Visually Representing Multi-Valued Scientific Data Using Concepts from Painting

David H. Laidlaw, David Kremers, Eric T. Ahrens, Matthew J. Avalos
Caltech Computer Graphics Lab
Mail Stop 139-74
Pasadena, California 91125 USA
{dhl,davidkremers,eta,avalos}@gg.caltech.edu
www.gg.caltech.edu/~dhl

Vector-valued and tensor-valued images are rich sources of information about many physical phenomena. Visually representing these images so that they can be understood is a challenge, however, because they contain so many inter-related components,[2,5] all of which must be represented simultaneously and intuitively.

We have applied concepts from oil painting to the display and understanding of multi-valued scientific data. For example, painters map components of a scene onto visual characteristics of brush strokes by varying their size, shape, color, texture, opacity, direction, and placement. They also convey information by stroke locations relative to one another. Using these variations in appearance, we can simultaneously represent many components of multi-valued data and show relationships among them. Painters also build up an image with multiple layers of paint, where each layer represents and encapsulates some components of the data. The lowest layer, or underpainting, often roughs out the form of the painting. Layers can be semi-transparent or sparse, and thus be built up without obscuring one another. We combined these techniques to create an interactive computer graphics system[4,7] for experimenting with visual representations of 2D images of vector- and tensor-valued data.

Artistically motivated rules guided our choice of brush characteristics and layering to represent components of the data.[6,8] Our examples are of three different data types: diffusion-tensor data showing the pathology of a mouse disease in the spinal cord,[1] 2D vector and tensor measurements of flow over an airfoil,[3] and six-valued magnetic resonance imaging data showing the embryonic development of the mouse brain. The images are effective because they display many data values simultaneously, they qualitatively represent the underlying phenomena intuitively and geometrically, and they emphasize different data values to different degrees, leading a viewer through the temporal process of understanding the relationships among them.

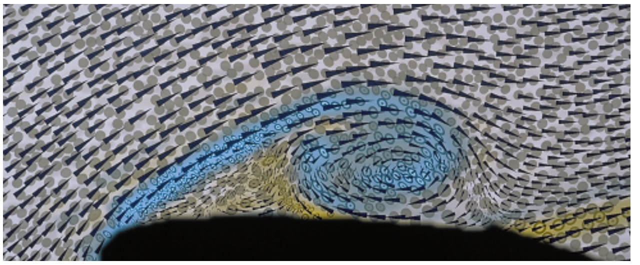

Figure 1 2-D flow field visualization. The image simultaneously displays the velocity (two values), the vorticity (one value), and the deformation-rate tensor (three values). The values are encoded, respectively, in the size and orientation of a layer of wedges, in a color base layer, and in the size, shape, orientation, opacity, and texture of a layer of ellipses.

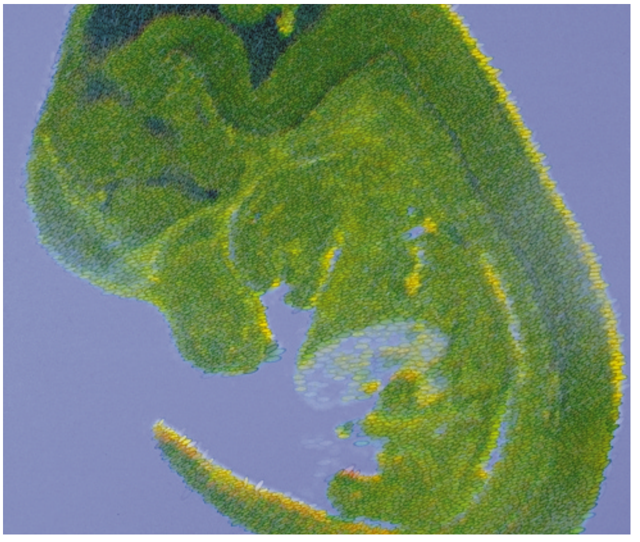

Figure 2 Simultaneous display of six-valued MR data. Four of the component data values are encoded in the color and transparency of an underpainting. The size and orientation of a layer of small elliptical outlines encode the other two values.

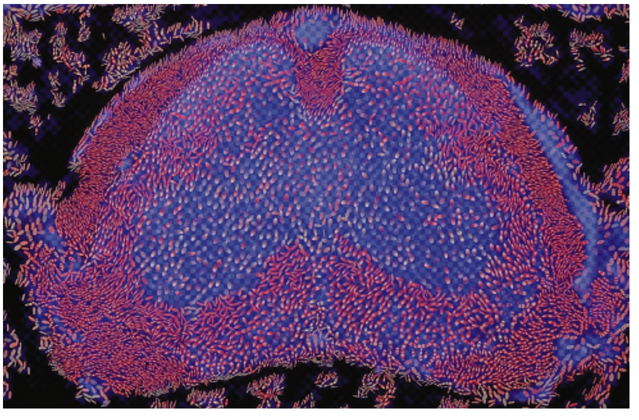

Figure 3 Layers of brush strokes displaying one slice of a second-order tensor field (six values) and two spatially correlated scalar fields (two values) over 3D. Eight interrelated variables are shown. This image is composited from four layers. Component data values are represented in the lightness of a purple underpainting; a transparent grid pattern composited over that; the direction, shape, color, and transparency of a layer of elliptical strokes over that; and the frequency of a texture applied to the elliptical strokes.

Support
NSF (CCR-96-19649); NIDA, NIMH, NSF (Human Brain Project); NSF (ASC-89-20219); Beckman Institute; Apple, DEC, HP, IBM.

References
1 E. T. Ahrens, D. H. Laidlaw, C. Readhead, C. F. Brosnan, S. E. Fraser, and R. E. Jacobs. MR microscopy of transgenic mice that spontaneously acquire experimental allergic encephalomyelitis. Magnetic Resonance in Medicine, (1998). (to appear)
2 T. Delmarcelle and L. Hesselink. Visualizing second-order tensor fields with hyperstream lines. IEEE Computer Graphics and Applications, 13 (1993), 25--33.
3 G. G. Gornowicz, Continuous-field image-correlation velocimetry and its application to unsteady flow over an airfoil. Eng. thesis, California Institute of Technology, 1997.
4 P. E. Haeberli, Paint by numbers: Abstract image representations. In Computer Graphics (SIGGRAPH 90 Proceedings), F. Baskett, ed., vol. 24, Aug. 1990, 207--214.
5 L. Hesselink, F. H. Post, and J. J. van Wijk. Research issues in vector and tensor field visualization. IEEE Computer Graphics and Applications, 14 (1994), 76-79.
6 G. Kreutz, Problem solving for oil painters. Watson-Guptill Publications, 1986.
7 B. J. Meier, Painterly rendering for animation. In SIGGRAPH 96 Conference Proceedings, H. Rushmeier, ed., Annual Conference Series, ACM SIGGRAPH, Addison Wesley, Aug. 1996, 477-484.
8 E. R. Tufte, The visual display of quantitative information. Graphics Press, Cheshire, Connecticut, 1983.