

My goal is to combine my background in physics and mathematics with experimental neuroscience to build quantitative models of how brains work. As a child, I fell in love with mathematical problem-solving but it was not until college that I knew what to do with that love. I considered several majors in my first few semesters at USC, but my persistent question - “yes, but how does that work?” – eventually led me to the physics department and an electricity and magnetism course with Dr. Paolo Zanardi. Using the mathematical problem-solving that I revealed in, we explored the physical mechanisms behind magnets, sunsets, and a wealth of fascinating natural phenomena. The uncompromising inquisitiveness of physics resonated with my own curiosity, and I was hooked.

I became especially interested in the physical basis of information processing and joined Dr. Zanardi’s Quantum Information Theory group in Torino, Italy the following summer under a USC Provost Research Fellowship. Through calculations and simulations, we sought to define an appropriate concept of thermal equilibrium in quantum mechanics. I learned a great deal about milking mathematical models and simulations for physical results, but most importantly, the excitement of constructing a new theory convinced me that I wanted to spend the rest of my life doing science. Combined with a desire to inspire other students as Dr. Zanardi had done for me, I knew then I wanted to become a professor.

It struck me that while I and other researchers grappled with the fundamental limits of computation, we still lacked a deep understanding of the very information processor that enabled us to do so – the human brain. When I thought about math, which neurons fired? How were the things I learn embodied in my brain? Was it possible to understand the physical basis of the human mind just as we understand a magnet or sunset? I searched for a neuroscience group at USC who might have need of a physicist and soon found Dr. Ted Berger’s group, who were having an issue with their simulations of neural synapses. Their numerical integration algorithm was having trouble with the multiple timescales present in biological dynamics, and I discovered the source of this difficulty and proposed an adaptive algorithm to significantly speed up simulations. I also assisted a graduate student in building compartmental models of hippocampal neurons, gaining valuable experience in using the simulation package NEURON. Trading lessons in differential equations for explanations of AMPA dynamics, I also rapidly expanded my budding knowledge of modern neuroscience. Working with the Berger group confirmed to me that (1) it was indeed possible to understand the physical basis of the brain, (2) a background in physics and mathematics was quite useful in doing so, and (3) seeking to understand the biophysical mechanisms of neural computation was exactly the science I wanted to do.

Since then, I have pursued neuroscience and physics in parallel – neuroscience for the questions that drive me and physics to better understand the physical basis of information processing and hone my ability to build and analyze mathematical models. I spent the first half of summer 2010 at the Institute for Quantum Computing (IQC) in Waterloo, Ontario working with Dr. Andrew Childs on the proof of a mathematical theorem that we felt might lead to new algorithms for quantum computers. Over six weeks, Dr. Childs and I iterated between provisional theorems and test cases generated by a computer program I had written, converged on a candidate for the theorem, and found our proof. I gave an IQC colloquium on our findings, and Dr. Childs and I are currently working on a generalization of our result for publication. Beyond offering new tools of analysis, my physics research has also influenced my neuroscience by giving me a visceral understanding of the play between theory, simulation, and experiment and how to iterate between them.

Seeking additional neuroscience experience beyond USC, I spent the rest of summer 2010 at Stanford working with Dr. Kwabena Boahen’s Brains in Silicon group through the sponsorship of the Amgen Scholars Program. My project was to investigate suitable conditions for the existence of a neural network substructure called a synfire chain that has been theoretically predicted to increase the reliability of spatially and temporally patterned responses. The goal of this line of research is to aid the experimental search for synfire chains by making predictions of their signature activity patterns as well as which regions of the brain are most likely to exhibit them. Using calculations and simulations, I

investigated locally and globally connected neural network models chosen for their biological plausibility through consultations with one of Dr. Boahen's experimental neuroscience students. By simplifying synfire chain formation into a Markov process, I found that learning rules and past activity play a crucial role in the development of computationally useful synfire chains and presented my findings at the Stanford Amgen Scholars Symposium. In addition to granting me confidence in pursuing graduate research, my project conveyed to me the subtleties and importance of collaborations with experimental neuroscientists to build biologically realistic yet mathematically tractable models, an approach that I will continue to emphasize throughout my career.

Currently, I am working with USC Professor Bartlett Mel to understand how brains rapidly and robustly encode information presented only once. In particular, we are investigating the optimal dendrite morphology for memory capacity during one-shot learning tasks and studying how the optimal morphology varies with input features such as noise and density of activation. We hypothesize that dendrite morphology is optimized to shift response variability to a regime efficient for memory capacity. We are also exploring various definitions of memory capacity and the connections between them. One of Dr. Mel's students has amassed a collection of simulation data, and my role is to build mathematical models that help explain his results, enable analytic calculations of memory capacity, and suggest new simulations to further refine our hypotheses. Our hope is that the optimal biophysical variables we identify will correspond with experimental values in the brain. Our approach is characteristic of what I believe is a unique and important contribution that physics and mathematics may offer biology – explanations for the functional role of biological mechanisms rooted in arguments for their optimality.

My strategy of pursuing research in both physics and neuroscience has provided me with unique insights into the brain, valuable experience with interdisciplinary collaborations, and clarity on my career goals. I would like to pursue a Ph.D. followed by a professorship to continue my research and share my passion for discovery with eager young minds. Through collaborations with experimentalists and my training in physics and mathematics, I want to explore the links between biophysical mechanisms and their functional roles in neural computation. In addition to my research, I have pursued and excelled in several graduate courses in physics and mathematics and even picked up new analytic tools from other graduate departments, such as information theory and mathematical optimization. Concurrently, I have attained a significant knowledge of modern neuroscience through extracurricular study and research. Thus I am confident in my choice of graduate research and in my preparation for pursuing it.

Furthermore, I am confident that the University of Washington's Physics program would be a great place for me to do so. I am attracted by the large community of faculty and students interested in biophysics and particularly interested in working with Drs. Adrienne Fairhall, Fred Rieke, and Eric Shea-Brown, each of whom I have contacted. As I prefer theoretical work closely coupled with ongoing experiments, I am especially interested in a project co-advised by Dr. Rieke and either Dr. Fairhall or Dr. Shea-Brown. Two interests I might pursue with Drs. Fairhall and Rieke are the roles of prediction and online algorithms in vision. In particular, to what extent does the prediction of common input patterns enable the visual system to increase processing speed and reduce energy expenditure, and how do the temporal demands of a visual task affect the processing of neural signals? Another possibility would be to study the interactions of adaptive mechanisms acting on different timescales, a topic on which I have recently submitted an NSF GRFP research proposal (available upon request). With Drs. Shea-Brown and Rieke, on the other hand, I might seek an understanding of single-neuron response variability, exploring the relative contributions due to input statistics, biological constraints, the exploitation of stochastic resonance, and other potential sources. Another potential focus of our collaboration could be the modulatory effect of persistent network activity on single-neuron responses and the role of this modulation in neural computation. Though the research is my main attraction to UW, I would be remiss if I did not mention that I do my best thinking in the outdoors and welcome the opportunity to spend weekends hiking and mountaineering in the environs of Seattle.