

# Modelling Interacting Networks in the Brain

Philippe De Wilde

Department of Computer Science  
Heriot-Watt University  
Edinburgh

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# Outline

- 1 Existing Modelling and Analysis Techniques
- 2 Interacting Networks in the Brain

# McCulloch and Pitts, 1948

- “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)

# Bishop, 1995

- “... 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

# Murray, 1987

- “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

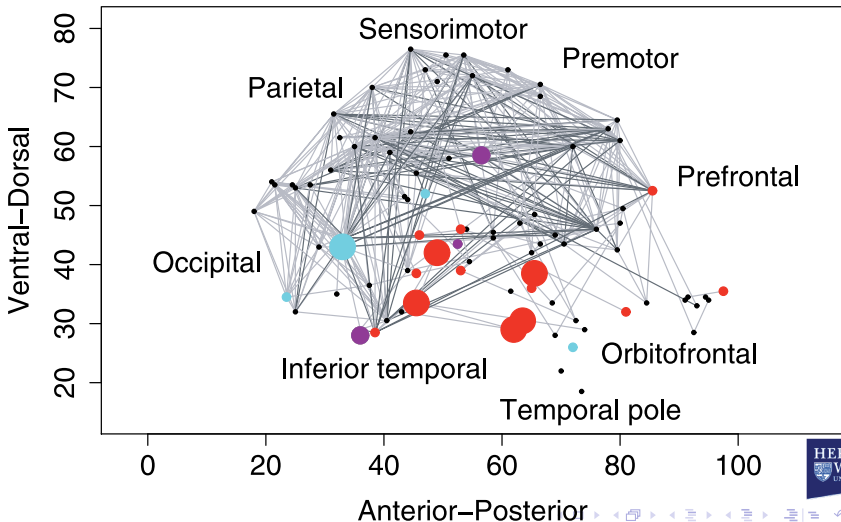
## Paun, 2000

- “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

# Minsky, 1988

- “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 than its huge masses of connection bundles.”
- -> small world models of the brain

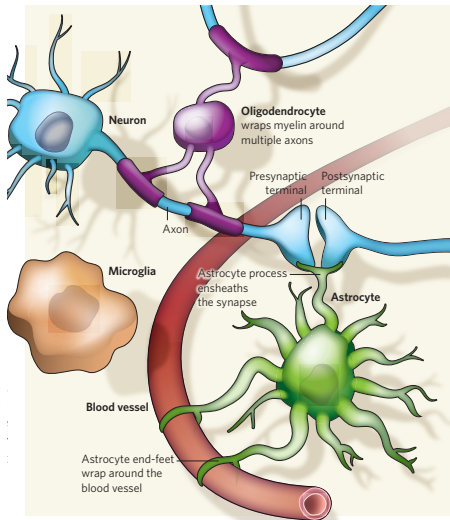
# Healthy old person's default brain network [Achard and Bullmore, 2007]



# Penrose, 1989

- “... 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

# A Low-level View [Allen and Barres, 2009]



# 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,  $10 \mu\text{mol}$  to  $100 \mu\text{mol}$ , not directly measured.
- **Capillary junctions:** non-Bernoulli flow of erythrocytes. State: diameter of upstream capillary (or arteriole),  $5 \mu\text{m}$  to  $500 \mu\text{m}$ .

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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.

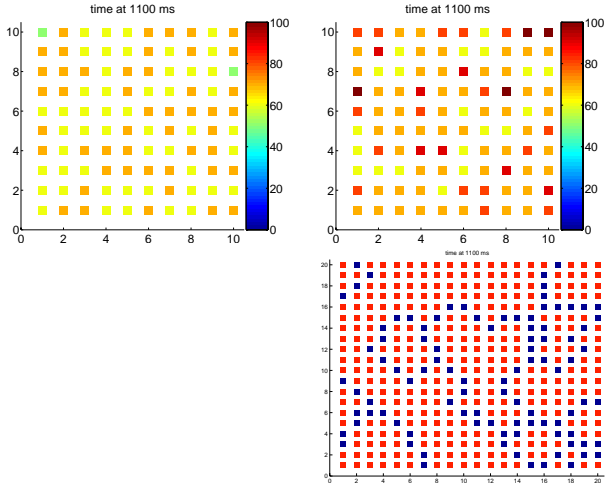
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# Example: Firing Patterns of Neurons and Astrocytes







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.*  
OUP, 1995.
-  Pierluigi Frisco.  
*Computing with Cells: Advances in Membrane Computing.*  
OUP, 2009.
-  Marvin Minsky.  
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Picador, 1988.
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MIT Press, 1969.

## Further Reading and Picture Credits II



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*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.

*PLoS Comput. Biol.* 3(2):e17, 2007.






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## Further Reading and Picture Credits III

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-  A.F. Murray and A.V.W. Smith.  
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and S. Woodworth.  
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# Further Reading and Picture Credits IV



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*Neurocomputing*, 70(7–9):1482–1488, 2007.



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# Further Reading and Picture Credits V



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*Neural Computation*, 20(8):2037–2069, 2008.



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*Electronics Letters*, 13(9):253–254, 1977.