Time-Integrative Geographic Information Systems

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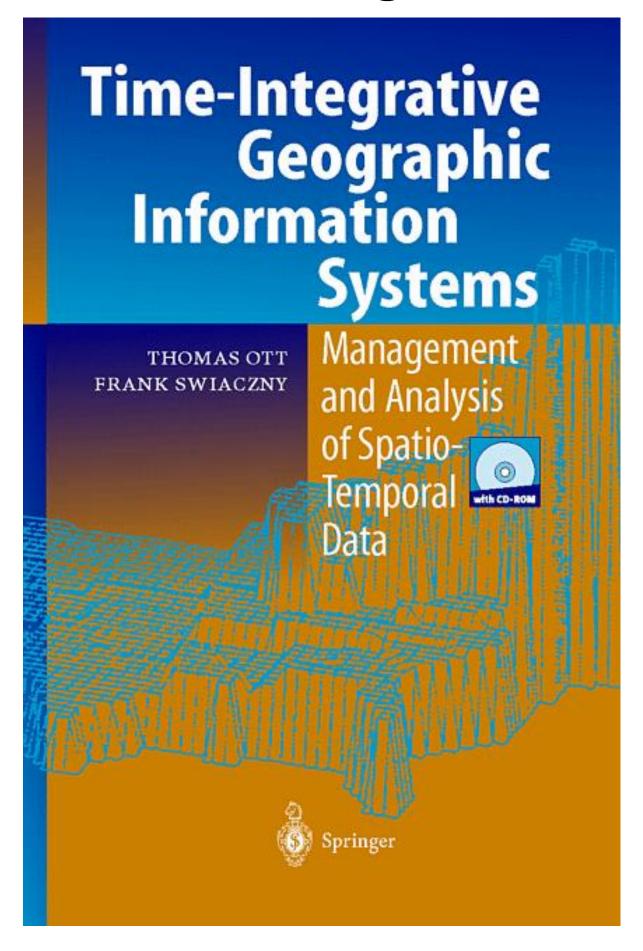## Management and Analysis of Spatio-Temporal Data

with CD-ROM

Springer

3 Integrating time in Geographic Information Systems

> "Time may basically be thought of as temporal relation-
> ships between events and objects in space. Time and
> space pervade all aspects of reality that constitute the
> data of geography, since everything material must exist
> in time as well as 3-dimensional space."
>
> (John Cole and Cuchlaine King 1969:405)

A spatio-temporal GIS extends a customary two or three dimensional spatial GIS on the time axis. Hägerstrand (1970) already used an orthogonal relationship between space and time to conceptualise the framework of his Time Geography approach. For his analysis of space-time paths, he made use of the fact that people can only be at one location at a time and that the moving from one location to another needs time.[26] A space-time path is defined by the changes of locations over time (see figure 3.1). This example shows, that in a spatio-temporal framework space and time are equivalent features of an event or a process. Furthermore each entity which physically exists in the real world is defined in a spatio-temporal context which can be conceptualised using spatial, temporal and attribute information (see figure 1.2).

"The concept of time is intuitive. We use it in many ways in our daily live. The passage of time is normally understood via changes we perceive occurring to objects in space – their transformation over time and their movements in relation to one another" (Peuquet 1994:441). In the previous chapter the conceptualising of the spatial dimensions of entities was discussed. It was stated, that entities must be spatially modelled in order to be used in a GIS. The same applies to a time-integrative GIS. The increasing levels of abstraction used as a guideline for the building of a spatial representation of the real world applies to the temporal aspects in a similar way. In complete analogy to space, time can be understood as an a priori continuous and infinite dimension, which must be reduced in complexity so that it can be stored in a GIS as finite and discrete data. This aspect is discussed in chapter 3.1.

Every spatial object used in a GIS has a temporal validity as well as one or many attribute values. The entity of a spatio-temporal process may change its spatial representation over time as well as its spatial relationship to other entities. In addition, the related attribute information may be subject to changes throughout

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[26] Cf. Wachowicz (1999:19) on the analysis of space-time paths with GIS.
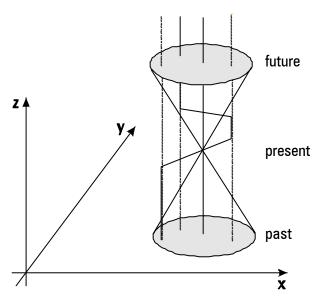
Fig. 3.1 Space time path (adopted from Peuquet 1994:453)

time. All spatial objects in a GIS are in the first instance defined by their spatial representation (see figure 2.25). This concentration on the spatial aspect of an object as the focal point of the conceptualisation of a spatio-temporal process in a GIS neglects the fact, that time and space are equivalent dimensions. The questions of what, where, and when defined as the basic components of the triadic framework are not interchangeable and equally important for the understanding of spatio-temporal structures and processes (see figure 1.1). Section 3.2 gives an overview of different approaches of the conceptualising of time related to spatial objects in a GIS. In this context "the concept of time implies that changes occur throughout the present, the past and future of the life span of a real-world phenomenon. A temporal GIS will aim to understand these changes and their effects over time rather than simply reproducing them by displaying a sequence of snapshots" (Wachowicz & Healey 1994:106).

According to Langran (1993:5) the following major functions of a temporal GIS can be distinguished:

?? *Inventory:* Storing a complete description of the study area, and accounting for changes in both the physical world and computer storage.

?? *Analysis:* Explaining, exploiting, or forecasting the components contained by and the processes at work in a region.

?? *Updates:* Superseding outdated information with current information.

?? *Quality control:* Evaluating whether new data are logically consistent with previous versions and states.

?? *Scheduling:* Identifying or anticipating threshold database states, which trigger predefined system responses.

?? *Display:* Generating a static or dynamic map, or a tabular summary of temporal processes at work in region.

To realise these functions in a conventional GIS, temporal information for objects must be added to the logical data models used in GIS. Different approaches to do so are discussed in chapter 3.5. "Thus, while great progress has been made in developing data models for GIS that go beyond the time slice approach, the creation of a truly spatio-temporal GIS remains an unmet challenge" (Couclelis 1999:35). The integration of time in existing desktop GIS packages is an even greater challenge today. In chapter 4 the treatment of this aspect will be succeeded by the introduction of practical approaches which can be applied using conventional technology at hand at the moment. As a prerequisite for this attempt basic concepts like event time and database time as well as different methods of versioning of databases and GIS have to be utilized. These basic concepts are explained in sections 3.3 and 3.4.

3.1
Different types of time

Time as well as space is a concept we instinctively use to understand and conceptualise our environment. Because we do not posses a sense to perceive time directly, we need to conceptualise the nature of time: Time structures several aspects of our perception. Time describes when something happens. In this sense time describes a certain event in a continuous dimension. The occurring of events could be measured in different ways. However, we experience not only that something happens but also that time passes by and that there is a duration between two incidents. A period of time can also be measured in different ways. From our understanding of the real world we may derive the concept, that time is closely related to changes, because every change, in what ever way, can only take place if time passes by. The complex nature of time may be added to a GIS by using additional concepts or perspectives. Although such aspects may lead to interesting insights, the options for the integration of temporal information in a GIS are restricted. Hence, time may be included in several ways (Laurini & Thompson 1992:104):
?? as a basis for recording events or attributes,
?? as an attribute of an entity with unchanging spatial properties, or
?? as a framework for observing changes in the spatial entities.

According to the taxonomic model of Frank (1998; see figure 3.2) time can be conceptualised either as a linear or a cyclical dimension.[27] A linear treatment of time implies a consecutive development on the time axis, while a cyclic treatment conceptualises the fact, that time may have a reoccurring character. The measure of time can also be differentiated according to whether time is transferred to a discrete scale or treated as an undivided continuum.

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[27] Cf. also Charalampos & Loucopoulos (1991)

		Total order	Partial order	Branching	Multiple
Linear	Ordinal	Single experience	Multiple experience	Branching time	Time with multiple perspectives
	Continuous	Continuous time			
Cyclic	Ordinal	Cyclic time			
	Continuous				

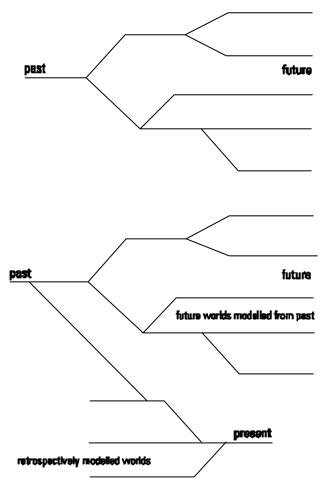**Figure 3.2** Taxonomic model of time (Frank 1998:45)

Fig. 3.3 Bi-directional branching time structure (adopted from Hazelton 1992:305)

Events measured on a linear ordinal scale can be differentiated further, according to the relationships of events. In a *total order set*, all relations between all events are explicit. In a *partial order set*, the relationship between some events may be given, the relationships between others are not known. On the other hand it is also possible, that there is more than one time line leading from present to past and future (branching time). This is a result of the fact that an event may occur more than once. The simulation of different future states is a potential example (see figure 3.3). On the other hand it is also possible to derive retrospective models from the present state (see chapter 4.4). From such a past state also different alternative future states may be simulated. In figure 3.1 the potential spatial range of events and processes for past and future time slices are depicted, evolving from „here and now" (Peuquet 1994: 453). Time with multiple perspectives refers to the fact, that „temporal models of reality cannot totally be synchronised with reality" (Frank 1998:54) (see sections 3.3 and 3.4).

For practical reasons it is necessary to use discrete measures in GIS. Calendar time is not the only kind of time possible for this purpose (Frank 1998:41). A lot of temporal information may not be addressed by a certain date, e.g. in geology or archaeology. The measurement can be made on different scale levels, reaching from an ordinal to an interval scale level. On the interval scale level of time discrete intervals with equal duration are used. The shortest interval used as a measure for a period and for the definition of the scale intervals used to define the time of an event on the time axis is called a chronon. The granularity of time, i.e. the smallest chronon applied, defines the level of precision and uncertainty with which time can be depicted as shown in figure 3.4.
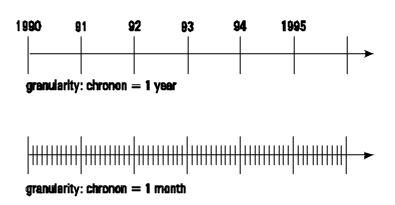
The length of a time span depends on the start and end, given by events. The length is also dependent on the granularity which is used to measure time. If for instance hours instead of days are used as the smallest chronon, the spatial resolution increases and the level of uncertainty decreases (Frank 1998:43; Kemp & Kowalczyk 1994:91). As time may always be divided further, no smallest chronon can be defined.

In practice the determination of an appropriate granularity depends on the scale of the time axis, which is defined by the duration of periods to be measured. As with spatial information, for temporal information scale dependency matters as well. Geological information can e.g. be measured with 1,000 years as the smallest measure, while data captured for meteorology must be measured using hours or minutes as a chronon.

When cyclic time is used, it is not possible to calculate time against an origin. Nevertheless it is possible to arrange the events according to a time scale with predefined equal intervals. If this is the case, e.g. using the hours of a day or the days of a week etc. a time span between two incidents may be calculated from cyclic time similar to linear time.

Using time scales with different chronons, it is possible to aggregate time measures, e.g. from hours to days or from months to years. The other way round, a temporal decomposition, is also feasible. In this case a suitable method of disaggregation must be used (see figure 3.5).

linear time

1990   91   92   93   94   1995

granularity: chronon = 1 year

granularity: chronon = 1 month

cyclic time

January
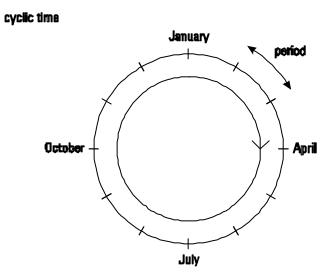
period

October — — April

July

Fig. 3.4 Granularity of linear and cyclic time (adopted from Frank 1998:52-53)

Finally, the question of time discretization is of great importance for the integration of time in a GIS. For most purposes it is too expensive or not possible to treat temporal phenomena in a continuous way. Depending on the size of the chronon used to define the time scale, measurements or readings from a data logger cannot be taken incessantly. In such cases it is important to chose a time sequence between two measures which corresponds both, with the time scale and the nature of the events or processes to be dealt with (Laurini & Thompson 1992:105).
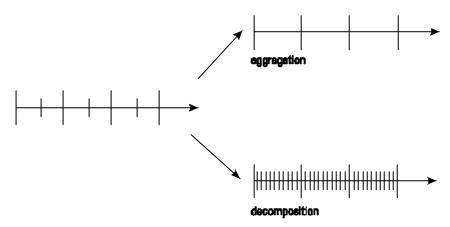
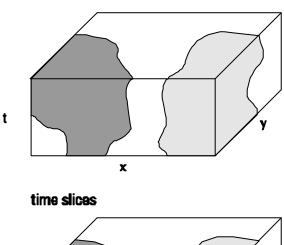**Fig. 3.5** Temporal aggregation (adopted from Lee & Kemp 1998:156)

3.2
Conceptualising time in GIS

Time can be conceptualised in different perspectives. While some conceptualisa-tions could rely on non temporal spatial objects, for most views on the world ob-jects will also change their spatial representations trough time. Spatio-temporal changes may occur in different types and forms (adopted from Snodgrass 1992:35):

?? Attribute and spatial object is invariant, the GIS spatially represents only one point in time or a past in present view based on one time step.

?? Attribute changes, spatial object is invariant, the GIS references different tem-poral steps of attribute data to only one spatial state represented by a time slice,

?? Attribute is invariant, spatial object changes, the GIS processes spatially chang-ing objects but only temporal invariant attribute data is available.

?? Both, attribute and spatial object change, the GIS needs to join changes of spa-tial objects and attribute data which could proceed independently from each other.

In the following sections approaches and concepts to conceptualise time are ex-plained. Using a relational database three alternative methods to build the concep-tualisations in a GIS may be distinguished. In general, temporal information has been incorporated into GIS spatial data models by time-stamping single layers, attributes and spatial objects (Yuan 1999:2).
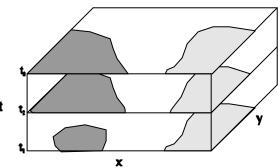
continuous boundary changes

time slices

Fig. 3.6 Space-time cube (adopted from Langran 1993:30)

3.2.1
Snapshot

The snapshot of a real world phenomenon is the most simple case of a temporal GIS. Using a mono-temporal set of layers is the standard case in a two dimensional GIS. Temporal content may be represented by assigning temporal data to the layer. The nature of temporal data used is not restricted to mono temporal data. Data representing temporal measures for elements of the selected time slice (past in present) may also be integrated. The temporal representation of data must match the time valid for the time slice, or lie within the validity of spatial objects represented by the layer. This basic concept can be implemented easily and will be used for mapping temporal information in chapter 6.