Animated Points: Storing and Retrieving Time-Dependent Information

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Abstract. In geosciences map animations help to explore, analyze and validate complex settings and to display – and ultimately understand – higher dimensions of information by combining attribute information from multiple sources. Despite the omnipresence of geographic information system technology (GIST), standard information systems (IS) are not designed to store temporal information on the same implementation level as spatial information is stored. However, it is possible to model temporal information as another object attribute despite several limitations.

The objective of this paper is to develop a structural model for storing and accessing spatial data primitives that are connected to their naturally temporal information for the purpose of creating map animations. We here summarize the nature of (carto-) graphic variables and discuss their potential use for map animation in general and for animated point symbols in particular. Scenarios of simple and complex feature animations complement this discussion. Our results lead to a simple data model in which temporal information can be stored on an attribute level, accessed using standard relational queries and animated as map features.

Keywords: point symbols, GIS, data model, map animation

1. Introduction

Within cartographic visualization each geo-object is described by its *geometric dimension, location* and in its *substantial attributes* (e.g. Dransch, 1997), and is stored within its *topological* context. Each real-world feature and process is inherently related to time and thus, time is an additional property of each geo-object. For mapping an event or process, Kraak & Ormeling (2010) describe three temporal cartographic depiction modes. The first two modes target at static maps in which change are depicted as *a single static map* or as *a series of static map*s. Although static maps can cover complex contents these types of visualizations have limitations in terms of efficiency (Hettner, 1910, Dransch, 1997). Such limitations can only be overcome by the third depiction mode described by Kraak & Ormeling (2010): *the animated map*. By making use of multidimensional visualization changes, processes and real-world features can be displayed cartographically in a more accessible way.

Prospects and complexity of cartographic animation have always been promoted and controlled by technical advances in hard- and software developments. In the course of the microcomputer revolution in the late 70s, computers became accessible to the masses. Fast technical evolution soon provided advanced multimedia hard- and software (e.g., Brynjolfsson, 2012). Such tools provided means for interactive visualization of information through efficient mapping of real and abstract objects and time-dependent phenomena (Friedhoff & Benzon, 1989).

Today we are literally overwhelmed by all kinds of abstract and realistic animations in our daily life, e.g. in entertainment, advertisements, gameplays or in science and education. In the field of geoscientific research process animations are commonly used for data visualization and exploration, model validation and demonstration (e.g. Dransch, 1997, 2014). For the use of animation in scientific research processes the reader is referred to DiBiase (1990) and Watson (1990). Cartographic animation of data and information has been supported by computer techniques since the 1960s (e.g. Harrower, 2004, 2009, Kraak & Ormeling 2010). With the help of animations the viewer is enabled to “deal with real world processes as a whole rather than as instances of time” (Ogao & Kraak 2002, p. 23) and, consequently, the reader of a cartographic map transforms to the viewer of a cartographic product. The conventional approach of displaying cartographic animation is by generating map sequences representing individual frames of an animation. That implies that all spatial-relevant parameters are directly linked to each individual frame. Thus, changes can be easily visualized as time-dependent sequence across a complete map rather than for particular map objects.

Nowadays, spatial data analyses are commonly conducted within modern GIS in which geometries of objects and all associated data are stored within the underlying database framework as attribute values or object properties (e.g. Bill, 2010). However, the full representation of data's temporal character has not been implemented in common off-the-shelf GI products yet (e.g. Andrienko, 2010). Nevertheless, in order to achieve this, the underlying software concepts – often based on core developments dating back to the 1980s – need to be re-developed and re-implemented. Based on this cartographic animation is currently implemented as an add-on to the existing data framework and time can only be modelled using relational attributes rather than an additional dimension. Once temporal information is stored in an accessible way each object can be animated using individual object properties as parameters for an animation. Temporal attributes are then independent of an object's geometric dimension. Consequently, when thinking about animation of cartographic information, not only visualization techniques need to be well-designed and considered appropriately but also the way of accessing and storing data in the underlying data structure (e.g. DiBiase et al., 1992, Egenhofer & Gollege, 1998, Harrower & Fabrikant, 2008).

The high-level aim is to develop a structural environment for storing and accessing spatial data primitives (see OGC, 2011) as temporally dependent objects in a way that they can be accessed, statically visualized and animated by making use of spatial feature attribute within a GIS-based data model.

To achieve this aim, we here focus on the following points:

- Precursory (thematic) work which his needed for generating a data model dealing with temporal aspects of the natural processes forming the landscape
- Depiction of typical scenarios and features that can be animated by restricting our view to physical real-world objects and natural processes.
- Options for cartographic visualization for time-based objects
- Storing and accessing temporal geo-objects within a data model.

We here focus on animations that visualize changes of an object through time by a process that is defined by a distinct starting event and by a terminating event (see also Dransch 1997). Animations which do not carry an inherent temporal information are disregarded.

2. Methods and Approach

In order to improve understanding the state of objects and processes in the real-world and in order to reflect interdependences between objects, they need to be described not only on the entity level but also on the level of their relationships, i.e. the overall system needs to be modeled. Consequently, we do not only need to describe an object's status at a single discrete time stamp but we also need to describe developments and changes delineated by at least two time stamps (e.g. Dransch, 1997).

The way a spatial object will be visualized cartographically depends on 1. an object's real-world geometry, 2. individual spatio-temporal mapping scales, and 3. hierarchical relevance of each object based on the map focus. Therefore, it seems straightforward to investigate temporal changes in state in the same way as geometries are investigated, described and stored: by coordinate tuples. If we make use of the OGC simple feature concept we need to cover three fundamental geometry types: points, curves and polygons/surfaces (OGC, 2011). Topographically 0-dimensional point features usually depict object status and location on a highly abstract level. Curves and polygons could provide means for geometric calculations based on their 'true' map extent.

We here concentrate on a point feature model for the reason that if point features can be covered in an animation model – either as abstract representative of a higher-dimensional real-world object or as part of a topologically higher dimensional representation – any higher-dimensional object (like curves and polygons/surfaces) can be represented consequently.

A data model that is able to store all necessary information about map animation, needs to handle not only the basic properties (Bertin's graphic variables) but also time-dependent control (DiBiase's dynamic variables). That means that *time* is one attribute which controls the behavior of properties represented by Bertin's graphic variables. Physical objects can be altered during time by changing their

1. substantial composition (qualitative and quantitative),
2. size (quantitative),
3. orientation (quantitative).

A relation of these changes with any temporal framework provides us with rates of changes, i.e. change in composition, velocities, rotation. The possibilities how changes can be displayed depend on the complexity and number of attributes but also on the level of measurement (Bertin, 1983, see table 1).

Level of Measurement		**Graphic Variable**
1	Nominal (qualitative)	location, shape, color
2	Ordinal (ordered)	location, size, value, texture, orientation
3	Interval (quantitative)	size, orientation
4	Ratio (quantitative)	size, orientation

Table 1 Acceptable level of measurement for using graphic variables in ascending order (derived from Bertin, 1983)

In this context Bertin (1983) proposed rules which help to describe and categorize appropriate use of these graphical variables. Over time, it has been argued that his typology-syntactic set of graphic variables does not suffice to cover all aspects (MacEachren, 1995); especially because of new advances and capabilities of computer-assisted mapping and map animation. In addition to the graphic variables used within static maps, “animated maps are composed of three basic design elements or dynamic variables – s*cene duration, rate of change between scenes, and scene order*. The dynamic variables can be used to emphasize the location of a phenomenon, emphasize its attributes, or visualize change in its spatial, temporal, and attribute dimensions” (DiBiase 1992, p. 201).

In summary, a simple point feature as currently implemented in GIS consists of four basic geometric properties that can be changed through time and controlled by object attributes: *shape*, *size*, *color*, and *direction*. Time-dependent animation can introduce rates of change for these graphic variables. Therefore it is possible to display four attributes at the same time which can undergo either no change, parallel change of at least two attributes or change of all attributes at different times and rates. Since changes in *shape* require more sophisticated techniques even for simple point representations, we here limit our view to the properties *size*, *color* and *direction*.

3. Concepts for Implementation

3.1. Precursory Work

All events that can characterize the natural environment are classified by their temporal component. Thus, within the data model the so called timeline differentiates between *temporal events*, i.e. an action that occurs at a discrete point in time, and *processes*, or time spans, in which an object undergoes modification (see figure 4). The *temporal range* is the time span between the temporal minimum and maximum and marks the lifetime of processes within an animation context (see also ISO 19108).

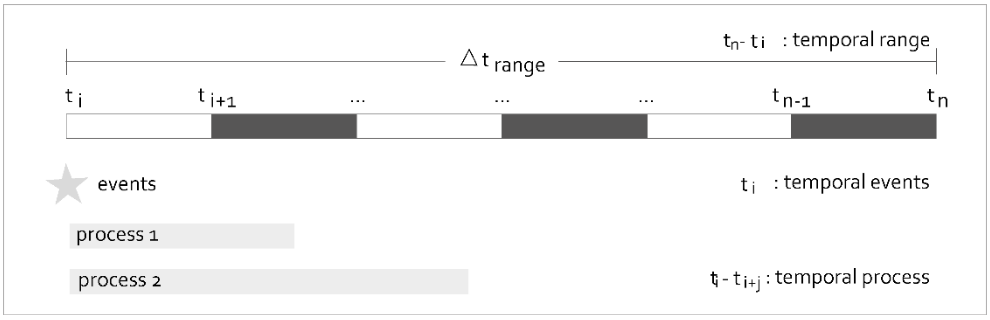

Figure 1 Time-scale showing the three different types of temporal occurrences forming the natural space.

Spatial data animations can depict change in *space* (position), in *place* (attribute), or in *time* (Kraak 2007, p. 317). As emphasized above all objects have at least two temporal attributes which are (1) time of origin or creation and (2) time range of an object's existence. In the same way as spatial location and extent are described by a map scale, time-relevant attributes can be described by a temporal scale. It seems appropriate to differentiate processes in terms of their extent and their duration in order to (a) understand different scenarios which need to be depicted within a map-animation data model, and (b) generate a rule set for calculations based on these scenarios. Figure 2 shows the possible scenarios of processes forming the natural space. Here both axes, size und time, are displayed on a relative logarithmic scale and the corner display extreme processes that are either short term (10^1 s) but on global scale (10^6 m), i.e. usually catastrophic events, or long term (10^{12} s) and on highly local scale (10^{-6} m). If these two cornerstones can be modeled, all other processes can be fit into and modelled as well.

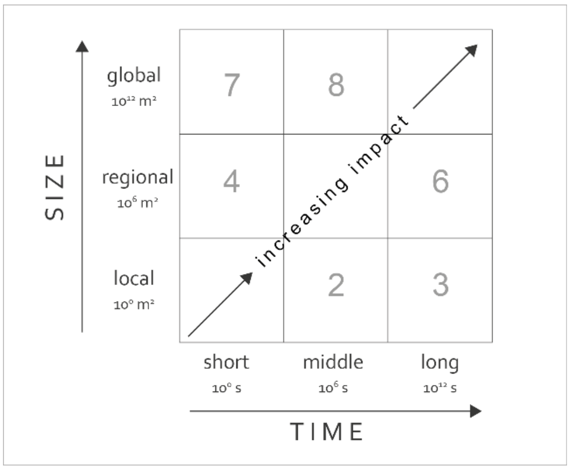

Figure 2 Object-oriented Size-Time-Matrix covers all processes forming the natural space.

In order to achieve map animations spatial object properties must be stored separately from temporal characteristics. That means the timeline should be modifiable and extendable whenever new data become available. Each event, however, must be associated with a value used for displaying the change. These changes are size, shape, value and colour, orientation.

3.2. Cartographic Data Model

The levels of complexity of real-world objects and processes are the driver for techniques that need to be developed and employed for visualizing cartographic entities. Complexity of cartographic depiction even increases if 3D+t real-world entities are displayed using 0-dimensional point symbols, primary as result of different generalization processes (e.g. Imhof 1972). While it is straightforward to describe the geometry and topology of a single point feature in space it becomes complicated if a set of point-related attributes need to be assigned and displayed at the same time. If time-related information, i.e. changes and processes, are part of this set of attributes, point-feature animation are the only way of communicating such information.

Objects and processes represented by point features can be substantially manifold and complicated. However, there is only little degree of freedom for manipulating spatio-temporal point features. Non-temporal graphic variables (primitives) are complemented by dynamic variables and require additional descriptions such as *start time*, *end time*, *animation rate* and information about the type of animation.

With such a set of primitives and information about rate of change, most physical processes can be modeled and displayed graphically within a map. As an example one might think of a hazard map depicting locations of landslides. The size of each point feature may reflect the normalized size of a landslide (basic physical quantity *length* given in unit *meters*). Changes in size or mass can easily be depicted by changes in the (normalized) *size* of a symbol. When switching to ordinal scales, changes may be depicted by changes in *color* or *brightness* attributes. Here, a landslide might pose a threat for which different classes have been defined and an appropriate color scale (green to red) might reflect the severity. Velocities of landslides for example, are derived basic physical quantities and may be depicted as change of attribute primitive per time. This could for example be depicted by symbol angle per time (rotation) or color transitions per time unit (see fig. 3).

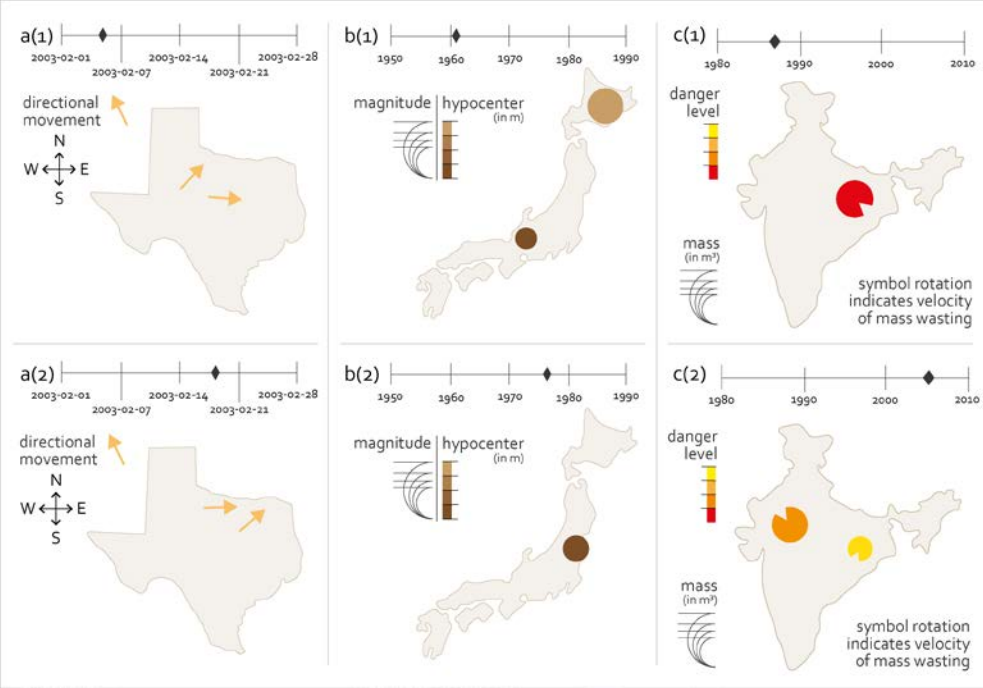

Figure 3 Examples of point symbols (fictional dates): a(1+2) shows one-dimensional symbol showing directional movement of tornados in Texas, USA recorded in April 2003; b(1+2) shows two-dimensional symbol showing Earthquakes occurring in Japan between 1950-1990; c(1+2) shows three-dimensional symbol showing Landslide measured in India between 1980-2010.

In figure 3 each case (1) and (2) shows different *spatial* locations at different *temporal* "locations", thus marking an *event* in time.

Example a(1+2) (in fig. 3) shows changes by modifying one parameter (direction of tornado movement) per unit time. When changes in direction become time-dependent and also rate of direction changes a rotation can be interpreted additionally.
In example b (fig. 3, table 2) two parameters change and depict earthquake locations, magnitude by changes in sizes and depth of hypocenter by changes in color (on an ordinal scale). Example c (fig 3, table 2) shows how three attributes are changed through time by rotating symbols to depict velocities, by changing symbol sizes to indicate changes in mass and by changing color to depict the level of threat.

example	**symbol change**	**communicated meaning**
a (tornados)	angle	direction
b (earthquakes)	size color	magnitude earthquake depth
c (landslides)	size color angle	mass danger level (nom) velocity (as function of time)

Table 2 List of symbol examples with one-, two, and three-dimensional attribute changes.

All these precursory thoughts lead to a basic data model which can be employed for storing spatial object information and for map-animating temporal changes (see fig. 4).

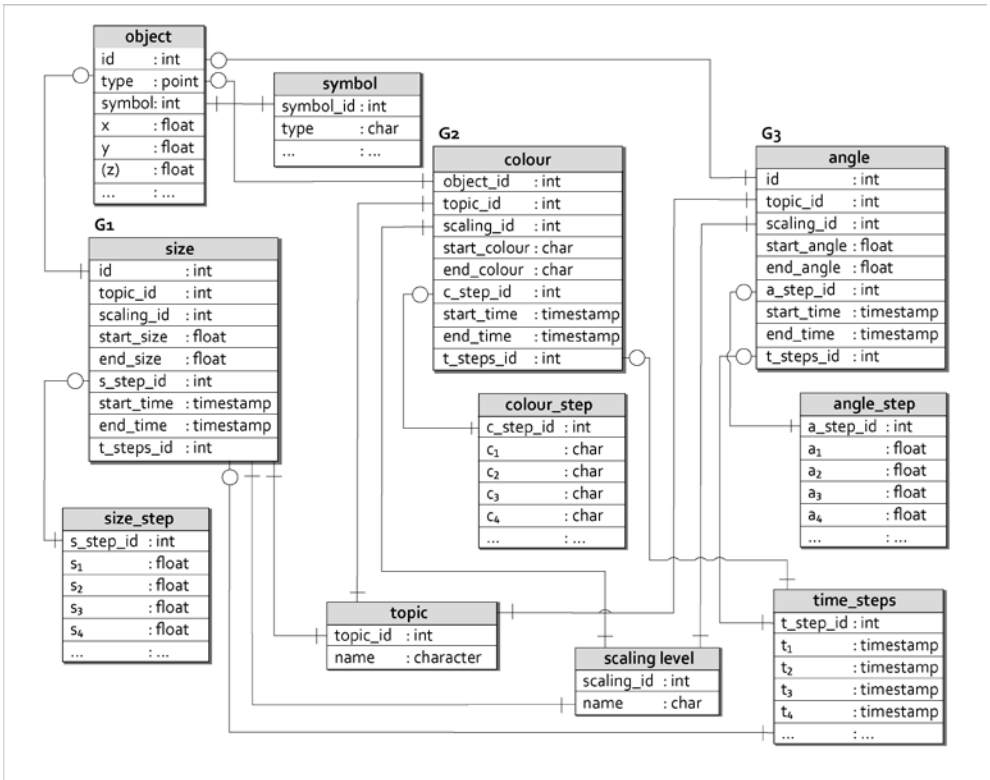

Figure 4 Data model handling point objects and referring to three possible basis animations.

The relation *Object* is the central relation and contains information on geometry type and its basic spatial attributes to which non-temporal attributes can be added. Types of feature changes are stored in relations *size*, *colour* and *angle* (as an example), marked as G1, G2, and G3, respectively. These relations contain all object modifications and all event information. Thus, an object can have zero, one, two or three modifications and the same number of timelines. The link between symbol changes and change rates and the topical information is established using a third relation, so that spatial properties, temporal properties and topical information are separated from each other.

4. Conclusions

In recent years, possibilities in the field of animated cartography have rapidly increased due to density of available information and accessibility of computer-based animation technology. Cartographic animations (CA) are used in various fields such as weather forecasts and simulation in news media or map animations on web pages, and they have the aim to communicate complex and mostly time-dependent information in an accessible way. It therefore seems convenient to display all sorts of physical shapes and processes using CA, in particular if spatial information is complemented by temporal object properties. If such information is conveyed in a natural way, it can be accessed intuitively by any recipient. For such data analyses and data representations GIS technology is frequently used as it allows to combine spatial information with non-spatial attributes and temporal characteristics and to relate them to other entities. However, since basically all spatial settings can be theoretically mapped as an event in time, CA could provide means to extend spatial information by introducing a temporal dimension.

In conventional GIS all information is stored as attribute values in relations. As long as temporal information is not readily supported in the same way as spatial information within such systems, workarounds need to be designed to store the temporal dimension within a common relational data model. Rather than designing feature sequences associated with time information for topological 1D and 2D objects, we have focused on animating single object, such as point features for which frame-based image sequences are not a feasible approach. This point-feature approach can then be employed to depict processes for higher-dimensional geometries. By sketching cartographic visualization options, a simple data model capable of storing spatio-temporal information for map animation is developed and discussed in this work. Ongoing and future work will focus on refinements and compiling more complex working examples. With respect to higher dimensional topological objects prospective data model strategies and rules need to be found to access and modify these temporal features efficiently.

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