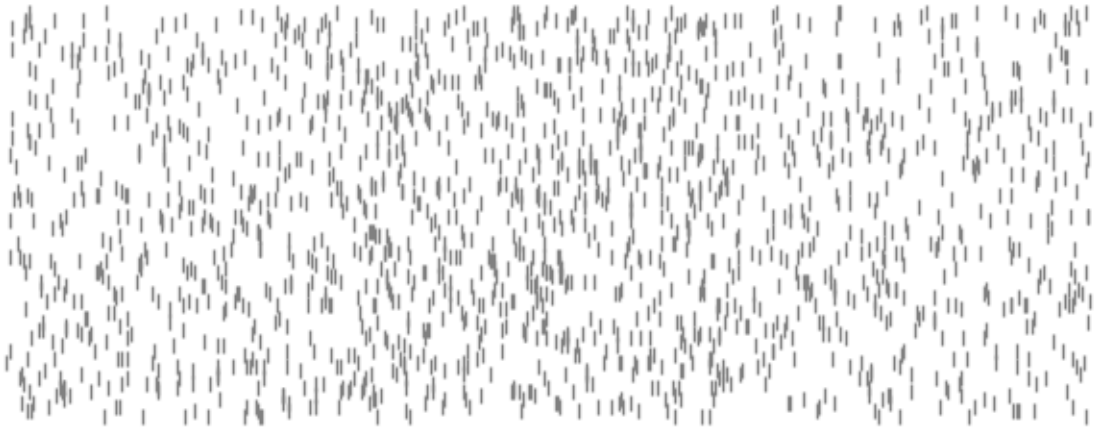

Spiking neural network simulation with Brian

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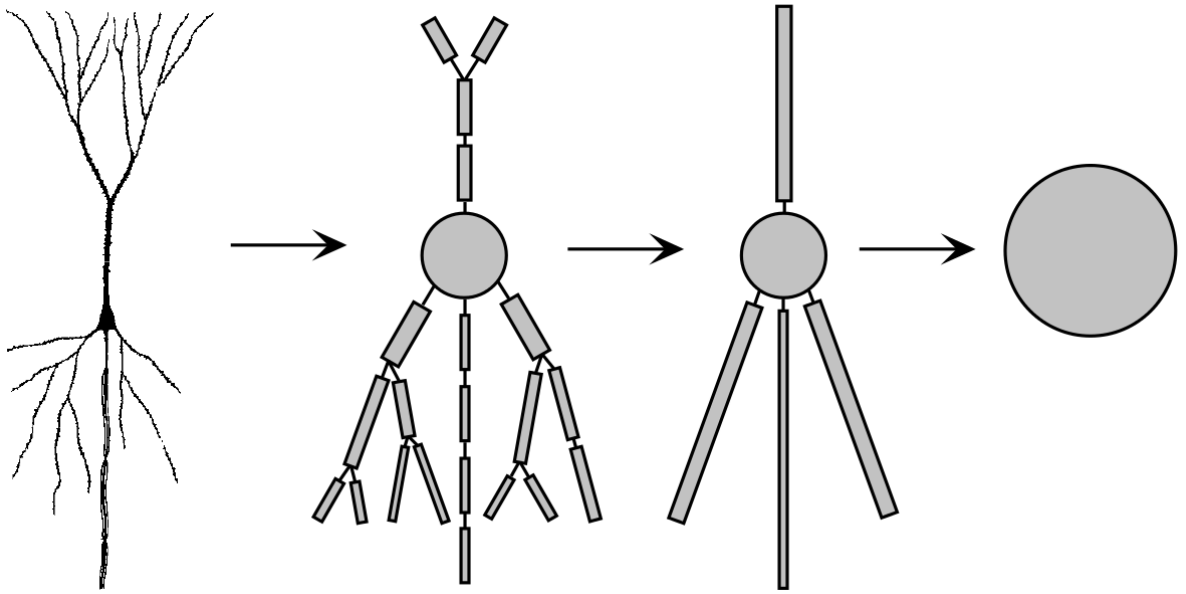
Why study networks of neurons?

- Studying neurons in isolation has its limits
  - the brain is highly recurrent, the output of a neuron affects the network and therefore its input
- Everything we perceive, think, or do, results from the activity of many neurons
- Memories (short and long-term) are stored on the network level, not in individual neurons

Modelling networks of neurons

Individual elements

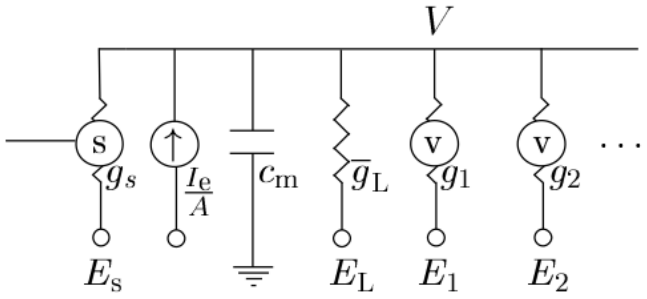


Detailed neuronal morphologies → point-neuron models

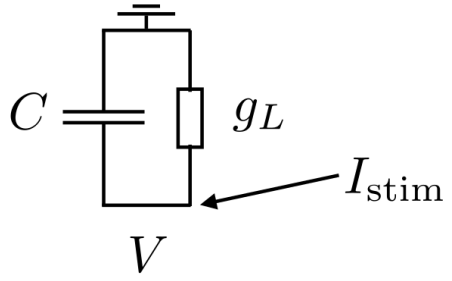
Modelling networks of neurons

Individual elements

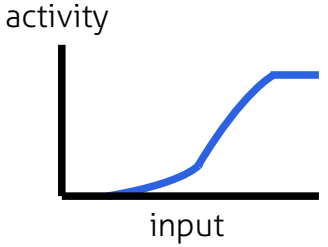
Point-neuron models



Hodgkin-Huxley formalism



integrate-and-fire model



firing rate models

Modelling networks of neurons

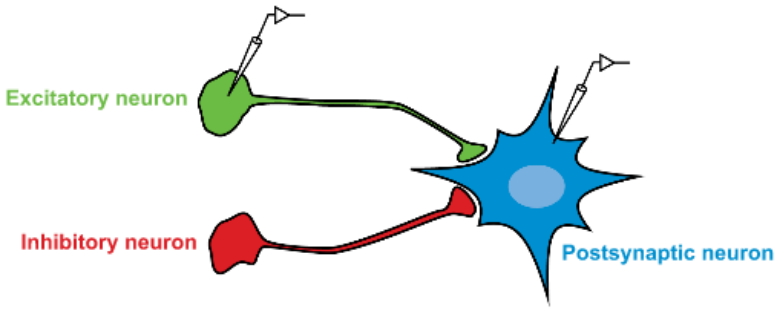
Synapses

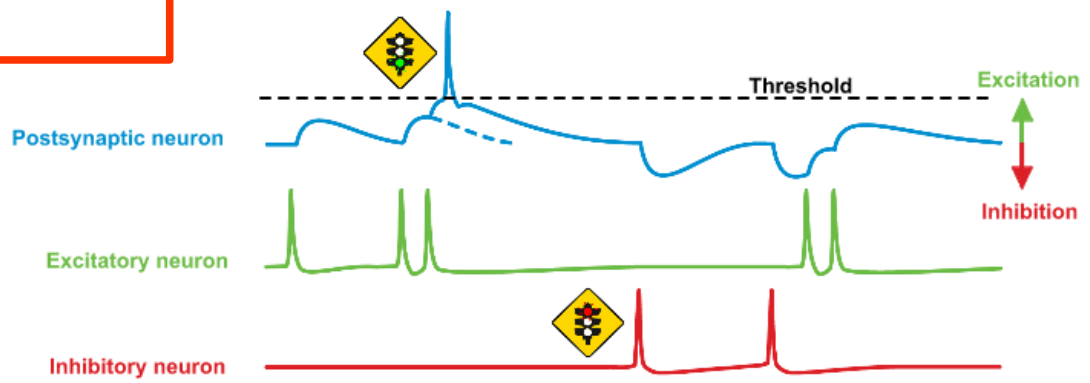
?

Why can we talk about excitatory/ inhibitory *neurons* and not just synapses?

!

→ "Dale's law"
Neurons release the same neurotransmitter(s) on every synapse





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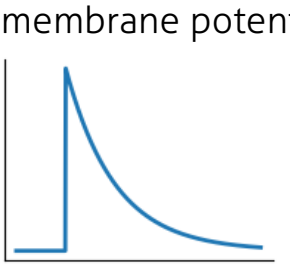
Neuroscience online

Modelling networks of neurons

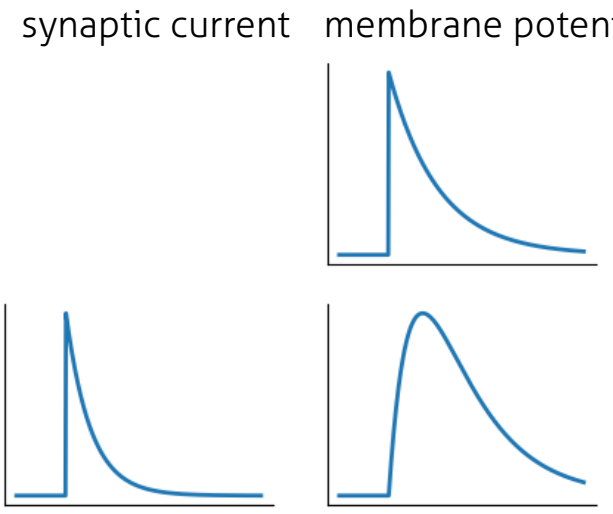
Synapses



“delta synapse”

Modelling networks of neurons

Synapses

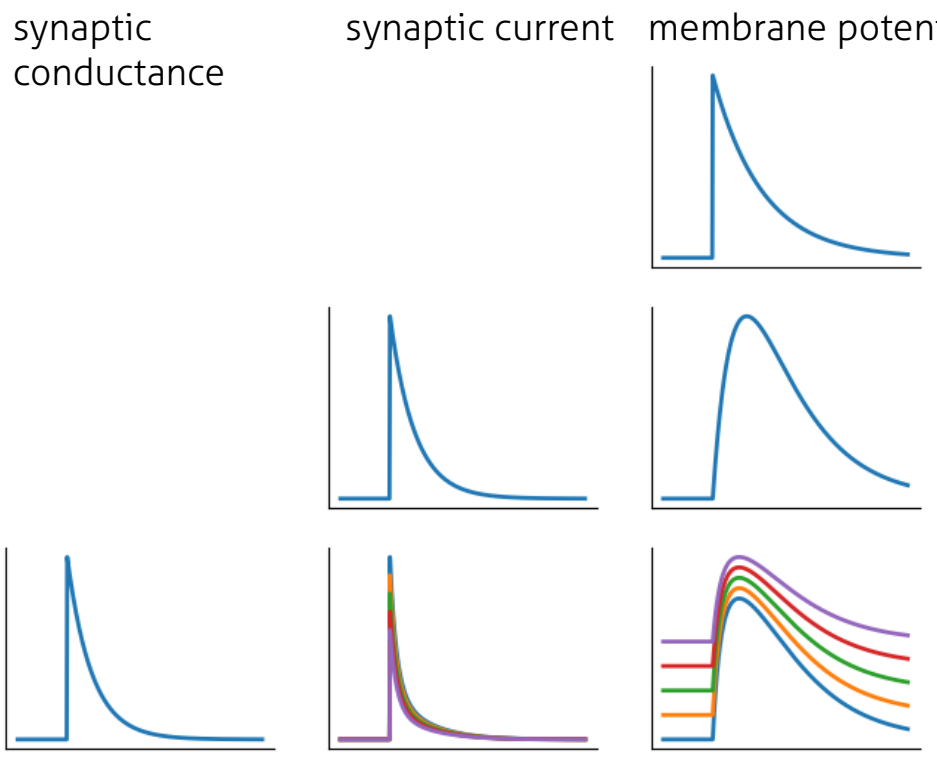


"delta synapse"

exponential
current-based

Modelling networks of neurons

Synapses

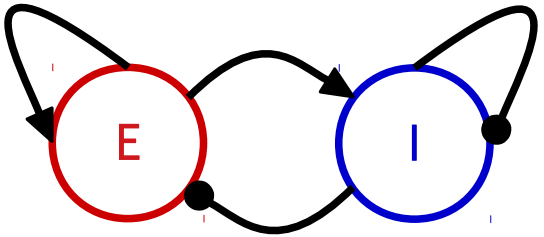


Dynamics in networks

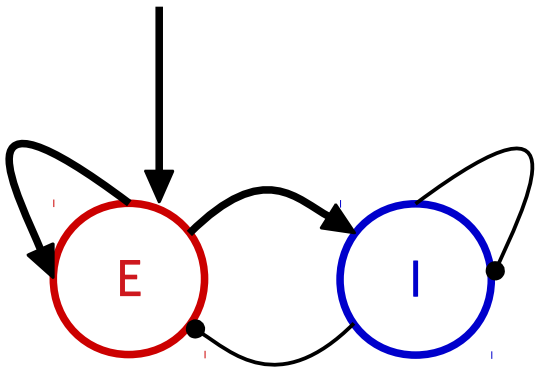
- Firing rate models are valuable tool:
  - general stability of a homogeneous system
  - global oscillations
- Firing rate models are limited
  - "high activity/firing rate" does not describe:
    - spiking statistics of individual neurons (regular/irregular)
    - synchronicity of spiking in population (synchronous/asynchronous)

Dynamics in spiking models

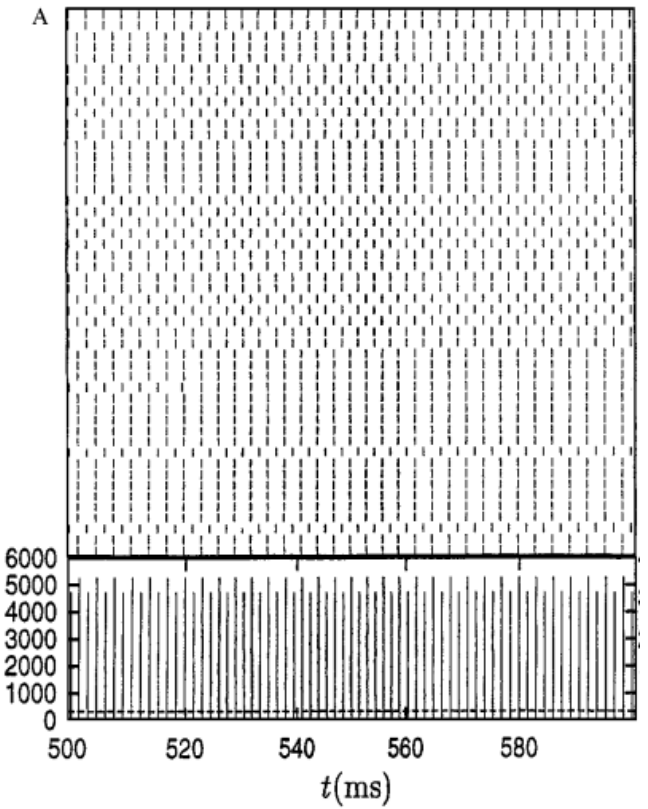
- Randomly connected (often: sparsely) neurons
- excitatory and inhibitory



Activity regimes



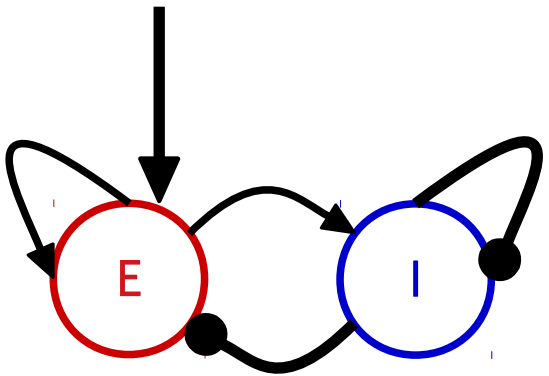
regular firing
global synchronization

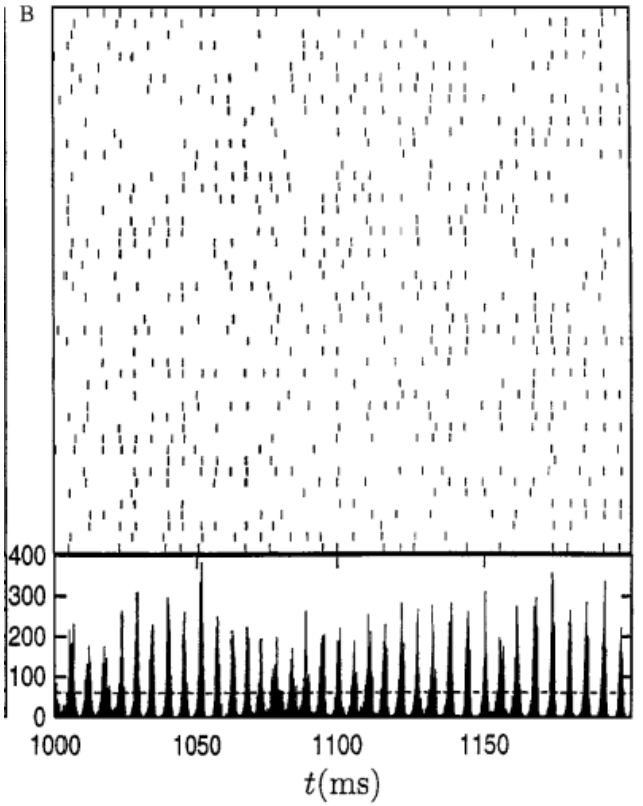


Brunel (2000)

Activity regimes

irregular firing
global synchronization

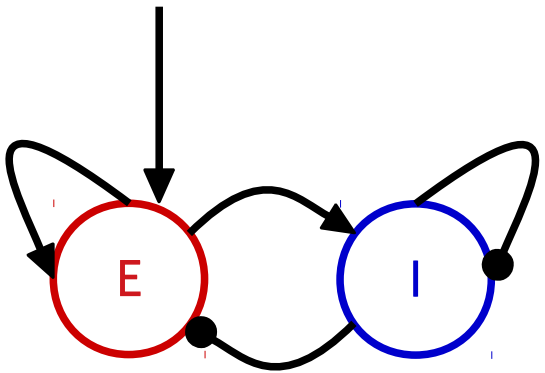


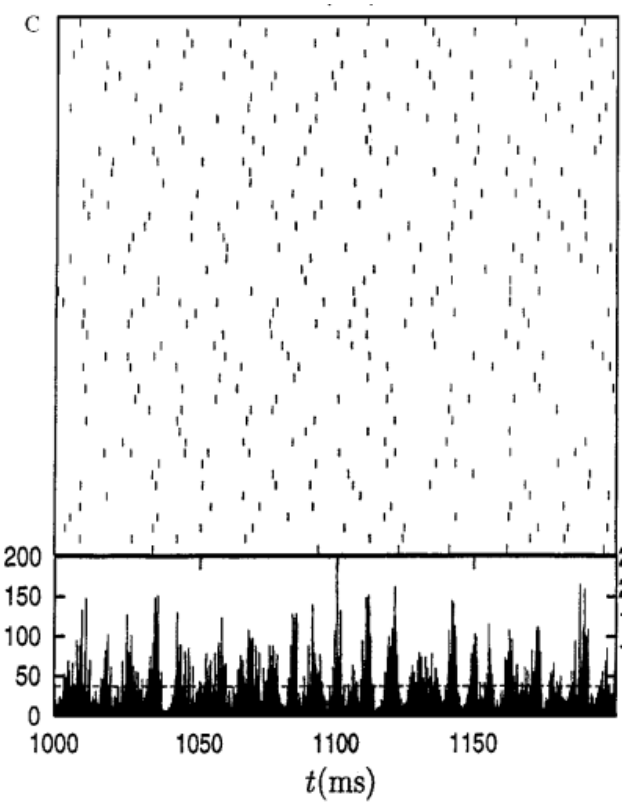


Brunel (2000)

Activity regimes

irregular firing
asynchronous activity





Brunel (2000)

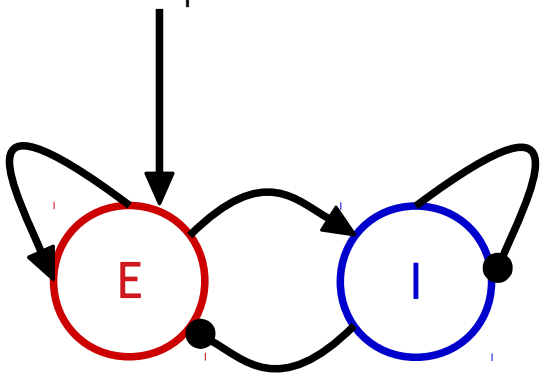
Functional dynamics

- structured connectivity + inhibitory/excitatory connections can create dynamical systems with desirable properties
- Circuit motifs:
  - feedback excitation
  - feedback inhibition
  - local excitation, global inhibition
  - delayed inhibition
  - ...

Functional dynamics: Example

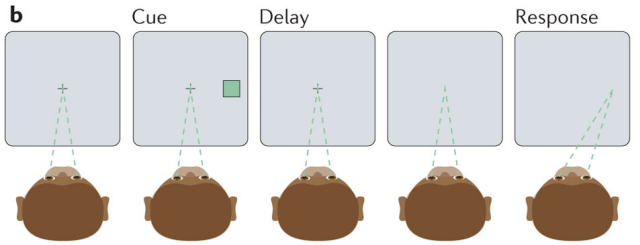
Sustained activity

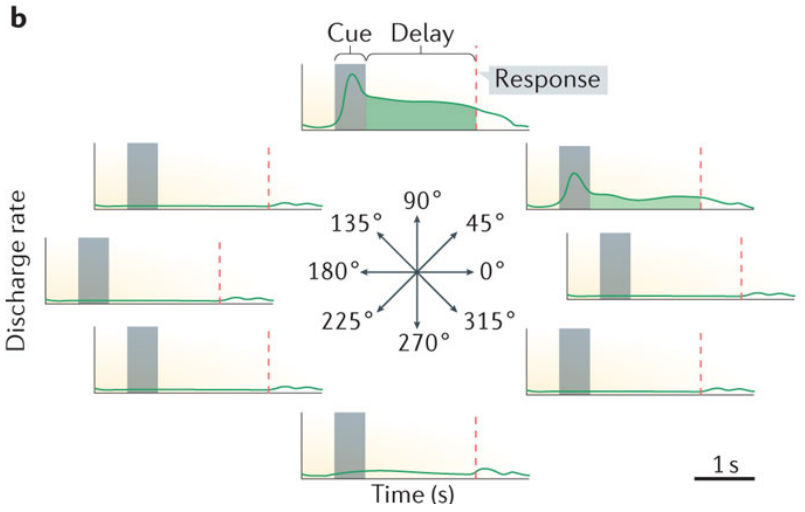
external input



excitatory feedback (amplification/ sustained activity)

inhibitory feedback (stabilization, prevent runaway activity)





Constantinidis & Klingberg (2016)

The

simulator

Brian's approach

- *Philosophy*: Mathematical model descriptions
  - Flexible system to define models with equations
  - Takes care of numerical integration / synaptic propagation
  - Physical units
- *Technology*: Code generation
  - High-level descriptions transformed into low-level code
  - Transparent to user

More info

Website: https://briansimulator.org

Documentation: https://brian2.readthedocs.io

Discussion forum: https://brian.discourse.group

Articles:

Stimberg, Marcel, Romain Brette, and Dan FM Goodman. "Brian 2, an Intuitive and Efficient Neural Simulator." ELife 8 (2019): e47314. https://doi.org/10.7554/eLife.47314.

Stimberg, Marcel, Dan F. M. Goodman, Victor Benichoux, and Romain Brette. "Equation-Oriented Specification of Neural Models for Simulations." Frontiers in Neuroinformatics 8 (2014). https://doi.org/10.3389/fninf.2014.00006