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Defining visualization operations for temporal cartographic animation design

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Abstract

Cartographic animation has emerged as a potentially effective visualization technique that has an intuitive power in representing dynamic geographical phenomena through its ability to show interrelations amongst geospatial data's components, location, attribute and time. Whereas cartographic animation has prominently featured in communicating geospatial information, their use as tools for visual exploration has been hampered by lack of the necessary functionality that is capable of allowing users to interact with the dynamic display. In this paper, we outline an approach that defines visualizations operations or basic visual actions that implement a viewer's task of exploration and characterization of geospatial structures in data or phenomena. The defined operations go along to reinforcing the quest in enabling users to perceive relationships and be able to manipulate geospatial data using more efficient visual tools while keeping low on cognitive demands.

Keywords: Visualization operations; Exploratory cartographic environments; Temporal cartographic animation

1. Introduction

The use of intuitive geographical visualization techniques that are characterized by enhanced interactive and dynamic tools is becoming a commonplace trait in geospatial applications. The techniques are also increasingly being used for qualitative analysis and as a precedent to the complementary computational approach to quantitative data analysis. An example of this trend is seen within the emergent realm of cartographic visualization—an exploratory environment that enables geoscientists to explore raw data creatively, in any combination and at any scale using highly interactive tools (MacEachren and Kraak, 1997). One of the techniques suitable for use in exploratory cartographic environments and which is increasingly being used to show the interrelations among the geospatial data components of location, attribute and time, is the temporal cartographic animation.

Cartographic animations have been used in mapping geospatial processes as seen in examples given by Kraak and Klomp (1995), Acevedo and Masuoka (1997), Weber and Buttefield (1993), and Ormeling (1995). They play an intuitive role when used to view geospatial transitions as they happen in time as opposed to simply viewing the end states. Thus, they enable one to deal with real world processes as a whole rather than as instances of time. This ability, therefore, makes them intuitively effective in conveying dynamic environment phenomena (Baek and Layne, 1988; Hays, 1996; Rieber et al., 1990).

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Despite their widespread use in the presentation of geospatial information, their use as exploration tools has not been fully developed. They lack the necessary functionality to enable users to interactively observe and describe geospatial events and processes as when one engages in an undirected search for geospatial structures patterns, trends in order to develop questions and hypothesis about the data.

In this paper, we address the question how, given the interactive and dynamic capabilities of present day computer graphics applications, do we go about defining effective and functional operations to both control the graphic representations on display and to access and interact with the data sets behind them. We specifically look at the role that interactivity plays in facilitating these operations for exploratory visualizations using temporal cartographic animations. We derive these operators by combining typical characteristic processes in spatio-temporal data and the probable perceptual operations that can be invoked during a visualization process. Our work here also diverges from earlier researches in animation in the sense that previous work have been mainly focussed on goal-oriented animations, whose objective was to communicate a priori fixed facts to users and to enable them to confirm derived hypothesis about the data. Here, we focus on interactive animations and their use by domain experts to perform exploratory tasks of unraveling hidden meaning in the raw data.

2. Related work

In the past, incorporating user needs in design was hindered by lack of an enabling technology together with an inadequate knowledge of user behavior. Early work in the field of data visualization focussed on general guidelines that would ease choice and accessibility in visualization systems. This was achieved by developing a list of criteria based on user needs, data characteristics and visualization goals. Their target was a mixed group of both expert and novice users. Among these researches were those of Bertin (1983) on general rules for graphic composition and design; Domik and Gutkauf (1994) on modeling general users needs; Card and Mackinlay (1997), Rogowitz and Treinish (1996), Wehrend and Lewis (1990), Keller and Keller (1992) on developing taxonomy of general visualization design; Mackinlay (1986), Casner (1991), Zhou and Feiner (1998) on automated design of visualization. Reported difficulties may arise when attempting to realize a expert system solution in visualizations (Wang, 1992; Treinish, 1999). This mainly occurs when design narrows its focus to the limited taxonomy based on data characteristics and application data domains. They neglect the wealth of knowledge that comes from the domain expert-knowledge that not only defines the tasks to be undertaken, but also to interpret the results.

A number of researches within the domains of user-interface designs have agitated for visualization functionality with the ability to vary the levels of abstraction in representations, or to dynamically look at data while varying the graphical and temporal resolutions. These functionalities tend to vary between enabling users explore geospatial data, and narrowing down to a set of items of interest that satisfies a given user need. A basic starting point to defining visualization operations is illustrated by Shneiderman (1996) and Goldstein et al. (1994).

Within the realms of cartographic visualization, suggestions have been made regarding the tools that ought to be embedded within visualization techniques. These tools are derived from within the range suggested by MacEachren (1995) and further enumerated by Kraak (1998) encompassing: display, navigation, orientation, query, multi-scale, re-expression, multiple dynamically linked views and animation. Elzakker (1998) outlines an approach that seeks to define functionality for cartographic visualization as regards the exploration of geographic data in a GIS environment. Albrecht (1994) argued the need to define a GIS user-interface on the basis of the user's tasks rather than the details of geometric modeling. Anson and Ormeling (1996) and Ormeling (1997) relate types of maps to components of map use (tasks) as way of adapting the visualized information to the user's needs.

A considerable amount of research has been done within the domain of space–time science especially in modeling geospatial phenomena and data structuring in temporal GIS. Okazaki (1993), Rex and Risch (1996) elaborate the requirements for temporal queries with respect to visualization have not been sufficiently tackled. What we see at present is animation functionality that allows for users to select, play and identify features in an animation frame using basic interface functionality as legend and media-player tools (Monmonier, 1990; Kraak et al., 1997; Peterson, 1999).

Section 3 highlights some of the generic animation functionality that exist and their roles in spatio-temporal data presentation and exploration.

3. Status of animation functionality

Developing animation functionality for geospatial applications has been influenced by a number of factors. Technological advances in computer speeds and graphic software, coupled with the faster rates of raw data acquisition has had great impact on the tools available. Tool developers want to keep abreast with technological development as well as help alleviate users' concern of sifting through the enormous data sets at their disposal. The users have distinct needs that charaterize their experiences with geospatial tools backed with domain knowledge. The uses for which they engage the animation tools could either be for presentation or exploratory purposes. For presentation purposes, the need is to develop simpler animations that are sufficient enough to convey the intended message and be understood. The animation should not be overused to a level that it distracts users from their goals. For exploratory purposes, the need is for tools that allow the user to look at spatial and other geo-referenced data in any combination, at any scale or resolution, with the aim of seeing or finding (hidden) spatial patterns. A distinguishing factor between the presentation and exploration functionality is the way the basic functionality is tailored to fit or match the cognitive structures and processes that humans employ in knowledge discovery and insight using visual imagery.

Animations as applied to geospatial applications have mainly been embedded with basic media-player functionality as seen in media-player controls of play, backward, forward and pause. These animations were pre-designed for playback only and to run with little or no interference from the viewers. The tools empowered users to control the pace, sequences and contents of the animation. This is more appreciated when one is dealing with a large volume of data, an aspect that could otherwise have taken more time if static maps were used, then becomes faster and more functional. Their equivalent role had previously been played by series of static maps, that like a flipbook could portray changes between the maps. As the needs of users stretches more into the exploratory paradigm, the nature of animations is changing and exhibiting more interactive operations.

When critically assessed, the developments in animation functionality are haphazard and uncoordinated in its efforts. There is no generic taxonomy from which functionality can be consistently derived and as users needs grow. In the following sections, we outline the role that animations can play in highlighting interesting structures and trends in space–time data sets. We revisit some of the generic characteristics exhibited by space–time processes as detailed in previous literature, especially the distinct structures and processes that users might want to manipulate when performing exploratory tasks.

4. Role of cartographic animations in understanding space–time structures

Claramunt and Theriault (1995) outlined a framework of spatio-temporal processes that characterize typical processes in geo-science disciplines. The framework outlines processes involving the evolution of features, functional relationships between features and those concerning the evolution of geospatial structures amongst features. Our intention here is to outline how temporal cartographic animations functionality can be defined based on typical patterns, trends and their relationship as highlighted in this and similar typologies (Blok, 1999; Yattaw, 1999).

A change is observed when new features appear and, or when, after being in existence for a while they disappear. Changes are also observed when features undergo changes in *shape*, *size*, *orientation* and, or *location*. An example of this is seen in satellite image interpretation for cloud cover identification. Here, clouds which in essence change location in time, can be identified from the attributes they exhibit. Their edges may be ragged or well defined in shape. These shapes and their sizes, together with the clouds attributes of brightness, texture and organizational patterns go along into identifying specific types of clouds (Conway, 1997).

Whereas the example on cloud identification affected only a single feature, there are cases where changes occur as a result of two or more features exhibiting a relationship among its attributes in time. An example can be seen in the building up of the *storm* phenomena. The basic building up phenomena for a *storm* are; *rain* and *wind*. Of these, the phenomena of *rain* arises when the weather attributes of *temperature*, *humidity* and *pressure* interact under certain conditions or constraints. As used here, animations are able to show changes between inter-dependent weather features and the results of their interaction and relationship in time. By this, they facilitate the process of enabling users to distinguish between the agent(s) invoking the change and those that are being modified by its action.

When dealing with single or more entities, the temporal structures that are of interest to users are those that allow the representation of occurrence of events or tracking of events as defined by Allen (1981).

Apart from highlighting the typical spatio-temporal changes, there are queries that can be posed in relation to the changes under observation. Langran (1992), and Peuquet (1994) derive queries based on the *what*, *where*, and *when* of the geospatial data's component. Whereas previously animations had been used mostly in relation to historical or previously recorded data, we are seeing more and more use in simulation and modeling tasks. Here, the *what if* aspect of the geospatial data queries can be used to forecast a future scenario.

When viewing temporal cartographic animations, there are a number of ways by which changes can be further characterized. Social science, linguistic, and psychological approaches to these characterizations are subjects of numerous researches (Blok, 1999; Yattaw, 1999). Changes can be *continuous* as in motion or movement, *cyclic* or it can be *discrete*, such as, the change in shape of geospatial objects over time. Changes can be *slow*, *fast*, or *abrupt*. Changes can occur on individual features or an agglomeration of such features. Users can identify distinct objects, their regularity, anomaly, and areas of interest. The emphasis during observation is on the ability for the user to spot, at an appropriate scale and temporal resolution, features or patterns that are surprising or anomalous in some way.

From the foregoing, we acknowledge the distinct spatio-temporal structures that characterize geophenomena and how temporal cartographic animations can aid in unraveling them. These structures encompass having identification of, when features appear (or within view) and when they disappear (or go out of view), the temporal structures involved in interval relationships and ability to track and control attribute and location relationships. In Section 5, we will look at ways by which these spatio-temporal characteristics can be modeled into specific visualization operations, an aspect that is a pre-requisite for our definition of the design model in the implementation level of animation tool design.

5. Relating user needs to visualization operations

The crucial role of users in present cartographic practice is depicted by what Morrison (1997) described as the "democratization of cartography", a trend within the electronic technology where the map user is no longer dependent on what the cartographer puts on the map. In essence users have a wider choice to maneuver and explore spatial data sets using the available functionality. This reflects a common trait in exploratory environments where the users role is central and drives the whole interactive search for structures and trends to provide hypothesis regarding a given data set.

During visualization, user needs may vary between presentation and exploration of geospatial data. The needs are made up of series of tasks or a list of processes that are undertaken and invoked within the confines of the user's thought processes. Fig. 1 illustrates the central role that users and the tasks they undertake play in a visualization process (Knapp, 1995). The task being undertaken has specific requirements in both data and map design strategy. The same data could be visualized using different techniques, with each technique supporting different tasks. Also, the availability of data will determine whether these needs are fulfilled or not. On the other hand, an effective map design is greatly influenced by the tasks that the user intends to undertake.

In our approach visualization operations through their visual accomplishments, describe the mechanism which user effectuates tasks. A user task may require one or more visualization operations and a specific technique may support more than one user task. These

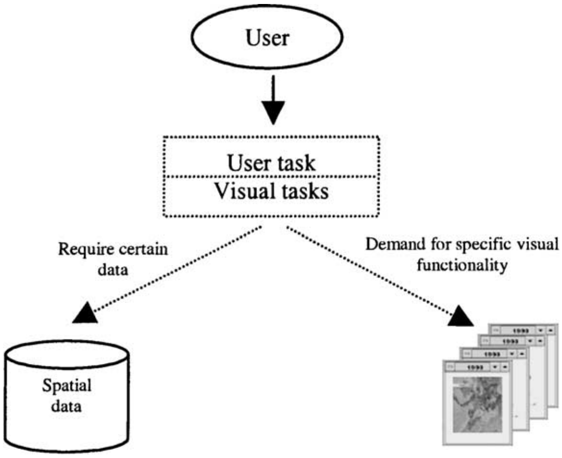

Fig. 1. The role of user task in an exploratory visualization process.

visualization operations may be directed to the map on display or the data behind it with the result that they effect some changes in the user's mental state or display environment. The visualization operations that follow might be perceptually motivated, and/or backed by concepts already known to the user. In essence, what is needed are prepositions that describe the probable tasks that a user is prone to undertake. In exploratory environments, the map serves as a starting tool to an iterative process of knowledge discovery (Anson and Ormeling, 1996; Ormeling, 1997).

To illustrate the concepts of user tasks, visual tasks and visualization operations we use an example in weather visualization. Take a case where a user intends to explore the dynamic weather sequences using satellite images, surface measurements and weather maps for regions in the United States. Undertaking these tasks involves executing a list of processes or user tasks. One will have to ensure that the correct weather data is available, and if not, where and how they are to be collected. One can select weather variables, techniques and geographic views when compiling weather maps in readiness for the playback (see Fig. 2).

A wide range of operations can be effectuated in such a set-up. One could select and animate single layers of weather variables, similar to the "six panel image that displays the six atmospheric variables mapped as color" (Fishman and D'Amico, 1994) or have different views of different weather variables on the same window for comparison purposes (see Fig. 3). Equipping the animation interface with playback and legend tools could enhance the process of

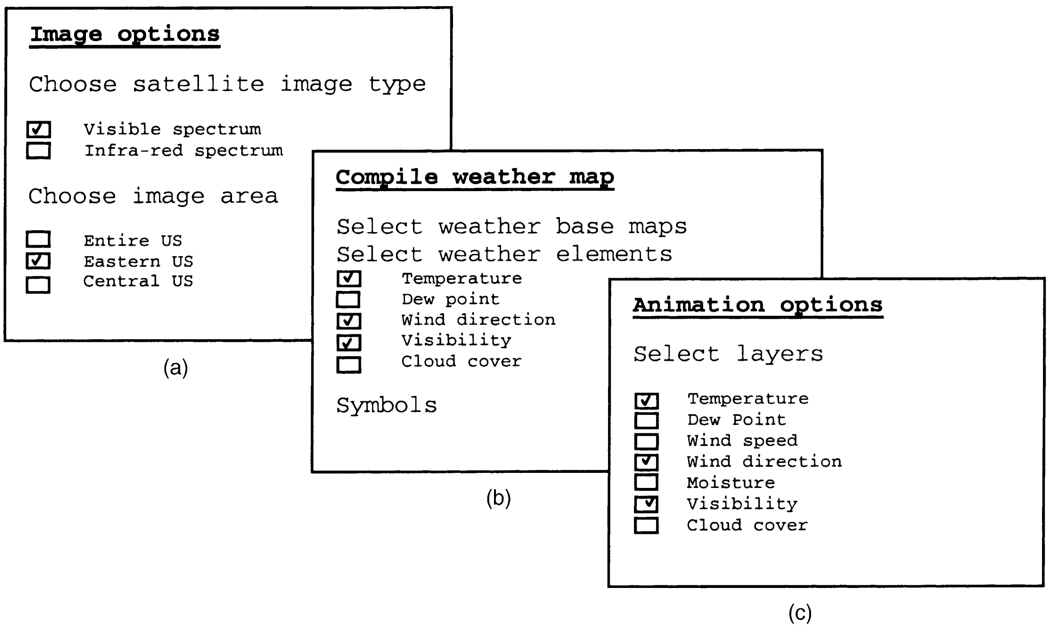

Fig. 2. Decomposing user needs into a series of tasks.

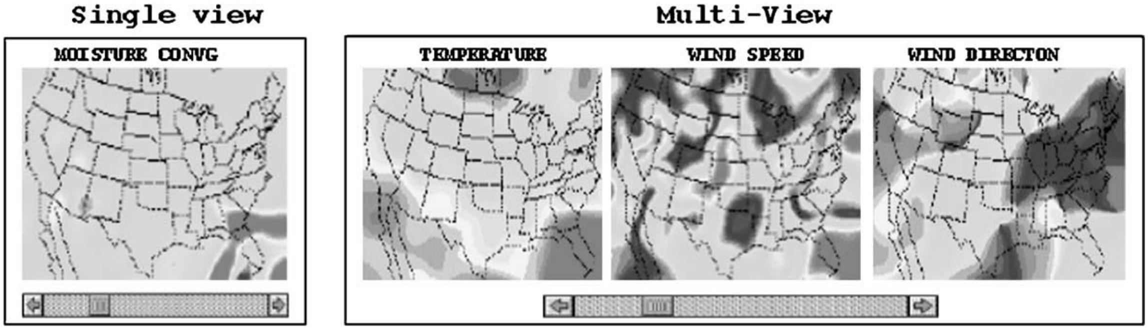

Fig. 3. A single view showing an animated moisture map and a multi-view consisting of synchronized animated views of temperature, wind speed and direction (images source: Fishman and D'Amico, 1994).

identifying and locating specific variables at specific instances or intervals of time. These operations that are performed on the image on display in an exploratory environment are triggered by the momentary features being displayed and from the user's wealth of domain knowledge. In Section 6, we focus on these visualization operations and the role they play in exploratory cartographic animation environments.

6. Visualization operators in cartographic animation

User-centered task analysis methods have previously been used in system and user-interface designs. The methods point to the importance of having explicit representation of users needs in design processes. Using Wehrend and Lewis (1990) and Zhou and Feiner (1998), the following domain-independent taxonomy of visualization operations are considered: *locate*, *identify*, *distinguish*, *categorize*, *cluster*, *distribution*, *rank*, *compare*, *associate*, *cluster*, *background*, *emphasize*, *generalize*, *rank*, *reveal*, *switch*, *encode*, and *correlate*. Knapp (1995) condensed these tasks into four; that is *identify*, *locate*, *compare*, and *associate*. Whereas these visualization operations can find application in various visualization techniques, our concern here is to apply only those that are relevant and functional in temporal cartographic animations.

Identify, *locate*, *associate* and *compare* form the basic visualization operations that are widely used and exhibit a more logical flow when analyzing geospatial data. The task *identify* refers to describing an object which was previously unknown, whereas *locate* indicates a search for an object whose identity was already known. These two tasks enable the user to track down particular process during run-time. Implementation of tools that effect these tasks can either be realized before (through training programs) or during run-time. Similarly, the ability to relate between two different features in the displayed image which is effected by using *associate* and *compare* visualization operations, should be amongst the basic tools. An example of the manner in which relating visualization operations to the observed changes can be effectuated in tool design is depicted in Table 1. The *identify* visual operator seeks to answer the *what* aspect of the spatio-temporal generic query. The *what* question seeks to identify objects in the display—a task that can fulfilled either by issuing an attribute name or by giving the geometrical descriptions of the object. Examples in which these tools have been implemented as in interactive maps are seen in *point and click* and, *mouse on/over* techniques commonly used with hypermedia environments.

Whereas some of the tasks in the table can be implemented on static interactive displays, their use in dynamic maps as with animation (while preserving the display's dynamic nature) remains a challenge. Similarly, some of the tasks in the table are better implemented using computational approaches to exploratory data analysis.

The definitive characteristics of results column in Table 1 relates the visualization operations to the expected visual result. Both qualitative and quantitative results are expected that incorporate time instants and intervals of time. Manipulating temporal cartographic

Table 1
The four main generic visualization operators

Visualization operator	Visualization sub-operator	Example of definitive characteristics of results
Identify	Spatial identification	Length, area, irregularity, minimum, maximum, range, distance, pattern of distribution
	Temporal identification	Extent: longest, shortest; sequence: first, last; category: nominal, ordinal, interval/ratio; movement: continuos, cyclical, intermittent
	Thematic identification	Name, symbols (legend)
Locate	Spatial location	(x, y), (φ, λ), grid locations (rows, columns), near, within, between, above, below, neighborhood of
	Temporal location	Event/valid time t, observed interval $(t_1 - t_2)$ before, after, together, next
Associate/compare	Spatial association/spatial comparison	Topological relations, spatial collocation, covariance, correlation
	Temporal association/temporal comparison	Temporal collocation, time between objects, orientation (before, after), adjacency (just before, just after), causality (correlation)

animations entails locating specific frames, sequences of frames as well as events. Operations specifically ought to include examination of relationships between features and events imbued within the spatio-temporal data.

Since temporal animations do show changes or interrelationships amongst geospatial data's components of location, attribute and time, users will want to view the state of a process at a particular moment in time and between intervals of time. There will be a need also to compare different processes at a particular moment in time and to track their movement, behavior over a given period of time. Based on the characteristics of the spatio-temporal processes reviewed in Section 5, and the visualization operators highlighted in Table 1, we list some essential visualization operations that geoscientists could benefit from when working with temporal cartographic animations.

- *Identify* or *locate* changes at a time t_1.
- *Identify* or *locate* changes between intervals t_1, and t_2.
- *Identify* or *locate* events before, after.
- *Compare* (or *associate*) states at a time t_1.
- *Compare* (or *associate*) changes between times t_1, and t_2.

Secondary visualization operations as with *collocation* extend the explorative capabilities of these four. As applied in an animation environment, collocation is the ability to locate specific animation frames from a set of many based on some user specified temporal, or spatial characteristics.

In exploratory environments, where enormous amounts of animation frames are involved, the need is for animation functionality that will enable users choose to frames from amongst stored images and define the specific paths for playback. Alternatively, images can be retrieved directly from the database computationally by having the user define the animation path and the system computes and fills in the appropriate images.

More flexible non-linear descriptions of animation frames confines animation not just to one path of view, but also to loops and branches. The ability to change what path an animation takes during run-time provides a greater range for interactive options. In this way, an animator just defines a lot of interpolating splines, and at run-time the system determines which one is used. However, this can be very time-consuming, since in order to make the animation feel very responsive the animator will need to define an awful lot of different segments of animation. What we need are new motion synthesis tools that are responsive in that they allow an animator to describe a range of possible movements concisely. This requires the development of new motion synthesis tools that allow the animation to respond to the user.

Effectuating a visualization operation like collocation involves sifting through vast amounts of animation frames, an aspect that can be taxing in terms of retrieval and structuring for animation play during run-time. Through a *query* operation, users can access the contents of the database with the display interface and results attained instantaneously. A query operation can in essence be a sub-operation of the operations discussed above, just as collocation can encompass the *identify*, *locate*, *compare* or *associate* operations.

7. Conclusions

By outlining the visual typology of spatio-temporal changes in animated maps, which ranges from changes in an entity's status of existence, processes and relationships, the paper suggest a list of generic tasks that can be useful during typical exploratory tasks. These are tasks that if translated into animation functionality could help users sift through raw data sets to unravel the hidden information. Attaining logical results entails collaboration with specific geo-experts in defining, interpreting and executing specific geo-problems using temporal animation visualization operators. This collaboration will ensure that the user-centered task model is meaningful, functional and effective since it is on the basis of the ability of the tools to solve specific geo-problems that the evaluation of the animation functionality must be based. Implementing the identified user-centered functionality entails giving accessing to the database from within the animation in order to cater for the wide range of user queries that may arise during the visualization process.

User actions as prompted by the visual display could be attained either through a database operation or by manipulating the image displayed. This will in essence augur well with attempts to enabling a versatile and human-oriented means of linking a visualization system to a temporal GIS. Coupling temporal database access and animation functionality will enable interactive visualization and visual data access with progressive real-time refinement of the displayed image.

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