurrence events. For example representation of annual period of sea level changes in a few minutes or an accident moment in larger duration of time may be considered. Thus each GIS, which use animation, must prepare the ability to control picture rate, too.

In the system implemented in this research, there are some abilities to represent graphical changes in addition to representation of database changes with animation. In this case, user must first store new snapshots in a path on hard disk and then this path, number of snapshots and number of loops that are required, have to be introduced to the system. Figure 4 represents a schema of the implemented system.

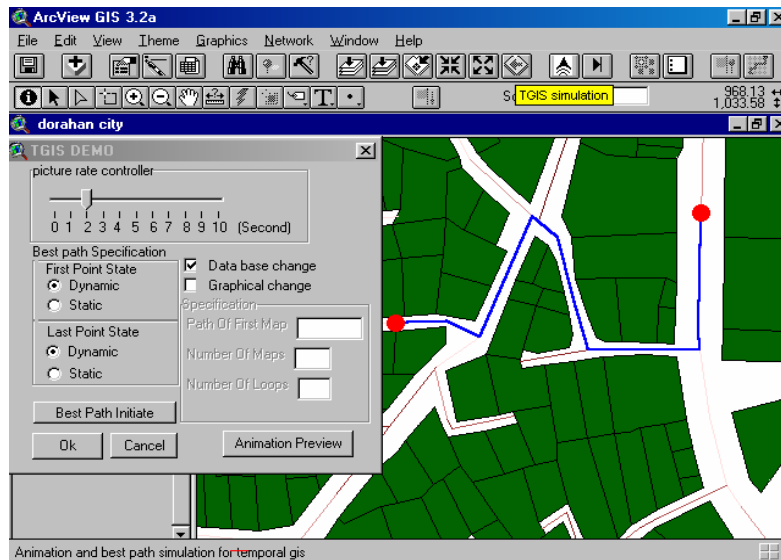


Fig. 4. A schema of implemented system interface

7- Conclusion

It can be concluded that the usage of temporal GIS instead of conventional GIS will be unavoidable in the near future.

Basic concepts of a temporal GIS such as temporal data types, possible temporal changes, temporal modeling and temporal GIS components were illustrated in this research.

In addition to reviewing the principal concepts of temporal GIS, a practical work including the implementation of traffic volume simulator's program, construction of a

temporal database and visualization as well as representation of a temporal GIS using the animation method were represented and illustrated.

System expansion in order to include different types of traffic analysis and test with the real data will be some of the next research context of this study.

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