Visualization Methods and Applications for Industry

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ABSTRACT

A wide variety of visualization applications for industry, including advanced techniques in visual data representation and visual user interface design are now in common use. Techniques for Telecommunications database visualization for network optimization, Semiconductor design and testing, and methods for high quality scalar field visualization using surface reduction and texture mapping are described. The common theme in these applications is the use of a visual user interface (VUI).

Visual User Interfaces

Understanding complexity, involving the conversion of appropriate data to relevant information, is a critical role for visualization. To improve understanding requires maintaining a high level of human involvement and participation in the processing and analysis of data through visual interaction. While non-interactive techniques such as statistical analysis and static graphs can uncover relationships and patterns in large data sources, visual tools incorporates the power of an additional analysis tool; the human eye. By interacting with visual images, the user is able to "explore" data and achieve a greater understanding of complexity.

Direct-manipulation visual user interface tools provide intuitive and interactive user interfaces that maximize information content. Users not only view data, but also explore what they see. Picking, drilling, or roaming inside data spaces are used to return summary information, launch additional queries into the data store, and propagate the applications interface components with particular information, thus promoting the process of discovery.

With a visual user interface, the on-screen image becomes concrete, immediate, and primary. The on-screen data object is "live" -- the object itself includes underlying data structures and properties, not merely a reporting window. The sense of immediacy and "speed-of-thought" interaction provides a superior interface for users.

Telecommunications Database Visualization

Telecommunications companies have traditionally been quick to recognize the potential of new technology and use it to improve their business processes. Visualization systems allow users to see complex information displayed in ways never possible before. As problems become more complex and as the patterns being searched for become more obscure, one-dimensional questions and two-dimensional reports simply fail to provide decision-makers with the input needed to understand the situation clearly. Visualization systems enable that change.

Information visualization (InfoViz) applications make it easy for engineers to see exactly what is happening in ways that no printed report can communicate. In some cases, products are used to watch current traffic patterns and flows through lines. Color, size and shape represent distinct load attributes on each section. In other cases, historical call detail data is accessed from geographic displays to pinpoint what kind of call activity is occurring and where.

The network capacity planning engineer needs to understand the network capacity required based on potential volume the network must be able to carry without incurring faults. In fact, most regulatory tariffs include a specification for the service level a carrier must provide to their customers.

One way customer service groups are using visual technology is to create visually based central clearing warehouses for all service-related activities. Using these facilities, dispatchers can get a 'birds-eye' view of where customers are having problems, the nature of those problems, and where the closest available service personnel can be located. Instant access to information reduces service call time, and improves the service provided to customers [2].

The following case study examines how data visualization has been applied by leading telecommunications companies to solve data analysis issues associated with large repositories of spatial and business data.

Industrial Example: *BRITISH TELECOM*

In the British Telecommunications network there are six thousand switches and twenty-five million customer lines generating megabytes of network status and control data every minute. Overlaid on the physical network is an expanding range of voice, data, and video services, each with their own data and

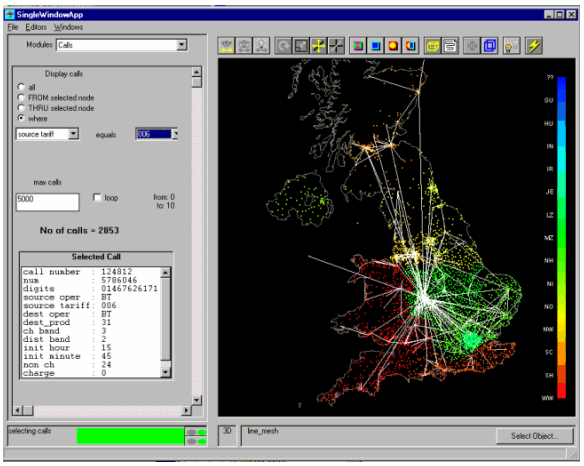

Figure 1: BT network capacity planning tool.

management requirements.

Applications of visualization to non-spatial data, such as financial indicators or traffic statistics, are of great interest to BT. Data visualization provides the users of financial and statistical applications with the ability to interactively explore data, and to spot trends, cycles, and patterns that would otherwise be difficult, if not impossible, to identify.

An example of a visual network capacity planning tool, is shown in figure 1**.** This application is used for network performance analysis, call volume record pattern analysis, and planning for upgrades within the British Telecom network. The application front-ends a database, where call attributes are held, and ad-hoc queries are made. The principle view of the data is in a map-based display, where geographic regions such as managed network zones and exchanges are shown. Network nodes are shown as glyphs on the map, selectable via mouse gestures to generate SQL queries. As the user "drills in" to the call data detail, further views of call routing and route volume is shown both in tables and in a visual display.

VLSI Layout Viewer Framework for EDA Tool Development

A template data viewer for VLSI design uses the underlying graphics display architecture of a standard visualization tool for very specific use. Using the template development system, new IC layout review tools with attribute overlays can be packaged as a customize application. For instance, GDS-II

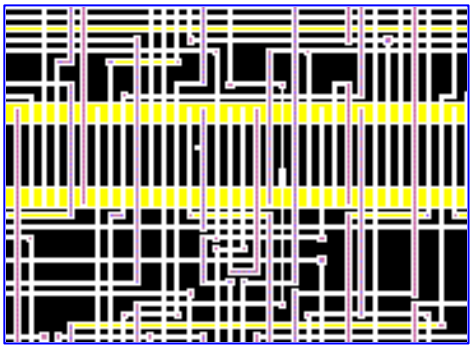

Figure 2: VLSI layout view.

hierarchical layouts can be reviewed, such as in figure 2. The geometry can also be merged with laser microscope data for process evaluation, and metrology.

Mask Layout Review Framework

The challenge of designing a generic visualization framework with the flexibility to allow appropriate configurations for the data source is considerable. A hierarchical approach is required to provide tools suitable for a wide variety of application areas, data structures and user interface needs.

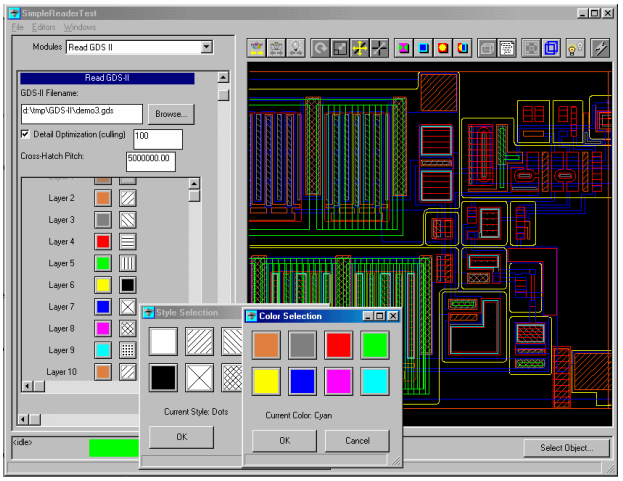

Figure 3. Custom user interface and application design for VLSI layout design review template application.

The VLSI design review template includes:

- Direct Access of GDSII Geometry Hierarchy Navigation, Display
- Single/Multiple View windows as needed.
- Cross platform GUI - Motif (UNIX), MFC (NT)
- 2D Graphical Hardware Acceleration through OpenGL
- High Level Application Architecture
- Direct Mouse Driven Interaction with IC Layout
- Interactive Pan-Zoom-Select

- Easily merge information overlays from other sources

Complex VLSI designs for IC mask fabrication use deeply hierarchical geometric layout formats. With even modest file size, nested structure references can easily generate many millions of geometric primitives. The custom render method is used to traverse the layout hierarchy at display time, using the native VLSI design data structure. Using this technique, 26 million graphics primitives have been viewed in a single view on a standard laptop PC.

Methods use Advanced Graphics Pipeline

In AVS/Express, the very flexible graphics architecture is exploited to minimize memory requirements and data structure conversions during rendering for large data problems. A thin layer OpenGL renderer provides a graphics display path, without dependence on scene tree, dynamic scene creation, or any requirement to hold the scene content in virtual memory. For small data sets and high speed interaction, stored scene tree mechanisms are used, but not required. Data source methods, and visualization methods are able to register user-defined draw methods providing a "chunking" mechanism to build up the scene using a multi-pass or data segmentation model. Visualization procedures are only executed as needed during the incremental updates, and do not need access to the entire model. In addition, this architecture allows procedural rather than stored data structure sources.

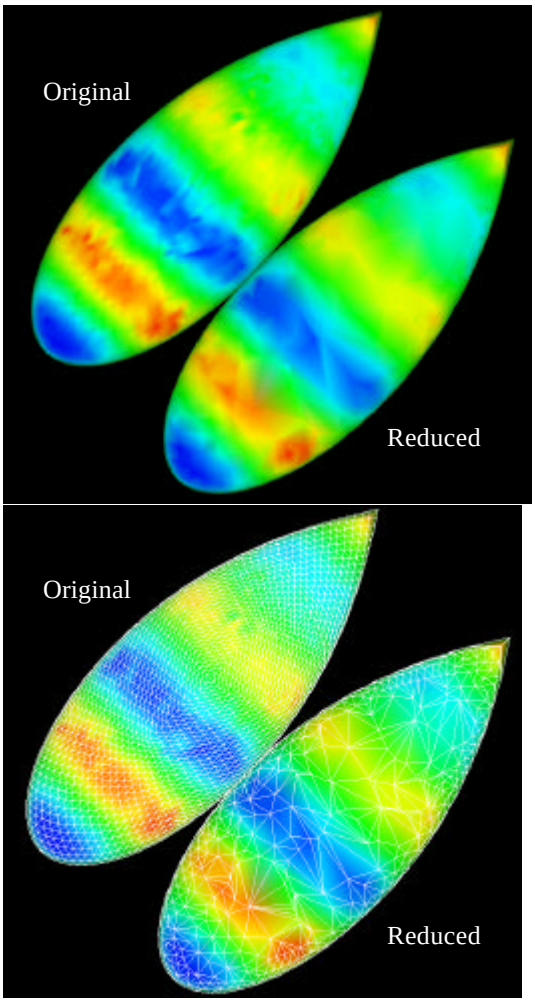

Figure 5: Teardrop shape with electromagnetic field data. Top image shows original and reduced mesh with interpolated colors, while the bottom image includes geometric mesh outlines. Both use data constrained simplification.

Visual Data Representation – Data Reduction Techniques

Large polygonal models are very common in technical visualization applications. They are frequently used for generating pictures, animations, and are processed by analysis programs. CAD and rapid prototyping systems often generate far larger models than can be processed by graphics systems. VRML browsers (used in web based 3D viewing) commonly available often perform poorly on large models.

A set of geometric data reduction techniques has been devised to aid the visualization of large models. They are of general use to any technical & scientific data visualization involving geometric shape data, or shapes derived from visualization techniques such as isosurface. Where geometric complexity inhibits interactive display, or transport over networks such as the internet, the ability to reduce the size of models while preserving key attributes for display can be critical to usability of the application.

Two different approaches to geometric surface simplification are based on unique assumptions. The first is designed to create an approximate geometry as efficiently as possible, so it can be used within the interactive visualization environment [7]. To enhance interactive display response, large models are rapidly simplified to yield higher display update rates. The amount of simplification is controlled by a set of user parameters, and uses a multi-pass iterative approach, converging on the target simplification.

The second method is based on global error estimates, such that the quality, especially the deviation error from the original geometry is constrained to user specified parameters. The resulting simplification is suitable for medical 3D reconstruction applications where error margins must be predicted [6].

An important advanced feature allows geometric surface simplification to be adaptive to secondary data attributes on the geometry. Where high data gradients exist, the simplification process retains detail in the generated mesh.

Texture based color maps on continuous field data

A method of using a texture mapping approach to color scale for the visualization of continuous field scalar quantities is described in this section. The technique is most appropriate where high gradients are present in the data, or where geometric surfaces are projected to significant screen area. The use of texture mapping takes advantage of widely available 3D display systems for interactive visualization system design. The technique yields a significant reduction in visualization artifacts caused by color interpolation. Multiple resolution textures are shown to improve visualizations of high dynamic range data.

When continuous field numerical data is presented in a visualization system as a continuously varying color, artifacts can be introduced due to color interpolation in the display system. A technique is described using texture map color in the visualization display, especially suitable where small non-linear regions in the data must be highlighted, or where the data contains sharp gradients. The characteristics of the artifacts caused by color are discussed first, followed by an explanation and example of the texture color map technique.

Most visualization systems contain operators to map data values to color. These operators are typically yield smooth contours, and are used to represent continuous field data. Color map systems are used to specify such mapping, such as blue for a low value, and red for a high value. When applied to data on geometry (meshes), data values are known only at discreet points on the geometry. Using continuous color maps, smooth changes in color are displayed between available data points. The way in which the color is smoothed, or interpolated between the points can have a dramatic effect on the interpretation of the underlying data [3]. At best these factors display an approximation of the data, with a possibility of completely hiding important features in the data, and at worst create misleading artifacts in the visualization [5].

In many systems, the data values are sampled and converted to color values, typically (Red, Green, Blue) triplets at each node or vertex of the geometry. During display, interpolation is left to the underlying display system, which then interpolates intermediate values by blending the two colors using low precision color interpolation. Triangulation can also affect color interpolation. In the illustration, the color of a point may change from orange to cyan under different triangulation directions. The more fundamental problem is that colors specified in the color map may be omitted completely. If two adjacent data points have the colors red and blue, color interpolation will generate purple at the halfway point. If the values are at extreme ends of the color map, and the color map has green at the center point of the scale, then green would be the expected color, not purple. Even when color space interpolation is desired, the problems with using an RGB are well known, and alternative color space models are available [4], but rarely implemented by display system vendors.

If the color map resolution matches the data value resolution, and the data variation across each facet of the model is very low or close to the resolution of the color map, then the color interpolation method is adequate and few errors will be observed. The highest chance of artifact generation occurs when the data gradient is high over individual facets, and relates the data range over significant portions of the color map.

Texture Based Color Display Method

A solution to this situation is to use a 1-dimensional texture mapping technique. Texture mapping is an advanced graphics technique that has become available on almost all graphics systems through its popular use in games such as Doom, Quake, and Tomb Raider. Texture mapping is also well supported through software interfaces such as *OpenGL* and *Direct3D*. Instead of passing pre-sampled colors to the display, parametric texture coordinates are passed, along with an RGB texture image. Interpolation is then performed directly on the texture coordinates (using floating point arithmetic), which are used to look up color values from the reference image. Pixel color assignment is indirect, using the color image as a lookup table. Textures have also been used to represent vector fields, or more complex feature display of scalar fields [1].

Using the same color map structure as used in Gouraud shading as the reference image, the same color map information may be passed to the display. Display update times may be slightly slower, since more operations are performed, and more data must be processed by the display system, however this is a small price to pay to achieve interpolation accuracy. Interpolation can now show much more detail in the original data, and show subtle variations that are completely lost using the usual color interpolation. Users can specify an order of magnitude higher resolution color maps, and the entire color map can be displayed between two adjacent data points if needed.

Since many texture display systems need a square image structure, a 1-dimensional color-map is placed down the diagonal of the image. A color map pattern is easily sketched using a paint program to create a color map image. As so many image-handling tools exist, our prototype uses standard TIFF images. Interactive performance of this technique has been verified on systems ranging from a small laptop PC to a Silicon Graphics immersive virtual reality environment.

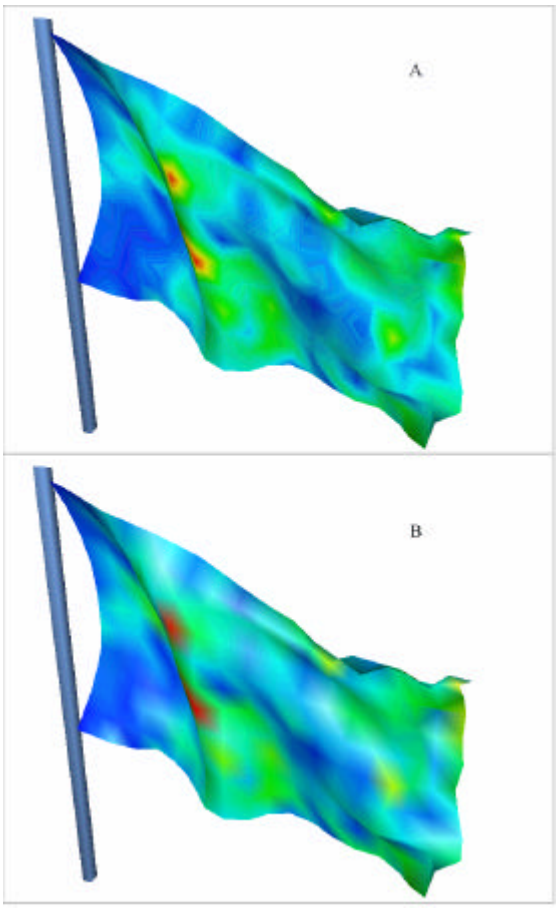

Figure 6. Flag forces shown using (A) texture based color map, and (B) color interplation with Gouraud shading. Note the yellow ring in A is missing in B.

Applications of Texture based Color Maps

This texture based color map technique has been implemented as a filter module in the visualization framework AVS/Express. The filter takes any geometric mesh with scalar node data, and replaces it with a mesh with UV texture coordinate data. The mapping matches the range of the input data, so that all positions on a texture image source containing color map values may be used. The texture image source is intended as a single dimensional color table source, with values sampled along the primary diagonal. Because the technique is a direct replacement for the color interpolation technique, no additional user defined parameters need to be specified.

The differences in detail presented in the visualization can easily be seen in the following comparison. In the bottom model (B), the data is displayed using a standard color hue range from low to high, with blue as the lowest color, and red the highest. In the upper model (A), the same colors are used as the texture based color map. Much more data variation detail is shown in the upper model than the lower, using the texture based color map technique. The model is of a 3D finite element analysis of a flag under windy conditions, with resultant force magnitude values displayed as color. Near the central crease, two bright red spots indicate the highest forces. In the top model (A), the red spots are surrounded by yellow, the next color in table. In the lower model, color interpolation skips over these values, so the yellow rings are missing.

Multi-resolution texture images are used where the data contains important information in different numerical ranges. In this case a special image is assembled with regions defined with independent color scales that will allow differentiation of the numeric ranges present in the data. In this way wide dynamic range data can be interpreted in the visualization system. Such detail is normally lost using color interpolation.

Implementation Available at Website

A technique is described to reduce visual artifacts due to color interpolation using a texture map display technique. The method is suitable for a wide range of numerical data visualization problems, and is especially suited to widely available hardware, and where high data gradients must be shown accurately. The software developed for the research presented in this paper is available at the International AVS Center site, http://www.iavsc.org, in the archive project "scalar2texture".

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