Supporting Visual Exploration of Object Movement

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ABSTRACT

The focus of the presented work is visualization of routes of objects that change their spatial location in time. The challenge is to facilitate investigation of important characteristics of the movement: positions of the objects at any selected moment, directions, speeds and their changes with the time, overall trajectories and those for any specified interval etc. We propose a dynamic map display controlled through a set of interactive devices called time controls to be used as a support to visual exploration of spatial movement.

Keywords

visualization of spatio-temporal data, interactive maps, animation, direct manipulation, exploratory data analysis.

1. INTRODUCTION

How to show in a map characteristics of spatial objects or phenomena that vary in time? This has always been a challenge for thematic cartography. At present, when people deal with maps on computer screens more often than with printed ones, there exist much more opportunities than ever for visualization of time-related spatially referenced data. A screen map may display dynamics of phenomena through changing its appearance in real time. Recently a number of activities on animated mapping have been undertaken [1-3].

At the same time, one can now observe a shift in thematic cartography from regarding maps as primarily means of communication towards recognizing them as important tools of analysis, aids in "visual thinking" [4]. The requirements to maps intended for communication and for exploration purposes are quite different [5]. This applies both to time-irrelevant presentations and to maps involving the temporal aspect of the shown phenomena. A simple "movie", e.g. showing the growth of city population by expanding the circles that represent cities, is often enough for demonstration of a known temporal trend to some audience. This is insufficient, however, for supporting exploration, i.e. revealing unknowns. An analyst needs special tools that can help to compare states at different moments, detect significant changes, assess magnitudes and speeds of the changes etc. Animation is only one of such tools. It can give a general idea about the development, but should be complemented by other instruments allowing more profound study.

The projects on map animation reported so far are still oriented more to communication than to exploration. Our interests are centered on the design of interactive maps for exploration purposes [6]. Recently we have started to work on map visualization of time-referred data and development of interactive facilities to support exploratory analysis of such data.

Design of tools for analysis should take into account what kind of time-dependent characteristics are to be studied: existence, spatial location, geometry (shape and size), or thematic (attribute) data. Thus, studying development of cities, one may be interested when cities appeared or, possibly, which cities disappeared due to some disaster (existence), how the cities spread territorially (geometry), or how their population grew (attribute). For a beginning, we have focused on visualization of changes of spatial location. The example data set we used in our experiments contains results of telemetric observation of migration of four storks to Africa and back to Europe in autumn 1998 - spring 1999. The data were provided by the German Research Center for Ornithology of the Max Planck Society (http://vowa.ornithol.mpg.de/~vwrado/).

2. ANALYSIS TASKS

The questions an analyst may pose in studying movement can be classified into the following categories:

- Overall view: what trajectories did the objects make during the whole time span considered?
- Moment view: where was each object at a selected moment t?
- Comparison: how did the positions of objects change from moment t_1 to moment t_2?
- Interval view: what were the routes of the objects on the interval $[t_1, t_2]$?
- Dynamics view: how did the movement progress with the time?

Seeking answers to these questions should be first of all supported by map presentation of data about movement.

3. THE MAP

The map presentation we propose (see Figure 1) shows routes of moving objects by employing a traditional technique from thematic cartography – directed line segments. As we have several objects, different color hues are used to differentiate the routes visually. The user may switch off presentation of data about any of the objects. This helps her/him to concentrate on the routes of the remaining objects.

The map enables overall view through showing the routes in whole. It is possible to receive data associated with any node of a root: when the user points with the cursor at a node (i.e. a segment end marked by an arrow), the information about the node is shown in a subwindow of the map window. It includes

AVI 2000, Palermo, Italy.

the name of the object and the date when the object was in this location. If the database contains any additional information referring to the node, it will be shown as well.

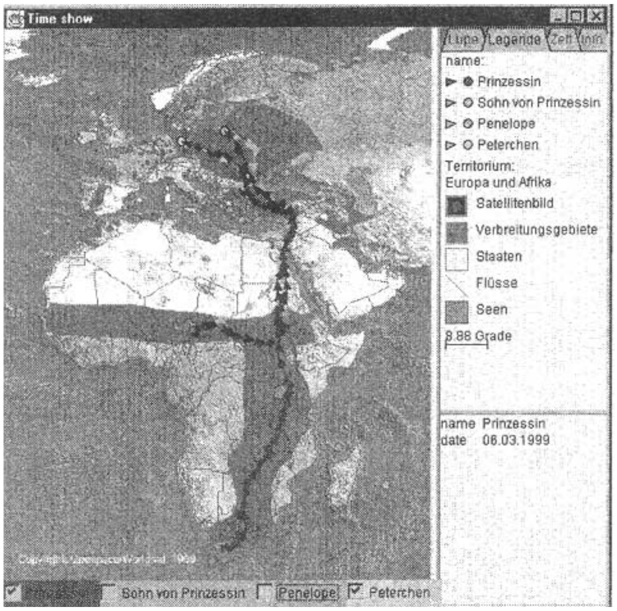

Figure 1. Overall view on the routes of storks.

Such an overall presentation does not explicitly show the information about time. This is a shortcoming in the cases when objects return back to the points from which they start or their routes cross themselves. In such cases, although the arrows indicate directions, it is difficult to figure out the relative order of route segments. To resolve this difficulty, we decided to differentiate visually earlier and later positions of objects and route segments. This is done through varying shades in that the nodes and segments are colored.

The initial idea was to vary color saturation: the older the data are, the less saturated shade is used to represent them. A similar technique was earlier proposed by Calkins [7]. However, we found the saturation scale to be too "short" for our purposes. First, the minimum degree of saturation used should be sufficiently high to enable recognition of the hue. Second, a human can effectively distinguish a rather limited number of saturation degrees. Our solution was to use a combined saturation-brightness scale: first saturation grows from minimum to maximum with fixed maximum brightness, then brightness decreases with fixed maximum saturation. The minimum brightness is selected so as to ensure recognition of the hue. The resulting scale is the scale of degrees of darkness that corresponds to Bertin's visual variable *value* [8]. This visual variable, according to Bertin, allows *ordered perception*. So, the use of it for representing order in time conforms to the principles of graphics design [8].

An important feature of the map display is that it is possible to limit the time interval $[t_1, t_2]$ that is to be represented (here t_1 and t_2 are any moments within the total time span to that the data set refers; $t_1 \leq t_2$). This means that the map will show only the data subset referring to this subinterval, i.e. the paths made during $[t_1, t_2]$. In particular, t_1 and t_2 may be equal. In this case the map will show positions of objects at the specified moment. So, the map, besides *overall view*, enables also *moment* and *interval view* as well as *comparison* of positions of objects at the beginning and at the end of a specified interval. Giving some increment to t_1 and t_2 or only to t_2 makes the map dynamically redraw. Recurrent fulfillment of this operation supports *dynamic view*. When the operation is performed automatically, we receive *animation*. For manipulating the map display in the described manner, we have developed a set of interactive widgets, the so-called time controls.

4. THE TIME CONTROLS

One of the controls (see Figure 2) is the time slider that allows selection of an interval or moment to present and at the same time shows the relative position of the currently represented interval within the whole time span. The width of the slider is proportional to the length of the interval. The user can manipulate the presentation directly through the slider widget: s/he may, by mouse click, set the beginning of the interval to be represented, or gradually move the slider forth or back causing the map being dynamically repainted. The beginning of the interval can be specified more precisely through entering the date in the edit field below the slider area. The next edit field is for setting the length of the shown interval, and the field below it controls the step, i.e. the value to be added to the beginning and the end of the interval in the course of studying dynamics.

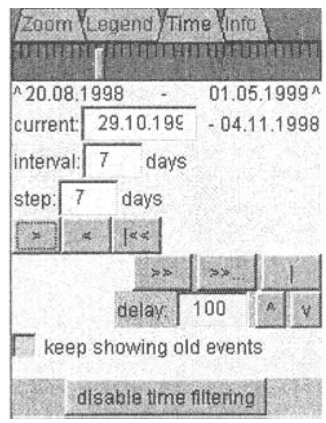

Figure 2. Time controls to manipulate presentation of time-dependent data.

One of the ways to consider dynamics is to push repeatedly the buttons marked by ">"or "<". Upon each button operation the presentation "moves" forth or back in time, respectively, by the number of time units (in our example days) specified as the step. So, it may be said that the user has full control over the display time: s/he can make it run either forth or back with variable speed. Another option is to delegate this power to the system (by pressing the button ">>" or ">>...") and get an animated presentation. In this case the display time runs only forward with constant speed regulated by specifying the delay. The button ">>..." makes the system start animation from the beginning after the end of the time span is reached. In this case the system will loop the animation until the user stops it by pushing the button "|".

Selection of the check box "keep showing old events" makes the map show the routes from the very beginning (the earliest moment referred to in the data set) up to the end of the currently selected interval. In fact, in this case the starting moment of the interval has no impact on the presentation, and all operations (moving the slider, adding or subtracting the value of the step) are applied only to the end of the interval.

5. EXPLORATION OF DYNAMICS

Lately animated presentations have been widely proposed for studying dynamics of phenomena in time. Animation typically means rapid sequencing of shots that show the states of the phenomena at successive time moments. With our tool it is possible (optionally) to combine animation (and, more generally, dynamic view) with *interval view*. In this case each shot represents an interval rather than a moment, and the user observes route fragments rather than locations of objects. Intervals represented in the successive shots may, in particular, overlap (if the step specified is less than the interval length).

In animation with interval view object routes look like worms crawling on the map. It is not merely fascinating: these "worms" help to study important dynamic characteristics of movement. The lengths of the "worms" show speeds of object movement. A "worm" being shrunken signalizes the movement of the object slowing down, "worm's" elongation means that the movement becomes faster. Sometimes a "worm" reduces to one point (shown in the map by a circle) meaning that the object stopped its movement and stayed for some time in the same place. All these observations would be practically impossible with state-oriented animation.

With Figure 3 we have made an attempt to simulate the interval-oriented dynamic view. The shots represent six 10-days-long successive intervals. The intervals overlap; the step between them is 5 days. The pictures show, for example, that one of the birds moved initially slowly over Chad and then with acceleration through Sudan and Uganda to the eastern bank of the Lake Victoria where it decided to stop for a while. Another stork, which was initially in the same place in Chad, first made some minor movements around this place (probably, looking for better food) and then rushed to the east. The third stork leisurely changed its place of residence from the left side of Nile to the right. The forth bird arrived at the southernmost end of Africa and circled there until a convenient place to stay (near Port Elizabeth) was found.

We invite the readers to explore the movement of the storks as well as our tools to support this exploration by running the Java

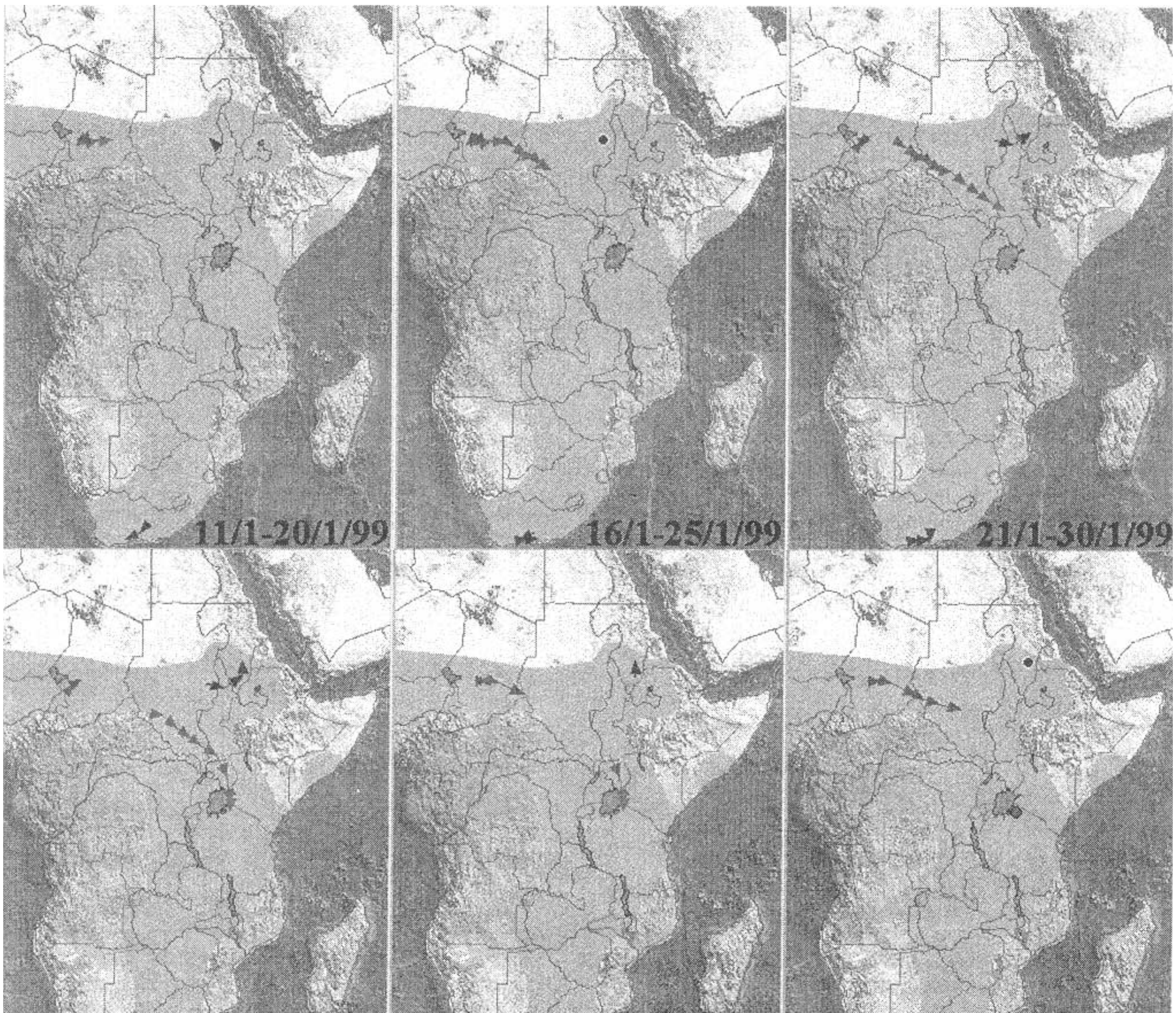

Figure 3. Behavior of storks in Africa

applet that is available in the WWW (http://borneo.gmd.de/descartes/java/birds/index.html).

6. APPLICATION TO OTHER DATA AND ANALYSES

Our time controls are universal in the sense that they can be applied not only to data about movement but also to other kinds of time-dependent data. Thus, the same applet was used for data about earthquakes and for presentation of observations of plants and animals made by schoolchildren (http://lo.san-ev.de/natdet/, in German). In the nearest future we plan to consider also time-referred attribute data.

Although in various possible applications the time controls may be the same, handling of interval selection needs to be different. As we demonstrated, in studying movement the map shows fragments of trajectories made during the interval. When existence is concerned, the map presents the objects that existed on this interval. In consideration of geometry the map should show how the shapes of objects changed (e.g. by means of "transparent" drawing).

Interesting analysis opportunities can be provided for studying changes in attribute data. Selection of intervals can be combined with time aggregation, e.g. calculation and presentation of averages of attribute values over the selected interval, or absolute or relative magnitudes of change, or speeds of change etc.

7. CONCLUSION

"Pure" animation is insufficient for supporting exploratory analysis of time-referred data. An analyst should have at her/his disposal powerful and convenient interactive facilities to control display time within the presentation. These facilities should support various tasks an analyst may undertake in the course of data exploration: the tasks requiring overall, moment, or interval view on the data, the tasks involving comparison of moments, and the tasks on studying dynamic characteristics of movement.

We have designed and implemented an interface to manipulate presentation of time-referred data. On the example of data about spatial movement we have demonstrated that the tool developed, in combination with appropriate visualization, really can support the designated groups of tasks. The tool is made as a reusable component that can be applied to various kinds of time-dependent data and diverse types of visual presentation, including non-map displays.

We have discovered that especially productive for analysis of movement is combination of dynamic change of display (in particular, animation) with interval view. We may expect that the same technique together with various methods of time aggregation will be also helpful in studying attribute changes.

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APPENDIX

The applet described in the paper was applied to a number of different data sets. One of the applications was made in Oregon State University within the framework of Marine Mammal Program. Scientists of the university used the applet to visualize movements of right whales. Some of the observations they made have been published in the WWW (http://hmsc.orst.edu/groups/marinemammal/). With the permission of Prof. Bruce R. Mate, we cite here three screenshots of the work of the applet (see color plate 1) and the explanation given in the page with the applet:

This right whale (#1421) traveled further offshore than any of the other tagged animals. Tagged in the Bay of Fundy in 1990, he traveled 700km south through the Gulf of Maine, across the NE tip of George's Bank to the NW wall of the Gulf Stream, 500km south of Nova Scotia in water 4200m deep. The 3 days of travel between George's Bank and the Gulf Stream had a distinct crescent shape, as did the following 4 days of northbound movement. The sea surface temperature image below reveals that the crescent-shaped movements coincided with the edges of a tapered cool-water mass being drawn from the Gulf of Maine along the eastern side of a warm core ring (WCR) and eventually into the WCR. WCR's spin off from the warm Gulf Stream. Zooplankton, like the copepods favored by right whales, become highly concentrated under such circumstances. They try to stay in their preferred cold-water environment which is 'shrinking' as it is drawn into the warmer water. Thus, the copepods upon which right whales feed may have been quite abundant in the 16°-18°C water to the east of the WCR where the tagged right whale traveled.

More information about observation of behavior of whales made by the group of Prof. Mate can be found in the paper:

Mate, B.R., Nieukirk, S.L., and Kraus, S.D., Satellite monitored movements of the northern right whale. *Journal of Wildlife Management*, 1997, **61** (4), pp.1393-1405

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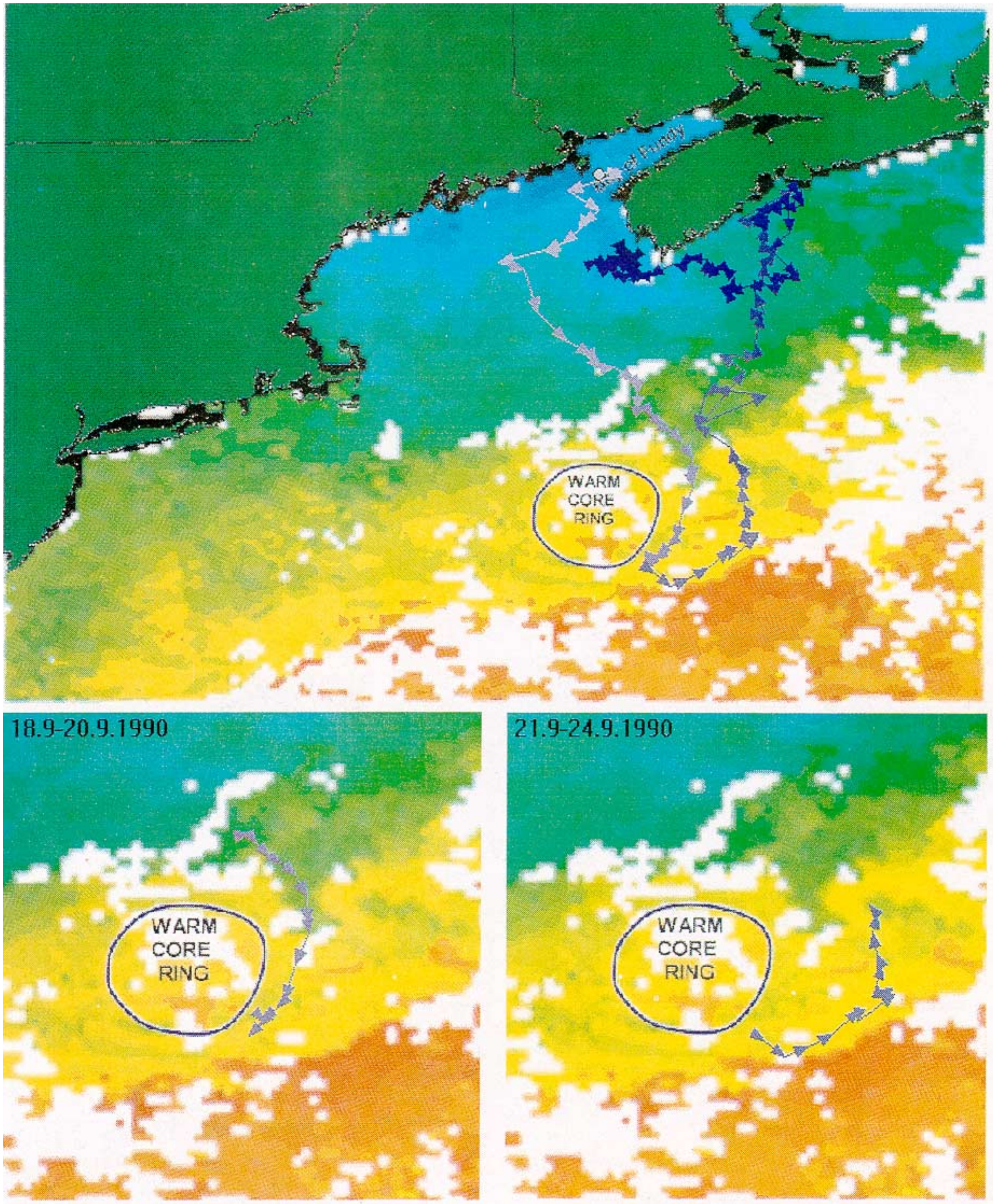
Color plate 1: Animated Right Whale Feeding Movements



The upper image shows the trajectory of feeding movement of right whale #1421 made during the time from 12.9.1990 (light blue) until 24.10.1990 (dark blue). The images at the bottom show two characteristic fragments of the route described in the appendix to the paper. Different colors of painting are used to show variation of temperature of surface water: the blue end of the color range blue-cyan-green-yellow-orange-red corresponds to cold, and the red one to warm.