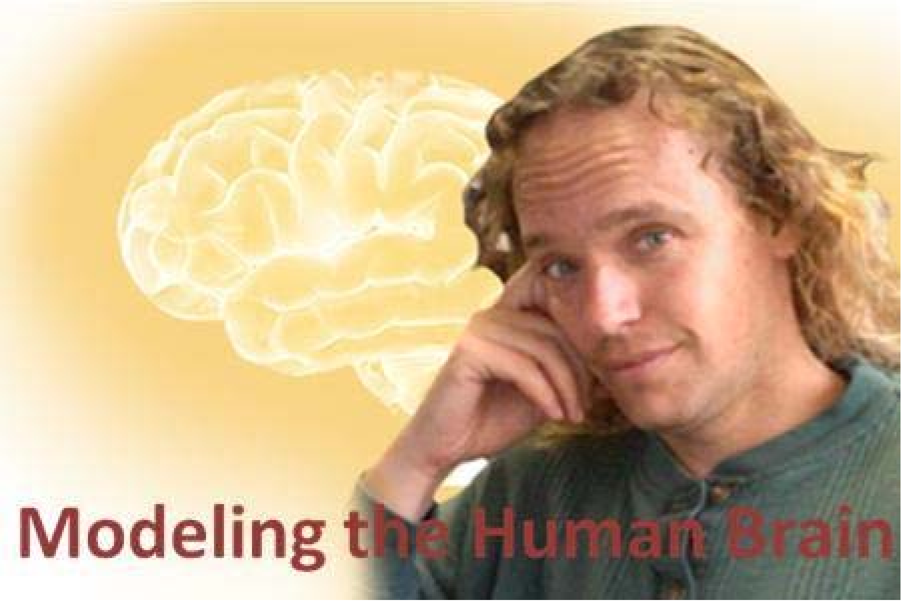
Research Profiles



What Fires Together, Wires Together

The power of modern computers grows, as does our understanding of the human brain…but can a computer ever model the brain? Traditionally there are two approaches to modelling the brain – one that simulates human thought, and the other that models its low-level network structure. Recently, these two approaches have been unified by a new method called the Neural Engineering Framework (NEF).

Chris Eliasmith is a professor in the Department of Systems Design Engineering and in the Department of Philosophy at the University of Waterloo. His NEF method is implemented in a software environment called Nengo (an amalgam of neural engineering objects). It simulates how neurons and neural systems interact to represent information, perform computations, and behave in perceptual, motor, and cognitive tasks.

"Nengo is a tool that can be used to model high-level cognition such as problem solving and learning using biologically realistic neurons," says Eliasmith.

The human brain consists of a network of several billion nerve cells called neurons. These neurons are connected to one another by synapses. Every time we think, move, see or remember something, a small electrical signal fires from neuron to neuron (an action potential) that is generated by differences in electric potential and moving ions in the cell membrane.

Nengo mimics this activity in detailed models of single cells. The basic computational element (a model neuron) can receive or send inputs to other elements. Much like the neurons in the brain, these model neurons send or receive inputs to each other using action potentials, which capture the change in voltage in individual cells, sending signals to one another.

Every time we learn something, the structure of our brain changes. Information travels along a network of synaptic connections, with more activity creating stronger synaptic connections. This phenomenon is called synaptic learning – and Nengo can do it too.

Each input in the model has an associated weight, which can change to model synaptic learning. The weighted sum of inputs is called a net input and its output signal can become an input for other neurons. This signal transmission in Nengo models represents synaptic communication between neurons and brain structures in humans.

Nengo has been used to simulate more than one million neurons, and requires extensive parallel processing to simulate synaptic communication and learning. SHARCNET provides the hardware resources required for the large amounts of data and calculations produced by the millions of model neurons. SHARCNET's number of large and powerful computers speed up the data collection by increasing the number of simulations run, as well as allowing more complex models with greater neurobiological details to be tested.

"The approach is versatile; it can be used to simulate simple tasks like a lamprey moving or be scaled up to more abstract and complex tasks such as taking a general intelligence test," says Eliasmith.

Nengo has been used to simulate motor control for arm movements as well as high-level cognitive tasks. It can model various learning and memory effects including, one trial learning, object recognition, and working memory. Nengo has also been used to build a brain model that solves the complex logic puzzle, the Tower of Hanoi, a task that requires planning and goal-directed action.

Other work by doctoral student Daniel Rasmussen has shown that Nengo can also solve Raven's Progressive Matrices, a measure of general intelligence. The purpose of the test is to identify the missing element that completes a pattern which is presented in the form of a matrix. Previous models used precoded rules to solve the problem, whereas Rasmussen's model learns to solve the problem on its own by comparing features of the symbols.

Performance on the Raven's Matrices declines in humans as they age as result of neuron loss and decreased processing ability. To investigate if the Nengo model can replicate this age effect, model neurons were removed, but the input remained the same. A population of Nengo models showed a performance declined on the task, mirroring the population data collected on humans. That means Nengo, can simulate high-level cognitive tasks as well as age-related changes in human performance.

The Nengo software and the underlying NEF methods have the ability to reproduce human cognitive performance effects found by neuroscientists and psychologists. Unlike traditional approaches, Eliasmith's combines high-level cognitive behaviour with realistic neurobiological simulations. Future studies will investigate performance on other cognitive tasks as well as try to further increase the realism and number of neurons simulated at the biological level.

Funding for this research is supported by SHARCNET, the Natural Sciences and Engineering Research Council, the Canada Foundation for Innovation, the Ontario Innovation Trust and the Canada Research Chairs program.

For more information on Dr. Eliasmith or his research please visit
http://watarts.uwaterloo.ca/~celiasmi/