16.16

CREATING EFFECTIVE VISUALIZATIONS FOR OPERATIONAL WEATHER FORECASTING

Lloyd A. Treinish*
IBM Thomas J. Watson Research Center, Yorktown Heights, NY

1. INTRODUCTION

Efforts to create generic visualizations, both content and interface, often fail when applied to operational forecasting. Such activities are typically composed of distinct tasks. Attempts to build generalized systems to address these tasks have been useful for research activities and applications development. However, they fare poorly in more mission-critical environments. Generic solutions, even when oriented toward weather, may lack sufficient focus to be effective for diverse forecasting tasks.

2. TASK-BASED VISUALIZATION

Consider three steps to defining visualization tasks:

i. Identification of user needs
ii. Composition of design elements and interface actions
iii. Establishing different techniques for various users

Tasks can be decomposed hierarchically by recognizing that the user's tasks are not the same as the visualization tasks. Hence, a given user may require one or more visualization tasks, and a specific technique may support more than one user task. Then consider goals for the user in visualizing (i.e., exploration, insight, presentation), with the need for:

- Feature or event identification
- Comparison or fusion of data from disparate sources
- Decision support
- Communication of results

Independent of the user goals is the definition of visualization tasks. These are graphical actions such as select, interact, animate, interrogate, etc. The actions are used for specific composition like browse, analyze or present. To test these ideas, they are applied to operational weather forecasting.

3. OPERATIONAL WEATHER FORECASTING

This work is an extension of the mesoscale weather forecasting project of the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) at the 1996 Centennial Olympic Games (Treinish and Rothfusz, 1997). It is a collaborative effort with NOAA Forecast System Laboratory (FSL). It provided a testbed for new visualization techniques, focused on meeting specific forecasting goals, yet affected by real, operational constraints.

3.1 Previous Work

The majority of visualization systems today for meteorology are typically designed from the perspective of "one size fits all". While there is variation among them, they individually provide one interface and style of visualization independent of the task supporting a single class of users. While such systems clearly can be successful, further efficiency in utilization is possible by recognizing that even a single user is likely to have more than one goal for visualization, and that there is more than one class of users.

Improvements in speed and effectiveness have significant impacts on operational forecasting, which is why weather agencies have invested in developing highly focused visualization tools. One example is the Advanced Weather Interactive Processing System (AWIPS) deployed by the NWS, which provides two-dimensional visualizations via its D2D subsystem (NWS, 1998). Conceptually similar tools are available from a plethora of other organizations worldwide. This category of traditional weather visualization tools is termed *Class I*. It consists of conventional representations of selected meteorological fields for analysis tasks by forecasters with minimal direct (graphical) interaction at a specific "layer", either the ground or at an isobaric level. Given a flat canvas for visualization design consistent with the display of a single layer, these tools can only show a few parameters simultaneously (e.g., overlaying wind as barbs or arrows, a scalar variable as line contours). Simplified versions of these representations have also been developed to support presentation to non-meteorologists, particularly for the media (e.g., Schroder, 1993). Figure 1 is an example of a typical visualization produced by Class I tools. It shows a precipitation forecast for August 4, 1996 at 8 pm EDT. Class I may also provide simple flip-book animation.

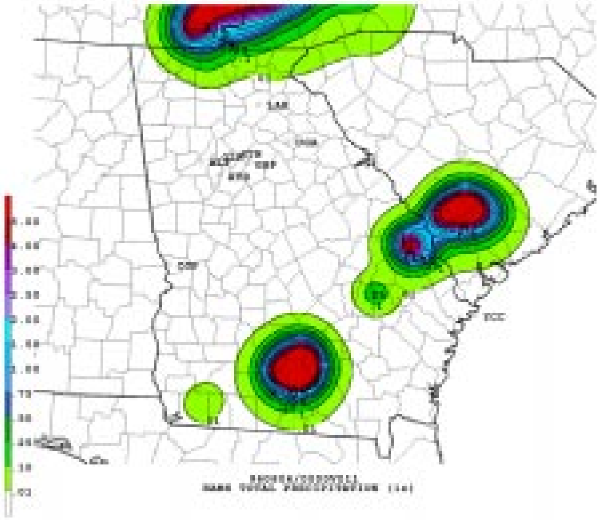

Figure 1. Class I Visualization.

Large, three-dimensional volumes are typical of current acquired and computed data, for which improved facilities are required for timely assessment and utilization in forecasts. However, two-dimensional techniques dominate in operational settings, even though their use can be burdensome with such data because of the aforementioned mismatch between interface and users. There are a few exceptions to this situation. Chief among them is Vis-5D developed at the University of Wisconsin. It has a fixed user interface with specific visualization tools typically tied to graphics hardware on Unix workstations, with support for a single class of data. The implementation focuses on regularly gridded data, preferably compressed to byte precision to increase the speed of operation. This yields an highly interactive tool that maps well to many meteorological data sets (Hibbard et al, 1994). However, for forecasting tasks such as model assessment and dissemination, it can be too generic and does not have the ideal interface or content, because of its primary focus on analysis.

In contrast, Fraunhofer Institut für Graphische Datenverarbeitung (FIGD) has implemented independent systems operated by meteorologists that are focused on specific tasks.

---

*Corresponding author address: Lloyd A. Treinish, IBM T. J. Watson Research Center, P. O. Box 704, Yorktown Heights, NY 10598, lloydt@us.ibm.com, http://www.research.ibm.com/people/l/lloydt

Their development has been in conjunction with the Deutscher Wetterdientst (DWD). The first was Triton, oriented toward generating two-dimensional visualizations for the non-meteorologist (Schroder, 1993). The second, TriVis, is based upon a related goal -- providing two- and three-dimensional visualizations for television broadcasts (Schroder and Lux, 1997). The third system, RASSIN, is designed to provide analysis facilities directly on the native grids of meteorological data (Lux and Fruhauf, 1998). The latter two systems are in use by DWD. The FIGD systems only share an underlying renderer.

4. COMPOSITIONAL GUIDELINES

The approach herein utilizes a *natural* coordinate system to provide a context for three-dimensional display and interaction. They provide representations of the atmosphere fully consistent with the data source that are registered with terrain and political boundary maps. Further, it uses correlative visualization, where each data set to be examined is processed independently and merging takes places at render time (Treinish, 1994). Both the design of the content and the choice of coordinate system has been dictated by the user task for conceptual and physical realizations.

Since color is a critical component, knowledge of human perception is applied via a rule-based advisory tool that is sensitive to the spatial frequency of data and the task (Rogowitz and Treinish, 1996). For example, noisy data such as wind speed are primarily mapped into luminance, while more smoothly varying data such as temperature are primarily mapped into opposing saturation pairs to impart an isomorphic or continuous representation. For moisture-related data, two colormaps are combined such that dry regions are mapped to brown ranging through yellow to green for modest values. At high levels, the data are mapped into blue, with decreasing luminance. For contouring, a segmented colormap with perceived ordinality is applied. For discrete three-dimensional representations (e.g., cloud surfaces), uniform but complementary colors are chosen to minimize the effects of color mixing. For direct volume rendering, this is extended with simultaneous mapping into luminance and opacity. Of course, some of these ideas are not directly apparent due to the monochromatic printing of these proceedings.

Several techniques are implemented for surface wind velocity, which are pseudo-colored by wind speed draped over the topographic surface. Vector arrows of fixed size are used to eliminate misleading motion cues during animation and to show gross atmospheric movement. In contrast, streamlines with directional arrows, although visually more complex, are superior at capturing fronts, convergence zones, vortices etc. On the other hand, waving flags that point in the direction of the wind have been effective to illustrate wind motion to the non-meteorologist. They can be either rigid or furled (i.e., straight at maximum speed and draped against a flag pole in the absence of wind).

5. RESULTS

The task decomposition leads to three other classes of visualization, each of which are described below. In each case, the user has a set of tools to design a visualization and interact with selected data. The available techniques are limited to focus on specific tasks, which are then supported by relatively simple interfaces.

5.1 Class II: Two-and 2-1/2-dimensional analysis

Class II can be viewed as a superset of Class I by including enhancements into three dimensions and the ability to leverage modern workstation hardware. Its focus is for analysis by forecasters, particularly to support data comparison. Because the appearance of the visualizations may be complex, direct manipulation is provided. As a result, up to five parameters may be visualized simultaneously. These two-dimensional variables may be any combination of surface or upper air layers from the same or different source. They may be illustrated redundantly by applying multiple techniques (e.g., color and height). The variables and techniques can be independently selected interactively. An example is shown in figure 2. Four scalar fields are visualized in the stereographic coordinates for December 5, 1995 at 11:00 pm EST. The primary features are precipitable water as the height of a shaded, deformed surface, pseudo-colored by temperature, and marked with the mean sea level pressure at discrete locations. Color-coded relative humidity contours at 10% intervals are overlaid along with streamlines of wind. The wind direction is indicated by arrows and the speed by color. The surface is also draped with local coastline (black), state boundaries (magenta) and river (blue) maps. For example, a correlation is visible between moderate levels of precipitable water and humidity with high temperature in south-central Georgia, and lower levels of precipitable water, wind and temperature along the coast.

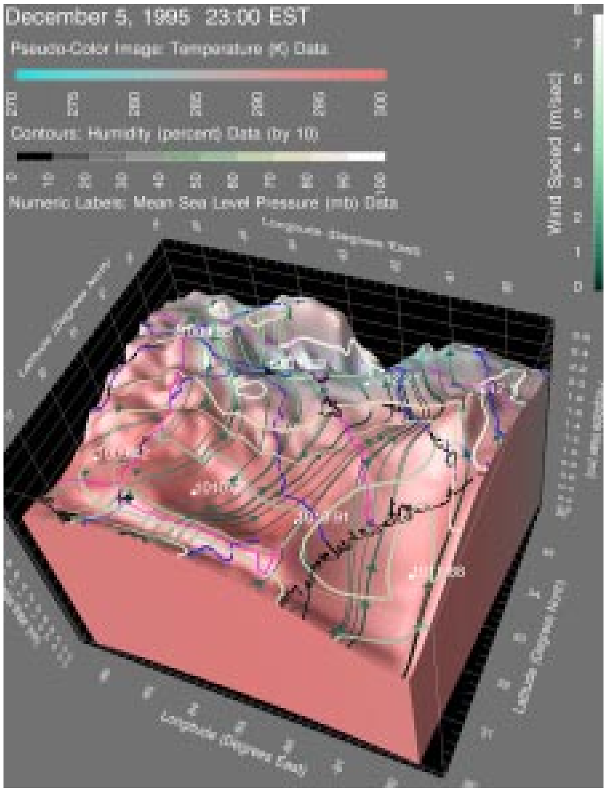

Figure 2. Class II Visualization.

5.2 Class III: Three-dimensional browsing

Class III enables forecasters to create qualitative three-dimensional representations for both interactive investigation and production of animation via browsing. The consumers may or may not be specialists but the interactive user is likely to be a meteorologist. Thus, the results may be suitable for media and public dissemination to support the explanation of specific forecasts. The visualizations have a simplified appearance to utilize pattern recognition for general understanding as well as feature identification. It requires high-resolution data (temporally and spatially) to enable a coherent presentation. Figure 3 shows a result from such an application, which enables interaction in geographic-altitude coordinates. The ability to create both time-based and key-frame (flyover) animations is available.

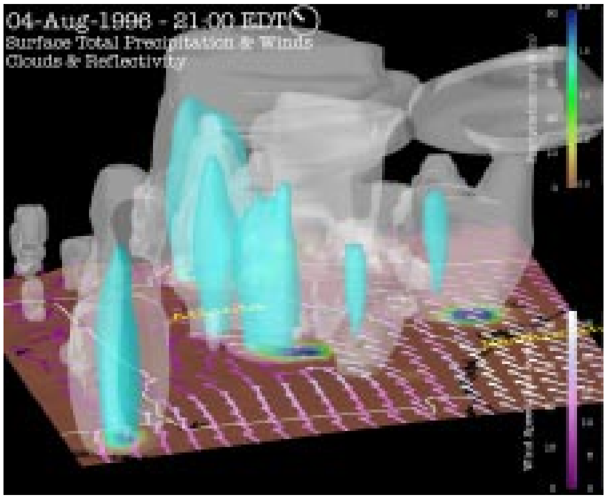

Figure 3. Class III Visualization.

A three-dimensional representation of predicted cloud structure is shown as translucent, white isosurfaces of cloud water density at 10^{-5} kg/kg for August 4, 1996 at 9:00 pm EDT. The cloud surfaces are registered with a terrain map overlaid with coastline (black) and state (white) boundary maps in a terrain-following, stereographic grid, where the cities of Atlanta and Savannah are marked. This *familiar* representation can effectively show gross atmospheric motion and potential distribution of moisture. The terrain is pseudo-colored by total precipitation to indicate where and how much rainfall is predicted. Translucent, cyan isosurfaces in the interior of the clouds are forecast radar reflectivities at a threshold of 25 dBz, approximating rain shafts. The correspondence between the rain shaft and the region of relatively heavy precipitation is quite clear. The surface is also overlaid with vector arrows of surface wind velocity, color-coded by speed.

The browser enables tracking of simulations during execution. Instead of direct interprocessor communication between the visualization and simulation, a custom file format was designed with a set of specialized readers. To further minimize the volume of data and latency in interaction, several parameters were computed within the application.

5.3 Class IV: Three-dimensional analysis

Class IV provides analysis, viewing, interrogation and interaction tools with standard products designed for AWIPS. This class is similar to the visualization tasks addressed by the aforementioned Vis-5D and RASSIN packages, but with greater emphasis on direct manipulation and the introduction of new realization methods. Figure 4 shows a result from such an application, which enables interrogation in a geographic-pressure coordinate system annotated with an axes box and base maps. One may probe the volume for specific values at selected locations within the data set.

The upper air three-dimensional wind velocity is visualized via interactive marking of geographic locations for *virtual soundings* within the model atmosphere. At each location, a vertical profile is extruded through the atmosphere, which is realized as a tube. The wind velocity along the profile is shown by a set of vector arrows that point in the direction of the wind. Horizontal speed at these points is indicated by the color and length of the arrows. Optionally, the locations on each *virtual wind profiler* can be used for seed particles for particle advection, which is realized as streamlines. These lines, which are also pseudo-colored by horizontal speed, indicate the instantaneous direction of the modelled wind from these locations.

6. IMPLEMENTATION

A suite of tools invoked through c-shell scripts on a UNIX workstation or shortcut icons on a WIntel workstation provides the facilities for visualization Classes II, III and IV. They present a user interface based upon XWindow/Motif for indirect interaction and OpenGL for direct three-dimensional interaction in cartographic coordinates. They have been implemented with IBM Visualization Data Explorer (DX) (Abram and Treinish, 1995).

DX is a portable, general-purpose software package for visualization and analysis. It employs a client-server architecture with an extended data-flow execution model. A generic toolkit was used to avoid having to implement a graphics and computational infrastructure. Unlike traditional meteorological graphics, DX enables the use of modern workstation hardware equipped with three-dimensional graphics accelerators and is parallelized for symmetric multi-processors. DX is built upon an unified data model that enables these applications to operate directly on the native grids without transformation or compression, which preserves the fidelity during visualization (Treinish, 1995). Further, such a toolkit is extensible to allow development to be focused on meteorological data and tasks, and reuse of tools between applications with similar user interface components. This simplifies training of users to employ the applications with different content matched to separate tasks. It also reduces the cost of development and maintenance, and enables more rapid iterative refinement with or adaptation to new users.

These tools are part of an integrated system that provides operational mesoscale numerical weather prediction in a wide variety of environments. It evolved from the aforementioned experiments to support forecasting at the 1996 Olympic Games (Snook et al, 1998). Additional information about the system as well as numerous visualization examples are available on-line at `http://www.research.ibm.com/weather`.

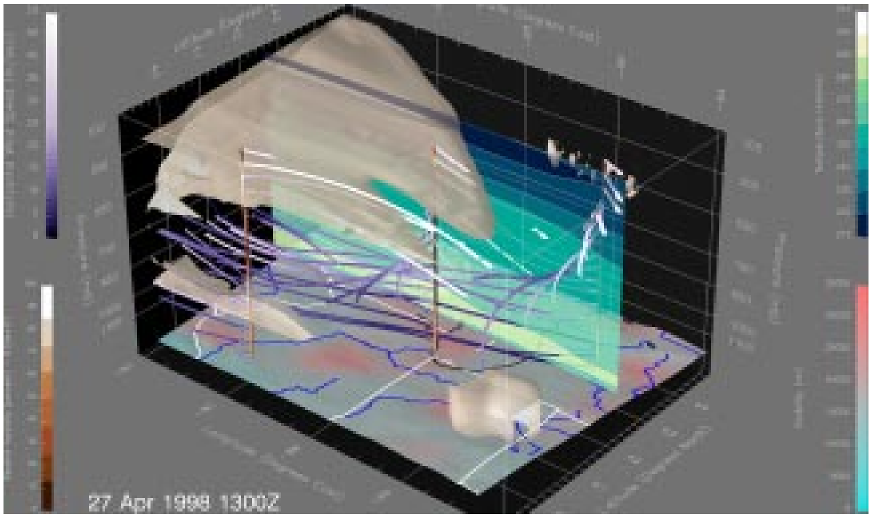

Figure 4. Class IV Visualization.

7. UTILIZATION

The browse application (Class III) enables model assessment. Typically, one or more animations with frames every ten minutes over the full model run (24 hours long) is created after the forecaster selects variables, techniques and geographic view for local playback at workstation resolution to support media briefings. They are MPEG-encoded and associated with an higher-resolution image for distribution on the World-Wide-Web. The contents of such a snapshot image can also be disseminated as a VRML geometry, key-frame flyover animation or as an image-based panoramic scene. The ability to track the model during execution provides quality control and comparison with results from earlier runs.

Analysis with the view application (Class IV) must wait until the post-processing phase is completed at the end of a run. As a result, such interaction takes place after the next run starts, which limits the ability to compare output.

8. CONCLUSIONS

Specialized interfaces and tools matched to user goals and underlying visualization tasks to support them is a promising approach for operational forecasting. Successful facilities can be characterized as being easy to master via simple interfaces, even if the underlying capabilities may be complex. Although generic systems can be employed, the lack of focus in the interface increases learning time beyond what would be considerable acceptable in time-critical activities. This is in contrast to what is often preferred in many research environments. An effective compromise has been developed herein, where the generic tools are used for both prototyping new applications and efficient implementation of complete systems by promoting high-level reuse of underlying tools and design elements. Thus, a set of visualization tasks coupled with appropriate designs can be developed a priori, and then refined through iteration. Further, generalized approaches to these design elements can be employed to more efficiently develop specialized interfaces and tools matched to user goals.

Class III visualizations proved to be more effective than initially expected by virtually eliminating the laborious evaluation of numerous Class I images via presentation of all the relevant information in an easy-to-interpret, four-dimensional display. Conceptual models that would normally require inference from a significant amount of two-dimensional data (e.g., the horizontal extent of cloud dissipation in the lee of the Appalachian mountains) are obvious in three-dimensional animations. Further, one could easily infer vertical motion based on a three-dimensional display of clouds forming. Although the data may not have indicated precipitation occurring in a specific location, the existence of clouds gives forewarning that precipitation may be possible in that vicinity.

The introduction of Class IV into operations complements Class III, but uncovered problems in utilizing data for AWIPS. Although the user can easily select a data set of interest, its organization is not ideal for the required access. Often the post-processed results (all variables and time steps) are collected into a single, large file. While convenient for the data generator, access to specific arrays forces unnecessarily long seeks across a local-area network, which limits performance until requested data are in memory. An additional post-processing step to reorganize the data would only further delay access and increase the disk space requirements. In addition, not all of the defined variables are consistently populated, and their metadata are incomplete, which leads to user error or increasing the complexity of the application and interface to compensate.

9. FUTURE WORK

This approach to visualization in operational weather forecasting was of immediate value at the 1996 Olympic Games, enabling the NWS to provide information for athletes, spectators and officials to plan around adverse weather conditions. These technologies could be applied in other areas where precision forecasting shows promise like tourism, aviation, agriculture, broadcast, energy, insurance, pollution monitoring, and fire control and management. For effective utilization outside of general forecasting, a refinement of the task decomposition will be necessary. Initially, that would imply customized interfaces, products and packaging, most likely for Class III. For aviation, that might include, for example, support for route planning, dispatch, etc. for both safety and efficiency, where predictions of prevailing winds, icing surfaces and clear-air turbulence are shown along a flight path.

Since there is prepondence of potential data sources that could be utilized with these tools, extensions to support them will be driven by the ability to leverage “standard” products (e.g., data formatted for AWIPS). Part of that effort will be to more tightly couple the interaction between Class III and the simulation to enable more efficient tracking/steering. Another aspect is to improve the organization of the model output, particularly for the post-processing (analysis) products.

Web-oriented visualizations can be generated by the current set of applications but an intermediate step of migrating the products to a web server is currently required. This has the advantage in an operational environment, where the forecaster has control over the content of the visualizations that may be disseminated to a variety of consumers. However, the task decomposition can be further refined by considering direct generation of visualizations within a web browser. Similar tasks could still apply, but the user interface and the content must be simplified to be effective. Thus, the current indirect interaction would be replaced with Java-based applets in the browser as a client that communicates with a DX server processing the data and generating the requested visualization for all of the aforementioned methods.

10. REFERENCES

Abram, G. and L. Treinish. *An Extended Data-Flow Architecture for Data Analysis and Visualization*. **Proceedings of the IEEE Visualization 1995 Conference**, October 1995, pp. 263-270.

W. L. Hibbard, B. E. Paul, D. A. Santek, C. R. Dyer, A. L. Battaiola, M. F. Voidrot-Martinez. Interactive Visualization of Earth and Space Science Computations. **IEEE Computer**, 27, n. 7, July 1994, pp. 65-72.

M. Lux and T. Fruhauf. *A Visualization System for Operational Meteorological Use*. **Proceedings of the 6th Conference in Central Europe on Computer Graphics and Visualization**, Plzen, Czech Republic, February 9-13, 1998, pp. 525-534.

National Weather Service. AWIPS Program Information. **`http://www.nws.noaa.gov/msm/awips/awipsmsm.htm`**, March 1998.

B. Rogowitz and L. Treinish. *How Not to Lie with Visualization*. **Computers in Physics**, **10**, n.3, May/June 1996, pp. 268-274.

F. Schroder. *Visualizing Meteorological Data for a Lay Audience*. **IEEE Computer Graphics and Applications**, **13**, n. 5, September 1993, pp. 12-14.

F. Schroder and M. Lux. *TriVis -- Professional Television Weather Presentation*. **`http://www.igd.fhg.de/www/igd-a4/projects/docs/trivis/trivis_e.html`**, October 1997.

J. S. Snook, P. A. Stamus, J. Edwards, Z. Christidis, J. A. McGinley. *Local-Domain Mesoscale Analysis and Forecast Model Support for the 1996 Centennial Olympic Games*. **Weather and Forecasting**, **13**, no. 1, 1998, pp. 138-150.

L. Treinish. *Visualization of Disparate Data in the Earth Sciences*. **Computers in Physics**, **8**, n 6, November/December 1994, pp. 664-671.

L. Treinish and L. Rothfusz. *Three-Dimensional Visualization for Support of Operational Forecasting at the 1996 Centennial Olympic Games*. **Proceedings of the 13th IIPS Conference**, February 2-8, 1997, Long Beach, CA, pp. 31-34.