Continuous Field Visualization with Multi-Resolution Textures

Ian Curington
Advanced Visual Systems Ltd.
Hanworth Lane, Chertsey, Surrey KT16 9JX, U.K .
ianc@avs.com

Abstract

A method of using a texture mapping approach to color scales is described, for the purpose of visualizing continuous field scalar quantities. 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.

Key words: Interpolation, Color, Visualization, Texture

1. Introduction

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.

2. Gouraud Shading

The common technique of Gouraud shading, used by many 3D rendering systems, computes shading and color information at discreet points, generally at the vertices of polygonal objects [5]. Once the color assignment has taken place, the graphics system displays the object by performing linear interpolation of the color across each face of each polygon. Although highly efficient, the technique ignores variations in the data or the lighting environment during interpolation, and simply blends the vertex colors across the faces. As shown in figure 1, the well-known artifact of "Mach Banding" occurs where a curved surface under a directional light source appears to have dark bands or discontinuities in the surface shading. If the surface color is derived from continuous numerical data, as is the case in visualization systems, the bands appear to be contour discontinuities. While more sophisticated lighting models can eliminate the banding effect due to shading, it cannot correct for color interpolation effects when the color is derived from numerical data.

3. RBG Color Interpolation

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

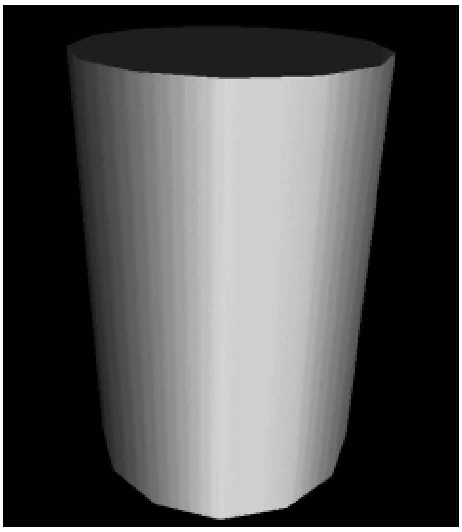

Figure 1. Illustration of "Mach Banding" effect in Gouraud shading.

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 [2]. 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 visualizations [4].

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.

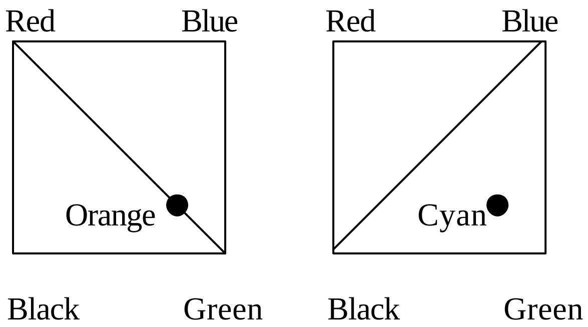

Figure 2. Triangulation effect on interpolation.

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 half-way 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 [3], 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.

4. Texture Display

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.

5. 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.

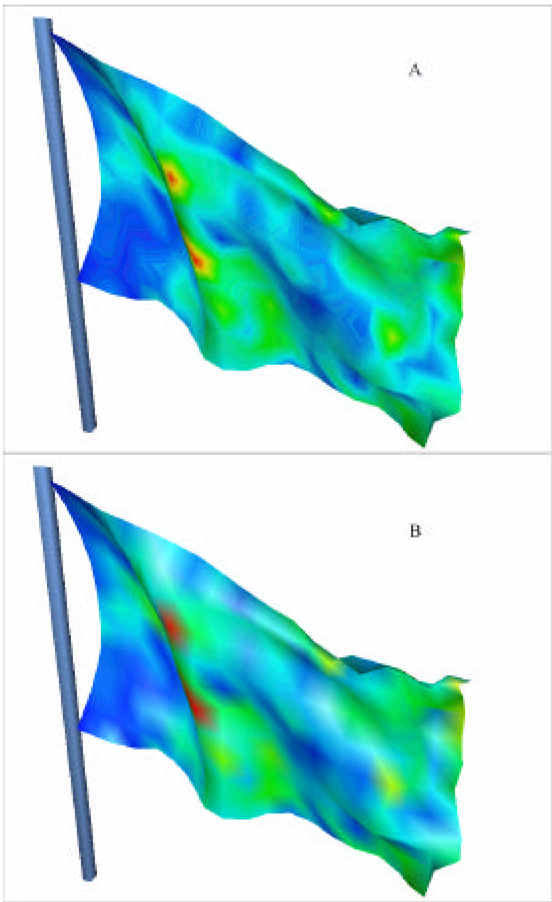

Figure 3. Flag forces shown using (A) texture based color map, and (B) color interplation with Gouraud shading. Note the yellow ring in A is missing in B.

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. The following example shows a geologic structure with simulated oil reservoir attribute values placed on the geometry using the multi-resolution texture map color technique. Such detail is normally lost using color interpolation.

6. Conclusion

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.

7. References

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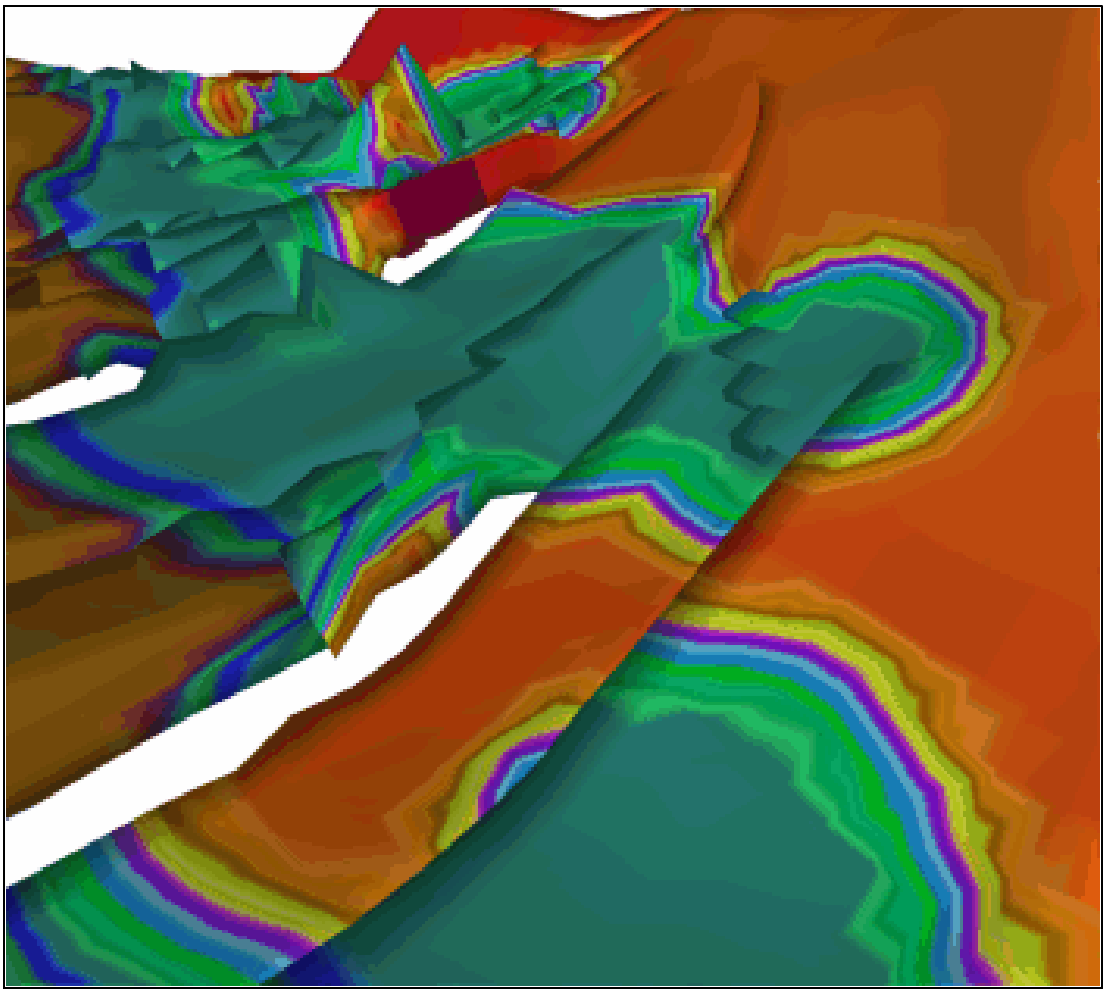

Figure 4. Geologic structure showing oil reservoir properties, using multi-resolution texture. (*Data Courtesy of Schlumberger Geoquest*)