Literature Review of the “T-Axis” (i.e. Time) in Visualization [/Interface] Design

Introduction

The Family Manager group in the Fall 2008 Interaction and Interface Design (IDIA 612) class is exploring the design of a location aware hand-held device that allows a user to have insight in to the combined calendar and whereabouts of themselves and their immediate family members. One of the interfaces which is being explored is a faux-3D display which allows users the ability to scan a visualization of schedule/location data forward and back along a time-line.

This design most-resembles a TV news traffic map, where the map is laid out on the X and Y axes, and the Z axis is used to create an appearance of foreshortened distance and isometric “three-dimensionality”, but does not otherwise show an aspect of the data. Users should be able to manipulate time in the display to see where the actors will be (or have been) based on the passage of time.

The primary research problem which this paper is attempting to define within the existing literature is how the visualization’s current state (i.e. its *now*) will be controlled by the user. A secondary related question might be how the passage of time will be shown most clearly.

To facilitate the literature review of the proposed interface, time can be conceptualized in two different ways: that of an element of a visualization, and that of as an interface control.

The first notion is that the continuum of time (i.e. the timeline) is a representation of time, which is one discrete element within a set of multiple dimensions of data that is being presented. From this approach there is a need to seek out data displays which endeavor to show time as a discrete facet of a visualization.

The second notion is that the continuum of time itself is a point of control of an electronic visualization tool – in other words, within the tool there is an interface element whose purpose is time manipulation. This idea can't be totally separated from the idea of a visualization tool *showing* the continuum of time, since of course the interface which allows a user to shift time must also *show* it. However, there is still a need to focus specifically upon the design of time-control interfaces in the literature.

Categories of Literature

The literature review yielded results that fall in five categories: The T Axis, Algorithms Related to Time, Visualization/Augmentation with Time, Tricks of Time Perception, and Network/Interactive Effects Related to Time.

The T Axis

In "Interactive Visualization of Serial Periodic Data" several researchers at University of Minnesota explore challenges in creating information displays which show incidences of data that happen on a cycle and at the same time allow them to be closely compared to one another. To simplify this model, something like a sine curve might be examined, and from their point of view the nodes of the sine pattern might be too far apart from one another to allow useful comparison. In describing the plotting of such data over time, they supply a useful metaphor/visualization in the idea of corkscrew-like spiral, which shows a range of movement which would be a circle along two axes being expressed along a third axis.

In "Real-Time Shaded NC Milling Display", researchers at Trancept Systems in North Carolina explored the "Boolean subtraction of solid objects" by a milling tool driven by a computer much the same way a printer or plotter are controlled by a computer. This also shows the inter-relationship of a modeled reality, a *real* reality, and the passage of time.

Finally, in "Holographic Video Display of Time-Series Volumetric Medical Data", medical researchers at the Surgical Planning Laboratory and Center for Neurological Imaging, Department of Radiology, Brigham and Women's Hospital; Isomics, Inc.; Harvard Center for

Neurodegeneration and Repair; and The MIT Media Laboratory use holography to show visible brain lesions of multiple sclerosis patients based on MRI data samples taken over a course of a year and rendered into holograms through a model building process. Their research "investigate[s] the usefulness of 3D technology for reconstructing time-varying lesions in spatial relation to other brain structures." The results of this effort is a "visualization pipeline that culminates in an electro-holographic display."

The significance of this work for the family manager is that the rendered display and interface must be oddly similar to what the time-line based family manager display design will allow users to do – which is to move along a time-line and have insight into changes in the data revealed by that progression. This sort of slicing and layer isolation is typical of MRI visualizations, which are famous for the ability to examine something layer by layer and to do so seemingly without any limitations of viewing from one axis or another. This research adds to that flexibility the ability to scroll time as well. One can imagine that some interesting forms of analysis would inevitably emerge that might be very anti-intuitive at first, just as adding a 3rd dimension allowed MRI analysts to do things that had previously been impossible.

Algorithms Related to Time

In "Indexing Spatiotemporal Archives", researchers at University of California, Riverside explore the highly technical topic of how to index 4-dimensional data in the most efficient way possible. The basic problem is that sensors, cameras, and other devices create a huge amount of data, most of which is typically useless. This research focuses on a single kind of query, known as a "historical" query and aims to overcome problems related to decreased query performance due to "excessive overlapping between index nodes". This has to do basically with a concept which might be called "growing and labeling trees", specifically, organizing the data into semi-digested hierarchical information about the objects mapped in 3D space, which are really what the data is *about*, and storing it in context of its temporal position.

In “Comparison of Access Methods for Time-evolving Data”, two researchers, one also at University of California, Riverside, and the other at Northeastern University also explore temporal queries in light of optimization of query performance. They consider space consumed, update processing (which is also a form of pre-processing/indexing). Their work favors prioritizing/optimizing storage of data by age – in other words more recent data should be easier to retrieve than data from a long time ago. One would think that this is a common feature of many calendar programs.

Finally, in “Anisotropic Volume Rendering for Extremely Dense, Thin Line Data”, researchers at the Stanford Linear Accelerator Center and University of California, Davis explore plotting and visualizing data that falls along predictable paths (which are themselves important) rather than randomly within a larger range. In some cases, these paths are fluid flow patterns, magnetic field patterns, etc. The basic problem is that comparing data sets to one another runs the risk of obscuring the *real* pattern of interest (the “vector field”) due to the inappropriate-but-inevitable literal comparison of one instance of data to another. The researchers refer to the collision of these two types of data as “path data” vs. “vector field plotting”. Fundamentally, they are trying to use instances of data that occurs over a temporal path to compare to one another, but struggling with the limitations of the display which is good at showing data points, but relatively bad at drawing the invisible lines which the data points are expressing. This seems similar to the T Axis researchers who were grappling with challenges representing “serial periodic” data.

Finally, in “Real-Time Visualization Of Scalably Large Collections Of Heterogeneous Objects (Case Study)” researchers at the Georgia Institute of Technology bring all these issues together with an exploration of the engineering behind a “Google Earth” type information display. The basic problem for them is how to slice the data in such a way that it is easy to zoom without downloading everything. They refer to a basic problem called an “out-of-core” visualization which one would imagine is like zooming into Brooklyn in Google Earth and then turning around to look at the New York City skyline with its many polygons. In their own words, their work “tends to focus on 3D data, and visual simulation, which places an emphasis on visual perception and real-time display of multiresolution data, [and] results in interactive terrain visualization with significantly improved data access and quality of presentation."

Visualization/Augmentation with Time

In a very dated article from 1980, researchers at Bell Laboratories explore "Real Time Animation Playback on a Frame Store Display System", focusing on technical issues which seem to have all been overcome by now. These include the fundamentals of mixing computer-generated and modeled content with video data. One reason that this is important to mention is to point out that constraining technical problems can be swept aside by the march of progress (i.e. waiting), as well as by first-person innovation and ingenuity.

In "3-D Displays For Real-Time Monitoring Of Air Traffic" SRS Technologies and the US Army Space and Strategic Defense Command evaluate whether 3D displays are productive compared to 2D alternatives for air traffic control. User goals in their milieu are to discriminate between legitimate actors and "illegal" actors who will be "engaged" and likely destroyed on the strength of the system operator's judgment. This is an example of a critical system to say the least. Incorrectly identifying a friendly plane as an enemy may result in it being destroyed. Failure to correctly identify an incoming plane may result in death of the operator. The result was a clear finding that the adding dimensions of resolution (i.e. 2D becomes 3D, or perhaps 3D becomes 4D) results in superior user-response times for correctly identifying incoming enemies.

In "A Real-Time Optical 3D Tracker For Head-Mounted Display Systems", a researcher at University of North Carolina explores "inside-out" tracking of a position of a camera/viewer within an artificial visualization (possibly of a *real* space). The significance of this kind of interactive tool is that the system's implicit knowledge of the exact position of the camera/viewer allows it to reduce rendering load (of computer-generated content) by ignoring surfaces that cannot be seen by the camera based on its position. To make this useful, the system must remain true to the modeled objects in terms of realistic lighting and shading of the remaining surfaces as if all the parts were "there" (including the ones intentionally removed from rendering).

Taking this sort of thing a step further, in "3D Video Surveillance With Augmented Virtual Environments" researchers at University of Southern California, Los Angeles created a system that has insight into actors appearing in video surveillance through a network of sensors, cameras, etc., and is capable of plotting their position even when they are temporarily occluded. Here the goal is to reduce the cognitive load on the viewer/operator by identifying things that "appear" to the system to be people or cars and which are tracked and identified while within the range of the system. In this case, the system is actually relating a 3D conception of the space it is monitoring to the stream of video and sensor data, and the behavior of human and car actors. Amazingly, this is being achieved by loading artificial models of people and cars into the system and allowing the system to recognize actors in the video data as significant, while ignoring non-human/non-car entities.

The dual nature of the idea that an object is an individual instance of a class, and also is a member of that class is very powerful, and could be used to do all sorts of amazing things through such a display, perhaps toggling back and forth between video data and model, perhaps highlighting classes of actors or individual actors as the proceed through the time-based display, perhaps drawing a box or circle around an actor, etc.

Finally, in "The Control Unit For A Head Mounted Operating Microscope Used For Augmented Reality Visualization In Computer Aided Surgery" researchers from the Kantonsspital in Basle, Switzerland along with researchers from the Ludvig-Boltzmann Institute of Nuclear Medicine, Vienna and the General Hospital at the University of Vienna explore augmented reality interfaces for microscopic surgery. The issues that are present in the other research about augmented reality are all present in this effort. For example, this critical system has to understand the relationship between the modeled (inside the system)/real (outside the system) environment and the camera. It also has to combine elements of video data and computer generated data together in real time, and monitor and overcome any time discrepancy between the two, keeping it within imperceptible limits.

However, it must also do this in a sterile operating room environment and be extremely reliable.

Tricks of Time Perception

In “Time-dependent Visual Adaptation for Fast Realistic Image Display” researchers at Cornell University studied “transient adjustments” to changes in scene intensity. These adjustments to changes in lighting affect how things look to us for a brief time as the intensity of lighting changes. This has two areas of application. The first is to exploit the appearance of changes of intensity to potentially make an artificial visualization look more like something real (i.e. video games, movies, visualizations, etc. can be made to have extremely high-fidelity representations of changes of light intensity). The second application is a system can be made to anticipate, adjust to, or compensate for changes in intensity, in order to make displays more readable, more natural, to appear more “real” in spite of changes in intensity.

In “Space-time points: 4D Splatting on Efficient Grids” researchers at Stony Brook University explore rendering 4D datasets (x, y, z, t) using different algorithms for creating the outputted model. In this case the researchers were seeking a sweet spot of high fidelity and high performance, which they measure in volume of data points. They also used a “3.5D visualization approach that uses motion blur to indicate the transition of objects along the dimension orthogonal to the extracted hyperslice in one still image. [This] approach uses interleaved rendering of a motion volume and the current iso-surface volume to add the motion blurring.” In other words, motion that is implicit in time-varying datasets can be made more obvious – even in still pictures of the action -- by synthesizing and rendering visual cues that describe its direction, intensity, etc. This is an interesting idea that might have applications for making data that change over time more readable. It brings to mind all the tricks that cell animators use to create the appearance of motion.

In a similar vein, University of Nebraska, Lincoln researchers explored adding sound as another dimension of data display in “Data Sonification From The Desktop: Should Sound Be Part Of Standard Data Analysis Software?”. Their methodology was to render patterns in data through pitch variations over time. This applies both to the time-line focus of the family manager visualization and also may offer some ideas about another design channel that could be exploited to carry meaning for the user.

Network/Interactive Effects Related to Time

Finally, in “Media Productions For A Dome Display System”, researchers at The Foundation of the Hellenic World [museum] in Athens Greece explore some of the limitations of producing content for an audience in the unusual circular medium of curved screen spherical projection dome theaters. Among these challenges is that sometimes the audience may each use separate sections of the display independently, and then parts of the application may need to be integrated into one another in order to maintain synchrony. This offers some insight into the challenges of making such a multi-dimensional display available to users in a network device, which would presumably need to send and receive updates in real time as the data changes and as the moment in time progresses.

Conclusion

The initial goal of exploring the literature related to the conception of time in multi-dimensional data displays has been satisfied. It has been explored by looking at the T axis, by looking at algorithms related to temporal data queries and database design, and by looking at some advanced concepts in visualization, perception, and network/interactive effects for multi-user systems.

Unfortunately the advanced goals of this research for answering how to best grant a user control over the T axis of a display remain unsatisfied by the literature review. One possible explanation is that few researchers conceive of time controls in multi-dimensional interactive data displays as a particular focus of attention – despite the overwhelming evidence that such interfaces exist. Timelines with a scrolling puck are implemented fairly consistently in video editing tools. Researchers such as the MRI researchers have built a time-shiftable visualization of MRI data, and various video researchers (of all stripes) who meld computer generated content with live video are able to shift through time in their interfaces. This lends credibility to the notion that there may in fact be some best practices and essential knowledge that could inform such a design process. Unfortunately these didn't appear clearly through this cursory literature review.

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