Visualization of the Temporal Dimension in Multimedia Presentations of Spatial Phenomena

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Abstract. Technological evolution has paved the way for a variety of small dynamic maps. The increasing use of the Internet and WWW has played a major role in the dissemination of map applications. Interactive map animations open a new way of thinking when visualizing spatial data. This paper focuses on the presenta-tion of the temporal dimension of spatial phenomena on dynamic maps. The proposed methods are discussed in the light of how people perceive time, and are modelled on the basis of theory for common visual variables in cartography. Multimedia presentations are not limited to graphic visualization. The audio-channels on a modern computer can impart useful information by sounds in interaction with the graphic display .

1. Introduction

Some years ago a GIS was usually known as a huge, advanced program sys-tem that was able to handle geographically related data. The system could solve a lot of different problems, and considerable training was required for the personnel who are to manage the system.

This situation has changed. The increasing use of the Internet has opened a new category of small applications that handle geographic information and map data. These are mainly small applications which solve very specific problems. Many users of the Internet have little or no skills in the field of geographic information systems. Consequently the applications must have a very simple user interface to make them easily understandable for non-professionals ([9]).

On an ordinary or "static" paper map, time has been an issue for hundreds of years [17]. In later years research has focused on spatio-temporal data models and management. In the visualization of these data, the temporal dimension has to be taken into consideration. Computer technology and dynamic maps open new meth-ods for these presentations. This, and the fact that the World Wide Web paves the way for numerous small map applications which are accessed by people without any technical qualifications in the field of cartography and maps, results in a demand for easily perceptible presentations of the temporal dimension.

The proposed methods in this paper are based on the assumption that a wide audi-ence should understand the resulting map application. Equivalent methods can be used in more complex combinations when the presentations are for expert users ([7]). Various authors have looked on how to visualize time-series data. [11] proposes the temporal brush, which is a kind of scroll-bar for the temporal dimension. [14] discusses active legends for interactive cartographic animation, and states the importance of breaking loose from paper-based thinking. Temporal map legends are explored further in [6], where the legends are classified as embedded in the map display or are shown in a separate area. This paper uses the term *temporal variable* when the temporal dimension is illustrated, and the term *main (or principal) phenomena* for the objects that are the main theme of the map. The paper also explores the situation where the temporal variable is presented simultaneously with the principal phenomena, and discusses this in the light of psychological theories for time perception. The paper also explores how time can be represented by sound variables, and thereby includes a second sense organ in the comprehension of the map.

2. How Do We Perceive Time?

Time is a dimension that is difficult to define, because each person has his/her individual perception of time. In the field of psychology there is of course a lot of literature on how people perceive time. [4] writes that psychological time consists of three major aspects: succession, duration and temporal perspective.

- ***Succession*** refers to the sequential occurrence of events that will be perceived by a human. The events will be stored as a kind of index in the human memory.
- ***Duration*** refers to several different characteristics of events:
  - Every event persists for a certain duration, which an individual may encode and remember.
  - Events are separated by intervals that may contain other events. The length of the intervals is of significance.
  - A relatively unified series of events forms an episode that continues for a certain duration.
- ***Temporal perspective*** refers to an individual's experiences and conceptions concerning past, present and future time.

These are the results of psychological studies of how a human perceives time. It will be a natural consequence to take this knowledge into consideration when time is illustrated on a dynamic map. Further, in addition to these basic elements, we have to consider if individual humans have common reference systems in their perception of time. Variations caused by the Earth's position to the sun are of course major elements. This will in the first place be variations over 24 hours and over a year. Cultural background and geographical location are significant factors for the individual's experience and conception of time. People from the same region, country, religion etc. may have a common basis for their own temporal perspective.

These aspects in psychological time have an obvious connection with the dynamic variables in [8]:

- **Succession** in the perception is utilized when frames, scenes or episodes are displayed in a certain *order.* The *display date* of several phenomena can also have an order.
- **Duration** - in the psychological sense - is utilized to show the *duration* of scenes or episodes on the display, and for the illustration of how long a phenomena exists by the *display date* variable.
- **Temporal perspective** depends very much on the individual's comprehension of time, and will in various ways influence the perception of all the dynamic variables.

In presentation of the temporal dimension *succession* is a key-factor. Succession of events in the presentation is necessary to make the change in time easy understandable. When using the dynamic variable *duration*, we have to take into consideration the type of animation. In an automatic animation, duration of events in the presentation can be made proportional with the duration in the "real life" of the object. But this can be a little bit confusing when using interactive controls for the animation. In that case events of equal sized periods can be more informative in the presentation of time. *Temporal perspective* and "time indexing" is difficult to implement on a general system. However, in a program system it is possible to let the user choose between several "temporal visualisation styles". In this way the user may look at a "style" that is adapted to his/her imagination of time. Time as a result of natural cycles or cultural dependent events will be more suitable for large groups of users.

3. Time as a Variable on the Map

According to [2] only one variable, in addition to the position, should be presented on a thematic map when the aim is to make a "seeing map", or in other words; keep the perception of the contents on a global level [3]. On an interactive map, where a phenomena changes over time, it is essen-tial to include a variable that shows the point of time for the present phenomena. Consequently the temporal variable has to be presented in parallel with the main phenomena we want to show.

[6] point out two major types of legends for temporal animation. The first is legends in a separate display area, where they identify three sub-categories: analogue clock, slide bar and numerical. The second is embedded into the map display. They show back-ground colour and sound as examples in this category and use the term "legends for temporal map". This term can be appropriate in the description of the first category. However, some of the examples later in this section show how the

presentation of time is built together with the principal phenomena in a way that it can be discussed if it is a legend, or that it should be considered as kind of variable.

The main issue is to harmonize the variables on the map in a such manner that the map reader perceives the information on the map, and simultaneously knows the point of time for the situation. The first bit of information must not drown the other - and vice a versa.

A paper map made for perception on a global level should mainly answer the ques-tion: "where is this phenomenon". In an animation we also want to answer the ques-tion: "what time is the phenomenon existing". Our aim is to maintain the perception on a global level. [5] describes the human eye/brain capacity in the perception process. The cones, which are sensitive to differences in wavelength (colours), are mainly centred around Foeva and have a "direct connection" to the brain. These photoreceptors cover a small sharp-sight area, while the second type, rods, cover the peripheral-sight area. The rods will respond to small changes in intensity (value), but are insensitive to differences in wavelength. In the light of this it can be concluded that legends with changing colour in the periphery of the ani-mation should be avoided. The use of changing legends or local animations in a sepa-rate display area will in most cases reduce the level of global perception. Ideally the change in time should be perceived without moving the glance away from the main phenomenon.

This paper uses the following classification of methods for presentation of the tem-poral dimension:

- **Temporal dimension visualized in an active legend outside the main presentation**
- **Temporal dimension visualized in an active legend within the main presentation**
- **Temporal dimension visualized by overall animation**
- **Temporal dimension imparted by sound**

As we can see, the classification is somewath different from [6]. To keep the global level of perception, both the presentation of time variables and the presentation of the main phenomena should be based on the visual variables of [2] *(location, size, value, texture, colour, orientation, shape)*. In such an interactive map animation, it is important to choose visual variables in a way that they do not confuse the map reader. Consequently the visual variable for the temporal dimension has to be distinct from the visual variable for the main phenomena. It will for example be very confusing to let a growing bar represent change in time, while change in the main phenomena is rep-resented by growing/shrinking bars.

3.1 Temporal Dimension Visualized in an Active Legend outside the Main Presentation

In this method the temporal variable is shown outside the main phenomena and will act much like a legend on a traditional map. Some sub-categories can be pointed out:

- **Local animation:** Several local animations can be distinguished. The *analogue clock* falls into this category. Most people have a psychological link between a snapshot of the clock and the corresponding time of day. The clock involves three of [2]'s visual variables; the visual func-tion of the handles is a combination of *orientation* and *location*, while the wide use makes the *shape* easily recognizable. A *slide-bar* manly benefits from the location variable. A *growing bar* may involve both size and loca-tion. To represent natural cycles (day, year) or cycles based on a calendar, "circular" animation is appropriate. Figure 2 shows the focus on a day in a week. In this example, location and size are the most important variables. Several animations can be constructed on the basis of [2]'s visual variables. However, since succession is an important factor in the human perception of time, a consequence is to choose variables with ordering qualities. The duration of events and intervals between events are pointed out by selective variables.
- **Alternating icons:** Another way to present time is to use descriptive icons. A sun-icon will for example indicate daytime, while a moon-icon indicates night. Icons are based on the variable; shape, and have associative but no ordering qualities. Icons can be used alone, or maybe in connection with a local animation, as a link to the individual's experience. A general presentation of time by such icons may conflict with the fact that each person usually has his/her own experience. A solution can be to let the users of the software make choices from an icon-library, and include icons that fit their own experience in the presentation of the temporal variable. This can be done first time the program is used.
- **Text-string:** Point of time is represented by a number, word or text string that changes when the point of time changes. A digital clock representing 24 hours, or the name of the months representing a year are typical examples. Let-ters or numbers cannot be classified as visual variables, and are consequently not preferable in a presentation where the perception should be on a global level. However, text can be used for a closer description of the phenome-na on a "reading map" ([2]).

On a thematic paper map, with a global level of perception, the user gets an imme-diate impression of the map before he/she studies the legend [8]. On an interactive map, or map animation, the temporal variable changes during the presentation. It is a matter of course that the variable is self-explaining and easily understandable for the map reader. However, when the temporal variable is presented in a separate area outside the main presentation, and both the temporal variable and the main phenomena change, it is difficult to keep the perception on a global level. To make this possible, the temporal variable has to be perceived by the peripheral-sight. As a consequence of this, colours in the temporal variable will make a poor contribution to the comprehension of the active legend.

When the user studies an interactive map, he/she needs to operate the application by some user controls. Those should be located close to the active legend or in close connection with the main phenomenon, to avoid spreading the information on the display. In some cases the legend itself acts as user control (for example by dragging a handle on a slide-bar).

3.2 Temporal Dimension Visualized in an Active Legend within the Main Presentation

To improve the simultaneous comprehension of the temporal variable and the main phenomena, the active legend can be located inside the main presentation. It is advantageous to keep the legend close to the phenomena that is examined. When the entire map is in focus the active legend should have a central location, and when a certain area is investigated the legend should be close to this. The active legend itself is one of the types described in the previous section. Two strategies for "local legends" are suggested: *movable legends* and *multiple legends*. A third type of legend is also possible.

- **Movable legend:** The active legend, often including a built-in user control, can be dragged around in the display by the mouse. The location is fixed by the user, based on his or her requirement for the map reading and the part of the map that is studied.
- **Multiple legends:** Several identical legends located in central spots inside or close to the main map presentation. The intention is to avoid too many "eye-shifts" when the map is studied.
- **Incorporated legend:** It is also possible to include the legend for temporal dimension inside the visual variable for the principal phenomena. If this phenomena is illustrated by proportional circles (size as the visual variable), an analogue clock can show the point of time (Figure 3).
- **Enclosing legend:** The active legend encloses the complete map presentation, or, from another point of view; the map is built-in the active legend. Particularly well suited for visualisation of time cycles. In Figure 1 the method is shown by “a satellite” that moves around the map according to the point of time it represents. It is important to design this kind of legend in a way that keeps the map presentation in focus, while the legend is percepted by the

peripheral-sight. In Figure 1 the intensity of the dark-grey satellite is perceived by peripheral-sight, while location of the satellite gives information on the point of time.

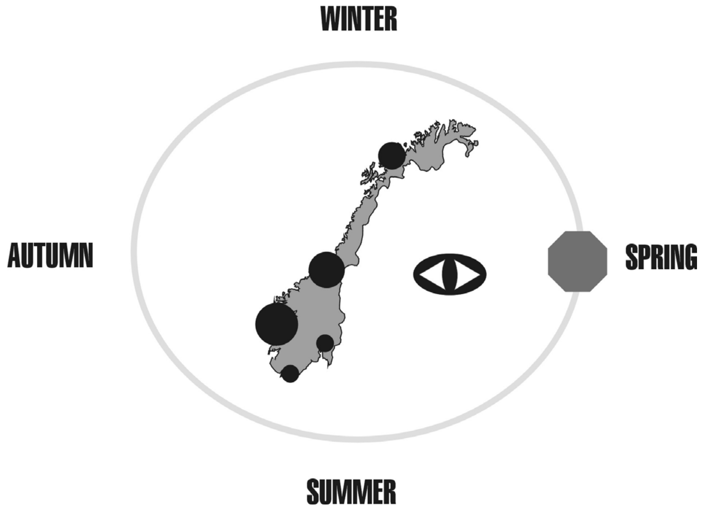

Fig. 1. The year is represented by a satellite that "circles" around the map animation.

Each circle contains a clock with the handle(s) in same position.When several active legends representing the temporal dimension are situated inside the main presentation, it is of vital importance that the legend has got a shape and behaviour that is distinct from the variable representing the principal phenomena.

3.3 Temporal Dimension Visualized by Overall Animation

The visualization of temporal change can be included more directly in the main presentation, as opposed to the local methods where one or several active legends represent the temporal variable. [6] refer to this type as legends embedded in the map display. They show how changes in background values and sound are examples of embedded legends. In this paper, sound is classified as a distinct method, because it is very different from a screen animation and it even includes another sense-organ.

The aim is still to make a presentation that gives a good comprehension of the tem-poral change simultaneously with an immediate impression of the principal phenomena. Again it is relevant to use Bertin's variables as a basis for overall animations, and again visual variables that include ordered and selective properties are important elements in the attempt to connect the visualization to human percep-tion of time. Above all; value, size and location meet these requirements. The fol-lowing shows some practical use of the visual variables in overall animations:

- **Altering value:** The value of the background *or* the map itself may change. A slowly darkening background can for example denote the end of the day and the beginning of the night. Changing value on the map itself can be used to illustrate the period between two points of time. However, the visual variable, value, has some limitations. The variable itself has variable visibility. Dark areas have more attraction to the eye than light areas. In the animation another important factor has to be taken into consideration; the contour between the map itself and the background may be weak or strong, all depending on the present value.
- **"The growing map":** Changing size of the map illustrates the temporal dimension for a phenomenon during a certain period. The map is small at the starting point of time, and grows towards the end point of time. The same effect is used to emphasize the feeling of temporal advancement by the arrows in Figure 1. It should be unnecessary to mention that a growing map cannot be used in combination with a phenomenon illustrated by the visual variable *size*.
- **"The gliding map":** Location of the map in the display area gives the information on the temporal variable. As stated earlier in this paper, in some cases time will be described by repeating cycles due to natural phenomena and the calendar made by humans. Figure 2 shows how this method is utilized in a local animation. When using a local animation, the eyes have to shift between the main presentation and the active legend during the animation. By using a "gliding map", the map itself is integrated in the description of the temporal dimension. In Figure 4 a phenomenon is presented that changes during a year. The year is represented by a circle, with January 1st on top, and progress clockwise on the circle. The map moves along the circle in accordance with the present point of time. The user needs some knowl-edge about the "legend" in front of the presentation, but during the animation the eye will focus on the map itself all the way, while the location in the dis-play is perceived by peripheral sight. The movement of the map in the display area does not need to be circular. The map may for example move between point of time A and B along a line, or along the sinus curve when several repeated cycles of a phenomenon are studied.

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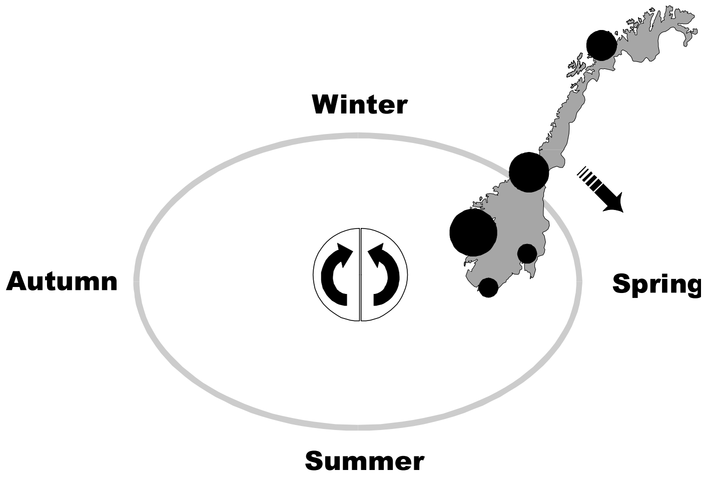

Fig. 2. Variation in amount of precipitation in cities over a year illustrated by a "gliding-map".

Methods for visualization of the temporal variable have to be considered thoroughly, and have to work in a harmonious combination with the main phenomena in the presentation. A poorly prepared presentation may result in more confusion than information. Combinations of methods may improve the final results. The gliding map can for example be combined with a background value in the description of 24 hours.

3.4 Temporal Dimension Imparted by Sound

Some simple experiments in [12] show that sound has a major effect in the presentation of the temporal dimension. While the previous methods are percepted by eye, sound includes a second sense organ and reduces the competition of attention in the graphical environment. Consequently the eyes can be focused on the presented phenomena, while sound can be used to impart information about the point of time. Sound can be used in several ways. It can for example be single tones in a few frequencies, a narrative voice etc. [7] and [8] classify sound in parallel to the visual varia-bles of [2]. The sound variables are listed below, and the correspond-ing visual variable is given in the brackets.

- *Location* (location). The sound can be located in space by using at least two loudspeakers.
- *Loudness* (size). Magnitude of a sound.
- *Pitch* (value). The frequency of a sound.
- *Register.* The relative location of a pitch in a given range of pitches.

- *Timbre* (form). The general characteristic of a sound.
- *Duration*. How long intervals the sound is heard.
- *Rate of change* (texture). Relation between sound - silence over time.
- *Order.* The sequence of pitches over time.
- *Attack/decay.* The time it takes a sound to reach its maximum or minimum.

A combination of sounds can of course be formed into words and sentences, but the aim of this paper is to focus on other sound effects for the description of time. When sound is going to describe time *variations,* a sound variable that can handle ordinal data is required. In the above list only timbre lacks this quality. How-ever, the general characteristic of a sound can be useful for reaching the proper tags in the human mind and emphasize the temporal perspective (e.g jingle bells - end of December). Because most sound variables can handle ordinal data, these are well suited for a description of the temporal dimension. As opposed to the graphical pres-entation, which is comprehended in parallel by millions of cells in the eye, sound is received as sequential information. Looking at the aspects for psychological time, the sound variables; *duration, rate of change* and *order* seem very suitable.

It is difficult to state a particular point of time using only sound effects (except when words are used). Sound effects will primarily help in the description of a rela-tive change in time. A small graphic figure or animation, shown in parallel with the sound variable, may act as reference system for the sound. The sound effects will dominate the perception of the temporal dimension when the user becomes famil-iar with their mode of operation. The list below shows some examples of how sound can impart information on temporal change.

- **Location:** By using dual-channel audio systems it is possible "to move" the sound along an axis. This method can be used to describe the change in time from the point of time A to B. On a 4-channel system it is possible to move the sound all the way around the person that receives the information. By these effects, time-cycles like a year, 24 hours etc. can be presented (Figure 5). A reference point can be defined somewhere in space. In a year cycle it may be natural to define January 1st in the front of the user, and July 1st right behind the user. In a cycle moving clockwise, spring will be on the right and autumn on the left.
- **Loudness:** Variations in the intensity describe changes in time. This may be used to present time in front of a particular event. The intensity is getting higher when information close to the event is presented. It can also be used in interaction with the variable attack/decay.
- **Pitch:** Time cycles can be presented by a frequency-pattern synchronized with time. Looking at time during a day, the frequency can increase in the period 06.00 am - 12.00 am, it decreases in the period 12.00 am - 06.00 pm, and increases in the period 06.00 pm - 12.00 pm etc.

- **Rate of change:** Can be used to indicate the transition between fixed time periods. For example a short break every hour. The rate of change is a significant variable for the storage of events and episodes in the human mind. This may be used in combination with pitch to point out fixed time-lag (e.g. every full hour). This is an important variable when using scroll-bars, because a temporal change in the map is viewed in varying pace.
- **Duration:** Duration of various sound variables is of course of major importance in the presentation of the temporal dimension.

4. Conclusions

Methods for multimedia presentation of dynamic, interactive maps are still at an early stage. However, the increasing use of small map applications, especially on the WWW, has accelerated developments. When presenting phenomena that change over time in a dynamic map, a rational visualization of the temporal dimen-sion is essential. Preferably it should be visualized in a way that is in accordance with the general human perception of time.

The temporal dimension will somehow act as an extra variable in addition to the visual variable(s) of the main phenomenon. The choice of variables has to be handled carefully. The variables must be in accordance with the presented phenomena, and the temporal variable has to be distinct from the variable of the main phenomenon. In an advanced system it may be possible to let the user design a "personal legend" for the temporal description, in order to achieve a visual model that is in accordance with the individual user's mind.

The active use of sounds in map applications may impart useful information without moving the focus away from the main points of the graphic presentation. How-ever, the audio equipment on a computer suffers from poor standardization. The sound effects can, to a degree, differ from computer to computer. Some problems can also appear in the graphic presentations distributed by the WWW. A neat map applet on your own PC can be misrepresented on another computer with a different configuration. Nevertheless, these problems are likely to be reduced as technol-ogy improves.

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