Development of *In Silico* Brain for DARPA REPAIR Project

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Introduction

Grasping is an important component of object manipulation, but most hand prosthetics lack somatosensory feedback. **Aim:** to create an *in silico* brain model of hand grasping with somatosensory-mediated learning for a brain-machine interface (BMI).

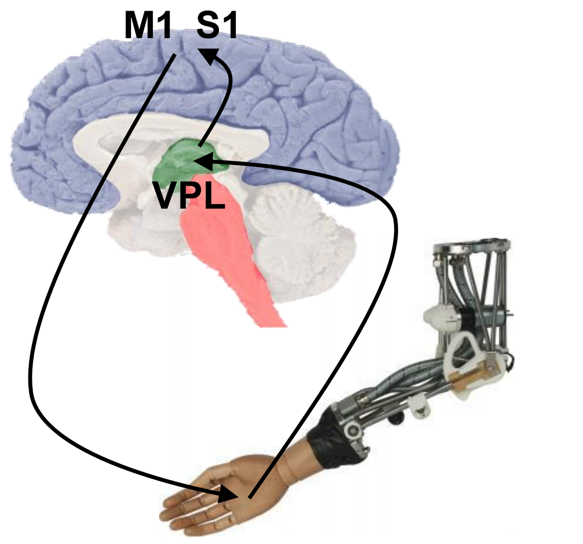

Fig. 1: Aim of project: to have a robotic limb operate with closed-loop somatosensory feedback. Major brain areas being modeled include thalamic VPL and cortical S1 and M1.

Approach

Standard BMIs use blind learning algorithms; our approach is based on real brain physiology.

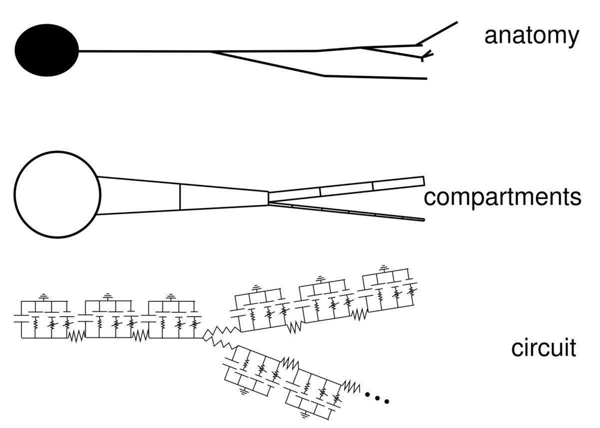

Fig. 2: Three complementary ways of viewing a neuron: as a biological construct (top), a spatial construct (middle), and a mathematical construct (bottom).

To capture the multiscale nature of the problem (Fig. 2), we use four simultaneous approaches:

1. Full-size multicompartmental models of neocortical and thalamic cells.
2. Single-compartment Hodgkin-Huxley models with full integration of linked ODEs.
3. Friesen formalism for integrate-and-fire-or-burst parameterizations.
4. An event-driven cortical model (Fig. 3), which provides a 20-fold increase in speed by utilizing a set of analytic integration rules.

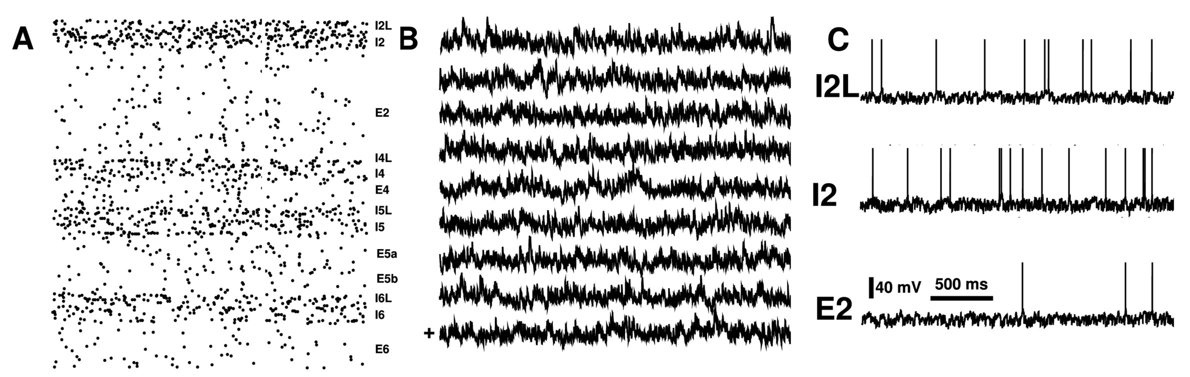

Fig. 3: Activity in the event-driven model, showing spike rasters (left), local field potentials (middle) and single cell voltages (right).

Thalamocortical model

This is based on the thalamocortical model of Bazhenov et al. (1998), with spatially continuous mapping from a thalamic nucleus to a cortical sensory area. We made this model three-dimensional and defined synaptic connections via probabilistic Gaussians (Fig. 4).

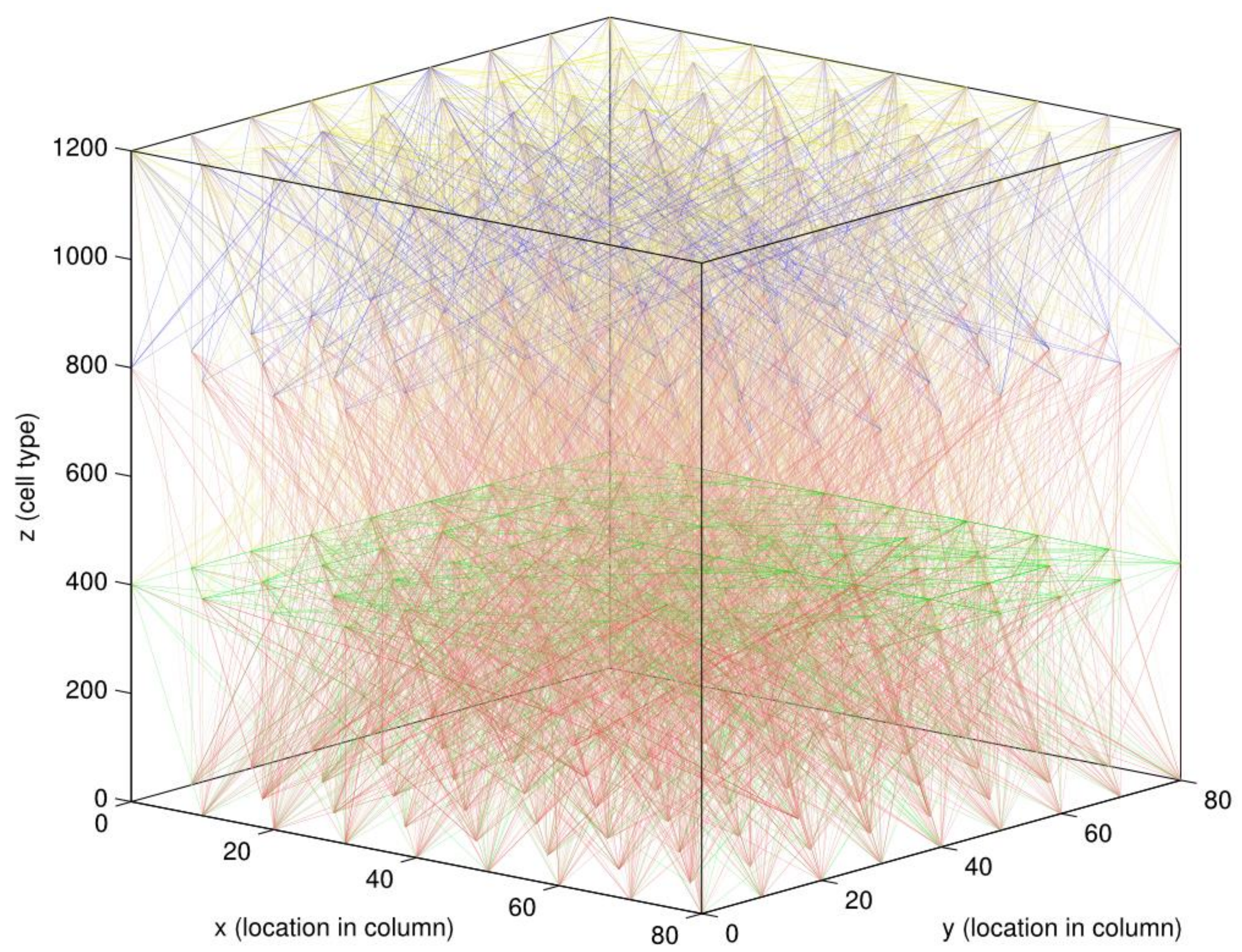

Fig. 4: Axonal connections in the thalamic model. Only 5% of connections are shown here. Color shows efferent cell type while intensity shows distance.

We also added a MATLAB-based graphical front-end for data analysis and visualization, allowing rapid and convenient use by members of the experimental group.

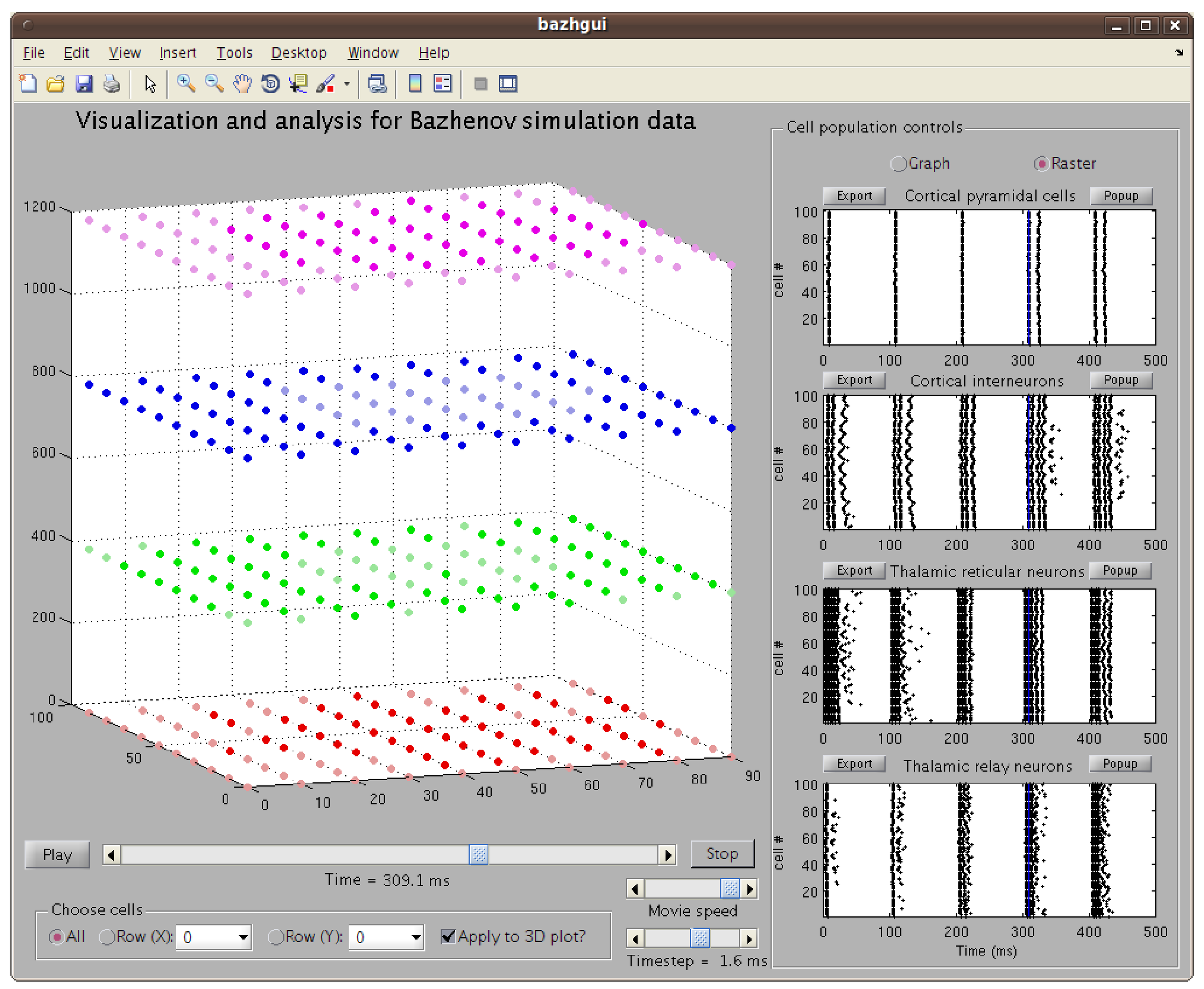

Fig. 5: Graphical user interface for the thalamocortical model, enabling "4D" plotting of model activity, as well as raster plots, summed activity graphs, and data extraction tools.

Event-driven cortical model

Efficient simulation allows a large number of cells to be used. This model produces excellent matches to experimental data (Fig. 6), and can be driven directly by *in vivo* intracellular recordings (Fig. 7).

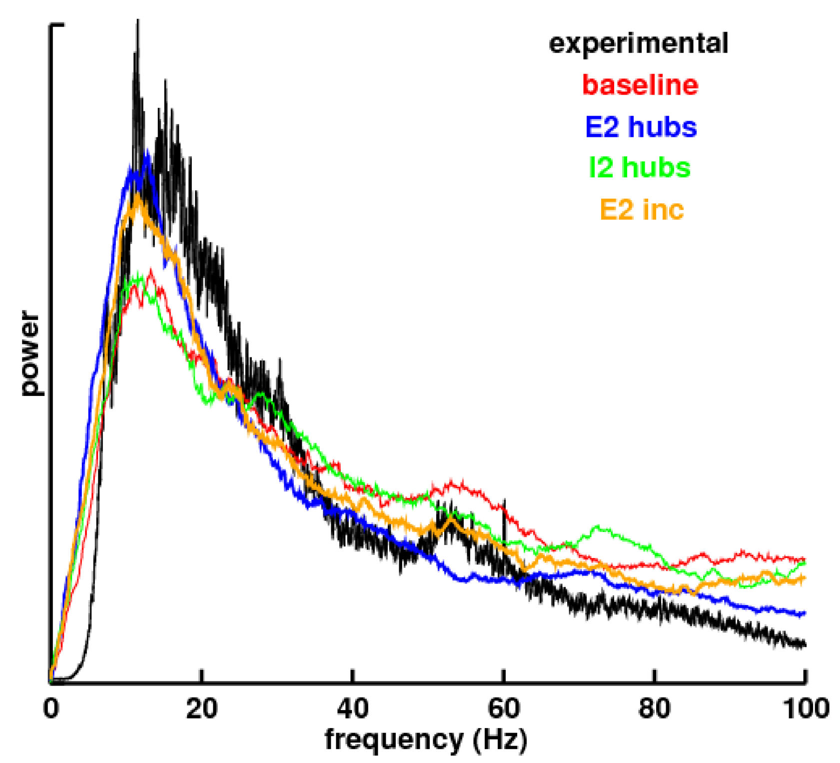

Fig. 6: Comparison of modeled spectra (colored) with an experimental spectrum (black) recorded from rat prefrontal cortex.

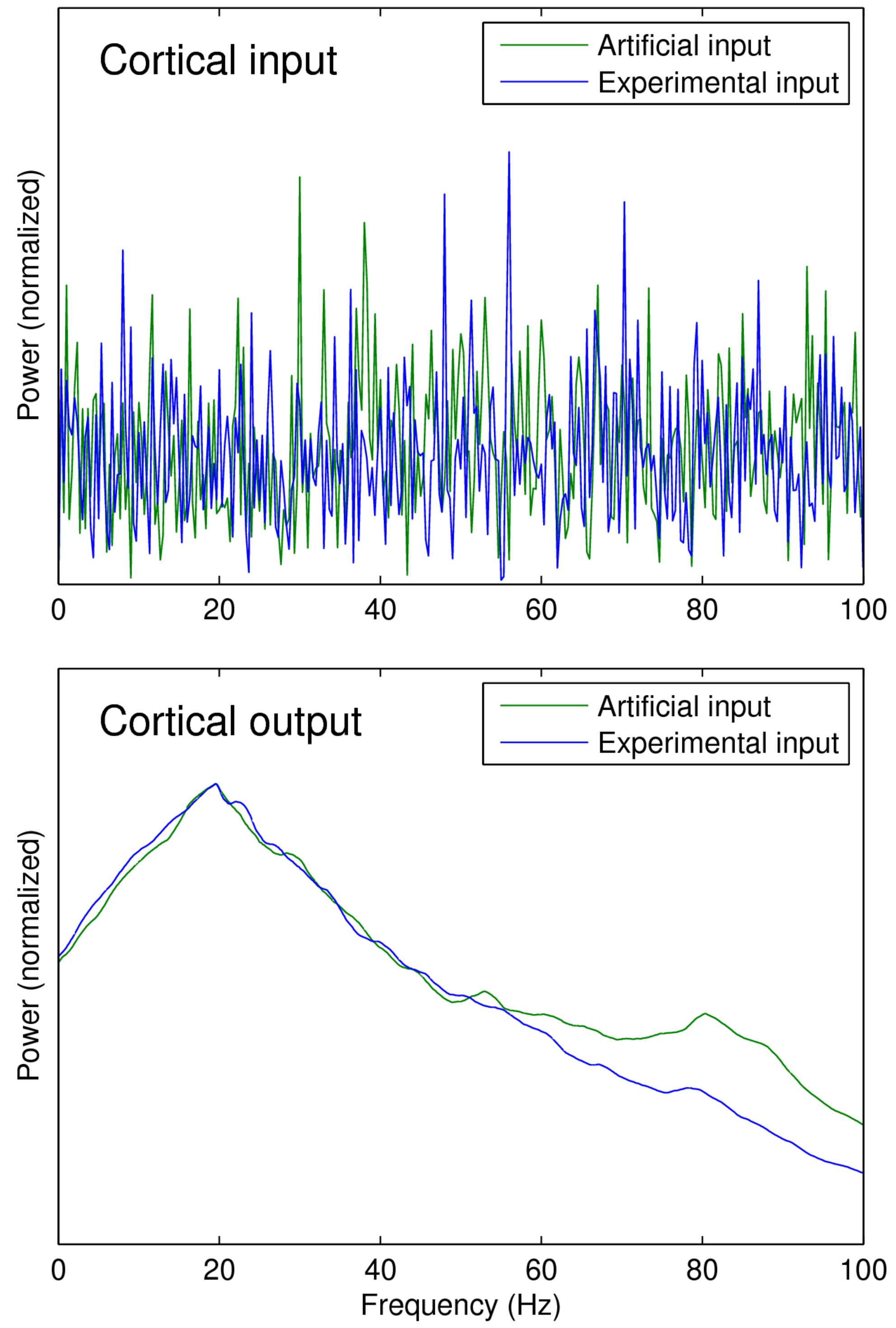

Fig. 7: The cortical model can be driven by artificial white noise (green) or by experimental data recorded from rat VPL neurons (blue). The two inputs result in similar outputs for most of the spectrum, but diverge above 60 Hz.

Development plans

Major goals, challenges, and projects:

- Integrate the existing models into a single model capable of covering a wide range of scales and realism
- Incorporate an effective and realistic learning algorithm at the synaptic level
- Evaluate the role, if any, that cortical columns play in the motor cortex (Fig. 8)
- Further develop collaborations with experimentalists, allowing rapid iterations of both models and experiments

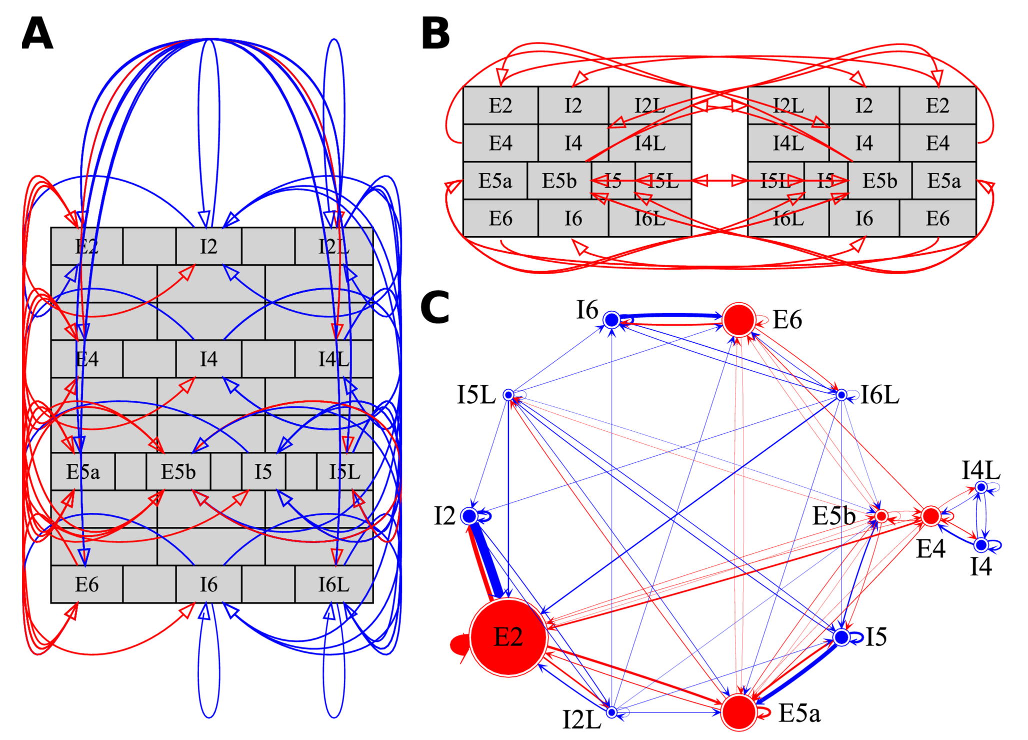

Fig. 8: Connectivity in the event-driven cortical model, showing difference between (A) intra- and (B) inter-column connectivity, as well as (C) relative connection strengths.

References

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