Chapter 15
The Simulation of Spiking Neural Networks

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ABSTRACT

This chapter is an overview of the simulation of spiking neural networks that relates discrete event simulation to other approaches and includes a case study of recent work. The chapter starts with an introduction to the key components of the brain and sets out three neuron models that are commonly used in simulation work. After explaining discrete event, continuous and hybrid simulation, the performance of each method is evaluated and recent research is discussed. To illustrate the issues surrounding this work, the second half of this chapter presents a case study of the SpikeStream neural simulator that covers the architecture, performance and typical applications of this software along with some recent experiments. The last part of the chapter suggests some future trends for work in this area.

INTRODUCTION

In recent years there has been a great deal of interest in the simulation of neural networks to test our theories about the brain, and these models are also being used in a wide variety of applications ranging from data mining to machine vision and robot control. In the past the majority of these simulations were based on the neurons' average firing rate and there is now a growing interest in the development of more biologically realistic spiking models, which present their own challenges and are well suited to discrete event simulation.

This chapter starts with some background information about the operation of neurons and synapses in the brain and sets out some of the reasons why simulation plays an important role in neuroscience research. Next, some common neural models are examined and the chapter moves on to look at the differences between continuous simulation, discrete event simulation and the emerging hybrid approach. The issues in this area are then illustrated with a more detailed look at the SpikeStream neural simulator that covers its architecture, performance, typical

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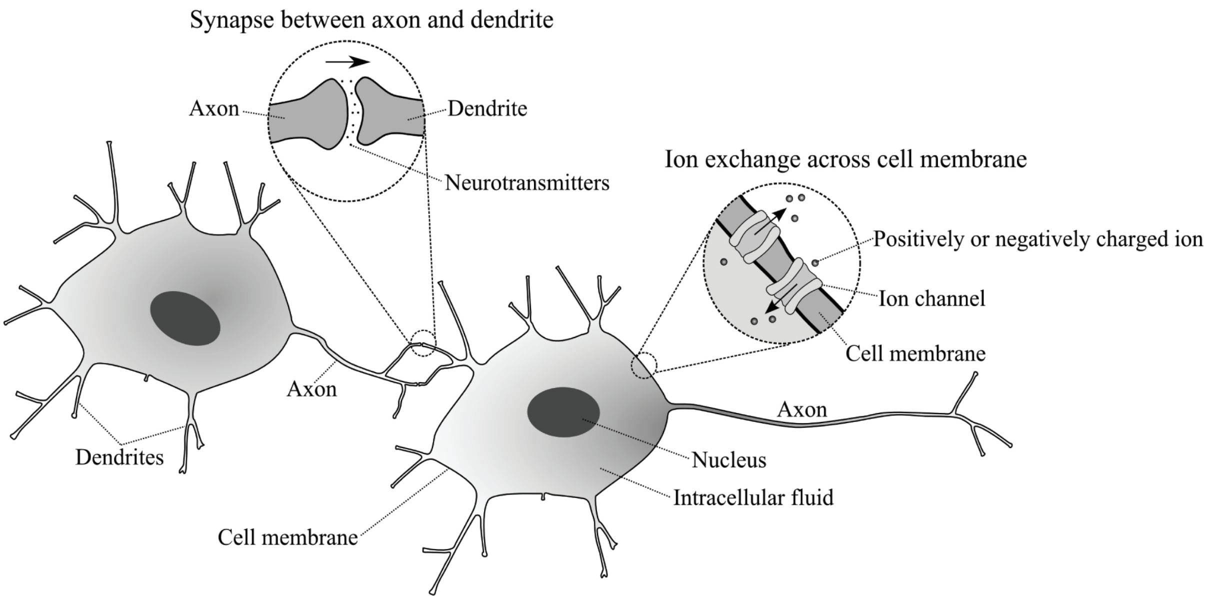
Figure 1. Two connected neurons



applications and recent experiments. Finally, the chapter concludes with some likely future directions for work in this area.

NEURAL SIMULATION

Neurons and the Brain

The main information-processing elements in the human brain are 80 billion cells called neurons that are organized into a highly complex structure of nuclei and layers that process different types of information.[1] Neurons send signals to each other along fibres known as axons, which connect to the dendrites of other neurons at junctions called synapses, as shown in Figure 1.

The body of each neuron is surrounded by a cell membrane that separates the nucleus and intracellular fluid from the extracellular fluid outside the cell. The cell membrane is crossed by porous channels that allow ions, such as sodium and potassium, to be exchanged with the extracellular fluid. Since these ions have a positive or negative charge, their movement through the cell membrane alters the voltage across it and neurons actively manage this voltage by pumping ions across the cell membrane so that the voltage remains at around -70 millivolts – a value known as the resting potential.

Neurons communicate by sending pulses of electrical energy along their axons that are known as spikes. When a spike reaches the dendrite of another neuron it increases that neuron's voltage, and if the voltage passes a threshold of about -50 millivolts, then the neuron 'fires' and emits a pulse or spike of electrical activity that is transmitted to other neurons. Since axons and dendrites have different lengths, these spikes take different amounts of time to propagate between neurons, and once a neuron has fired there is a period know as the refractory period in which it is unresponsive or less responsive to incoming spikes (see Figure 2). In the human brain each neuron fires at around 1-5 Hz and sends spikes to between 3,000 and 13,000 other neurons (Binzegger, Douglas and Martin, 2004), leading to approximately 10^{22} spike events per second.

The axon of one neuron connects to the dendrite of another at a junction known as a synapse. When