INTERACTIVE VISUALIZATION AND STEERING FOR WEATHER COMPUTATIONS

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Summary: The Vis5D system, first demonstrated in December 1988 at the ECMWF, is widely used to visualize the output of numerical models of weather, oceans, atmospheric chemistry and hydrology. This system runs on most UNIX workstations and on Pentium personal computers running Linux. The Vis5D file format has been registered as an Internet media subtype for exchange via the World Wide Web, similar to the way GIF images are exchanged via the Web. There is also a documented programming interface between Vis5D and its user interface that makes it easy to integrate Vis5D as the visualization subsystem of larger systems, such as interactive modeling systems. The VisAD system has been developed to explore interactive steering of Earth science computations. VisAD may be used to optimize algorithms for analyzing satellite images, to visually track down problems in algorithms, or to perform interactive experiments with simple dynamic models. Both Vis5D and VisAD are freely available over the Internet from the World Wide Web page at: http://www.ssec.wisc.edu/~billh/vis.html.

1. INTRODUCTION

Beginning in the late 1980's, high performance workstations have enabled rapid improvements in scientists' capability to visualize their data (DeFanti, Brown, McCormack, 1989). Prior to that period, scientists could display images and graphics on computer screens, and could animate sequences of images or graphics by pre-computing them and storing them in large memories. The McIDAS system applied stored-frame animation to meteorology (Chatters and Suomi, 1975) and its 4-D subsystem applied stored-frame animation of 3-D graphics to meteorology (Hibbard, Krauss and Young, 1985; Hibbard, 1986a; Hibbard, 1986b). The revolution in visualization was created by the capability of workstations to compute images and graphics (including 3-D graphics) at the rate required for animation. This capability enabled the creation of interactive software systems that provided users with immediate control over displays, for example to rotate a scene in 3-D. The 4-D McIDAS software was ported to Stellar workstations and modified for real-time animation to create the Vis5D system (Hibbard and Santek, 1990a). Vis5D was first demonstrated at the ECMWF during a workshop in December 1988 and was used to make a video of a well known ECMWF data set (Hibbard and Santek, 1990b).

Vis5D was specifically tuned to the needs of weather modelers. This enabled it to provide weather modelers with high performance, efficient use of memory and a user interface focused on their needs. At the same time that Vis5D was developed, Stellar developed a general purpose system initially named StellarVision and later named AVS (Upson, Faulhaber, Kamins, Laidlaw, Schlegel, Vroom, Gurwitz and van Dam, 1989). This system, and its competitors Iris Explorer and Data Explorer (Lucas, Abrams, Collins, Epstein, Gresh and McAuliffe, 1992), enable scientists to build a wide variety of visualization applications.

2. Vis5D

Vis5D takes its name from the fact that the data sets produced by simulations of the atmosphere and oceans are 5-D rectangles. Vis5D organizes these as 2-D arrays of 3-D grids. The grids regularly sample 3-D space. The 2-D array is indexed by time step number and by the set of fields produced by the model (e.g., temperature, pressure, humidity and wind velocity components).

Vis5D transforms grids into 3-D images by a two stage process. In the first stage, 3-D grids are transformed into 3-D geometries including iso-surfaces, contour lines on horizontal and vertical 2-D planes, pseudo-colored images on horizontal and vertical 2-D planes, and volume renderings (i.e., transparent fogs). In the second stage, the 3-D geometries are rendered onto a 2-D workstation screen in a way that gives the illusion of a 3-D scene (i.e., objects close to the viewer occlude objects behind them and surfaces are shaded according to a simulated light source). Except with very large data sets, the intermediate 3-D geometries are saved so that animation does not have to be synchronized with the first stage of processing. This allows much higher performance for animation.

Vis5D also computes a variety of 3-D geometries from motion vector fields (winds or ocean currents). These include particle trajectories, streamlines on 2-D planes, and wind vectors on 2-D planes.

Users have interactive control over graphics, including 3-D rotation, selecting arbitrary combinations of fields and rendering techniques for display, levels of iso-surfaces, locations of horizontal and vertical 2-D planes, spacing of contour lines, colors maps for pseudo-colored planes and volume rendering, and locations of starting points for trajectory calculations.

We recently added a capability to display satellite images in Vis5D. They are texture mapped onto the topographical map and allow comparison of model predictions with satellite observations, as seen in a recent Siggraph video (Hibbard and Paul, 1995a). We plan to add displays of other kinds of observational data to Vis5D.

Vis5D currently runs on the following platforms / operating systems:

1. Silicon Graphics / Irix 4.0.1 or higher
2. IBM RS 6000 / AIX version 3 or higher
3. HP series 7000 and 9000 / HP-UX A.09.01 or higher
4. Sun Sparc / SunOS 4.1.x or higher
5. DEC MIPS / ULTRIX V4.2 or higher
6. DEC Alpha / OSF/1 V1.3 or higher
7. Pentium / Linux 1.2 or higher

Vis5D reads data from the .v5d file format, which consists of a 5-D rectangle and associated metadata. Metadata include the dimensions of the rectangle as numbers of fields, time steps, rows, columns and levels. Note that each field may have a different number of levels, which is typical of atmosphere and ocean simulations. Metadata also include names of fields, dates and times of time steps, a map projection and its projection parameters (current options are cylindrical equidistant, rotated cylindrical equidistant, Lambert conformal and polar stereographic), a vertical coordinate system (current options are equally spaced altitude, a list of altitude levels and a list of pressure levels), and a data compression factor (current options are 1 byte integers, 2 byte integers and 4 byte floats).

Vis5D also provides utilities to help users convert their data into .v5d files. First, there is a library of C and Fortran callable functions for creating .v5d files. An initialization function is called once to set the metadata values, another function is called once for each combination of time step and field to set values in each 3-D grid, and a third function is called at the end of file conversion.

There is also an interactive file conversion program named v5dimport that converts from a variety of existing file formats to .v5d format. This program allows users to combine data from multiple files, to select fields and time steps, and to resample to new map projections and vertical coordinate systems. It can be run either using a graphical user interface (GUI) or by a text dialog.

Finally, there are conversion programs contributed by Vis5D users for a variety of different file formats. Of course, conventions for organizing grids and for metadata may vary between different uses of the same file format, so one user's conversion program may not work for another user's data even in the same file format.

3. THE Vis5D API

The key development in Vis5D version 4.2 is an application programming interface (API) between Vis5D and its user interface (Hibbard and Paul, 1996b). This enables developers to incorporate Vis5D as the 3-D graphics component of their own systems. For example, Vis5D is being incorporated into NASA/GSFC's Interactive Image SpreadSheet (Hasler, Palaniappan, Manyin and Dodge, 1994). The API has also enabled us to develop a scripting language for Vis5D based on tcl/tk. This makes Vis5D into an off-line animation system for weather models. For example, a NOAA group is using the Vis5D scripting language to automatically create 3-D MPEG animations from the output of the CRAS model.

The API consists of a set of a library of functions for controlling all aspects of Vis5D graphics production. The API enables multiple Vis5D contexts to be created, where each context includes a data set (i.e., a .v5d file) and a 3-D graphics window. The API also enables data sets to be changed in a context without restarting Vis5D. Coupled with the library for creating .v5d files, this allows systems to use Vis5D to dynamically create and visualize data. For example, this would allow Vis5D to be incorporated into an interactive simulation system.

4. ADVANCED VISUALIZATION TECHNIQUES

The VisAD system (Hibbard, Dyer and Paul, 1992; Hibbard, Paul, Santek, Dyer, Battaiola and Voidrot-Martinez, 1994) was developed to overcome three specialized assumptions of the Vis5D system. First, Vis5D runs as a post-process to a simulation model, whereas VisAD can serve as an execution environment for simulations and other scientific algorithms. This enables scientists to use VisAD to interactively steer and visualize their computations. Second, the Vis5D data model is limited to 5-D rectangles of data, whereas VisAD allows users to define their own data structures appropriate for their applications. In particular, the VisAD data model is based on mathematical lattices (Hibbard, Dyer and Paul, 1994; Hibbard, 1995) and integrates metadata for missing data, map projections, satellite navigation, etc. Third, the Vis5D display model always maps the three dimensions of the atmosphere and oceans to the three dimensions of graphical space, and always maps time to animation. However, VisAD gives users interactive control over how data are mapped to graphics. Thus users are free to design time series, histograms, thermo-dynamic diagrams and scatter diagrams, or even to invent new types of displays.

The VisAD system currently runs only on SGI workstations. However, it includes a large number of demos that show how it can be applied to a variety of different data sets and computations. Because of its flexibility, it can easily mimic functions of other systems such as McIDAS and Vis5D.

Simulation data sets are often too large to fit on workstations. This has motivated experiments with a client / server architecture for Vis5D. Specifically, Vis5D was divided into a graphics client running on a workstation and a data server running on a supercomputer (Hibbard, W., D. Santek, and G. Tripoli, 1991). In our first set of experiments, the client and server communicated over an OC-12 line (622 Mbps) between the Space Science and Engineering Center and the National Center for Supercomputer Applications that was part of the Blanca Testbed of the Gigabit Testbed Project. The supercomputer server computed graphics primitives and sent them to the graphics client for rendering, so the server was "in the loop" for most user interactions. This worked well with dedicated access to the Cray YMP at NCSA and the OC-12 line, but there were significant delays (seconds or even tens of seconds) with shared access to the YMP.

In response to these delays, our second set of client / server experiments used much larger network transactions. Specifically, the transmission time for transactions was designed to be roughly equal to expected delays. These experiments used an OC-3 line (155 Mbps) between a graphics client at the Supercomputing 95 Conference in San Diego and an IBM SP-2 server at Argonne National Laboratory in Illinois (Hibbard, Anderson, Foster, Paul, Jacob, Schafer and Tyree, 1995). These experiments were conducted as part of the Conference's GII Testbed. The basic idea was to divide a large simulation data set into many .v5d files. One file covered the entire time span of the simulation at reduced time resolution, and was stored in the client. Other files covered sub-intervals of the simulation time-span at high time resolution and were stored in the server. The user started visualizing the low time resolution data set, but could then request any of the high time resolution data sets from the server. While waiting for a high time resolution data set the user could still interact with the low time resolution data set.

Because Vis5D generates a graphical 3-D Earth environment it can easily be adapted to generate immersive virtual reality. The CAVE system (Cruz-Neira, Sandin and DeFanti, 1993) gives the user the illusion of being located in a 3-D graphical space by surrounding the user with graphics projection screens, by providing binocular stereo, and by adjusting 3-D perspective according to the user's head location. The CAVE is the best approach to virtual reality that we have seen, so we adapted Vis5D to work with the CAVE. This was used for the graphics client at the Supercomputing 95 Conference and for a demo at the Siggraph 94 Conference (Hibbard, Paul, Battaiola, Tripoli, Pokrandt and Cohen, 1994). Our experience indicates that while immersive virtual reality displays are dramatic and worth further development effort, large reductions in cost, as well as improvements in quality, are necessary before virtual reality can be regularly used by scientists.

5. THE WORLD WIDE WEB

The World Wide Web provides an extremely easy user interface for presenting information, including text, images, animations and sounds. For example there are numerous institutions serving up-to-date weather charts and satellite and radar images via the Web. It is relatively simple for any institution with real time weather data and an Internet connection to serve text and image information. See http://sunsite.unc.edu/boutell/faq or http://info.ox.ac.uk/help/wwwfaq/index.html for general information about the World Wide Web.

Beyond simply serving text and images, the World Wide Web includes other capabilities that make it a very powerful tool for building interactive weather systems. These capabilities include:

1. Forms. Web pages are defined using the Hyper Text Markup Language (HTML). Forms are a part of HTML that allows Web pages to be forms that users fill in and return to the server. The server can process the information and generate new Web information (e.g., text and images) based on the user's responses on the form. The forms capability makes the Web is a valuable tool for developing interactive weather systems. Follow the link labeled "Fill-out Forms" on http://www.ncsa.uiuc.edu/General/Internet/WWW/HTMLPrimer.html for information about forms.
2. Media extensions. These allow Web servers to define new media for transmission via the Web, and to define specialized software for viewing (or hearing) these new media. See http://www.cis.ohio-state.edu/htbin/rfc/rfc1590.html for information about media extensions.
3. Java. This is an interpreted programming language that allows programs to be transferred and executed much as text or images are transferred and viewed via the Web. That is, Java defines a programming language as a Web medium. This makes the Web into a very flexible tool for developing interactive systems. See http://java.sun.com/ for information about Java.

4. VRML (Virtual Reality Modeling Language). This is similar to the HTML language, but VRML uses 3-D graphics where HTML uses text. See http://vrml.wired.com for information about VRML.

These capabilities, plus its extremely wide acceptance, make the World Wide Web a development tool that should not be ignored in any future development of interactive weather systems. We will describe some examples of how the Web is being used to develop interactive systems.

McWeb is a simple implementation of McIDAS using the forms capability of HTML. Users fill in a simple form to define a satellite image that is extracted from the McIDAS real-time satellite database at SSEC (Bywaters and Prins, 1996). There is currently no publicly accessible Web site for McWeb.

The Globe Project is using Web pages and the forms capability to provide up-to-date environmental information to school children around the world, and to allow them to enter their own local observations into a global database. See http://globe.gov/ for information about the Globe Project.

The U. S. Environmental Protection Agency is using the Web as an interface to scientific visualization (Rhyne, 1995). This is not only easy to use, but makes sophisticated visualization accessible from virtually any desktop computer. Information about this is reachable from the general EPA Web page at http://www.epa.gov.

The SSEC Visualization Project has registered Vis5D files as an Internet media type (Hibbard and Paul, 1996a). This allows modelers to embed pointers to model output data sets in their Web pages, just as they would embed pointers to GIF images in their Web pages. When users click on these embedded pointers, their Web browsers (e.g., Mosaic or Netscape) invoke Vis5D to view these files, just as browsers invoke the xv program to view GIF images. Daily U. S. weather forecasts from both the CRAS and UW-NMS models are available in this form. See http://www.ssec.wisc.edu/~billh/view5d.html for information about serving and viewing Vis5D files via the Web, and for access to output from the CRAS and UW-NMS models.

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