A 3D Computational Model for Analyzing the Effect of Ephaptic Coupling on Neural Stimulation

Andrew Gilbert*, Kyle Loizos, and Gianluca Lazzi
Department of Electrical and Computer Engineering, University of Utah, Salt Lake City, UT, 84112, USA

The hippocampus is the region of the brain responsible for long-term memory formation. Impairment of the hippocampus can disrupt the memory creation process, which can lead to disabilities such as Alzheimer's disease and dementia. A prosthesis is being developed (Berger et al. 2011) to potentially restore partial memory function. This prosthesis relies on a biomimetic model of the non-linear transformation between sections of the hippocampus. The model uses spike train inputs from downstream in the hippocampus to predict resulting firing pattern upstream, bypassing the dysfunctional section. Artificial memory restoration is facilitated through electrical stimulation following the predictions of this model. However, one aspect that is not yet well understood is the optimal stimulation parameters including current magnitude, frequency, electrode placement, etc. We constructed a multi-scale model to predict the response to electrical stimulation within the Cornu Ammonis (CA) of a rat hippocampus. Initial studies were conducted to characterize the current magnitude thresholds for stimulation of a CA1 pyramidal cell.

One of the mechanisms that could cause a change in threshold currents is ephaptic coupling. Neural activity can modify local field potentials. Ephaptic coupling is the process by which these local field potentials alter the membrane potential of adjacent neurons. This is particularly important within the hippocampus due to the high cellular density in the CA. This effect has been shown to cause synchronization of firing rates within a group of neurons, which is believed to strengthen memory formation (Rutishauser et al. 2010). However, it is challenging to experimentally separate the effects of synaptic coupling and ephaptic coupling on neuron firing patterns.

This work explores the effects of ephaptic coupling on cell spiking. We constructed a 3D model of a cell to determine a) the magnitude of the local field generated by an action potential and b) how this field affects surrounding neurons. This model is combined with the previously mentioned hippocampus model to determine the effect on stimulation thresholds and the interaction between the two fields. We will present a series of increasingly complex computational models to explore the importance of including ephaptic coupling in modeling neuroprosthetic stimulation. Results will include a comparative study of the firing patterns of two adjacent cells with and without ephaptic coupling. In addition, input from a stimulating electrode will be included to study implications on current magnitude thresholds. Through this work we hope to enhance the accuracy of computational models for neuroprosthetic stimulation.