Map3d: Interactive Scientific Visualization for Bioengineering Data

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Abstract

This paper describes a scientific visualization application to display and edit complex, discrete geometric models and to provide rapid viewing of distributions of data recorded or computed at multiple sites in three dimensions. We wrote the software in ANSI-C with the Graphics Library (GL) from Silicon Graphics Inc., and have used it to create multichambered models of the human torso, to visualize the results from forward and inverse computations based on torso models, and to display results from epicardial, intramyocardial, and body-surface recording systems in experimental and clinical applications.

Introduction

Modern biomedical research frequently includes the generation of time-varying signals from numerous sites in three-dimensional space. While each of these signals can be evaluated as a scalar function of time, important spatial relationships are best revealed by combining temporal and spatial elements in the display of this data. Traditional visualization methods often assume that spatially sampled data approximate a bivariate function, *i.e.,* space is assumed to be two dimensional and the third dimension (height) in the display represents the data values. In reality, however, data is often recorded or computed at sites which do not lie in a plane, and bivariate representations of this data, which are typically based on planes lying close to a subset of the sampling sites, inevitably result in distortion of the spatial relationships of the actual sites.

Even if spatial relationships are preserved, however, in many applications, it is not enough to sacrifice temporal information for spatial fidelity. The phenomena of interest possess strong time dependencies, so that both spatial **and** temporal features must be extracted, and visualized. Hence, there is a need for scientific visualization systems that represent spatially sampled data in a geometrically accurate manner, at speeds that allow rapid viewing of sequences of distributions. Current workstation hardware now provides the necessary performance, both in terms of general purpose computations and specialized graphics subsystems, to address visualization problems of this complexity. In this paper, we report on our approach to scientific visualization of electrical signals arising from both experimental and mathematical modeling research in cardiac electrophysiology. We describe a visualization application called *map3d*, which provides rapid, flexible, interactive viewing and editing of geometric models and bioelectric data.

Geometric Modeling

The spatial display of information cannot occur without knowledge the geometry of the sample locations. Regularly spaced meshes contain this information implicitly in the indices used to address the data, but for any irregular mesh, geometry must be specified explicitly. For two-dimensional geometries, robust algorithms require only the sample site locations to compute an optimal set of connectivities, in the form of the triangles, which provide the framework for subsequent interpolation and visualization algorithms [1]. For irregular, three-dimensional geometries, however, such general algorithms are the subject of current research. What do exist are semi-automatic algorithms that make use of certain features of the geometry, with the aid of user intervention, to generate either surface (triangle) or volume (tetrahedra) descriptions [2].

We initially developed the program *map3d* to manually correct the output of existing semi-automatic modeling algorithms. The basic organizational element of *map3d* is the 'metasurface', minimally defined as a set of nodes, which need not form a closed surface but are in some sense logically connected. To the nodes of a metasurface can be added connectivities, in the form of line segments, triangles, tetrahedra, or hexahedra. To each element of the metasurface can be associated any number of scalar, vectorial, or tensorial quantities, *e.g.,* electrical conductivity tensors. The capabilities of *map3d* include display of the geometry as a set of nodes, connected polygons (triangles or tetrahedra), or rendered surface, with indication of the orientation of the surface facets (outward or inward facing). In order to analyze and edit the geometry, we needed to be able to interrogate elements of the geometry, to link nodes into triangles (tetrahedra), remove existing triangles (tetrahedra), and to flip the orientation of surface facets. Managing complex geometries also required that we be able to combine multiple surfaces in the same display and control them both synchronously and independently, rotate and translate the geometry, and apply adjustable clipping planes, depth cueing and perspective.

We were able to maintain acceptable interactive performance by dividing large geometries (80,000 nodes and 500,000 tetrahedra) into smaller, independent units, which *map3d* could manipulate individually, or in groups. We also made extensive use of the high performance drawing routines of the Graphics Library (GL) from Silicon Graphics Inc., in which all the graphics code was written. The *map3d* program also provides a very simple, efficient interface, which allows users to select the best compromise of features to balance display quality and interactive responsiveness.

Data Visualization

The creation of geometric models is the end point of some tasks, but it is only the beginning of most. The geometry provides the basis for computational models of the heart and thorax [3], but also defines the underlying structure for visualization of both experimental and modeling results [2]. *Map3d* incorporates such data by extending the metasurface paradigm to include data values, *e.g.,* electric potential, activation times, or current vectors, by linking them to the elements of the geometry. At present, the display of data values in *map3d* is based entirely on surfaces, *i.e.,* there is no volume rendering. This reflects both performance concerns and the fact that most bioelectric measurement systems record values at relatively few (in comparison to imaging modalities like MRI and ultrasound), discrete sites, which are often bound to a physical surface, as, for example, in heart, body, and cranial surface mapping. Even when the data is available throughout a volume, isosurface construction provides a useful means of describing the distribution, especially if multiple isosurfaces can be generated and then rotated and manipulated interactively.

Data values are bilinearly interpolated over the triangular surface elements and displayed as isocontour lines, or Gouraud shaded surfaces. Variable settings determine the color map and scaling parameters, and control the display of textual labels with absolute data (or node number) values at the appropriate sites in the display. To provide a temporal context for the spatial displays, *map3d* displays selected individual time signals (scalar lead) in separate windows. This window also provides an interactive (via the mouse) means of selecting the instant in time at which the spatial distributions in the other windows are displayed. The basic premise for all design of the user interface was to begin with accepted "quasi-standards", as they often exist in research, and offer a fairly limited choice of alternatives, with more choices added based on user feedback. To facilitate the comparison of distributions that is frequently a part of research data viewing, *map3d* synchronizes the movement in space (rotation, translations, scaling) and time of the displays from different windows. We have extended this concept beyond a single instance of *map3d* to permit multiple instances of the program, each launched independently, to be linked via Unix message passing.

In order to capture the temporal continuity of dataset in some form of hardcopy output, we have devised a video driver interface for *map3d.* This interface allows complete control of *map3d* from the driver, which also controls a video output card and, via a video local area network (V-LAN), a frame-accurate video recorder. Driven by simple user-written scripts, the driver program runs *map3d*, gathers the desired images, and writes them in sequence to the tape.

Conclusion

The creation of *map3d* was driven initially by a combination of powerful new graphics hardware and a lack of appropriate software. As frequent users of the program, we felt that any lack of programming skills would be balanced by a keen notion of what functionality was required. We knew that interactive performance was a primary goal, as were the flexibility to add features, modules, and options, as our needs dictated, and the desire not to be dependent on proprietary sources to support our needs. Despite the considerable investment in programming efforts, we feel *map3d* has met all those requirements and allowed not only us, but many of our colleagues, to enjoy visualizing and editing geometric models which represent the state of the art in terms of complexity and size, to view massive datasets with ease, and to publish images taken directly from *map3d* in leading scientific and computer graphics journals.

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