Management and Visualisation of Spatiotemporal information in GIS

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ABSTRACT

Although Geographic Information Systems (GIS) have been recognised as the most advanced technology for the management of geospatial information, they are still unable to efficiently manage the temporal dimension. Originally this problem affected only the study and analysis of highly dynamic phenomena. Today's expansion of GIS technology, the ease to acquire and store geospatial data and the increased capacity of computing technologies to manage large amount of data have contributed to the propagation of this problem across the whole geospatial sector. The extended use of GIS in decision-making processes is increasing the demand for tools able to manage and to analyse dynamic geospatial phenomena where the temporal dimension is crucial. The only temporal model available in commercial GIS packages is based on discretisation of temporal data. Changes are represented as a succession of snapshots. The dynamics and what happens between those stages are not registered. In addition, this approach presents severe problems due to unavoidable multiplication of data volume, abundant redundancies, loss in query efficiency and the impossibility of knowing when the exact timing of changes occurs. Since the late 1980s and particularly in the 1990s, researching the temporal changes and the conceptual and technological options available has been undertaken by the GIS and DBMS sectors. The primary objective of the research presented in this paper is the development of a model for the integration of temporal data with GIS. The method adopted to achieve this objective is based on the combination of Time Geography principles, its graphic language and dynamic segmentation techniques used in GIS. Past research has demonstrated that the difficulty to integrate time with GIS has its origin in the continuous nature of time. Dynamic segmentation in GIS network analysis has the potential to provide the means for a time-GIS integration in a continuous manner. Lifelines, one of the main Time geography's graphic language elements, has been modelled as a set of network segments where the dynamics in attribute information has been attached to different time segments rather than distance segments (for example Euclidean or cost-based) as normally occurs in dynamic segmentation. This paper summarises initial findings of the project. These outcomes have the potential to improve the way the geospatial sector currently handles temporal information. However, the static nature of current GIS technology impedes an appropriate visualisation of dynamic temporal phenomena. To this effect, the paper also explores the possibilities offered by multimedia techniques as a complement to GIS capabilities.

Keywords and phrases: GIS, Temporal GIS, Spatio-Temporal Querying, Time Geography, Dynamic Segmentation, Multimedia

1.0   INTRODUCTION

In broad terms, a Geographic Information System (GIS) is defined as a technology (information-system) that enables the capture, modelling, manipulation, retrieval, analysis and representation of geographical data (Worboys 1995). During the past three decades there has been a rapid growth of theoretical, technological and organisational development in the field of GIS (Maguire, Goodchild & Rhind 1991). GIS is an enormously powerful tool for inventory, query, analysis, and decision-making in many diverse applications and industries (Foresman 1998). However, GIS remains static and unable to adequately model and represent space and time due to its lack of capabilities and its limitations in three and four-dimensional representations. In addition, the diversity of GIS applications has compounded the need for a Temporal GIS (TGIS) to store, represent, query and analyse dynamic phenomena (for example Location Based Services (LBS), health, transportation and criminology). Time is an important factor in the representation of cartographic data - time allows analysis and visualisation of how cartographic elements change and evolve. Thus, incorporating the temporal dimension into GIS has been under investigation in recent years. This can be seen from the vast amount of literature on the topic (Kwan 2000; Christakos, Bogaert & Serre 2001; Ratcliffe 2000; Langran 1992b; Huisman & Forer 1998a; Wachowicz 1999; Peuquet 1994; Egenhofer & Golledge 1998a).

There is a general agreement in the GIS scientific community that the technology lacks appropriate protocols to exploit the temporal dimension of geographic information. The most relevant international GIS research institutions recognise that 'time' is an important dimension in GIS. The University Consortium of GIS (UCGIS), suggest that the time dimension in GIS is in need of additional research (UCGIS 1996). The U.S. National Center of Geographical Information and Analysis (NCGIA) since 1990, has been fostering an initiative on 'time', as it is an area in need of further investigation (NCGIA 1995). The project is named Research Initiative 10 'Spatial-Temporal Reasoning in GIS' (Egenhofer & Golledge 1998). A number of more specialised research agendas have appeared, one being the Australian Research Agenda for GIS in Health. This agenda has noted that the incorporation of the time dimension is crucial to edify better-informed decision making (Escobar et al. 2001). Research has suggested that the current GIS are somewhat lacking and have not achieved their full potential. The time dimension in the next generation of GIS is critical for improved decision-making (Wachowicz 1999; Langran 1992a; Egenhofer & Golledge 1998a; Raafat, Yang & Gauthier 1994; Wachowicz & Healey 1994; Kemp & Kowalczyk 1994).

There are many reasons why a fully operational TGIS does not exist at present. The shortcoming of current GIS is the abstract view of the world and how it deals with the complex ways in which phenomena change over space and time (Goodchild 2000; Hornsby & Egenhofer 2000; Wang & Cheng 2001). However, current GIS vendors and researchers are intent on developing spatial originated GIS, without considering the time dimension. This is being done despite the fact that space and time are inseparable in human life and evolution (Minkowski 1908). Current GIS software presents numerous deficiencies in (a) visualisation methods for events where time and location are of equal importance, (b) inventorying spatiotemporal data, and (c) interpolation functions for the management of a continuous time (Longley & Batty 1996; Hornsby & Egenhofer 2000). At present, the only commercial technique incorporating the time dimension into GIS is the snapshot (time-slicing) model, storing data as discrete slices over time. This technique possesses problems due to the semantics (dynamics) of time and how time is captured as slices of reality. Consequently, there have been various integration attempts made from different perspectives without one particular temporal data model being agreed upon (Hornsby & Egenhofer 2000).

A pseudo-continuous time data model is proposed. In this model, the temporal query model is independent of temporal scale, this is queries can be at any scale from years down to seconds. This model is implemented using Time Geography (TG) principles, Dynamic Segmentation (DS) techniques, GIS data models and continuous temporal data, as explained later in this paper. Lifelines, one of the main TG's graphic language elements holds the key to representing time in a continuous manner and modelling events in a pseudo-continuous manner. A successful completion of this project would resolve some of the current problems with the snapshot model and would contribute to the advancement of the discipline.

The objective of this research project is to develop a model for the integration of time within a GIS environment, thus facilitating the development of temporal queries and representations.

Specific objectives are:
- To develop a TGIS data model that will allow integration with both existing and newly collected temporal data.
- To develop a model that will allow temporal information in the GIS to be incorporated with non-temporal information such as the cadastre and the road network.
- To model lifelines using the DS data model, thus facilitating temporal queries.

- To develop a temporal query model that incorporates time in a pseudo-continuous manner using the TG framework.

The next section of this paper discusses time and GIS, and introduces the attempts at modelling time in GIS to date. Section 3 presents an overview of the TG framework. Section 4 introduces the attempts of integrating the TG framework within GIS. Section 5 presents the proposed spatio-temporal data model. Section 6 summarises the findings and discussion of the paper.

2.0   TIME AND GIS

In recent years the topic of how time will be integrated into GIS has been a key issue in GIS literature (Christakos, Bogaert & Serre 2001; Egenhofer & Golledge 1998a; Huisman & Forer 1998a; Langran 1992a; Ratcliff 2000; Peuquet 1994; Wachowicz 1999). There have been various integration attempts made from different perspectives without one particular temporal data model being agreed upon, including perspectives from cartography, data models and spatial databases (Hornsby & Egenhofer 2000). In recent years extensive research has been directed at temporal, spatial and spatio-temporal query languages, databases and models (Wang & Cheng 2001; Tansel 1993). This research has been undertaken in two domains: computer science and GIS domain. However, there are still some important unsolved issues, such as:

- The debate on temporal data models continues without a definite agreement. (Hornsby & Egenhofer 2000; Castagneri 1998)

- A similar model to that developed for the minimum mapping unit has to be developed for time representation. Temporal resolution or "granularity of an object version" (Yeh & Viémont 1992) also needs be investigated in order to establish appropriate mechanisms for temporal generalisation; and

- Problems related to storage, maintenance and database longevity need to be addressed. Protocols to ensure the usability of historic data and the currency of formats are required.

At present there are two distinct approaches to understand and model time within a GIS: the region-to-entity representation and the space-time entity representation (Wachowicz 1999).

2.1   Region-to-entity representation

All information integrated in GIS includes time in an implicit way. In fact, Parks and Thrift (1980) state that the temporal dimension is what makes Geography different from Geometry. The expansion of GIS technology, the increased ease to gather digital geographic data and current computing capacity to manage great volumes of information have led to a situation where most geographic databases have a temporal component. It is therefore imperative to develop new models and protocols aiming at leveraging the temporal dimension. Current TGIS aim at storing and analysing changes in both objects and attributes (Castagneri 1998). In other words, GIS should be able to answer questions like 'what has changed?' and 'how and when changes occurred?' (Peuquet 1994; 1999). The ability to respond to queries related to changes necessitates a dynamic vision, which leads to searching a more appropriate way to digitise the temporal dimension.

Presently, the only commercial technique incorporating the temporal dimension into GIS is the snapshot model and this is only an ad-hoc solution using existing spatial structures. For a review of such a model refer to Modelling and Using History in ArcGIS™ (ESRI 2002) or (Armstrong 1988). Changes are represented as a succession of snapshots. The dynamics and what happens between those stages are not registered. This technique possesses problems due to the semantics (dynamics) of time and how time is captured as slices of reality. The world does not change with neat increments. It is, in fact, continuously changing (Hornsby & Egenhofer 2000; Kwan 2000). The snapshot technique models continuous change and/or time as discrete snapshots, changing the continuous characteristics into discrete ones. We are not suggesting that the snapshot model can not perform certain analysis on particular temporal data, however there are many problems that remain unsolved (Stead 1998). These severe problems cause unavoidable multiplication of data volume, abundant redundancies, loss in query efficiency and the impossibility to know the exact time when changes occur. Consequently, the snapshot model cannot be used to implement a fully functional TGIS. One thing is still clear, current GIS are still fundamentally lacking in an appropriate data structure which can incorporate the time dimension (Huisman & Forer 1998a). There is a need to develop a spatio-temporal data model to overcome the limitations of the snapshot model and represent time in a continuous manner.

Langran (1992b; 1993; 1992a) outlines four ways to understand and to represent time in GIS. The first one is supported by a continuous space-time tetra-dimensional cube or hypercube similar to the principles establish by TG. Kemp and Kowalczyk (1994) however state that "it is not possible to store time as a continuous entity, it must be represented as a series of discrete events".

This 1994 vision summarises the main issue this research is addressing. Through the GIS modelling of lifelines, it is envisaged that advances can be made in the continuous representation and analysis of temporal information.

2.2   Space-time representation

The Space-Time approach also known as the TG framework has many potential advantages when incorporating the temporal dimension in a GIS, one being the model is based on disaggregated data. The approach adopted in this research adopts the TG framework as a data model to allow time to be modelled in a pseudo-continuous manner.

Huisman and Forer (1998a) developed a space-time approach using a three-dimensional raster model based on TG to incorporate the time dimension into a GIS. The model was developed to model accessibility, spatial opportunity and potential integration. This model compacted space into the x and y-axis and modelled time in the z-axis of a cube. A number of different entities including: static structures such as buildings and dynamic activities such as human accessibility can be modelled. Buildings can also be modelled as unlimited access zones (such as a home) with a continuous time dimension or as limited (intermittent) access zones (such as the opening hours of a shop from 9am to 5pm) with a fractured time dimension. Individual accessibility can also be modelled through a wandering continuous path with a collection of taxels surrounding the individuals' taxel (Voxels – Taxel representing the time dimension). One limitation of this method is that the individual is represented as a volume and the cell size must represent the individual, this causes some problems (cell size, scale limitation, storage volume, constant cell size, limited to smallest unit, unable to represent multiple-scales, etc). Due to these problems it is not easily implemented to other regions. Kwan (2000) also suggests ".. the raster data structure is not suitable for representing the complex topology of a transportation network..". Nevertheless, the raster approach adopted by Huisman and Forer show the potential of the temporal dimension within GIS.

The strength of this approach is that accessibility masks can be created in the three-dimensional raster model. Masks can be an individual, event, or facilities. For each mask, each taxel is either blank (inaccessible) or has a value (presence or potential presence). Queries can be answered about where and when and for how long meetings are possible by combining masks of several individuals. By combining building masks with individual masks queries about how individuals and structures interact can be obtained.

Recently, Morris and his development team designed the Water Information System (WIS) to analyse and warehouse large quantities of environmental data. The WIS is a generic data model designed to store many types of data including space-time information and relationships. The model is based on the raster approach modelling data in a three-dimensional cube. However, this model does not address the continuous nature of time. The axes of the cube are comprised of spatial, thematic and time observations (where, what, & when properties) in a discretised manner (Morris, Hill & Moore 2000).

Kwan (2000) identifies several GIS-based three-dimensional revisualization techniques, incorporating the temporal dimension of human activity-travel patterns. This research tries to model location, timing, duration, sequencing and type of activities and/or trips. The following techniques are used to model the temporal relations of human activity patterns. These include, simple activity patterns in space-time, activity density patterns in geographic space, and space-time activity density surfaces. These techniques raise a number of issues such as, the static representation of the temporal dimension, slow rendering of graphics (slow interactivity) and not allowing queries.

There is a need to develop a spatio-temporal data model to overcome the limitations of the raster model and represent space and time at multiple scales. However, queries similar to these produced by Huisman and Forer (1998a) should be achieved.

Apart from the aforementioned 'snapshot' model, approaches adopted to incorporate time into GIS have mainly focused on the development of object-oriented models (Wachowicz 1999; Worboys 1992; Raper & Livingstone 1995; Raafat, Yang & Gauthier 1994; Tansel 1993) or the development of models based on the definition of time as a fourth dimension (Hazelton 1998). Few institutions and researchers around the world are involved in initiatives aimed at linking TG's graphic language and principles with GIS. This could be due to a lack of appropriate mechanisms for data collection or the traditional use of non-computerised techniques in TG, which make it difficult to integrate with a technology such as GIS. Despite these limitations, TG is still repeatedly referenced as a valid paradigm in publications on temporal GIS (Miller 1991; Kwan 2000; Huisman & Forer 1998a; Huisman & Forer 1998b; Mark 2001; Wachowicz 1999; Raper 2000; Salado 2001).

The literature on this area highlights the fact that difficulties in integrating time with GIS have their origin in the continuous nature of time. DS in GIS network analysis combined with the principles of TG has the potential to provide the means for a time-GIS integration in a continuous manner. Recent developments in the field of

multimedia and the ability to integrate multimedia products with GIS databases provide a way to analyse, and dynamically represent, temporal information (Raper 2000). The combination of DS, TG and multimedia constitutes the novel approach proposed in this project.

3.0   TIME GEOGRAPHY

3.1   Background

Torsten Hägerstrand developed the paradigm known as TG at the University of Lund, Sweden in the 1970s. It constitutes an ambitious proposal applicable to all fields in Regional and Human Geography. The relationship between GIS and TG has been scarce. The main reasons for it being that in the 1970s and 1980s, when TG research appears to be more active, GIS was still an immature technology (Coppock & Rhind 1991) and that GIS was first closely related to the quantitative geography paradigm or 'spatial perspective' and only in recent years other dimensions, like time, have been attempted to be incorporated and analysed in GIS (Löytönen 1998).

TG constitutes a paradigm aimed to explain relationships between social organisations and their physical base, and the dynamics of such relationships. TG focuses in the relationship between people and their most immediate environment throughout their daily activities. These activities are associated to our human condition (i.e. working, learning, living in a place, shopping, etc). Activities are usually undertaken in specialized places, which leads to a fundamental human activity: displacement. Extensive documentation on TG paradigm principles can be found in Hägerstrand (1970), Lenntorp (1976) and Salado (1991).

Thus, TG is concerned with the location of activities, the agents who undertake such activities and the spatio-temporal region in which such activities take place. It proposes a contextual approach in the analysis of individual activities. It allows the apprehension of all components of the environment and its necessary coexistence on space and time. Studies following TG are undertaken at the maximum possible level of disaggregation. The individual constitutes the unit under investigation.

3.2   Graphic language

The main contribution of the TG paradigm is its graphic language. It is a simple, flexible and easy to understand language. The basis of the graphic language is the spatio-temporal region, which is represented by two horizontal axes, the space, and a vertical one, time.

TG shares with GIS its physical and objective language. It does not contemplate subjectivity. The facts are presented on their location at the time they occur but do not include any judgments or values. It is independent from spatial scale (locality, island, region, nation…) and from temporal scale. It is adaptable to daily activities, family life studies –several generations- or only few minutes. In other words, events that take place over hours, days, weeks, months or years, can be equally analysed.

3.2.1   Basic terminology

Figure 1 below represents the following basic elements in TG graphic language.
Lifeline or path (a) is the representation of an event or a person along a period of time on a defined environment. It always grows in a positive direction. Station is the graphic that represents an event or a person in a fixed position on space (b). Bundle is formed when several lifelines meet in a station at the same time (c). Prism is the graphic that analyses "budget of time" (d). It allows the visualization of the hypothetic spatio-temporal region to which a subject has access to depending on his/her transportation mode and the amount of available time. (e) Bi-dimensional vertical bars. In this graphic space is not considered as a two-dimension environment. It only considers functional places but do not deal with their physical location.
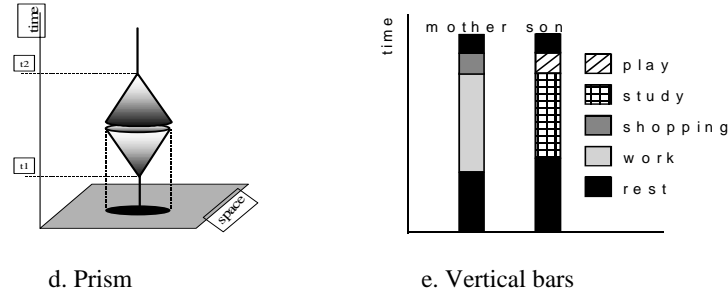

a. Lifeline or path   b. Station   c. Bundle

d. Prism   e. Vertical bars
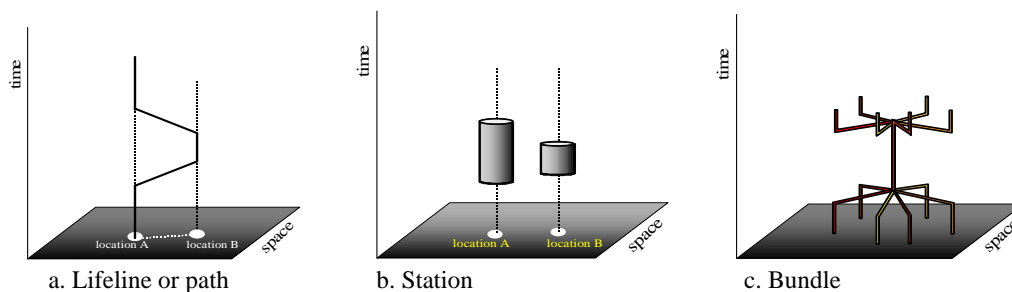
Figure 1: Basic Time Geography Graphic Elements

3.3   Method

The method to acquire and process information is simple. It is based in the collection and graphic representation, assisted by the diagrams shown above, of diaries of activities. A questionnaire similar to the one presented in Table 1 has to be filled out by each of the individuals under study. All activities taking place in the period of time under observation have to be registered. In order to facilitate this task, authors in TG provide standard lists on activities, functional places and transportation modes. Today most of these lists are adapted from classifications established by United Nations Statistics Division (www.un.org.Depts/unsd/timeuse/icatus/icatus_3_1.htm). Not only *ad hoc* collected data can be represented as lifelines but also any data that contains ID, location, time and activity, such as transportation timetables, emergency services dispatch records and other existing temporal datasets.

Activity	Started at	Finished at	Functional place	Postal Address	Transport
Working	8.00	16.00	Office	161 Sturt St	N/A
Going home	16.00	16.30	Public transport	N/A	Public Transport

Table 1: Sample Activity Dairy

4.0   TIME GEOGRAPHY AND GIS

A fully generic TGIS has eluded researchers so far, although many attempts have been made to incorporate the time dimension into a GIS using the TG framework. These include developments from many different perspectives both in research on applications domains and on data models. Such research on application domains include: - accessibility (Huisman & Forer 1998a; Miller 1999; Miller 1991; Salado 2001; Kwan 2000), lifelines for health events , administrative boundaries (Wachowicz 1999) geovisualization for activity-travel patterns (Kwan 2000), simulating the daily shopping behaviour of individuals (Makin, Healey & Dowers 1992) and anthropology (Escobar & Moral 2002). The research undertaken on the data models viewpoint includes: - raster models (Mark et al. 2001; Huisman & Forer 1998a), vector models (Miller 1999; Miller 1991; Kwan 2000; Salado 2001) and the Object-Oriented (OO) data models (Wachowicz 1999; Makin, Healey & Dowers 1992). In addition, TG has also been applied to studies in economic production, labour markets, spatio-temporal organization of pre-industrial societies, evolution of human settlements, daily activities in domestic units and transportation systems in relation to people's mobility/accessibility amongst others. For an in-depth review of pre-GIS TG implementations and applications see (Carlstein, Parkes & Thrift 1978; Lenntorp 1976; Pred 1977).

Significant attempts to add the temporal dimension to GIS through Time Geography include work by Huisman and Forer (1998) the application of time-geographic concepts to urban micro-processes.
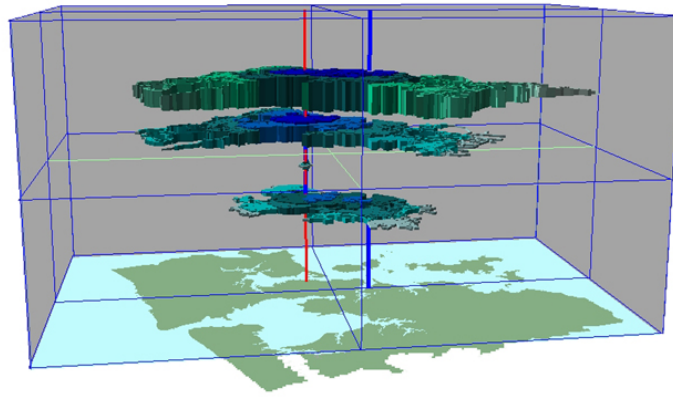
Figure 2: Student's lifeline and action volume, markers and prisms (from Huisman and Forer, 1998)

Kwan (1998) and Miller (1991; 1999) developed a vector approach for modelling accessibility. Miller demonstrated how space-time prisms could be applied to modern transportation systems using GIS procedures. Kwan demonstrated that space-time prisms using network travel times and network-based GIS operations could show disparities in gender and ethnic accessibility. More recently the work presented in Spain by M. Salado (2001) where spatio-temporal values of accessibility to public services were included in the nodes of a GIS-based street network.

Kwan (2000) later investigated three dimensional geovisualization methods for handling spatial and temporal data for human activity-travel patterns. This research expands on her previous research in 1998. Kwan investigated different visualization techniques for human activity-travel patterns related to gender and ethnic type. The visualization methods included both raster and vector techniques.

Figure 3: A close-up view of downtown Portland from the 3D scene (from Kwan, 2000)

Wachowicz (1999) has implemented an Object-Oriented model based on Time Geography framework for administrative boundaries. Makin *et al.* (1992) is another example of modelling the Time Geography framework within an Object-Oriented GIS for simulating daily shopping behaviour. This research investigates the temporal and spatial constraints placed on individuals shopping activities, modelling accessibility of shop locations via particular routes. This can be used to analyse the potential earnings of shops with certain accessibility to the population.

David Mark and his colleagues at the National Center for Geographic Information and Analysis (NCGIA) propose a research project that focuses on the extraction of health-related information from geospatial lifelines (Mark et al. 2001). They propose to model space-time in a discrete manner allowing searching for space-time clusters.

More recently, Salado (2001) has explored the possibilities of GIS and TG integration in the study of spatio-temporal accessibility to community services and then Escobar and Salado (2002) have applied TG principles with GIS and cognitive information in the same area.

All these attempts have improved the understanding of time within a GIS. They have also demonstrated that the TG framework is a valid paradigm for the incorporation of the time dimension within a GIS. However, there is still the need for further investigation, as these methods have mainly focused on creating prisms (space-time reach) for accessibility and not on creating a fully generic TGIS model, representing time in a continuous manner. Lifelines, one of the main TG's graphic language elements may hold the key to this (Hägerstrand 1970).

5.0   PROPOSED MODELS

DS models discrete events continuously; TG represents these discrete events into a continuous framework. Human life is continuous, however, activities (events) occur discretely throughout ones life and every activity has a starting and a finishing time (duration). DS offers a unique opportunity for modelling lifelines as network elements possessing attributes in their different sections.

5.1   Data Collection

The data for this project is split into two categories: geographical data and temporal data. The geographical data is the topographic data representing the transportation and property layers. Land Victoria (LV), the Victorian custodian of geospatial information facilitated access to its datasets. The temporal category is the data containing the time information. There are two types of temporal information collected for this project: GPS fieldwork data and existing temporal datasets such public transport timetables. The information needed to collect lifelines were time, location and activity of an entity, in this case a person. However, the entities could be vehicles or even buildings with fixed location and changing temporal states. The lifelines were captured by Mobile GIS (iPAQ with Arcpad™), Wireless devices, GPS & Time. The simple collection of lifelines was captured to allow for initial model development.

5.2   Dynamic Segmentation Model

Whilst the traditional arc-node data model can facilitate the storage of data associated with lifelines, the approach is complex and inefficient when attributes (i.e. activity and functional place) are attached to different sections of the same arc (ESRI 1997; Gascoigne 1994). DS offers a solution to such data management concerns by storing multiple instances of attribute data onto single arc segments without altering the underlying arc-node topology. Routes and events in DS reduce modelling complexity and storage inefficiencies, such as data redundancy (ESRI 1997).

Modelling lifelines through the DS model requires a route path to define the location of the individual through space whilst the point and linear event tables are used to record the time and attributes values being modelled (eg. activity, transport…) at various locations along the route. This concept is illustrated in figure 4. Point event tables store the data associated with the vertical components of lifelines, where an individual's positional location is static over time. See (Table 2). While linear event tables are used to store the displacement component of lifelines, where an individual's positional location is dynamic over time. See (Table 3). Thus a lifeline can be sufficiently modelled using the DS model through a combination of routes and point and event tables.
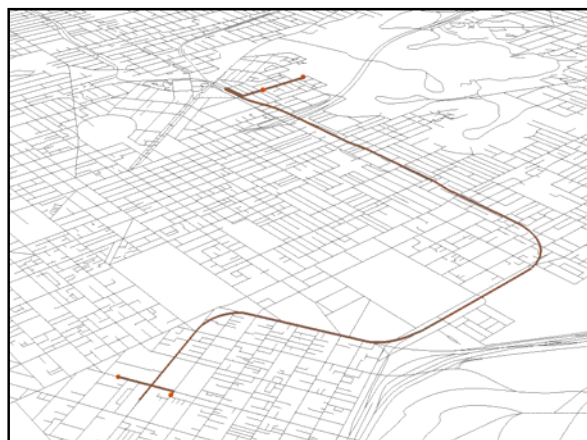

Figure 4: The DS modelling approach to lifelines

OBJECTID*	ACTIVITY_ID	POSITION_	ACTIVITY	STARTED_AT	FINISHED_AT	FUNC_PLACE	TRANSPORT	Shape*
1	1	430.753	Sleep and related activities	24/09/2002	24/09/2002 7:30:00 AM	Own house	Not applicable	Multipoint M
2	1	430.753	Eating and drinking	24/09/2002 7:30:00 AM	24/09/2002 8:00:00 AM	Own house	Not applicable	Multipoint M
3	1	7310.279	General education	24/09/2002 8:30:00 AM	24/09/2002 12:00:00 PM	Education establishment	Not applicable	Multipoint M
4	1	7631.352	Eating and drinking	24/09/2002 12:05:00 PM	24/09/2002 12:55:00 PM	Eating and drinking locale	Not applicable	Multipoint M
5	1	7310.279	General education	24/09/2002 1:00:00 PM	24/09/2002 2:30:00 PM	Education establishment	Not applicable	Multipoint M
6	1	430.753	Doing nothing, rest and relaxation	24/09/2002 2:55:00 PM	24/09/2002 4:30:00 PM	Own house	Not applicable	Multipoint M
7	1	0	Games and other pass-time activities	24/09/2002 4:35:00 PM	24/09/2002 5:55:00 PM	Public area	Not applicable	Multipoint M
8	1	430.753	Eating and drinking	24/09/2002 6:00:00 PM	24/09/2002 6:30:00 PM	Own house	Not applicable	Multipoint M
9	1	430.753	Homework	24/09/2002 6:30:00 PM	24/09/2002 8:30:00 PM	Own house	Not applicable	Multipoint M

Table 2: Table of daily activity path, using point events

ACTIVITY_ID	MEAS_FRO	MEAS_TO	ACTIVITY	STARTED_AT	FINISHED_AT	Physical_Location	TRANSPORT
1	430.753	430.753	Sleep and related activities	24/09/2002	24/09/2002 7:30:00 AM	Own house	Not applicable
1	430.753	430.753	Eating and drinking	24/09/2002 7:30:00 AM	24/09/2002 8:00:00 AM	Own house	Not applicable
1	430.753	830.663	Travel related to learning	24/09/2002 8:00:00 AM	24/09/2002 8:08:00 AM	Public area	Walking
1	830.663	856.025	Travel related to learning	24/09/2002 8:08:00 AM	24/09/2002 8:10:00 AM	Public area	Walking
1	856.025	7017.785	Travel related to learning	24/09/2002 8:10:00 AM	24/09/2002 8:25:00 AM	Public area	Train
1	7017.785	7310.279	Travel related to learning	24/09/2002 8:25:00 AM	24/09/2002 8:30:00 AM	Public area	Walking
1	7310.279	7310.279	General education	24/09/2002 8:30:00 AM	24/09/2002 12:00:00 PM	Education establishment	Not applicable
1	7310.279	7631.352	Travel related to personal care and self-maintenance	24/09/2002 12:00:00 PM	24/09/2002 12:05:00 PM	Public area	Walking
1	7631.352	7631.352	Eating and drinking	24/09/2002 12:05:00 PM	24/09/2002 12:55:00 PM	Eating and drinking locale	Not applicable
1	7631.352	7310.279	Travel related to learning	24/09/2002 12:55:00 PM	24/09/2002 1:00:00 PM	Public area	Walking
1	7310.279	7310.279	General education	24/09/2002 1:00:00 PM	24/09/2002 2:30:00 PM	Education establishment	Not applicable
1	7310.279	7017.785	Travel related to personal care and self-maintenance	24/09/2002 2:30:00 PM	24/09/2002 2:35:00 PM	Public area	Walking

Table 3: Table of daily activity path, using linear events

5.2.1 Data Display

The visualisation of lifelines is a very effective means of displaying space-time coincidence and proximity (Mark et al. 2001). Though the DS data model can adequately facilitate the storage of lifelines data, conventional GIS are restricted to only 2-dimensional representations of the data. In this research, preliminary attempts have been made to visualise lifelines data, which has been stored in the DS data model using ESRI's Arcview 3D Analyst software package.

The key limitation of the GIS is its inability to visualise the vertical components of lifelines data, with only data representing travel through space-time being displayed. Another limitation to visualisation within GIS is the inability to animate the progression of a lifeline through time and space.

The following is an example of some preliminary attempts to visualise lifelines in 3D Analyst. The lifeline in figure 5 represents an attempt at generating a lifeline by using the time value field as a Z extrusion value. Because only one Z value may be used to extrude each line segment, a series of disjointed horizontal lines (representing a constant Z value along the line) are generated. The vertical spaces between the horizontal lines represent both the missing data points, where the individual has not moved in space, only time, and the inability of the software to link together continuous lines.
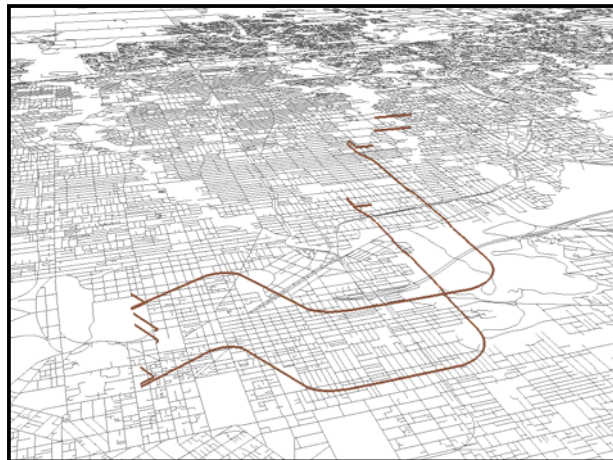

Figure 5: Attempt at visualising lifelines through Z-value (time) extrusion.

5.2.2 Queries

GIS are inherently well established at facilitating spatial and thematic searches: otherwise referred to as selection and database queries respectively. Attaching time stamps and activity attributes to lifelines, allows for the use of the two aforementioned querying types. These queries are based on the TG framework hence they must consist of the 4 main elements (i.e. ID, Location, Time, and Activity).

The DS data model facilitates spatial search queries, however, the limitations in visualising lifelines in space-time ensues that such queries are only undertaken within the 2-dimensional plane. Thus spatial search queries such as visual temporal information queries are restricted in the temporal domain.

A multitude of spatio-temporal query languages were proposed and many issues are still of concern (access methods, protocols, etc). These new proposals include extensions of SQL through Abstract Data Types (ADT). Erwig & Schneider (1999) describe these proposals in great detail. However, many of the proposals do not consider the TG framework and are reliant on the snapshot model (discrete models).

5.3 Multimedia Model

The above method to integrate lifelines in GIS through the DS model makes possible temporal information retrieval and gives answer to queries like 'what has changed?' and 'how and when changes occurred?' expressed by Peuquet (1994; 1999) and mentioned above. However, this method is still unable to provide appropriate means for visualising dynamic temporal phenomena. Current multimedia developments and the possibility to program some of the GIS functions in a multimedia environment can assist in managing and visualising temporal geographic information. The example shown in figure 6 demonstrates how multimedia tools can facilitate animations and queries on spatiotemporal information. It is accessible at www.as.rmit.edu.au/courses/geospatial/timedistance/. As opposed to GIS, this tool assists in visualising dynamic temporal information. Despite advances in programming languages linked to MM software (i.e. Lingo in Macro Director), it still lacks appropriate mechanisms for data querying.

Other examples of multimedia adoption for the representation of TG information have been provided by Huisman & Forer (1998) (http://divcom.otago.ac.nz/SIRC/GeoComp/GeoComp98/68/gc_68a.htm) but in this case only animations, not queries have been accomplished.

Figure 6: Example of animations and queries in multimedia

6.0 DISCUSSION

As stated before, the spatiotemporal data model proposed in this paper is based on the combination of Time Geography principles graphic language and dynamic segmentation techniques in GIS. Merging the TG paradigm and the DS data model shows potential in the modelling of time in GIS. The static nature of current GIS technology impedes an appropriate visualisation of dynamic temporal phenomena. To this effect the possibilities offered by multimedia techniques as a complement to GIS capabilities have also been explored.

Dynamic segmentation has four major advantages when modelling dynamic phenomena, these include: (i) Entities are modelled in a continuous manner since each of the lifelines are single linear elements. This has the

potential to contribute to temporal scale-independent queries. The entities are modelled as events and not as snap shots through time, thus allowing queries to extract the entity at any moment during the event and consequently not reliant on the temporal granularity. (ii) The entity's temporal and attribute information are stored as events (not confused with activity events) in the DS data model, thus modelling the entities as routes on the transportation network. These so called "entity-routes" are independent of the arc-node topology. (iii) The DS data model permits mass data creation. The lifelines collected with the PDA's and the use of the DS data model allows trivial data entry. One of the strengths of the proposed spatio-temporal model is the use of United Nations classifications (standards), which would permit cross-domain analysis in future applications. (iv) The DS data model allows various standard spatial and temporal queries. However, the DS data model has limitations in the visualisation of dynamic temporal phenomena.

Due to the limitations in the display of spatio-temporal information with the DS data model and the recent advances in multimedia (Raper, 2000), multimedia was proposed as the mechanics to bridge the gap in current GIS software for the visualization of spatio-temporal information. Software developments in the field of multimedia are continually improving, however the queries achievable in current multimedia packages are limited. Nevertheless, the approach in merging multimedia and GIS is a powerful method, utilising the best in both worlds: GIS for storage and querying capabilities and multimedia for display and animation facilities.

Most of the research in incorporating the temporal dimension into GIS using TG paradigm is not generic and adaptable. Miller presents a similar view "… much of the work on the "new" time geography is ad-hoc and disconnected: there is no coherent framework for designing and developing GIS software tools..." (Miller 2002). In future research the project will investigate adapting the generic data model to other application domains such as transportation and health.

This paper introduces some methods for creating lifelines in GIS through data collection with PDA's and using the DS data model. At present there are limited amount of techniques for recreating lifelines in GIS.

The work presented constitutes only one of the many steps required to achieve a new generation of geospatial information analytical tools where the time dimension would be considered as relevant as the spatial dimensions. There is still a long way to go but a future development of a spatiotemporal model where events, people, activities and entities could be integrated would open new analytical and decision-making possibilities in geospatial science.

7.0   ACKNOWLEDGEMENTS

8.0   REFERENCES

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