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A Reference Model for the Visualization of Multi-dimensional Dab

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This paper presents a reference model for the development of systems for the visualization of multidimensional data. The purpose of the reference model is to build a conceptual basis for thinking about multi-dimensional visualization and for use in developing visualization environments. We describe the reference model in terms of the fundamental concepts of PHIGS (Programmer's Hierarchical Interactive Graphics System), but extend those concepts to the representation of objects of arbitrary dimensionality.

1. Introduction and Background

Scientific visualization has recently developed as one of the fastest-growing areas of computer graphics research and application. A recent National Science Foundation Workshop Report [McC87] identifies the importance of this field, as well as the critical need to develop improved techniques for data visualization. Traditional graphics techniques have proven extremely powerful when applied to visualization applications arising from problem domains that are essentially geometrically three-dimensional. Impressive results have been reported recently under the generic category of volume rendering [Sab88, Ups88, Dre88]. Many domains, however, produce data whose dimensionality is considerably greater than three. We have barely begun to understand what constitutes effective visualization tools in these environments. (See [Gri89a] for details.) To some extent color and time can be used to extend display dimensionality. In principle, color itself represents three independent dimensions (such as hue, intensity and saturation). but it is not clear to what extent those three dimensions can be transformed to a perceived extension of dimensionality in the human viewer. In the first place, given a two dimensional display device, we typically use color intensity variations as the principal technique for showing the three-dimensionality of the ob]ect(s) being displayed. If we now use the three dimensions of color for representing other aspects of the data, we may lose the third geometric dimension. At best we may be able to achieve perhaps five dimensions of display using a two-dimensional display plus color. Perhaps stereo displays might achieve six dimensions and animation (time) could in some applications present a seventh dimension. How can we display data values representing points in a ten-dimensional data space? What kinds of display techniques demonstrate patterns in such data in a way that a scientist can perceive those patterns?

The development of our Visualization Reference Model was instigated by our studies in the use of icons as a tool for multidimensional visualization [Pic88, Gri89a, Gd89b]. Our iconographic technique represents an extension of the classic visualization approaches by providing displays of multi-dimensional data, with each data record represented by or displayed as a graphic icon whose features (visual and auditory) are under control of the various fields of the record. Color pixels are thus generalized by icons whose features can be controlled by more than three fields. Figure 1 (taken from [Pic88]) shows for example that using the angles of the five segments as icon features, we can map up to seven dimensions of data simulaneously (x and y plus the five icon features). Icon features that may be under data control include not only angle, but also other geometric attributes of the body or limbs, such as length, thickness, and color. More complex features that may be under data control include dynamic properties such as changes in angle, length, or color and auditory properties such as pitch and intensity

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