FUTURE DIRECTIONS IN 3-D METEOROLOGICAL DISPLAY

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1. INTRODUCTION

Three-dimensional display is finally becoming widely used for meteorological data. This is occurring now because:

1. 3-D displays are ambiguous, since many points in 3-D space are mapped to the same point on a 2-D display screen.
2. The best way to resolve this ambiguity is to allow users to interactively rotate 3-D scenes (in particular, interactive rotation is much more effective than binocular stereo for resolving 3-D ambiguity).
3. Interactive rotation requires fast 3-D graphics hardware, which has only recently become affordable.

Meteorological data naturally divides in simulation and observation. Simulation output is generally much easier to work with because it has more regular sampling geometries and does not require complex calibration. That is, simulation output has a simpler *data model* (*Haber, Lucas and Collins*, 1991).

The Vis5D system was developed to provide interactive 3-D display of numerical simulations of the atmosphere and oceans (*Hibbard and Santek*, 1990; *Hibbard, Paul, Santek, Dyer, Battaiola and Voidrot-Martinez*, 1994). By exploiting the relatively simple data model of simulation output and the availability of 3-D graphics hardware, Vis5D has become widely used for 3-D meteorological display. In this paper, we discuss the next steps for 3-D meteorological display in terms of our plans for the Vis5D and VisAD systems.

2. THE NEAR TO MEDIUM TERM

Our near to medium term plans focus on increasing functionality for Vis5D in the following areas:

1. Visually comparing multiple simulation data sets, from ensemble forecasts or from multiple environmental media (e.g., atmosphere, oceans, lakes and ground water).
2. Visually comparing simulations with observations.
3. Improved capabilities for interactive data analysis integrated with visualization.
4. Improved network access to data.

2.1 Comparing multiple simulation data sets

Currently, atmosphere and ocean simulations are being merged into a single Vis5D data set by forcing them to the same horizontal map projection and sampling, and the same temporal sampling (they are forced to a unified vertical coordinate system, but not the same levels). Also, ensemble forecasts are being visualized, at ECMWF and NCEP, by putting 2-D fields from each ensemble member on a different vertical level of a merged 3-D field.

The next version (5.0) of Vis5D will be able to manage multiple data sets within a single session, each stored in its own natural spatial and temporal sampling. Vis5D will support two basic modes for displaying multiple data sets:

1. Overlay fields from multiple data sets in the same 3-D "box". For example, a coupled ocean / atmosphere simulations would be displayed with the ocean data set in the bottom of the box and the atmosphere data set in the top of the box.
2. Display data sets in an array of 3-D "boxes" arranged in a 2-D spread sheet. This is the 3-D analog of image processing spread sheets (*Hasler, Dodge and Woodward*, 1991; *Baltuch*, 1994).

The spread sheet display mode will include a capability to define groups of 3-D boxes with linked user interfaces. If each data set in the group includes, for example, a field named "T", then a request for a 290K isosurface of T will generate isosurfaces for each data set in the group. Similarly, horizontal or vertical slices of T will be generated for all data sets in the group. When the user drags a slice in one data set to reposition it, slices in all data sets will move together. Similarly, grouped data sets will animate in lock-step.

2.2 Comparing simulations with observations

Currently, Vis5D allows simulation data sets to be visually compared with time sequences of satellite images which are texture mapped onto a flat or topographical map near the bottom of the 3-D box.

Future versions of Vis5D will support irregular data typically generated by observations. That is, whereas simulation data and satellite data are organized in regular grids of spatial locations, most observations are not and each field value must be tagged with a spatial location. Support for irregular data will include:

1. Defining appropriate internal data formats and interfaces for reading from files.
2. A variety of visualization modes.
3. Analysis operations including objective analyses for generating gridded fields from irregular observations.

2.3 Improved data analysis integrated with visualization

Currently Vis5D can compute derived fields as simple arithmetical expressions of existing fields (for example, "SPD = SQRT(U*U + V*V + W*W)"). These expressions are typed interactively by the user. Users can define more complex calculations as Fortran functions that are compiled using special scripts that allow them to be dynamically linked with Vis5D. Input to these functions are the value grids for all fields currently stored in Vis5D, and output is the value grid for a new field.

Future versions of Vis5D will support a greater variety of operations in the interactive type-in expressions, including differential and integral operators.

2.4 Improved network data analysis

Currently, Vis5D files are registered as a MIME data type. This allows links to Vis5D files to be embedded in web pages. Appropriately configured browsers will download the file and start Vis5D as an external viewer.

Future versions of Vis5D will be able to import Vis5D files retrieved via browser into the spread sheet for comparison with other files.

3. THE MEDIUM TO LONG TERM

The VisAD system was originally developed to address the more complex data model and data analysis algorithms needed for observational data (*Hibbard, Dyer and Paul*, 1992; *Hibbard, Paul, Santek, Dyer, Battaiola and Voidrot-Martinez*, 1994). At the start of 1996, we decided to rewrite VisAD in the Java programming language in order to combine Java's portability to most computing platforms with VisAD's adaptability to most numerical data (*Hibbard, Anderson and Paul*, 1997). This combination will enable scientists to share data between different machines, different data sources and different scientific disciplines. It will also enable collaborative user interfaces, where scientists share visualizations and share interactive controls over analysis and visualization operations.

The basic design decisions in VisAD are:

1. The use of pure Java for platform independence and to support data sharing and real-time collaboration among geographically distributed users. Support for distributed computing is integrated at the lowest levels of the system.
2. A general mathematical data model that can be adapted to virtually any numerical data, that supports data sharing among different users, different data sources and different scientific disciplines, and that provides transparent access to data independent of storage format and location (i.e., memory, disk or remote).

3. A general display model that supports interactive 3-D, data fusion, multiple data views, direct manipulation, collaboration, and virtual reality.
4. Support for two distinct communities: developers who create domain-specific systems based on VisAD, and users of those domain-specific systems. VisAD is designed to support a wide variety of user interfaces, ranging from simple data browser applets to complex applications that allow groups of scientists to collaboratively develop data analysis algorithms.
5. Support for developer extensibility in as many ways as possible.

By supporting a general data model, and by supporting many different user interfaces, VisAD provides a path toward interoperability of data analysis and visualization systems. That is, VisAD can be the basis of many different systems, each with its own user interface. However, by sharing a single data model, these systems will be able to exchange data with each other. This data exchange may take place through files, or may take place through memory or network connections between live sessions of the different systems.

VisAD provides more active integration of analysis with visualization. An application consists of data objects, displays, analysis (computation) operations, and user interface components. These objects may be connected in arbitrary networks. Data values may be changed by running computations, by direct manipulation (i.e., users change data values by re-drawing their graphical depictions), or by user interface events (e.g., a real number data value may be connected to a graphical "slider"). These changes in data values trigger re-display of those data, and also re-evaluation of any analysis operations taking the data as inputs. This may change other data values, and so on. A network of connected data displays and user interface components create a sort of scientific analysis spread sheet for users, supporting a variety of "what-if" experiments with statistical analysis, etc. Furthermore, data, display, analysis and user interface objects may be connected together independent of their location on the network allowing geographically remote users to collaborate in their numerical experiments.

4. REFERENCES

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