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Cognitive Effects of Animated Visualization in Exploratory Visual Data Analysis

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Abstract

The goal of this research is to study the role and effects of the use of animated information visualization in early stages of exploratory data analysis tasks. Despite the existence of a large body of research on information visualization, there has been little known regarding how and when one should use and how to interact with animated visualization to help exploring data. By animated visualization, we mean a type of information visualization technique that produces autonomous motions of representations. This research has explored the issue from two aspects: what cognitive effects animated information visualization has, and what interactions people would have with animated visualization when exploring data. We have conducted two user studies to investigate each aspect, and identified research challenges for designing an interactive animated information visualization environment that supports early stages of exploratory data analysis. These findings help us further study how to extend the notions developed in the spatial visualization to the temporal visualization; for instance, what Focus+Context means when applied to the time dimension in animated visualization.

1. Introduction

Graphic representations, such as charts or diagrams, help people grasp the meaning of information more easily and quickly [13]. Computers have been used to visualize information, and a number of graphical representation methods have been explored, including 3D and animations [4].

The problem, however, is that abuse of such powerful visual representations may make people misinterpret the information or obscure the focus of the information. It is important to understand when, and how we should use complex visualization to help people understand and explore the information space more easily, and more accurately.

Our research has focused on animated information visualization. Animated visualization means a type of information visualization technique that produces autonomous motions of representations along the time dimension. Existing research on *information animation* has regarded animation as providing one more dimension; enabling 4D graphs by adding motions to 3D graphs [15]. We argue that the effect of animation is more than the fourth dimension. Motions produce certain cognitive effects and appropriate use of motions empowers users in exploratory data analysis.

Despite the existence of a large body of research on information visualization, however, there has been little known what cognitive effects animated representations have, and how and when we should use animation especially in the domain of visualizing abstract data [6]. Moreover, we have very little understanding about how to apply the notions developed in the spatial visualization to the temporal visualization. To take the notion of *Focus+Context* for instance, how can we support a user to *focus* on a particular time in playing an animation; should we play it slower, faster, or pause the play; and how can we provide the *context* of the whole animation while playing an animation?

As a first step to address these issues, we have conducted two user studies. First, we have conducted a user study comparing effects of representations among tables, graphs and animations (animated graphs). Through the study, we have found that animations work effectively when one needs:

(1) to focus on transitions of values of the time-based data, and
(2) to view the data from a particular viewpoint.

In the second study, we have developed an interactive animated visualization environment that visualizes the evolution of a large object-oriented programming library, and observed how a programming expert examines the data interacting with the environment. As a result, we have found that a user interacts with animated information visualization:

(1) to identify data points where the values change prominently,
(2) to find a snapshot of a particular point of time, and

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(3) to acquire feeling of immersion to more intuitively understand data.

Through these studies, we have identified requirements for interactive animated information visualization systems:

- they need to help users understand the context of changing data, for instance, whether the value is increasing or decreasing;
- they need to help users understand the context of changing time as the animation is played, for instance, in what point of time (e.g., in an early phase or in a late phase) the current snapshot represents; and
- they need to allow users to have hands-on control over both time and space.

In what follows, we first discuss the use of animated visualization. Then we present two user studies followed by discussions on findings. We then discuss research challenges for designing interactive animated information visualization environments and present ongoing prototyping efforts addressing the challenges.

2. Animated Information Visualization

Our approach is to use animated information visualization to support exploratory data analysis tasks. This section first describes characteristics of such tasks, and discusses related work in animation and in interactive visualization.

2.1 Exploratory Data Analysis Tasks

Information visualization has long been studied to use *computer-supported, interactive, visual representations of abstract data to amplify cognition* [4; p.7]. Information visualization amplifies human cognition in *increased resources, reduced search, enhanced recognition of patterns, perceptual inference, perceptual monitoring, and manipulable medium* [ibid; p.16].

We have been using animated visualizations to support early stages of exploratory data analysis. An early stage of data analysis is better supported by viewing it as an exploratory task rather than by applying standard statistical analysis techniques [8]. In exploratory data analysis, a user plays many what-if games to discover interesting aspects of the data, gradually understands what phenomena were taking place [8][17]. Enhanced recognition of patterns, perceptual inference, perceptual monitoring, and manipulable medium that information visualization offers help users perform such exploratory data analysis.

The field called *visual data mining* has emerged to specifically support exploratory data analysis [16]. The visual data mining approach integrates information visualization with autonomous analytical data mining techniques.

We focus on the use of visualizations in supporting the exploration and understanding of the data. In this approach, users try to find verbalizable relationships among aspects of data and make hypothesis on cause-effect relationships. Although we do not support any analytical data mining techniques, our approach in visualization can be used as a visualization support for visual data mining systems.

2.2 Animation: Autonomous Motions in Visualization

In this paper, by *animated information visualization*, or *animation* for short, we mean autonomous motions of representations. Many information visualization systems dynamically change representations while interacting with users. Animation, in contrast, by definition, produces changing representations along the time dimension by representing one aspect of data (see Figures 1(b) and 2(b)).

Some systems actually use animation to simulate changing phenomena over time on computer displays. The use of animation on computer systems can be categorized along the spectrum that has the following two ends:

(1) systems that represent the motions of existing objects, and

(2) systems that represent the changes of abstract data.

A type of animations which are close to the first end is represented by animated movies. Animated movies, for instance, Disney animation, represents motions of real-world objects, such as humans, mice, or balls, using CG technology. This type of animations does not necessarily have to truthfully reflect the reality. They sometimes exaggerate a certain aspects of motions. A body of knowledge has been developed and shared among the community how to effectively represent motions in producing this class of animation, for instance, one can exaggerate the movement with a take, sneak, or stagger [14].

Another type of systems that fall into the same category is scientific visualization. Their goal is to simulate the reality based on models developed after the reality. The approach represents otherwise impossible phenomena on a computer so that users can have a better understanding of what will be or has been happening in the real world. While some of simulation systems produce static information as a result of simulation, many of

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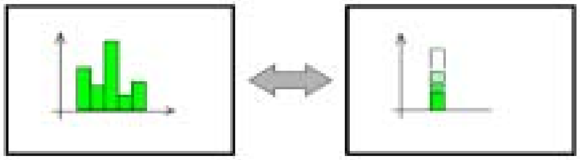

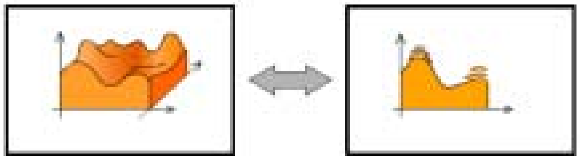

(above) Figure 1. 2D graph (a) versus animated 1D graph (b)
(below) Figure 2. 3D graph (a) versus animated 2D graph (b)

simulation systems simulate changes by dynamically changing representations on a computer display over time based on the underlying model. For instance, they are used to predict courses of typhoon or flows of molecules. Virtual reality also uses animation to represent movements of virtually represented objects.

The type of animation systems that are close to the second end is what we call animated information visualization. Such systems visualize abstract data and represent changes of the values of the data over time using motions. The goal of these systems is not to model the reality, but to help users in analyzing data and making decisions by uncovering meanings hidden in the data. Breathing Earth [3], for instance, visualizes magnitudes of earthquakes that happened during a three-month period by putting bubble shaped objects on the corresponding surface points of the earth along the much-shortened time scale, making the earth look like breathing. Wright uses the term *information animation* to describe 3D graphics with motions [15]. In presenting complex data in the domain of capital markets, he uses the time dimension of animation as the fourth axis to 3D graphs. The system uses motions and interactions as a means to increase reliability, accuracy, and preciseness of 3D graphs.

We argue that the effect of animation is more than the fourth dimension. Motions produce certain cognitive effects and appropriate use of motions empowers users in exploratory data analysis. And surprisingly little is known about such cognitive effects.

To illustrate our argument, let us take a simple example.

Figure 1 represents (a) a bar chart represented in 2D and (b) an animated single bar, and Figure 2 represents (a) a 3D graph and (b) an animated 2D graph. Animation, or motions over time, adds one more dimension to what is represented in a 1D, 2D or 3D space. We could argue that the 2nd dimension (the horizontal axis) of Figure 1(a) is replaced with the time dimension in Figure 1(b) and the 3rd dimension (the depth axis) in Figure 2(a) is replaced with the time dimension in Figure 2(b). In this sense, Figure 1(a) and 1(b) are semantically equivalent, and so are Figure 2(a) and 2(b).

However, as one can easily imagine, these two representations, a static graph and an animated graph, have very different cognitive effects. As we will describe below, our study has demonstrated that people get very different impressions from a static graph and an animated graph, and have certain preferences on one over the other. One aspect of our research goal is to identify what cognitive effects animated information visualizations have. Once we have a better understanding of effects of animated graphs, we can provide more effective visualizations to support exploratory data analysis.

2.3 Interactive Visualizations

Information visualization systems, by definition, do not only present visualized information, but also allow users to interact with the visualized information [4]. Some systems actually use animation to help users maintain the context while the users interact with the representation and move the focus within the representation [5][7].

Dynamic query systems [1] [10] are interactive systems for searching for information from databases. A Typical dynamic query system consists of an interface that allows a user to specify a query for data retrieval, and a visual representation that displays a result of the query. Query specification is typically done by moving slider bars or clicking on toggle buttons. The result of the data retrieval based on the query is almost simultaneously done, which gives users a feeling of “direct manipulation;” a fast feedback reflecting changes in a user's query makes users feel as if the user manipulates data directly by changing the query specification [11].

Because moving a slider bar in such a dynamic query system changes the visual display on time, this gives users a feeling that the user is producing animation for data display. However, the goal of dynamic query systems is different from that of animated information visualization in two ways. First, the goal of dynamic query systems is to filtering information; the user's task is to find what he/she is looking for. In contrast, information animation is for users to understand the whole data by finding meaningful aspects within the data, not necessarily locating particular data points. Second, animation, by definition, produces autonomous motions. Dynamic query systems, on the other hand, produce changes in their visualizations in

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response to a user's interaction. Although we also stress the importance of interaction with users for animated information visualization systems (as described in Section 4), the emphasis is put differently.

In the next section, we present our first user study on cognitive effects of animated graphs. The following section then describes our second user study on how a user interacts with animated visualizations.

3. Cognitive Effects of Animated Visualization

This section describes our preliminary user study, which compares cognitive effects of information animation with those of static tables and graphs.

In this study, a list of numbers is represented in a table, in a bar chart, and in an animated bar chart (Figure 3). We observed how users get different impressions from the three types of representations, and how they differently interpret the data in the three types of representations.

3.1 Method

We have used two types of data sets, each of which was represent in the three different representations: (1) table, (2) graph, and (3) animated graph.

- 1D-DataGroup: Each list has ten numbers.
- 2D-DataGroup: Each list consists of three lists each of which has ten numbers.

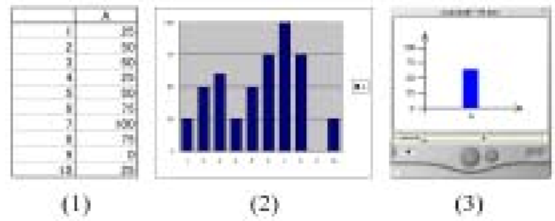
Each number is between 0 and 100 and put in a random order. Figure 3(a) represents an example representation of a data from the 1D-DataGroup, and Figure 3(b) represents one from the 2D-DataGroup. In preparation for the experiment, we used a regular Microsoft Excel to produce 2D and 3D graphs, and Macromedia Director 8 to produce animated graphs.

In order to avoid any learning effects, we prepared seven different data sets for each of DataGroup. Six of the seven were used for each of all the possible orders of the three types of representations (e.g., graph -> animation -> table) and the seventh data is used to show three representations at once.

Three subjects were asked to view seven patterns for each of 1D-DataGroup and 2D-DataGroup and instructed to do think-aloud reporting which aspect of the representations they pay attention to. The sessions were video-taped and protocols were scribed.

3.2 Results

(a) used for 1D-DataGroup



(b) used for 2D-DataGroup

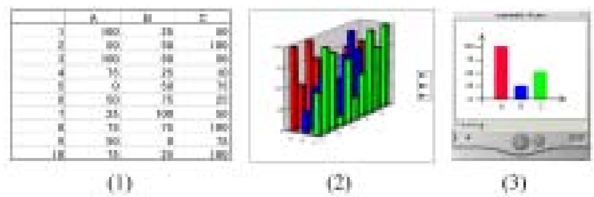


Figure 3. Three representations used in the user study

While detailed results are given in [12], this subsection briefly summarizes what we have identified.

Table 1. Coding Scheme for the User Study

Code	Meaning	Exemplary protocol	Representation
CD	chunking data	*I tend to count the number of "peaks" and "waves" in these representations*	graph, animation
ID	interpreting data	*I know that these may not be related to each other but still, I tend to see them as a flow.*	graph, animation
GW	grasping the whole	*It is really hard to understand what happened in the end*	animation
EX	expecting next	*Up and down and up and down, so the next should be up*	animation
CP	comparing	*Wow, theese three values get 100 simultaneously!*	table, animation
ST	statistically analyzing	*I can easily tell what the average is in approximation*	graph
FO	focusing/filtering	*It is good that this one forces me to stay with one viewpoint*	animation

By analyzing protocols collected from the user observations, we have developed a coding schema consisting of seven codes (Table 1). We encoded transcripts, and categorized which aspects were more frequently emphasized in which representations.

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From the result, our finding is summarized as follows:

- Animation gets positive reactions for data viewing cognitive aspects including CD, ID, EX, CP, FO, but not favored in aspects including GW and ST; tables and graphs were preferred in these two.
- All of the three subjects liked graph representations for 1D-DataGroup. In contrast, one subject explicitly favored animation for 2D-DataGroup, and the other two subjects also expressed positive reactions to the use of animation for 2D-DataGroup.
- From post-experimental interviews, all the subjects mentioned that animation was helpful in focusing on the changes of data, and in limiting a point of view in a single aspect.
- In viewing animation, all the subjects frequently used a control bar (the bar beneath the animation window) to change the speed of animation and to repeatedly view a certain segment of the animation.

This result has indicated that adding motion to graph representation is effective even if the graph is not 3D. And while animation means autonomous motions, users need to interact with them by having control over how to play animation. The next study focused on the aspect of interaction with animated visualization.

4. Interacting with Animated Visualization

In order to observe how users interact with animated graphs, we have first constructed an interactive environment that produces animated graphs. We used a data on Smalltalk class library as a case example and asked an expert programmer to view the animated visualization.

4.1 An Experimental Setting

Figure 4 represents an animation system that we have developed. We used data consisting of the number of classes, that of class methods, and that of instance methods of each of 360 versions of an open-source Smalltalk class library, called, Jun, that has evolved over five years [2]. We have developed an animation so that each frame represents a single version. Three 3D bars represent the numbers of classes, class methods and instance methods of a version. Users can control the viewpoint for the 3D graph as in a regular 3D viewer, and control the playing speed and position of animation using the bar underneath the window as in a regular movie viewer.

During our pretest sessions, we have found that users often request for a means to allow them to compare the currently displayed value with the previous value or the following value. So we have added blue and red value indicators (see Figure 4) that represent a value in the previous frame in blue and a value in the next frame in red embedded in the display of the current value.

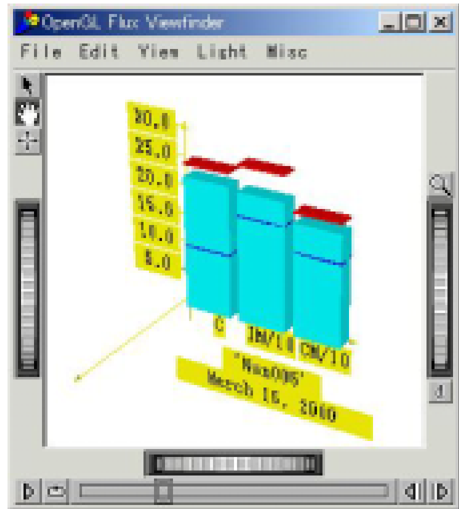

Figure 4. The animated visualization used in the second user study

We asked an expert programmer to be a subject, who is familiar with the Jun library. The subject was engaged in interacting with the animated visualization for about 90 minutes. The session was video-taped and the protocol was transcribed.

4.2 Results

In the experiment, the subject first scanned the whole animation a couple of times. Then, the subject started using the play controller (located at the bottom of the window) to have a control over the play speed and position of the animation. After that, the subjects started expressing interesting comments interacting with the animation.

The result of this case study can be summarized from the following five aspects. Detailed results are described in [12].

(1) *Control over time*. The subject very frequently held the play controller to fine-tuning the playing time and displaying certain frames of the animation. When the subject found seemingly interesting snapshots (frames), the subject went back and forth between a certain time-

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span playing forward and backward. Often the subject played a particular part of the animation extremely slowly by gradually moving a play-controller examining changes of data.

(2) *Differential representations*. The subject depended on the presentations of the previous and next values (blue and red value indicators; Figure 4). From the protocol, the subject often tried to find where a drastic value change takes place in the data using the red and blue value indicators.

(3) *Feeling of immersion*. The subject sometimes changed the viewpoint in the 3D representation so that the representation is extreme in its projection (Figure 5). This helped the subject to also identify where a drastic value change happens. The subject liked that the system allowed him to use this view because it helped him "*feel dynamism of the data*."

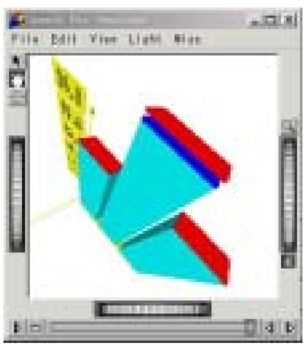

Figure 5. A view that emphasizes feeling of immersion

(4) *Focusing on information*. After the experiment, we showed a 3D graph of the same data that had been produced using Microsoft Excel program. The subject preferred animation because "*this is too much. The animation was good that it forced me to scan through the versions one by one*." The animation made the subject focus on a limited aspect of the data at a time, helping him better understand what was happening in the data.

(5) *Context in time*. For a couple of times, the subject got lost in terms of the time dimension by saying "*when was this?*" That is, the subject had to interpret the data in terms of the whole data. He needed to know which version the values in a particular snapshot represent. The subject used the location of the play-controller handle in terms of the length of the whole bar to understand whether the snapshot is in an early, middle, or late stage of the project lifecycle. In addition, the subject sometimes wanted to annotate the time. He wished he had mechanisms to "*bookmark*" snapshots so that he could remember where he looked at and which time-span interested him.

In summary, the subject found that the animated visualization was useful understanding the data. By interacting with the animation of data, the subject has found interesting aspects regarding object-oriented programming. One example is when comparing how the number of classes and how that of instance methods grow over time, the subject mentioned that:

> *"the number of classes grows first and then the number of classes grows like this following the class increase. This is a good way of programming (an object-oriented program) indicating a good design."*

While saying this, the subject keeps holding the play controller, and repeatedly plays among several shots very slowly confirming what he has just found.

5. Toward An Interactive Animated Information Visualization Environment

Through the two studies, we have found that animated visualization is effective for exploratory analysis of certain types of data. We have also confirmed that interaction with animated information is an essential element. Based on the findings, we have identified research challenges in the design of system that uses animated visualizations to help users perform exploratory data analysis. We also have started constructing prototype tools that address the challenges using ARTWare, a 3D, multimedia application construction kit [9].

- *How to effectively visualize changes of data.* Users need to understand the context of changing data, for instance, whether the value is increasing or decreasing. Our blue and red value indicators (Figure 4) were found helpful but too simple. We have started using the depth as representing "afterimage" and "forefeel" (Figure 6). We need further study and prototyping to confirm the effects and produce alternative visualizations.

- *How to effectively visualize context of time*. If we watch a movie, we tend to have a pretty good remembrance on whether a certain frame was at the beginning, middle, or end of the movie because the frame is often associated with a story. In contrast, with animating graphs, it is hard to remember each snapshot. Currently our play-controller helps users understand the context of time, but we need better mechanisms for this purpose. One approach that we have started looking was to use more elaborated movie controller, consisting of a series of snapshots from the animation (Figure 7).

- *How to provide more easily accessible hands-on control over both time and space*. The subject appreciated that he could change viewpoints to the animated graph. It provides a simple 3D viewer, but also has a mechanism to help the user understand where the viewpoint is; what we call a *metaview* (Figure 8). In general, navigating in 3D is hard because users often get lost where the viewpoint is located in terms of the whole space. The metaview allows the user to look at where the user's viewpoint is located. We need a similar mechanism for *time*, which helps users understand in which point in time the user is currently situated.
- *How to support the entire process of exploratory data analysis.* By interacting with animated visualization, users not only view it but also identify interesting aspects in a trial-and-error manner gradually externalizing findings. We have been prototyping a system that allows users to (1) segmenting a part of the animation, (2) to put the segmented in a 2D space, (3) to textually annotate each segment, and (4) to compile a summary report in a html format (Figure 9) [9].

6. Discussion

This paper presents our approach to support exploratory data analysis with interactive, animated information visualization. We argue that animation has more power than just yet another dimension to 3D representations. We have conducted user studies to identify research issues in designing system that uses animated visualizations to help users perform exploratory data analysis. The goal of such an environment is to use animated information visualization to complement what is otherwise excluded from regular graph representations.

Figure 6. Representing "afterimage" and "forefeel"

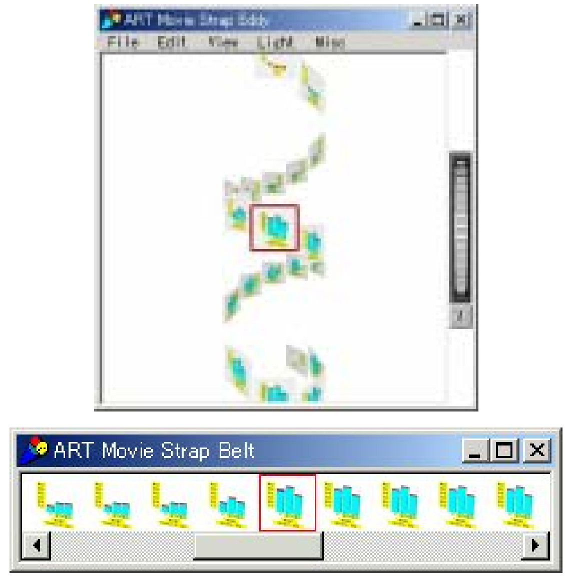

Figure 7. Elaborated play controllers

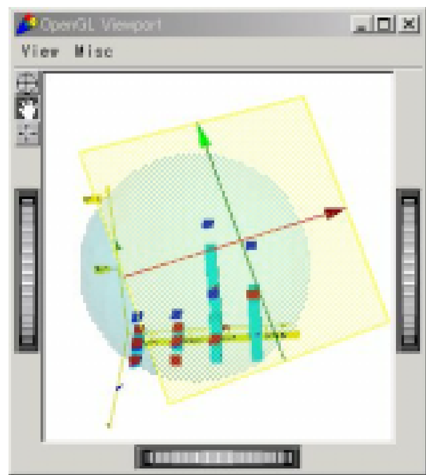

Figure 8. a metaview for the space

Based on these findings, we will further study how to extend the notions developed in spatial visualizations to the temporal visualization. Our next step is to find ways to provide *Focus+Context* for animation. In regular "spatial" visualization, a *focus* on a particular point in a space and its *context* is achieved by enlarging an adjacent region of the point, while distorting the remaining surrounding area. In temporal visualization, however, *focus* on a particular point of time does not necessarily mean to play animation frames around the point of time slower. It may be necessary to play them faster, or to repeat playing them. Figures 6, 7 and 8 presented in the previous section are some of our initial efforts to represent *context* over multiple frames, i.e., time. We are currently designing

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more representations for temporal *Focus+Context* and

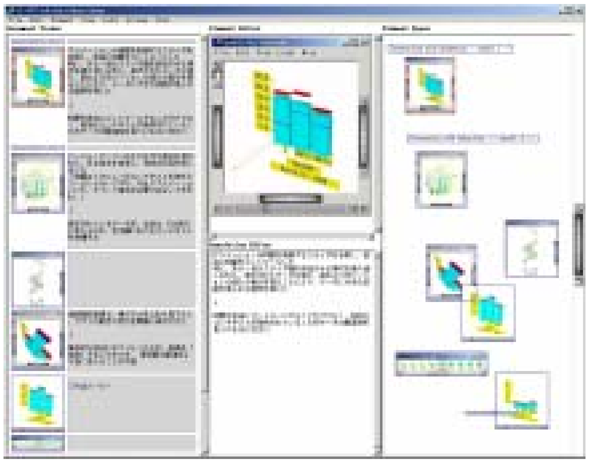

Figure 9. An integrated animated visual information environment for exploratory data analysis

conducting empirical studies to further study these challenges.

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8. References

[1] C. Ahlberg, B. Shneiderman, Visual Information Seeking: Tight coupling of dynamic query filters with starfield displays, Proc. of ACM CHI '94 Conference, Boston, April, pp. 313-317. 1994.

[2] A. Aoki, K. Hayashi, K. Kishida, K. Nakakoji, Y. Nisinaka, B. Reeves, A. Takashima, Y. Yamamoto, A Case Study of the Evolution of Jun: an Object-Oriented Open-Source 3D Multimedia Library, Proc. of International Conference on Software Engineering (ICSE'2001), Toronto, CA., 2001 (to appear).

[3] BreathingEarth, http://www.sensorium.org/breathingearth/

[4] S.K. Card, J.D. Mackinlay, B. Shneiderman, Readings in Information Visualization: Using Vision to Think, Morgan-Kaufmann Publishers, San Meteo, CA, 1999.

[5] G.W. Furnas, The FISHEYE View: A New Look at Structured Files, Murray Hill, NJ: AT&T Bell Laboratories, 1981.

[6] I. Herman, G. Melancon, M.S. Marshall, Graph Visualisation and Navigation in Information Visualisation: a Survey, IEEE Transactions on Visualization and Computer Graphics, Vol.6, No.1, pp.24-43, 2000.

[7] J. Lamping, R. Rao, The Hyperbolic Browser: A Forcus + Context Technique for Visualizing Large Hierarchies, Journal of Visual Langueges and Computing, Vol. 7, No.1, pp.33-55, 1996.

[8] W.E. Mackay, M. Beaudouin-Lafon, DIVA: Exploratory Data Analysis with Multimedia Streams, Proc. of CHI'98, ACM Press, pp.416-423, 1998.

[9] K. Nakakoji, Y. Yamamoto, A. Aoki, ARTWare: A Component Library for Building Domain-Oriented Authoring Environments, ACM Multimedia'01, July, 2001 (submitted).

[10] C. Plaisant, B. Milash, A.Rose, S. Widoff, B. Shneiderman, LifeLines: Visualizing Personal Histories Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'96), pp. 221-227, April, 1996.

[11] B. Shneiderman, Direct Manipulation: a Step Beyond Programming Languages, IEEE Computer, Vol.16 No.8, pp.57-69, 1983.

[12] A. Takashima, Information Animation for Understanding Data, Master's Thesis, Graduate School of Information Science, NAIST, Nara, Japan, March, 01.

[13] E.R. Tufte, Visual Explanations, Graphics Press. Cheshire, CT, 1997.

[14] T. White, The Animator's Workbook, Watson-Guptill Publishing, Toronto, Canada, 1988.

[15] W. Wright, Information Animation Applications in the Capital Markets, Proceedings of InfoVis '95, IEEE symposium on Information Visualization, pp.19-25, color plates 136-137.

[16] P.C. Wong, Visual Data Miing, IEEE Computer Graphics and APplications, Vol.19, No.4, pp.22-31, 1999.

[17] Y. Yamamoto, A. Aoki, K. Nakakoji, Time-ART: A Tool for Segmenting and Annotating Multimedia Data in Early Stages of Exploratory Analysis, CHI'01, Extended Abstract, pp.113-114, April 2001.