SAND2011-1090C

Parallel design simulation for neurologically inspired systems.

Richard Schiek[1], Christina Warrender[2]
Sandia National Laboratories, Albuquerque, NM
[1]Electrical Systems Modeling, [2]Cognitive Modeling

Introduction

Simulation of neural systems opens many avenues of discovery. Through detailed, neural-circuit simulation, we are investigating:

- **Scaling of neurologically based designs**
- **extraction of governing parameters from large experimental data sets**
- **understand the dynamics and stability of natural systems**
- **constraining the design of new, experimental systems.**

Approach

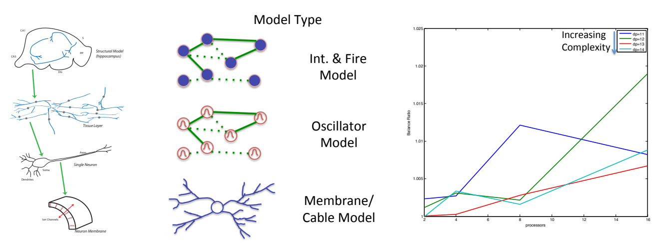
While neurological systems carry information as electrical signals, the typical neurological circuit topology is very different from a circuit topology. For example, neurons within the brain connect to on the order of 10^4 neurons, and not always the nearest neighbors. Additionally, the underlying electrical signal is analog in nature and has many forms from a sub-critical, bias like behavior, single spikes to spike trains or packets. The resulting functional unit is capable of apparent computational efficiency at very low power

The goal of this work is to develop computational and statistical tools to enable efficient parallel simulation of neurologically inspired systems. Specifically, we're extending traditional Spice style circuit simulation to accurately model individual neuron behavior in a highly connected circuit. An important additional aspect to this work is uncertainty quantification of neural model parameters so that one can gauge stability of a neural based system. We have implemented common neurological ion-channel models (e.g. Hodgkin-Huxley, Connor-Stevens) in a dynamic cable-equation format within a circuit simulator, Xyce (xyce.sandia.gov); see simulation outline below. This allows one to use a netlist style syntax to describe a collection of neurons for simulation. As with any circuit simulation, the model parameters for the circuit components are critical in determining the circuit's performance.

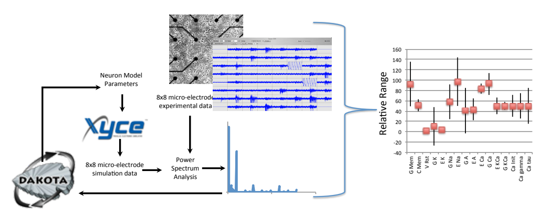
Experimental data from micro-electrode array recordings on hippocampus cell cultures (data courtesy of B. Wheeler & D. Khatami, U. of Florida) were used to bound the simulation parameters. Specifically, transient data from the simulations is compared to micro-electrode array data. However, direct comparison cannot be made between the experimental and simulation data in the transient domain because of the unknown initial condition state of the experiments and the unknown topology of the experimental system. Two approaches are taken to mitigate these problems. First, by transferring the results to a frequency domain and constructing a power-spectra, one can compare the two sets of data and infer important properties. Differences between the simulated and experimental power-spectra allow one to both optimize the fit of the simulation to the experiments and calculate the uncertainty allowed in the simulation's model parameters. Second, since the underlying cellular topology is unknown for the experimental system, random topologies (and some directed topologies for verification) are generated and used in the simulation. Thus, both the model parameter space is searched and the circuit topology space is searched for systems that dynamically mimic the experiments. This allows one to quantify what is unknown or unrepresented in both the experiments and simulations leading to a better understanding of both results

Finally, because the computational process can be automated, tens to thousands of simulation parameters and or topologies can be tested for their sensitivity on the results. To confront the geometric scaling for simulation needs, we utilize a hierarchical parallel simulator. Xyce can run on multiple processors in a distributed or shared memory system and the uncertainty quantification controller, Dakota, can control and dispatch multiple jobs in parallel. Thus, one can efficiently utilize a computing cluster where each compute node has multiple cores and there are multiple compute nodes.

Altering Model Abstraction / Complexity Impacts Scaling



Using Fourier analysis for parameter extraction



By coupling simulation with fitting to experimental data, we can find not only an optimal fit, but the range within which the simulations dynamically behave the same as the experiments.

References:
Shepherd, Gordon M., "The Synaptic Organization of the Brain," 5th edition, Oxford University Press, pg 7 & 458 (2004).
Brown, M. W. & Bashir Z. I., "Evidence concerning how neurons of the perirhinal cortex may effect familiarity discrimination," *Phil. Trans. R. Soc. Lond. B*, 356, 1082—1095 (2002).

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.