Modelling Interacting Networks in the Brain

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Outline

1. Existing Modelling and Analysis Techniques

2. Interacting Networks in the Brain
“For every [millisecond] there is therefore one proposition ... such that knowledge of its truth or falsity describes the neuron completely ...”

“... all the significant relations within a nervous net can be expressed as propositional relations which only involve truth values.”

- Perceptrons (Minsky and Papert, 1969)
- RAM networks (Aleksander, 1977)
“... a network which has a feedforward architecture in which each hidden unit generates a nonlinear function of the weighted sum of its inputs.”

“... a neural network model can be regarded simply as a particular choice for the set of functions...”

“... biological realism would impose entirely unnecessary constraints.”

-> Bayesian inference
“The incoming excitatory and inhibitory pulse stream inputs to the neuron are integrated to give a postsynaptic potential that varies smoothly from 0 to 5V. ... The resultant periodic waveform is then converted to a series of voltage spikes.”

-> Smith
“The objects evolve by means of spiking rules, which are of the form $E/a^c \rightarrow a; d$, where $E$ is a regular expression over $a$ and $c$, $d$ are natural numbers, $c \geq 1$, $d \geq 0$. The meaning is that a neuron containing $k$ spikes such that $a^k \in L(E)$, $k \geq c$, can consume $c$ spikes and produce one spike, after a delay of $d$ steps. This spike is sent to all neurons to which a synapse exists outgoing from the neuron where the rule was applied.”

- Frisco
“The nerve cells in an animal’s brain can’t always move aside to make room for extra ones. So those new layers might indeed have to be located elsewhere, attached by bundles of connection wires. Indeed, no aspect of the brain’s anatomy is more striking that its huge masses of connection bundles.”

- small world models of the brain
Healthy old person’s default brain network [Achard and Bullmore, 2007]
“... there is an essential non-algorithmic ingredient to thought processes.”

“... something of significance is actually calculated before the one-graviton level is reached.”

-> quantum computing
Glia — more than just brain glue

Nicola J. Allen and Ben A. Barres

Glia — more than just brain glue

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So what exactly do glia do?

Lots of things. The traditional view has been that glia look after neurons and maintain their proper functioning, having a somewhat passive role themselves. Established functions of glia include supporting neurotransmission, maintaining ionic balance in the extracellular space, and insulating axons to speed up electrical propagation of an action potential. Further, they participate in information processing.

Neurons are arranged in networks (circuits), and communicating with each other via specialized intercellular adhesion sites called synapses. Neuronal signalling involves the binding of the released neurotransmitters to receptors on the post synaptic membrane of another neuron; and the subsequent process is the depolarization of this second neuron; and the subsequent potential down a neuron's axonal propagation of an action potential.

Where do they originate from?

Glia are evolutionarily conserved, being present in one form or another in most species examined, from the simplest invertebrates to humans. The proportion of glia seems to be much more diverse and specialized, but whether they are helpful or harmful in these conditions is a matter of debate.

Meanwhile, there are several classes of glia. In mammals, there are astrocytes and the related Schwann cells and neurons and the surrounding blood vessels. Oligodendrocytes wrap myelin around multiple axons. These resident immune cells to the worm have only a few glia; some 25% of the fruitfly brain consists of glia; the mouse brain 35% of these cells; and the brain of a 65% of these cells; and the human brain has about 90% of these cells. As animals have more diverse and specialized, evolved, glia have become not only more diverse and specialized, but also essential: without them neurons die. Furthermore, astrocytes are activated in many neurodegenerative diseases, but whether they are helpful or harmful in these conditions is a matter of debate.

But emerging research suggests that glia, particularly astrocytes, also have active roles in brain function and information processing. But emerging research suggests that glia, particularly astrocytes, also have active roles in brain function and information processing. In all neurons, for example, glia are classified as microglia, but instead surround and ensheath neurons. Glia do not fire action potentials, but instead maintain the ionic gradient across the membrane and release of neurotransmitters; and the depolarization of the terminal presynaptic terminal; and the subsequent propagation of an action potential down a neuron's axonal propagation of an action potential.

How do glia differ from neurons?

Neurons are classified as microglia, which are part of the immune system and enter the brain under surveillance for damage or infection. They make crucial contributions to the formation, operation and adaptation of neural circuitry. For example, glia are classified as microglia, which are part of the immune system and enter the brain under surveillance for damage or infection. They make crucial contributions to the formation, operation and adaptation of neural circuitry. Oligodendrocytes (Fig. 1).

What is known about the evolution of microglia?

These resident immune cells are found in all vertebrates and some invertebrates. They are located throughout the nervous system and communicate with each other via specialized intercellular adhesion sites called synapses. Synaptic connections and axons throughout the nervous system survey the brain for damage and infection, engulfing dead or harmful matter. Microglia have also been implicated in synaptic remodelling during adulthood. Microglia are activated in many neurodegenerative diseases, but whether they are helpful or harmful in these conditions is a matter of debate.

Are all glia the same?

No. On the basis of morphology, glia can be classified into a broad class termed glia. Where do they originate from?

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What is the specific function of microglia?

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Three Types of Nodes

- **Neurons**: integrate-and-fire neuron with noisy membrane potential. State: membrane potential, -100 mV to 0 mV. Dynamics modelled by several stochastic ordinary differential equations per neuron.

- **Astrocytes**: control synapse function and vascular tone. State: $\text{Ca}^{2+}$ concentration, 10 $\mu$mol to 100 $\mu$mol, not directly measured.

- **Capillary junctions**: non-Bernoulli flow of erythrocytes. State: diameter of upstream capillary (or arteriole), 5 $\mu$m to 500 $\mu$m.
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Three Types of Networks

- **N Neurons**: random directed graph with out-degree $\Theta N$, $\Theta \in [0.05, 0.9]$.
- Astrocytes: random directed graph with edge probability inversely proportional with distance between astrocytes.
- Microvascular: a single binary tree.
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Example: Firing Patterns of Neurons and Astrocytes

With astrocytes, more neurons fire at higher frequency.
Summary

- Computer Science has inspired brain models.
- There are three networks in the brain: neurons, astrocytes, and capillaries.

Next
- Blue Brain, using Blue Gene
- neuroeconomics
- systems biology -> systems neuroscience
- stroke: software for revalidation
- dementia: software for care
Further Reading and Picture Credits I

Chris M. Bishop.  
*Neural Networks for Pattern Recognition.*  

Pierluigi Frisco.  
*Computing with Cells: Advances in Membrane Computing.*  
OUP, 2009.

Marvin Minsky.  
*The Society of Mind.*  

Marvin Minsky and Seymour Papert.  
*Perceptrons: An Introduction to Computational Geometry.*  
Further Reading and Picture Credits II

Roger Penrose.  
*The Emperor’s New Mind: Concerning Computers, Minds and the Laws of Physics.*  
OUP, 1989.

Sophie Achard and Ed Bullmore.  
Efficiency and Cost of Economical Brain Functional Networks.  

Nicola Allen and Ben Barres.  
Glia - more than just brain glue.  
Further Reading and Picture Credits III

Warren S. McCulloch and Walter Pitts.
The Statistical Organization of Nervous Activity.

A.F. Murray and A.V.W. Smith.
Asynchronous Arithmetic for VLSI Neural Systems.

Normal forms for spiking neural P systems.
A New Spike Detection Algorithm for Extracellular Neural Recordings. 

Xi Shen and Philippe De Wilde. 
Long-term neuronal behavior caused by two synaptic modification mechanisms. 

Xi Shen and Philippe De Wilde. 
Robustness and regularity of oscillations in neuronal populations. 