GRID GENERATION FOR BRAIN VISUALIZATION AT THE CELLULAR AND TISSUE LEVEL

David A. Batte[1] and Bruce H. McCormick[2]

[1]Scientific Visualization Laboratory
Texas A&M University, College Station, TX
E-mail: dbatte@cs.tamu.edu
[2]Scientific Visualization Laboratory
Texas A&M University, College Station, TX
E-mail: mccormick@cs.tamu.edu

ABSTRACT

Numerical grid generation is used to provide a framework for brain and neuron visualization. Smoothing spline surfaces are fit to contour data to generate 3D solid model reconstruction of brain tissue. Finite element methods are then used to subdivide the solid models into biologically-consistent finite elements. Numerical grid generation is employed to provide a curvilinear coordinate system within the finite elements. Synthetic and manually traced neurons are mapped into the gridded solid model using the curvilinear coordinate system. To this end grid generation tools, neuron mapping tools, and visualization tools have been implemented.

1. INTRODUCTION

The goal of this work is to provide effective techniques for the visualization and interpretation of neuron data sets within a volume of reconstructed neural tissue. The interpretation and modeling of these neuron data sets rests on having a biologically-consistent framework in which the neuron populations can be visualized. For brain visualization at the cellular and tissue level, a coordinate system must be generated within a brain nucleus or cortical area to produce a biologically-consistent model of the volume filled with a sparse representative population of neurons. Numerical grid generation [1] is a well-established method for producing boundary-conforming curvilinear coordinate systems in irregular 2D and 3D regions. Its development arose from the need to solve partial differential equations within physical regions

Computational Neuroscience
edited by Bower, Plenum Press, New York, 1997

with complex geometry. Due to the complex, folded nature of the human cerebral cort we use numerical grid generation to embed a 3D coordinate system inside cortical tissu Neurons, either individually traced or synthetically generated, are then embedded inside th gridded solid model of the cortical tissue and visualized in this environment. More generall similar considerations apply to brain nuclei.

1.1. Objectives

Biologically-Consistent Finite Element Decomposition and Grid Generation o Brain Tissue Our primary objective is to embed boundary-conforming grids within soli model reconstructions of cortical areas and brain nuclei. Numerical grid generation tech niques rely on boundary information to produce the grids. We first decompose the solid mode into finite elements to provide the boundary information for the numerical grid generatior methods. To establish finite elements in a manner consistent with developmental neurobiol ogy, the elements are chosen to follow the natural symmetries of the tissue, as defined by its primary native neuron type and thinking how a neuroanatomist would cut tissue locally to make successive sections look as alike as possible. Numerical grid generation can then be employed to establish a curvilinear coordinate system within each finite element, and hence throughout the solid model. This coordinate system provides a means of orienting neurons and specifying physical barriers and chemical gradients within the volume.

Biologically-Consistent Mapping of Neurons into the Gridded Solid Model Our second objective is to embed the gridded solid model with a population of neurons. Sparse populations of neurons can be drawn from databases of measured neurons, or stochastically generated using L-system modeling as described by McCormick and Mulchandani [2, 3, 4]. The grids provide a means of positioning the neurons in the solid model of reconstructed tissue, and specifying positional forces within the volume. The embedded neurons are chosen to be statistically consistent with those found in the actual tissue.

Visualization of Neuron Populations within the Gridded Solid Model Our third objective is to visualize a population of neurons within reconstructed tissue using computer graphics in conjunction with the grid generation and neuron mapping methods. An interactive approach allows the user to freely explore the environment.

2. RESULTS

In this section results generated with the software developed for this project are presented.

2.1. Reconstruction

A small section of human cerebral cortex is reconstructed from a data set containing images collected from the brain of a 76 year old normal female human cadaver. The images were obtained from the UCLA Laboratory of Neuro Imaging World Wide Web site (http://www.loni.ucla.edu)[5]. The brain was cytosectioned through the horizontal plane in 100 μm increments on a heavy duty cytomacrotome. The cytomacrotome was equipped with a high resolution camera for digital image capture of the serial images $(1024^2, 24 - bit)$. The

images were scaled down ($512^2, 24-bit$) for distribution over the Internet. Forty-two serial slices were used for the reconstruction.

Contours were collected from each of the images using *Elastic Reality* (Avid Technologies). *Elastic Reality*, a special effects tool for 2D and 3D animation allows contour construction using piecewise cubic bezier curves and facilitates comparison of consecutive contours. Contours were generated for the outer and inner cortical boundaries. The contours are resampled and the resulting points used for 3D reconstruction.

2.2. Reconstruction with Smoothing Splines

The contours were sampled, and smoothing spline surfaces were fit to the samples using the FORTRAN surface fitting routines written by Dierckx [6]. Interpolating surfaces are first fit to the data. The reconstruction using interpolating spline surfaces is very rough. This most likely demonstrates the "wiggly" noise that is picked up in the surfaces when no smoothing is used. Next, smooth approximating surfaces are fit to the data. A smoothing factor $S = 1$ is used. Figures 1 and 2 show two views of the reconstructed tissue using the smooth approximating surfaces. The resulting reconstruction is much better than the interpolated surfaces.

2.3. Finite Element Decomposition

The finite element decomposition which was used here is a simple sampling of the parameter domain. A grid was constructed for both surfaces in parameter space by choosing lines of constant u and v at even parametric increments. The grid lines in parameter space define u,v grid curves on the surface. The w lines are linear segments connecting the u,v intersection points on the outer surface to the u,v intersection points on the inner surface. Figures 1 and 2 show the finite element grid lines on the surface of the reconstructed tissue. There was no attempt to construct elements which follow the crest lines in the tissue. The finite element lines, which follow the crest and valley lines in the two figures, were purely accidental. Techniques to follow crest and valley lines are described in Batte [8]

2.4. Grid Generation

The 3D transfinite interpolation grid generator was used to generate grids in the reconstructed human cerebral cortex and rat hippocampus. Figure 4 shows the boundary edges of a single finite element from the human cerebral cortex.

A slice of rat hippocampus was reconstructed from an illustration taken from *The Rat Nervous System* [7] using the same reconstruction techniques as above. Figure 3 shows the boundaries of the finite elements.

2.5. Mapping Neurons

Finally, a sparse network of neurons is mapped into the reconstructed tissues. Figure 4 shows a set of pyramidal cells mapped into the the cerebral cortex finite element. Figure 5 shows a set of pyramidal cells mapped into the rat hippocampus finite elements.

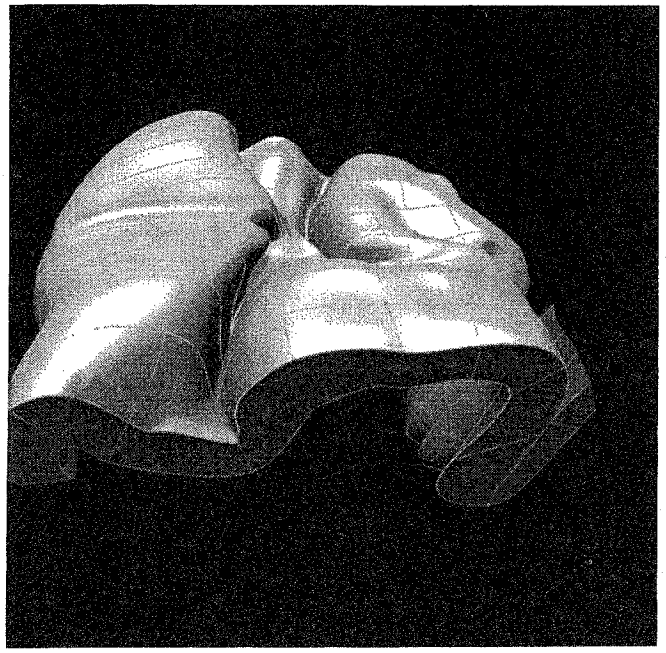

Figure 1. Finite element decomposition of the solid model (outer view).

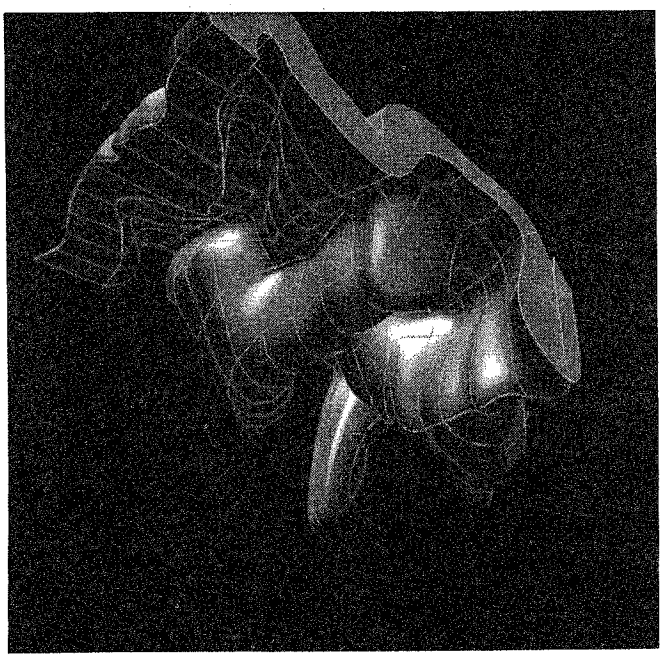

Figure 2. Finite element decomposition of the solid model (inner view).

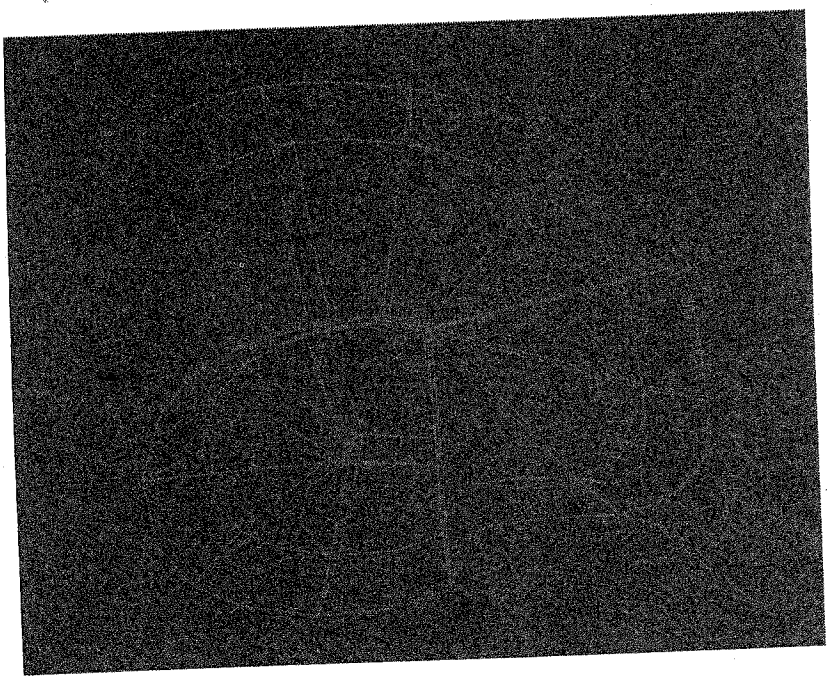

Figure 3. Hippocampus finite element boundaries.

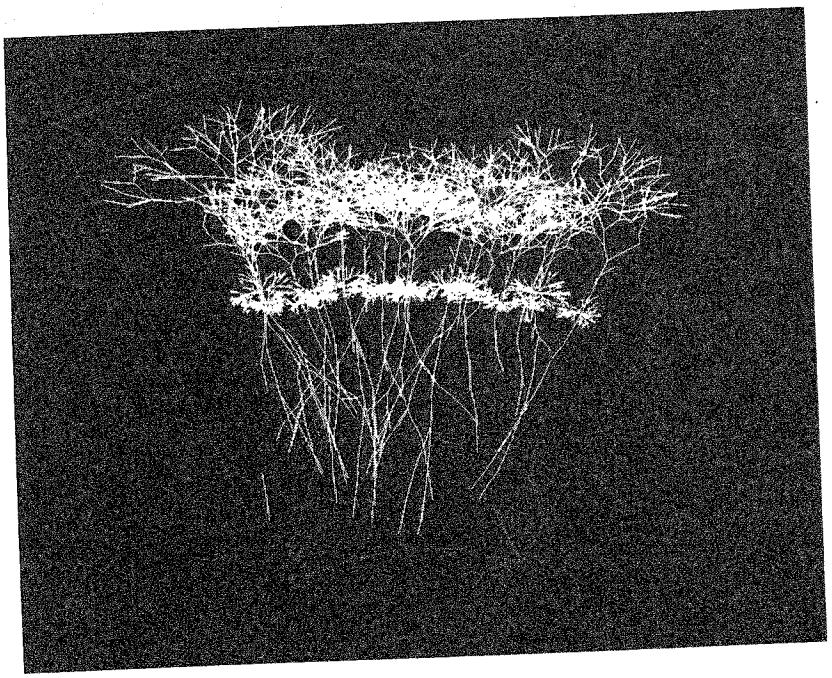

Figure 4. A population of pyramidal cells embedded in a cortical finite element.

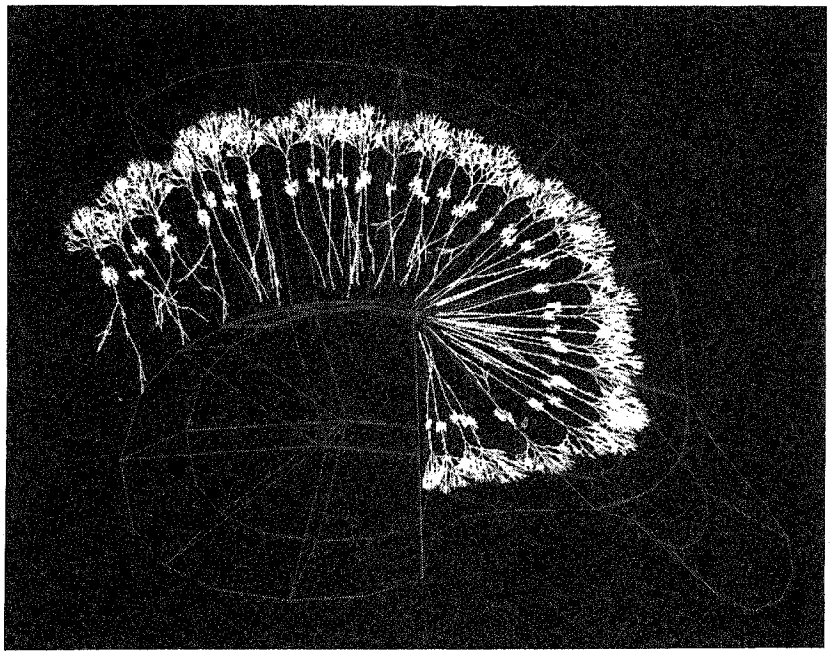

Figure 5. A population of pyramidal cells embedded in hippocampal finite elements.

3. SUMMARY

In this work, smooth approximating B-spline surfaces are used to reconstruct brain tissue from scanned section data. A proposed technique decomposes the reconstructed tissue into finite elements in such a way that preserve symmetry within the tissue. Grid generation methods are used to provide a curvilinear coordinate system within the finite elements. The grids and mappings provided by the grid generators allow either synthetic and manually traced neurons to be embedded inside the finite element model of the tissue. Finally, tools which visualize these grids and neuron data sets were implemented.

REFERENCES

[1] P. Knupp and S. Steinberg, *Fundamentals of Grid Generation*. Boca Raton, FL: CRC Press, 1994.
[2] B. McCormick and K. Mulchandani, "L-system Modeling of Neurons," in *Proc. Visualization in Biomedical Computing*. SPIE, 2359 pp. 693-705, 1994.
[3] K. Mulchandani and B. McCormick, "A Framework for Modeling Neuron Morphology," *Computational Neuroscience: Trends in Research 1995*, J. Bower ed. San Diego, CA: Academic Press, Inc, 1996. pp. 453-458.
[4] K. Mulchandani, "Morphological Modeling of Neurons," Masters thesis, Department of Computer Science, Texas A&M University, 1995.
[5] Toga, A, Ambach, K, and Schluender, S, "High-resolution anatomy from in situ human brain," *NeuroImage*, vol. 1, pp. 334-344, 1994.
[6] P. Dierckx, *Curve and Surface Fitting with Splines*, Oxford, England: Oxford University Press, 1995.
[7] D. Amaral and M. Witter, "Hippocampal Formation," *The Rat Nervous System*, G. Paxinos ed., San Diego, CA: Academic Press, Inc, 1995.
[8] D. Batte, "Finite Element Decomposition and Grid Generation for Brain Modeling and Visualization," Masters thesis, Department of Computer Science, Texas A&M University, May, 1997.