Project B

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Introduction

There are two general approaches to creating an artificial intelligence that rivals biological brains. The traditional approach evolved out of computer science and psychology, and revolves around introspection about intelligence and the translation of one's ideas and perceptions about thinking into computer programs. This approach began with the Dartmouth conference in 1956, and achieved numerous small victories in the 1960s and 1970s, but began to fall short of its promises after about 1975. On the other hand, the neuromorphic approach is based on modeling actual brain structures, to various degrees of accuracy and abstraction. Nearly all secrets of life - from evolution to the structure of animal tissue to the mechanisms of heredity - were unlocked by observation and experimentation, so there is some reason to believe that the process of thought will follow the same pattern. In addition to the goal of strong artificial intelligence, accurate neuromorphic models are the only conceivable route to the eventual goal of brain uploading: a process for the mapping of a human brain and subsequent extraction of its intelligence, memories, and identity into a computer backup. Among the most notable current projects in modeling brain structures is IBM's Blue Brain Project. The project succeeded in mapping the 100 million synapses in a single rat neocortical column, but as the exact function of neocortical columns is unknown, it was impossible to verify the model's accuracy (nor did the project produce any insight into how the neocortical column works or even what it does).

Our approach is to begin with a very small organism and emulate its entire nervous system, before beginning to look at mammalian brains. In projects with such massive complexity, it is important to be able to verify and gauge progress at every step, and beginning with a neocortical column that has an unknown function does not satisfy that condition. By modeling an entire organism, we will be able to create a virtual reality environment to process the inputs and outputs from the virtual nervous system, and observe its behavior as compared with the actual nematode's. In addition, as the system is on a much lower level of complexity, it is conceivable that we will gain some insight into how the nervous system is structured to produce the behaviors it exhibits.

Background

Caenorhabditis elegans (C. elegans), a species of nematode, is the one of the simplest organisms with a nervous system, and has been studied so thoroughly that the development of all 1031 cells, including the 302 neurons, is known. The organism has a number of well-understood behaviors that can be verified, such as chemotaxis, thermotaxis, and mating; and there is also a great deal of data about various mutants that exhibit pathological behavior (e.g. rolling instead of swimming forward). As such, C. elegans is a promising subject for the development of the first computational model of the complete nervous system of an organism.

In recent years there have been several computational models published of portions of the C. elegans nervous system. None of them model the entire nervous system, however.

In 2001, Feree and Lockery published a computational model for chemotaxis in C. elegans, along with a simplified model for the physical mechanics of the nematode's body and locomotion. While the nonlinear neural network they used was biologically motivated, it is only loosely based on the actual neuroanatomy.

In 2004, Suzuki, Tsuji, and Ohtake modeled 18 of C. elegans' neurons using a neural network, simulating the organism's motion when it receives gentle touch stimulation. While they used the actual topology of the connections between those neurons, they used a genetic algorithm to evolve the weights in their network. They were able to reproduce the behavior of the nematode quite well, but their approach was limited insofar as they only modeled a small subset of the C. elegans nervous system, and that they did not employ any numerical measurements of the actual nervous system (only a map of which neurons were synaptically connected to others).

In 2009, Zhang, Schafer, and Breitling created a circuit model of the temporal pattern generator of the C. elegans egg-laying behavior. Their model makes detailed testable predictions, but, like the above, is limited to a small subset of the organism's nervous system.

Plan

We shall begin by replicating the work of Suzuki, Tsuji, and Ohtake. Given that the two primary weaknesses of their approach are (a) the scope of the model (it does not cover all neurons), and (b) the resolution of the model (it implements a highly elementary neuronal model), we will proceed to improve on their work in these two directions. As far as (a) is concerned, we will apply their methodology to increasingly larger subsets of the entire nervous system. To improve upon (b), we will incrementally improve the model of individual neurons and synaptic connections. The key to both of these paths will be the proper investigation of measurement, data collection, and verification methods. Throughout the entire process we will retain a tight experimental confirmation cycle, and collect electrophysiological data as needed.

Throughout this project we will strive to find the optimal balance between minimizing the space and time complexity of our algorithms while still emulating the essential features of the C. elegans nervous system, and making use of a tractable volume of biological measurements. It is currently unknown to what degree of biological accuracy a proper emulation would require, and we expect to make important discoveries about this matter throughout the project.

Verification Mechanisms

So far, we have developed several promising methods for verifying the accuracy of our computational model. With each iteration of our model, we intend to:

- Train it against some subset of behavioral data, and verify the emergence of other behaviors.
- Train it against typical behaviors, and show the emergence of experimentally confirmed pathological behaviors under "mutant" conditions.
- Train it against a fitness function that combines behavioral data with increasing levels of electrophysiological data
- Train it against a subset of electrophysiological measurements and verify the reproduction of the rest.
- Use it to formulate testable predictions about the actual organism and design experiments that would verify them.

Objectives

Our primary objective is to produce a computational model of the entire C. elegans nervous system, and confirm it by all possible metrics by July 2011. Along the way, we expect to achieve several important sub-objectives:

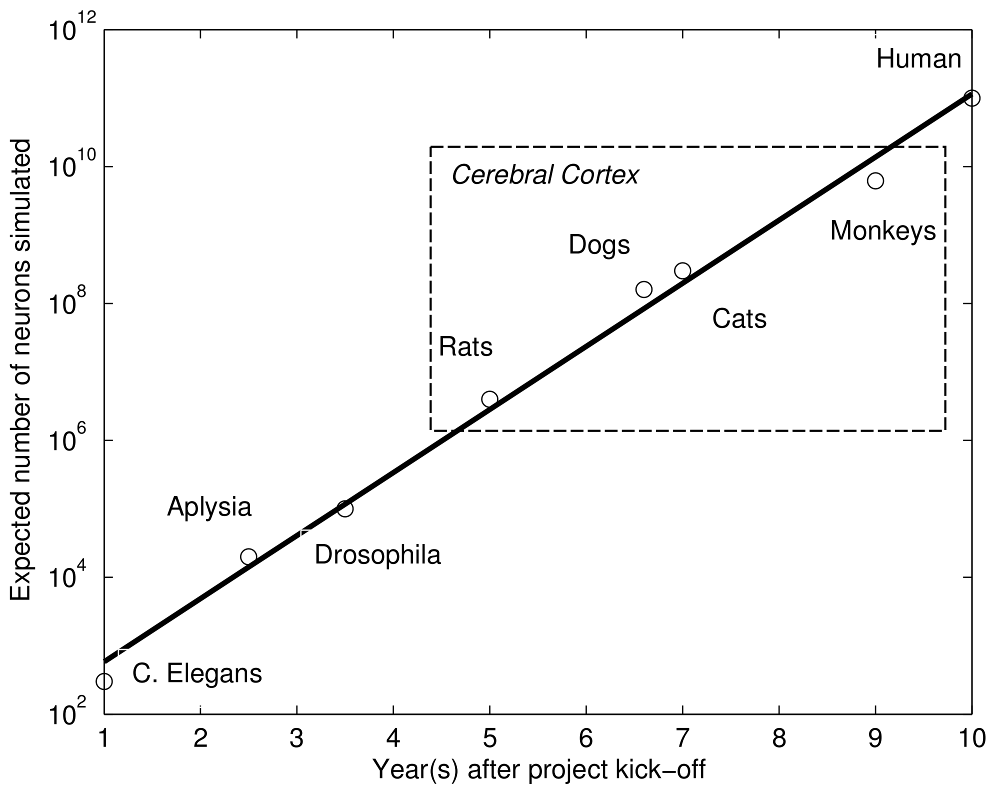
- Learn the degree and resolution of biological accuracy required to properly model behavioral input/output.
- Learn more about C. elegans neurons, and the functional blocks that nature uses to produce behavior.
- Improve techniques for taking detailed elecrophysiological measurements from neurons and implementing them computationally.
- Lay the groundwork for more complex neuromorphic AI.

Budget

- 3 researchers for one year - $100,000
- Lab equipment - unknown

Future Work

The goal of this project is to emulate the behavior of C. Elegans in a bacteria bath as a proof-of-concept. If we succeed in this, we will bring the same tight-cycle approach to emulating classic neuroscience model animals such as aplysia (~20,000 neurons), and then we will work with insects such as drosophila (~100,000 neurons) and ants (~300,000 neurons). Finally we will emulate the behavior of mammals with increasing complexity including rats (~4,000,000 cerebral cortical neurons), dogs (~160,000,000 cerebral cortical neurons), cats (~300,000,000 cerebral cortical neurons), and monkey(~6,200,000,000 cerebral cortical neurons). The ultimate goal is to simulate human brain (~10^11 neurons, 10^14 synapses). The larger the number of neurons, the higher the observed intelligence of that animal. At each stage, we will verify our animal model with the behavior observed. If our progress follows a smooth exponential progression, we would estimate reaching human level within 10 years.



Our Team

Rosa H. M. Chan is a Ph.D. candidate in Biomedical Engineering at University of Southern California (USC), where she has also received her M.Sc. in Biomedical Engineering and Electrical Engineering. Her research interests include computational neuroscience and the development of neural prosthesis. Before coming to USC, she received a B.Eng. with first class honors in Automation and Computer-Aided Engineering and a minor in Computer Science from the Chinese University of Hong Kong (CUHK). She also worked as junior research assistant at the Center for Micro and Nano Systems of CUHK, researching the manipulation of carbon nanotubes using dielectrophoretic force. She is the recipient of the prestigious Croucher Scholarship, Sir Edward Youde Memorial Fellowship for overseas study, and other 17 scholarships and awards. Her studies have brought her to New York University (USA), Kyushu University (Japan), and Boğaziçi Üniversitesi (Turkey) where she studied computer animation and visual effects, microfluidics for satellite applications, and biocomplexity. Thus far, she has authored and co-authored 14 papers in micro-electro-mechanical systems and computational neuroscience.

Michael Chen started programming computers when he was 4 years old, in 1989. After spending the next 13 years of his life programming and designing software, he started his first company when he was 17, and he has founded and built numerous companies since then. In 2009, Michael graduated Phi Beta Kappa from Oberlin College with High Honors for his research on consciousness. Michael is driven by an extreme passion for exploration and discovery, and is confident that Strong Artificial Intelligence is the single most beneficial invention human beings can develop.

David A. Dalrymple was born in 1991, graduated from University of Maryland Baltimore County with degrees in computer science and mathematics in 2005, worked for several small software companies and then started graduate school at MIT at 14. He got his master's degree in Media Technology from MIT at age 16, with Marvin Minsky as a thesis reader, and is now a Ph.D. student in the Mind Machine Project at MIT. His research interests are in efficient, massively parallel hardware and programming languages.