Graduate Research Proposal - Background

Today almost 2 million people in the U.S. face functional impairment due to limb loss and amputations with more than 185,000 amputations occurring every year. Neural prostheses are devices that aim to return full functionality to patients through brain-machine interfaces (BMIs). Emerging neural prostheses decode the user's intention from neural signals recorded directly from the brain and create a closed-loop sensory feedback system through neural stimulation as shown in figure 1. The primary components of this technology are the neural signal interpretation algorithms and the neuromodulators (implanted neural recording and stimulation hardware). Recent advances in neural decoding techniques indicate the achievable high accuracy of BMIs. Previous work by Dr. Rajesh Rao demonstrates the viability of an unsupervised hierarchical k-means clustering algorithm to predict human behavior from brain recordings [2]. Advances in neuromodulators include recent work by Dr. Jan Rabaey on OMNI a wireless, low-power modular and distributed closed-loop neuromodulation device for chronic use [3].

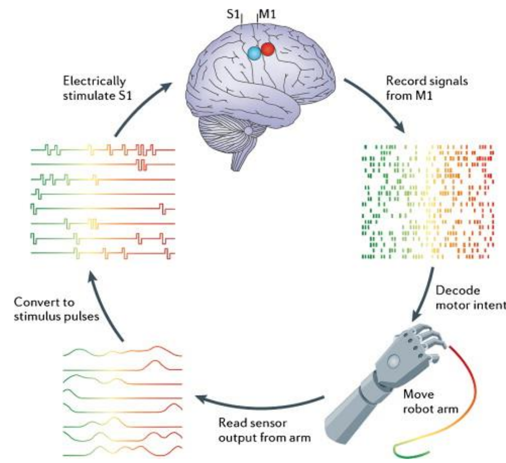

Figure 1: Closed-loop Feedback System [1]

Proximity of neuromodulators to neural tissue results in stringent power restrictions; any neural decoding algorithms must occur on external machines. Neuromorphic computing systems, hardware designed to function like biological neurons, are highly capable of enhancing brain-machine interface functionality. Classification algorithms on neuromorphic processors use 2 or more orders of magnitude less energy than on existing digital hardware. Implementing a neuromorphic processor in neural prostheses has the potential to improve BMI power consumption and mobility by eliminating data transmission and external hardware. **A need for the consolidation of these 3 components - neural decoding, neuromorphic computing and neuromodulation - in hardware for BMI implementation has been clearly identified** [4].

Proposition

Throughout my undergraduate degree, I have conducted research on neuromodulators' hardware-software interface, gained experience in neural signal processing and learning algorithms (such as SVMs, PCA and hyperdimensional computing), and worked on and gained an understanding of neuromorphic computing for adaptive learning hardware. I had the experience of working with three distinguished professors - Dr. Jan Rabaey, Dr. Rajesh Rao and Dr. Hugh Barnaby - on these distinct yet complementary areas. If I have the honor of receiving the NSF GRFP, I propose to fuse my knowledge in each to **implement complex adaptive learning algorithms on neuromorphic hardware integrated with a neural recording and stimulating system.**

Research Plan

Year 1: *Evaluation and integration of neuromorphic hardware models with neural recording and stimulation devices.* Cutting-edge neuromorphic chips such as, but not limited to, Intel's *Loihi*, IBM's *True North*, and the commercially-available Intel *Curie* module (if unable to obtain the former two) will be evaluated on power consumption, learning capabilities, applicability to neural decoding and accessibility. Consequently, an interface between the neuromorphic processor and the neuromodulation system including data transmission to and from each module will be designed.

Year 2: *Implementation of adaptive learning algorithm on neuromorphic hardware for neural signal decoding/interpretation.* Various filters and learning algorithms will be evaluated including, but not limited to, k-means clustering, support vector machines, and spiking neural networks given potential performance on neural data and constraints of the selected processor. This involves research, design, implementation and testing of the algorithms on the neuromorphic processor to determine functionality and competence.

Year 3: *Testing, validation, improvement and finally study of system to advance knowledge of possibilities/limitations of neuromorphic applications in neural engineering.* This process will involve testing of the system as a whole, ensuring data transmission between the neuromodulator and neuromorphic processor and functionality of the algorithm on the processor. Once the system is finalized, studies will be conducted to determine accuracy, speed, and power consumption of the system signifying operability in brain tissue.

Further study: Research beyond the initial 3 years will include 2 years of *in vivo* studies to test and validate the system's recognition of motor intention from neural data in animals.

Facilities

To conduct this study, I will work with Dr. Jan Rabaey at UC Berkeley. He has expressed considerable interest in working with me if I receive the NSF GRFP. I will integrate the neuromorphic hardware model with his group's previous work on OMNI, the neuromodulation device. The neuromodulator is the primary component of my proposal on which the neuromorphic processor and learning algorithm are built. Working with Dr. Rabaey in UC Berkeley and continued mentorship from Dr. Barnaby and Dr. Rao on the neural decoding and neuromorphic modules will provide the resources I need to meet the goals of this proposal.

Intellectual Merit and Broader Impacts

Previous work claims that a neuromorphic neural interface will eliminate the need for external machines and significantly reduce power consumption enabling the possibility of a fully-implanted system. Potential for success has been demonstrated through simulations and modeling but the lack of a direct hardware implementation limits understanding of the true feasibility and impediments of utilization of neuromorphic processors in a closed-loop feedback system particularly regarding accuracy, speed and power consumption. **This project will develop enabling technology that will advance the knowledge of the capabilities and limitations of neuromorphic applications in neural engineering**. The work produced from this project will be presented at national and international conferences.

Medically, the highly competent neural interface this research addresses has the potential to change lives through applications in bypassing spinal cord injury, deep-brain stimulation, and engineering plasticity for neurorehabilitation. Socially, this interdisciplinary project promotes collaboration between academic institutions. My experience with TYE taught me that the drivers of interest in engineering are role models and incredible technology. When I talk to middle and high school girls about my research - mind-controlled prosthetics - their eyes light up with possibilities. Throughout my graduate career, I will continue mentoring young girls to pursue engineering and will use this research to spark excitement for engineering in young minds.

[1] S. J. Bensmaia et al., "Restoring sensorimotor function through intracortical interfaces: progress and looming challenges," *Nature Reviews Neuroscience*, vol. 15, no. 5, pp. 313–325, 2014. [2] N. X. R. Wang, R. P. N. Rao et al., "Unsupervised Decoding of Long-Term, Naturalistic Human Neural Recordings with Automated Video and Audio Annotations," *Frontiers in Human Neuroscience*, vol. 10, 2016. [3] A. Moin, J. Rabaey et al., "Powering and communication for OMNI: A distributed and modular closed-loop neuromodulation device", *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2016. [4] F. Broccard et al., "Neuromorphic neural interfaces: from neurophysiological inspiration to biohybrid coupling with nervous systems," *Journal of Neural Engineering*, vol. 14, no. 4, p. 041002, Feb. 2017.