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A two-dimensional temporal model: base of a spatio-temporal model and a spatio-temporal data format

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Introduction

Nowadays, Geographic Information Systems (GIS) are typically used to analyse static geographic information. However, the temporal aspect is too often neglected. Although there are several spatio-temporal conceptual data models, most researchers use the similar temporal model, being the linear temporal concept. [Abraham T. & Roddick J.F., 1999], [Ott T. & Swiaczny F., 2001], [Peuquet D.J., 2000] Therefore, one could ask if it would not be better to develop a new way to conceptualise time. In this paper a two-dimensional triangular temporal concept is introduced. The concept offers several advantages compared to the classical linear concept. Secondly, the temporal concept is extended with two spatial dimensions which are fully supported by the common commercial geographic information systems.[1] This way, a spatio-temporal model is created which in turn offers a solid base for a so-called Spatio-Temporal File Format (STFF).

Data model

A geographic information system is a computer system (software, hardware, data and organisation of the data) used to save, analyse and visualise geographic information. To make this possible the data has to be transformed from reality into the information system making use of a data model. Such a data model is the strictly necessary step between reality and the geographic information system.

Temporal data model

As time encompasses an enormous complexity (e.g. topology of the time axis; different sorts of changes, dating and updates; fuzziness, multiscaleness and multidimensionality of time) the focus has been on research from a lot of domains e.g. philosophy, psychology, history, logic and computer science.[Van de Weghe N., 2002], [Van de Weghe N. & De Maeyer Ph., 2002] In the current paper we will focus on one single aspect of time, namely the modelling of time intervals (I). A time interval has a beginning (I^-), an end (I^+) and a duration (T). The duration is reduced to zero if $I^- = I^+$. This paper only considers pure intervals with $T > 0$.

A time interval is usually conceptualised as a finite line segment drawn on a linear, one-dimensional time axis (see FIG. 2A). The segment starts at the beginning of the interval (I^-) and ends at the end of the interval (I^+). It is a fact that linear time is used in many model applications and therefore deserves, without any doubt, further detailed study. However, it is also a fact that the linear time concept is too restricted to handle complex temporal and spatio-temporal queries. Therefore we introduce the triangular concept (see FIG. 1). In this concept two straight lines (L1 and L2) are constructed for each time interval, with L1 through the beginning of the time interval, L2 through the end of the time interval, $slope_{L1} = -slope_{L2}$, $slope_{L1} \geq 0$ and $\acute{a}_1 = \acute{a}_2 = \acute{a}$, with $\acute{a}$ being constant for the complete conceptual space. The intersection of both lines is called the interval point *I*, visualising the interval. The linear concept presents an interval using a one-

[1] Detailed studies regarding 3D-GIS, see: [Zlatanova S., 2000] and [Billen R., 2002].

dimensional line in a one-dimensional space. On the other hand, in the triangular concept an interval is visualised via a zero-dimensional point in a two-dimensional conceptual space, which offers the latter various advantages. Interesting, for example, is the possibility to use the model to select specific interval characteristics of a huge dataset by means of scanning via different aspects (e.g. the shortest interval point is selected via scanning from south to north). Another improvement is that the thirteen temporal relationships introduced by Allen [Allen J.F., 1983] can be merged into one single figure (see FIG. 3), which offers many more answers to some problems concerning temporal relations.[Van de Weghe N., 2003].[2] To get the best visualisation offering the most symmetry, interval 2 is pointed out in the centroid of the isosceles triangle. In FIG. 2 the relation 'before' is worked out. Several intervals can exist before I_2[33;66], e.g. I1a [10;23], I1b [20;25], I1c [6;20]. If all possible intervals are pointed out, one gets a so-called interval zone, in this case the interval zone 'before'. If the other twelve zones are constructed, one gets FIG.3.

Spatio-temporal data model

A spatio-temporal data model combines temporal data with spatial data. It is important that the whole (spatio-temporal model) offers more than the sum of its components (temporal model + spatial model). The model presented is an extension of the formerly presented triangular temporal concept. The model is explained by means of an example: The evolution of a water boundary during a period of nine timestamps, studied in a GIS with vector geometry (see FIG. 4). The water border is a linear border, composed of points. The border divides the region in two polygons, the water in the north and the land in the south. Firstly, the triangular concept is extended with only one spatial dimension, the X-co-ordinate. In other words, two-dimensional space is projected on the horizontal X-axis (see FIG. 4). For the moment, the changes in the Y-direction are neglected. As such the two-dimensional triangular temporal concept is transformed into a three-dimensional spatio-temporal concept (see FIG. 5), with: $D_1 = T_1$, $D_2 = T_2$ and $D_3 = R_x$. Every point of the water border is studied in detail by pointing out during which period the specific point exists. Since the triangular temporal concept is combined with the two-dimensional spatial concept, advantages of both can be utilised. Thanks to the temporal concept, data can be scanned and temporal relations can be analysed. Because of the spatial concept one could use well-known techniques such as distance formatting, georeferencing, constructing topological relations; for the moment only within the X-dimension. Secondly, an analogous study is made for the Y-co-ordinate. Finally a unique link between time (T_1 and T_2) and two-dimensional space (R_x and R_y) is created. As a consequence one has to go from three to four dimensions, which cannot be visualised in a conventional manner. Therefore we use analytical geometry where a four-dimensional space can be studied.

Spatio-temporal data format

Since analytical geometry uses orthogonal axes, transformation formulas have to be used to make transformations from interval co-ordinates to orthogonal co-ordinates. So, every point existing during a certain period of time is written down as a quartet of four co-ordinates. Finally we get a list of co-ordinate quartets storing in a compact way the evolution of the water border during nine timestamps. This list could form the base of a new file format, which will be called the Spatio-Temporal File Format (STFF). The file format consists of a header and a body. The header consists of several spatio-temporal parameters, e.g. temporal resolution, the beginning and end of the study period, the possibility to store infinite small time intervals. The body consists of the list of quartets standing for the evolutionary data of the points. An example of a data set is shown below.

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[2] The thirteen temporal relationships between two time intervals (symbol representing the temporal topology between the intervals): before ( ), after ( ), meets ( ), met-by ( ), overlaps ( ), overlapped-by ( ), during ( ), contains ( ), starts ( ), started-by ( ), finishes ( ), finished-by ( ), equal ( ). The symbols were introduced in [Van de Weghe N., 2003]

```
BEGIN
  HEADER
  BODY:
      4.5    4.5    0    4
      1.5    1.5    2    3
      4      1      2    2
      5.5    0      2    0
      1.5    1.5    4    3
      6      1      5    1
      7.5    0.5    5    2
      4.5    4.5    6    4
      3      2      1    2
      6      1      1    0
      7.5    0.5    1    2
      8.5    0.5    1    3
END
```

Conclusions and future research

This paper studies the problems of time in GIS. It shows that new insights in temporal modelling could form the base of a spatio-temporal file format. Of course the concept has to be tested in depth in the near future via several applications, where we will try to consider the whole complexity of time. Interesting domains are archaeological research, cadastral mapping, criminological research, historical soil studies and mobility study.

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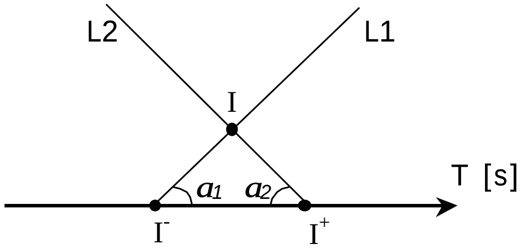

Figure 1. Triangular concept: construction rules

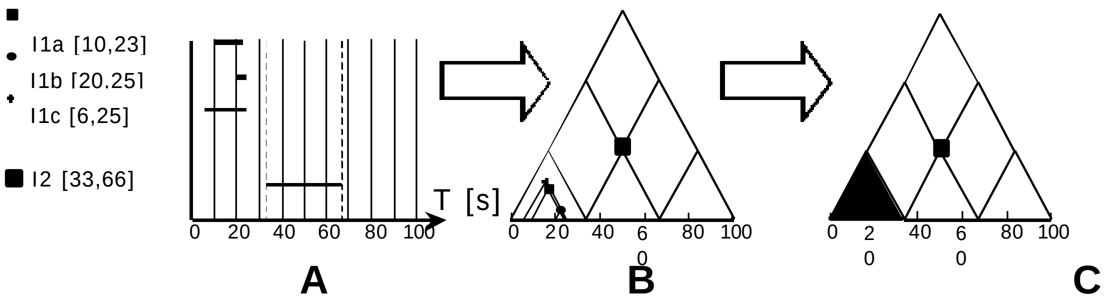

Figure 2. Transformation from the linear concept (a) to the triangular concept (b) and selection of the interval zone 'before' (c)

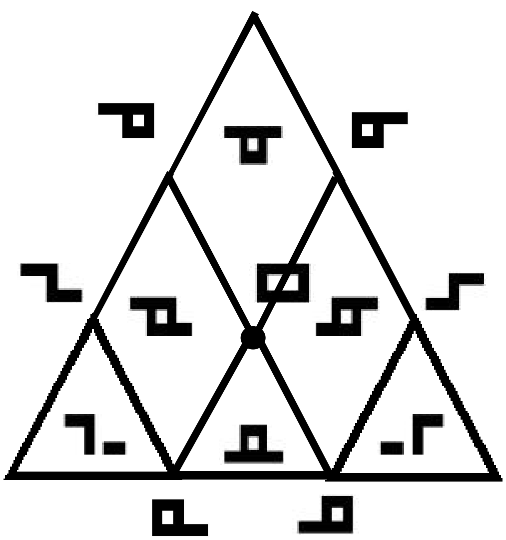

Figure 3. Triangular concept: the thirteen temporal relationships merged into one figure

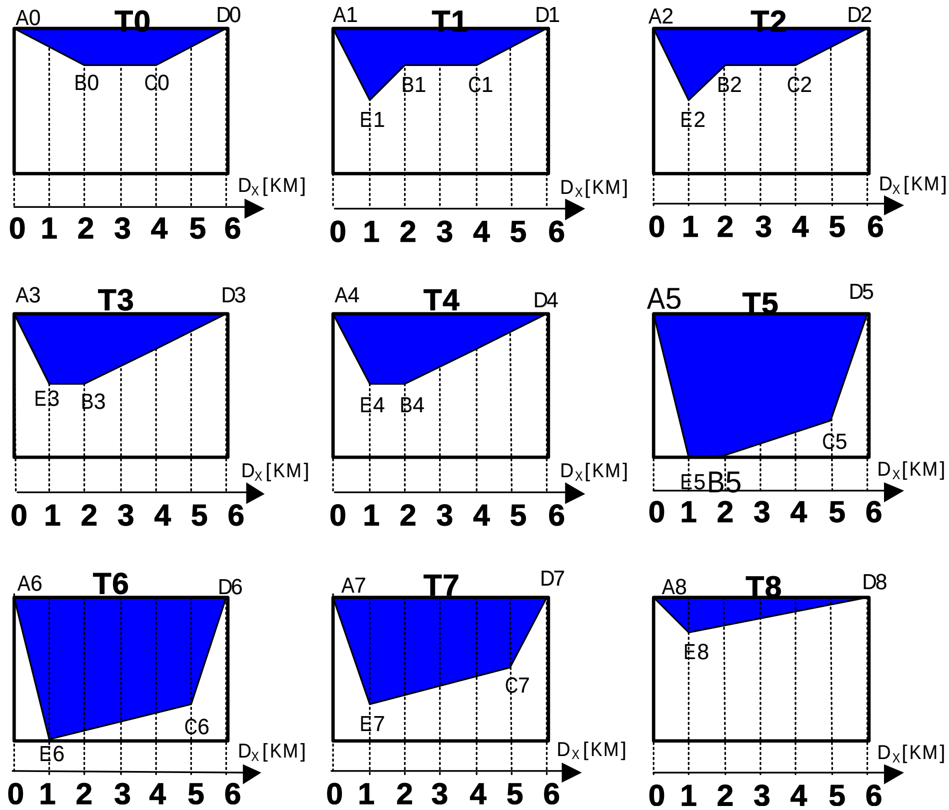

Figure 4. Example: evolution of the points of the water border: x-coordinates

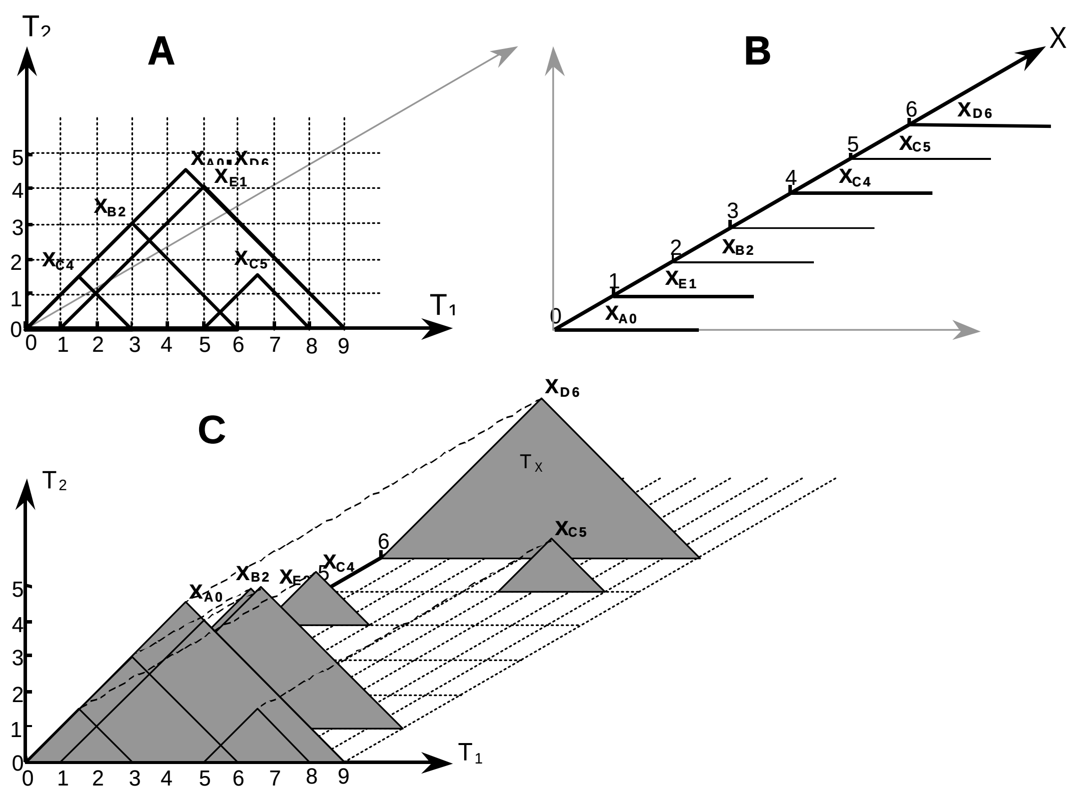

Figure 5. Example: spatio-temporal visualisation of the x-coordinates