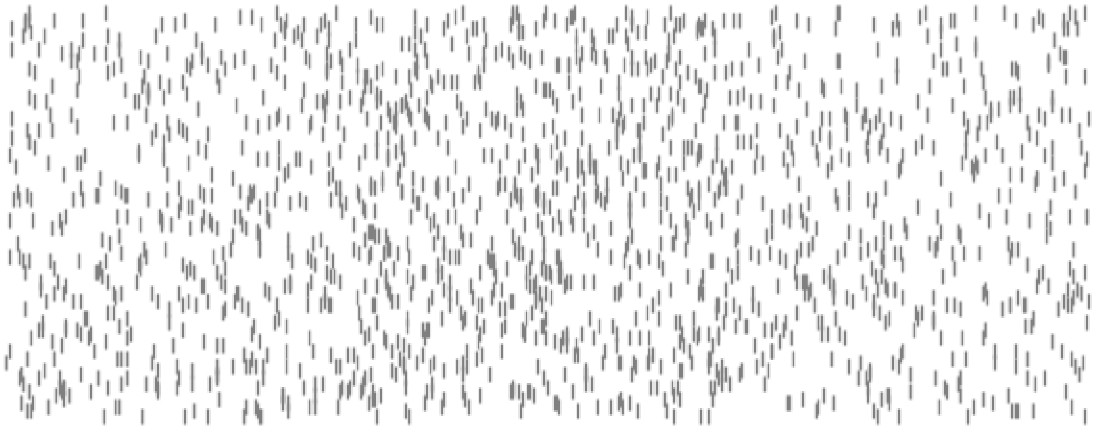

Simulating neural computation and information processing (with *Brian*)

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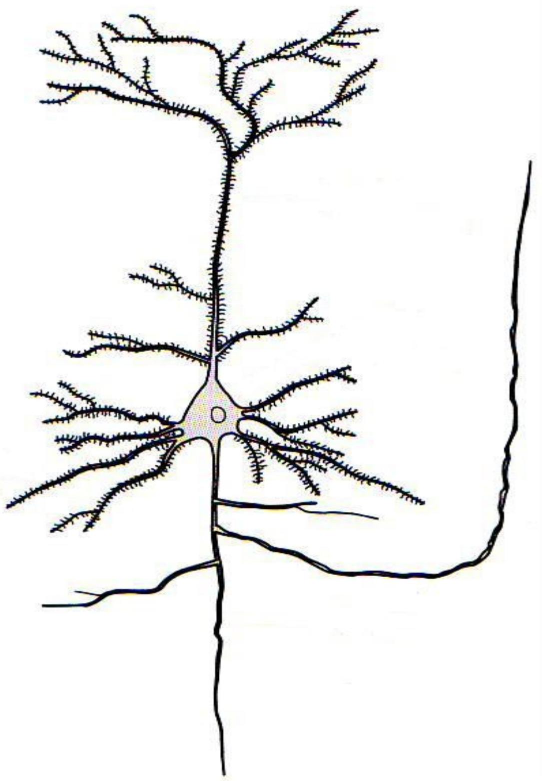
Course material

The jupyter notebooks for the practical introductions to neural simulation will be made available at:

https://github.com/brian-team/brian-material/tree/master/2023-TD-Brian-Sorbonne

Plan for today



Practical introduction to neural modeling

Part 1: neurons

Part 2: networks of neurons

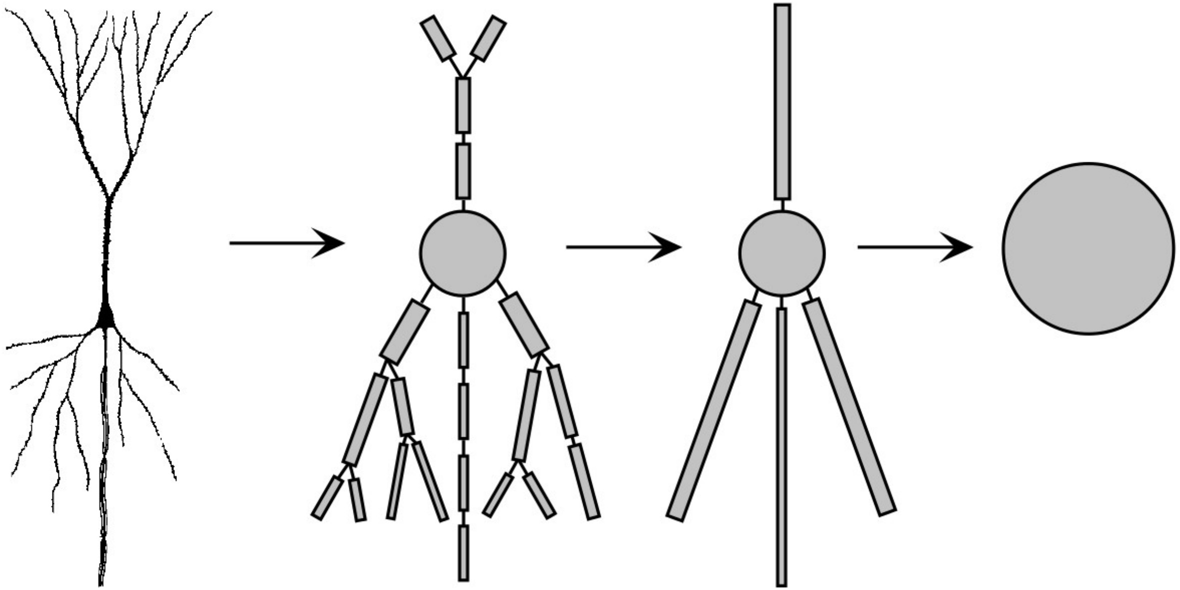
Part 3: case study (binaural sound localisation)

Each part:

some slides + practical simulation in Brian

Part 1: **Neurons**

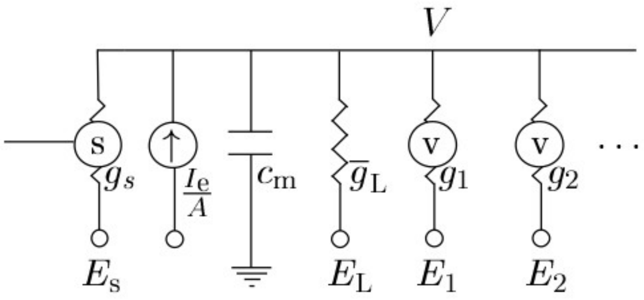
Modelling neurons



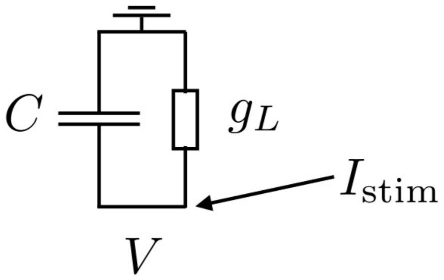
Detailed neuronal morphologies → point-neuron models

Modelling neurons

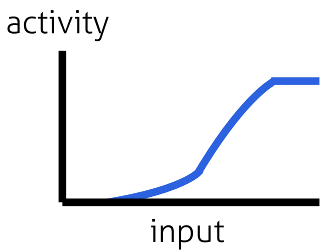
Point-neuron models



Hodgkin-Huxley formalism



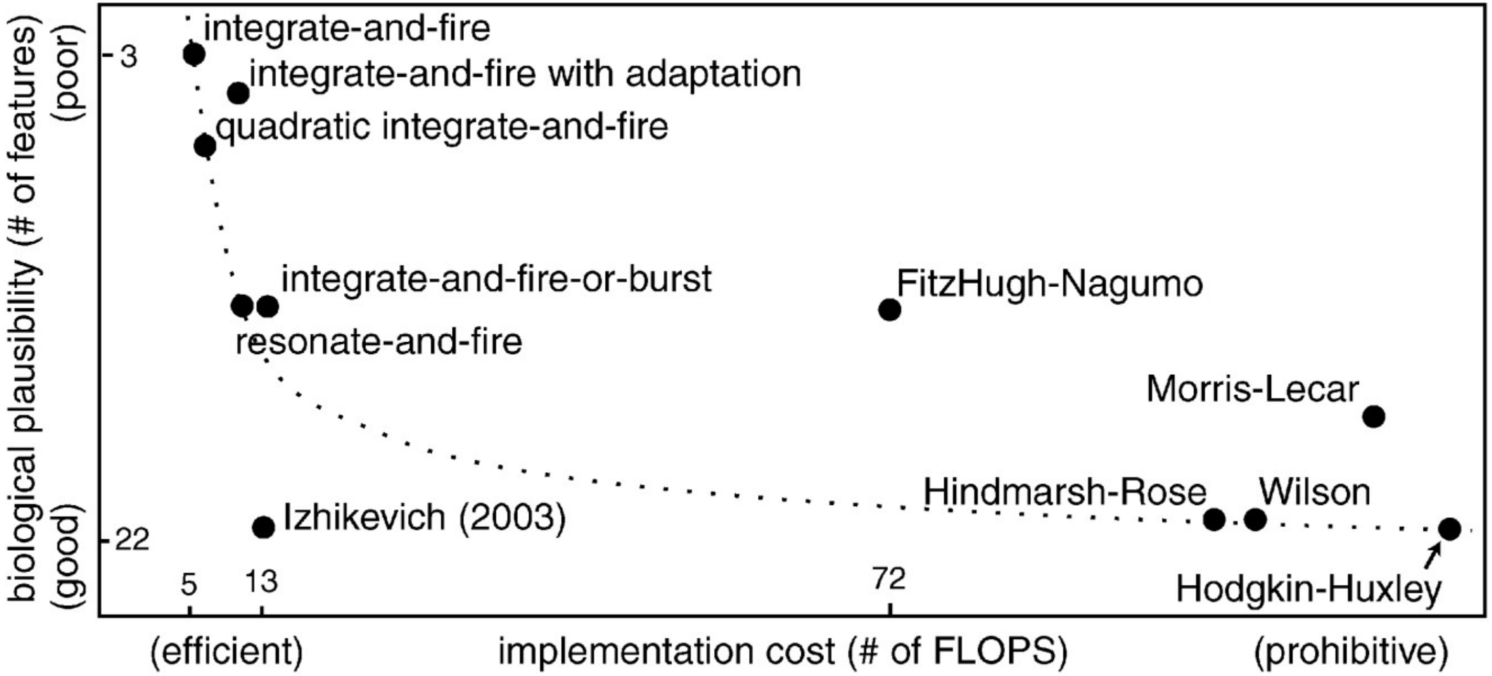
integrate-and-fire model



firing rate models

Modelling neurons

Point-neuron models

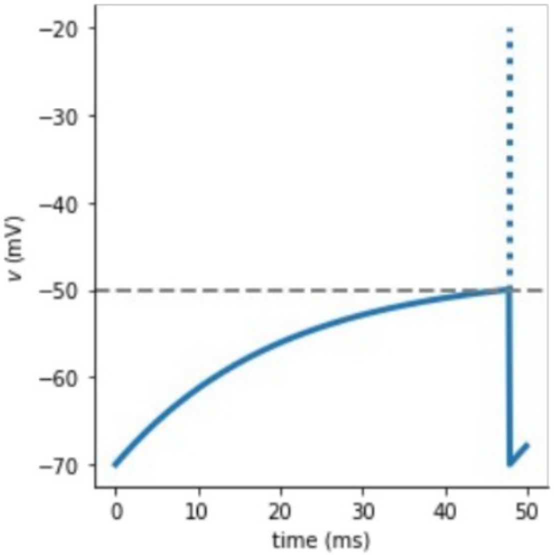


Izhikevich (2004) IEEE Neural Networks

Integrate-and-fire neuron

$$C\frac{\mathrm{d}V}{\mathrm{d}t} = g_L(V_{\mathrm{rest}} - V) + I_{\mathrm{stim}}$$

$$V(t) > V_{\mathrm{threshold}} \quad \rightarrow \quad \mathrm{spike} + V(t) = V_{\mathrm{reset}}$$



threshold

Computing with spikes

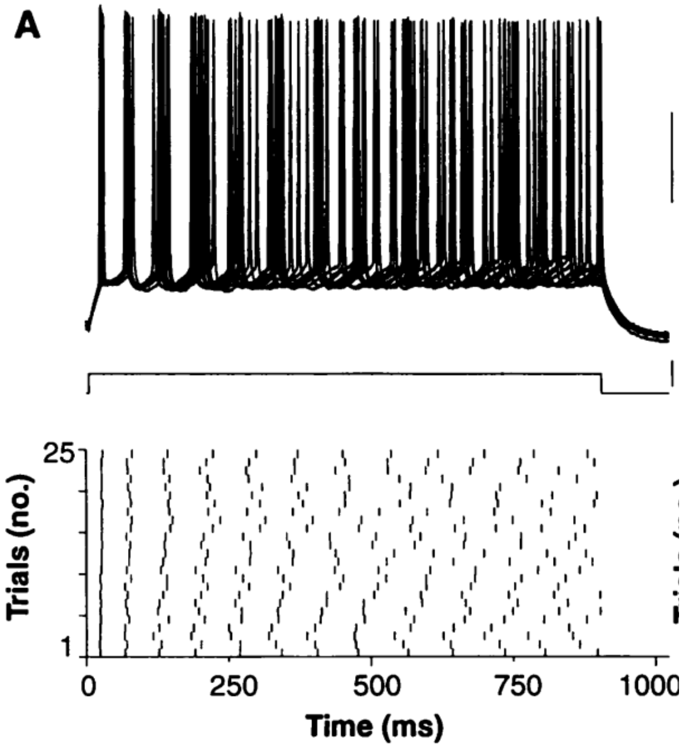
- An argument that is sometimes made:

  "Spike timing in individual neurons is unreliable ('noisy'). Therefore, only the firing rate (averaged over neurons or over time) matters, not the time of individual spikes."

- Is spike timing really "unreliable"?

Computing with spikes

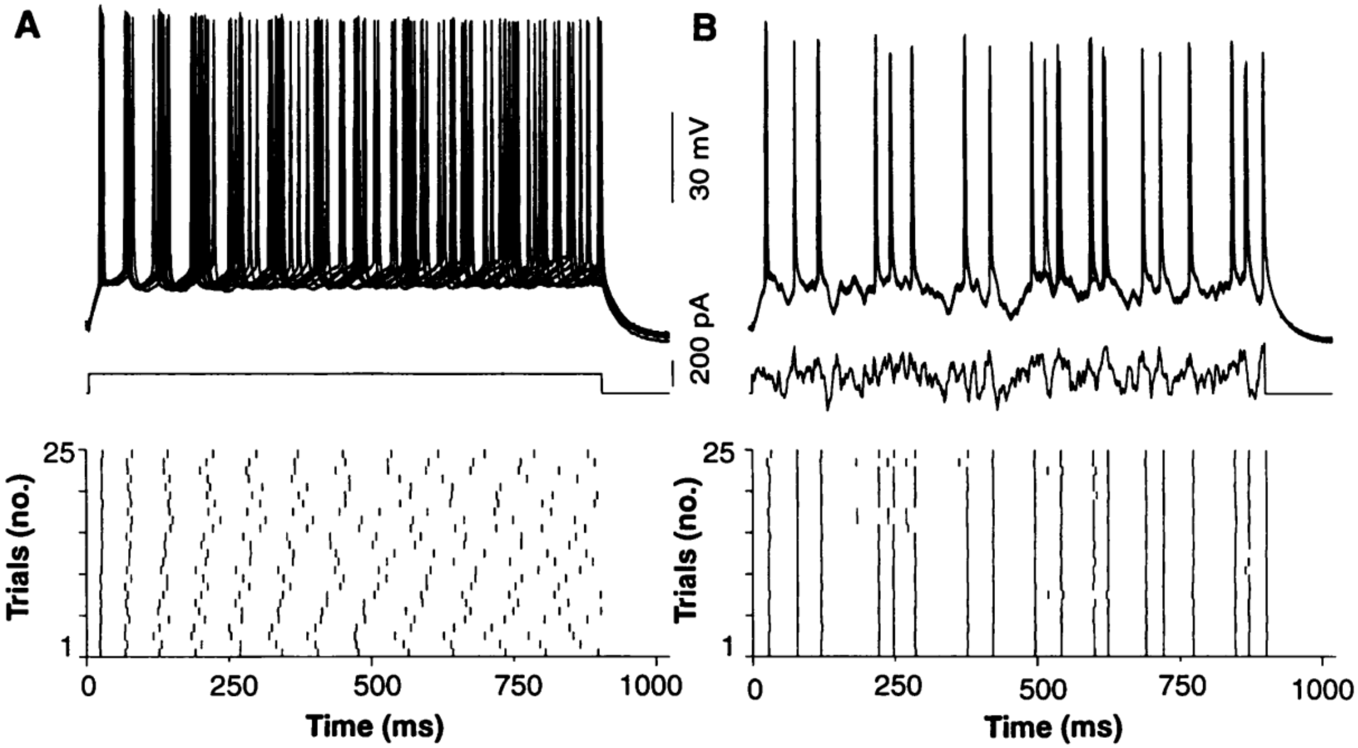
Constant current injection = **unreliable** spike times



Mainen & Sejnowski, Science (1995)

Computing with spikes

Constant current injection = **unreliable** spike times
Fluctuating current injection = **reliable** spike times



Let's try with

Mainen & Sejnowski, Science (1995)

The

BRIAN

simulator

Brian's approach

- *Interface*: Mathematical model descriptions
  - Flexible system to define models with equations
  - Takes care of numerical integration / synaptic propagation
  - Physical units
- *Behind the scenes*: 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

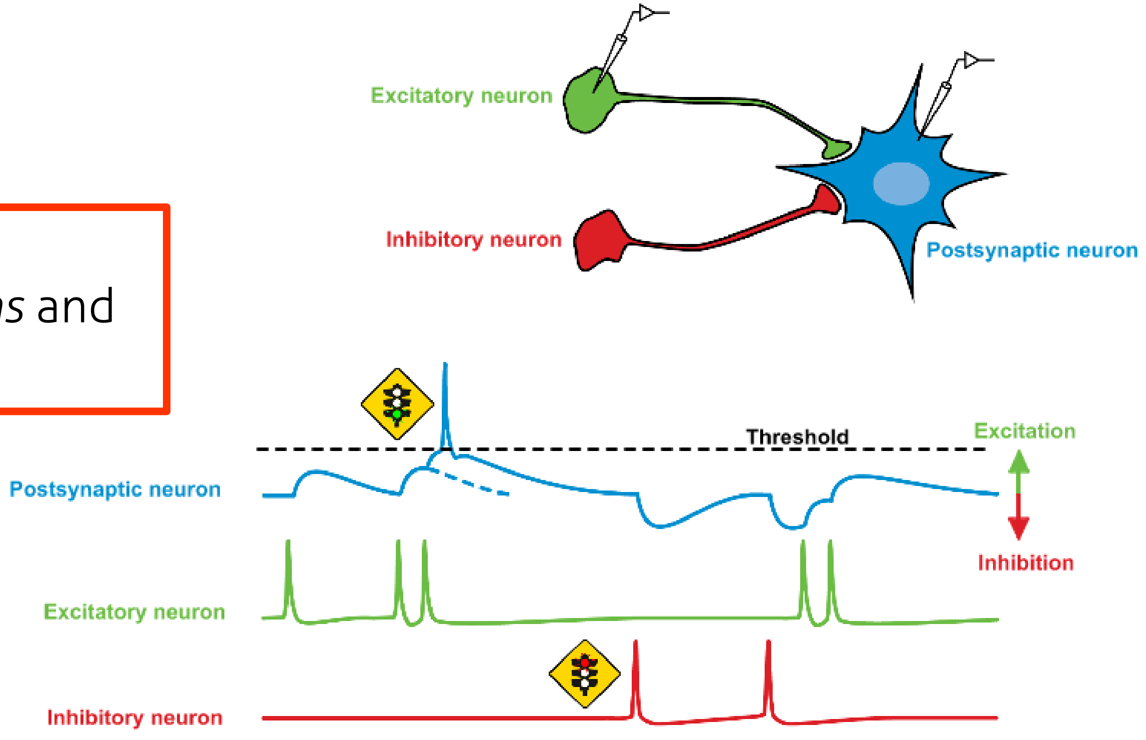
Part 2: **Networks**

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



Neuroscience online

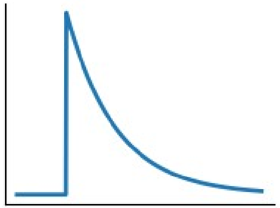
Synaptic models

Synapses

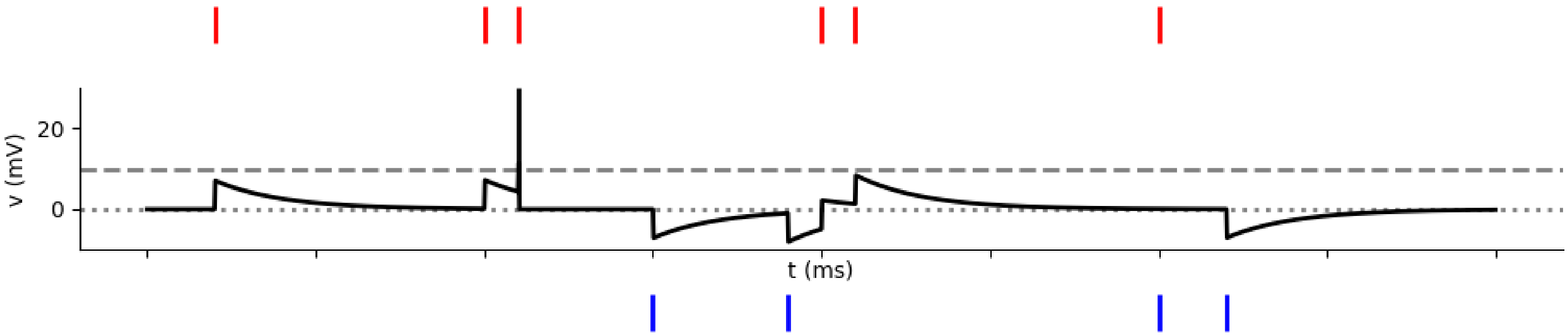
For each spike: increase V_m by J_{ij}

weight from j to i

membrane potential



“delta synapse”



Synaptic models

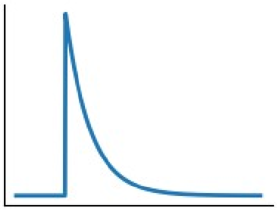
Synapses

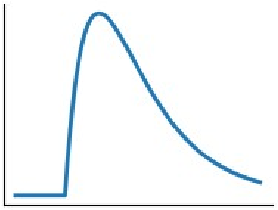
For each spike: increase I_{syn} by J_{ij}

Between spikes: I_{syn} exponentially decays to 0

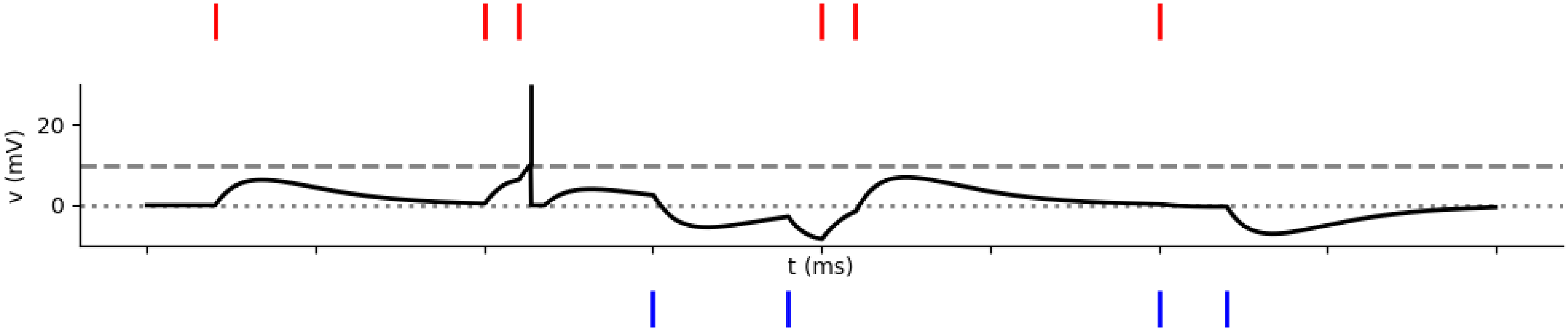
synaptic current

membrane potential





Current-based synapse



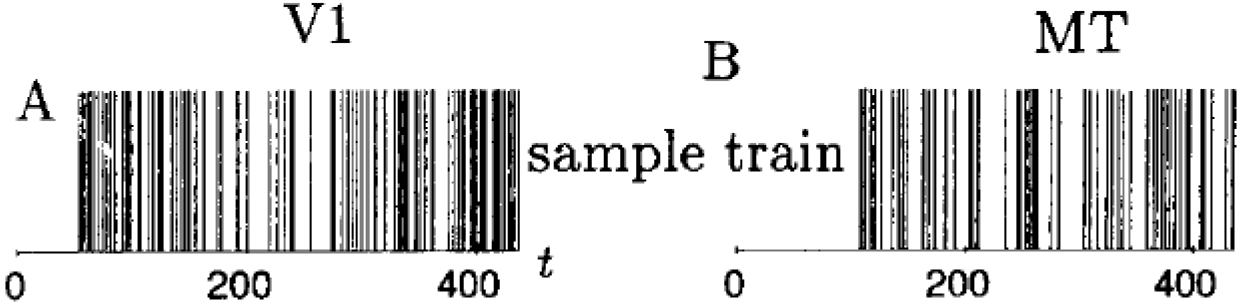
Input integration in neurons

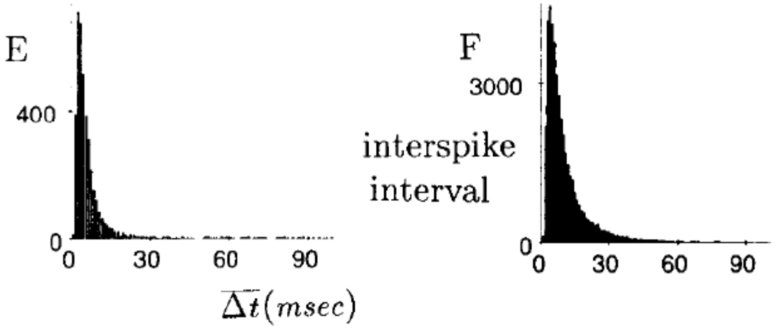
- Cortical neurons: ~10000 synapses
- If spikes at synapses are independent
  → total input relatively constant
  → neuron should fire regularly

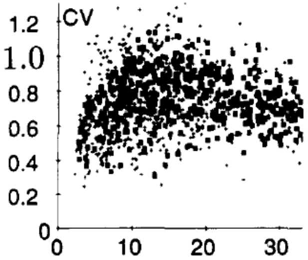
Note: "regularly" and "reliable" are different things!

Irregularity of spike trains

Cortical neurons fire irregularly (in vivo)





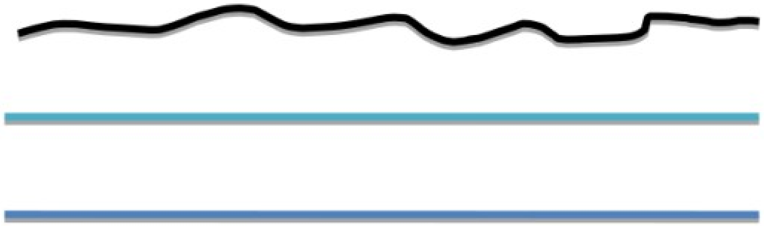


Coefficient de variation

$$CV = \frac{\sigma_{ISI}}{\langle ISI \rangle}$$

Mean-driven vs. fluctuation-driven

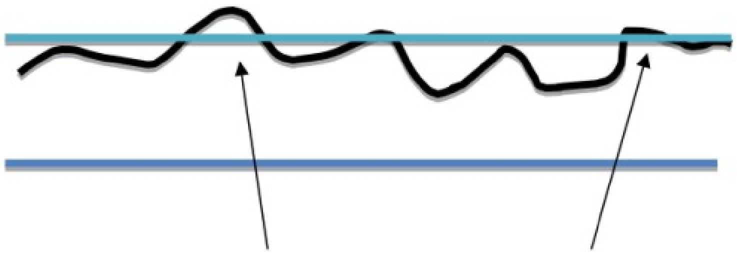
Mean-driven



$$\langle I \rangle > I_{\text{threshold}}$$

Small variability (average of many inputs)

Fluctuation-driven



$$\langle I \rangle < I_{\text{threshold}}$$

0

Let's try with

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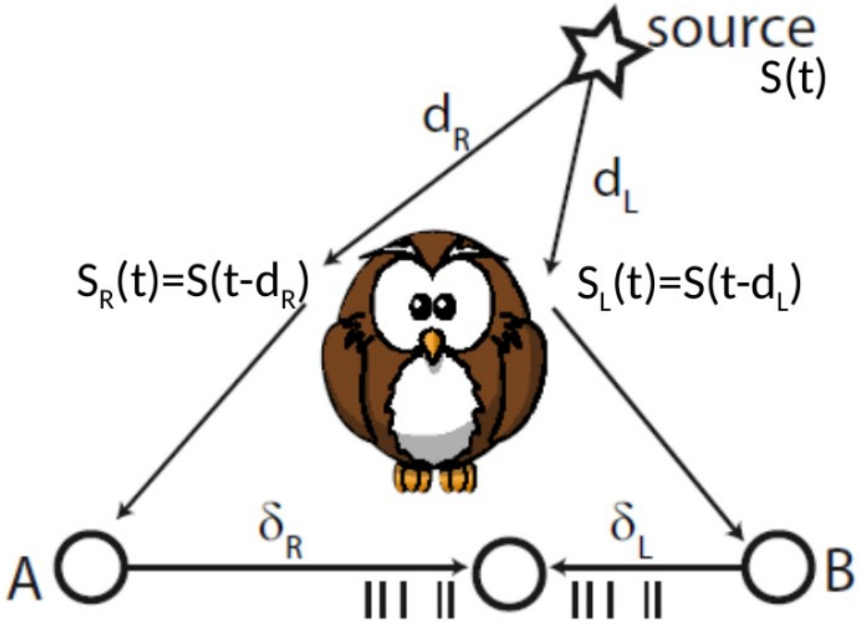
spikes can only occur at times when the input fluctuates above the mean

Part 3: Case study
Binaural sound localisation

Binaural sound localisation

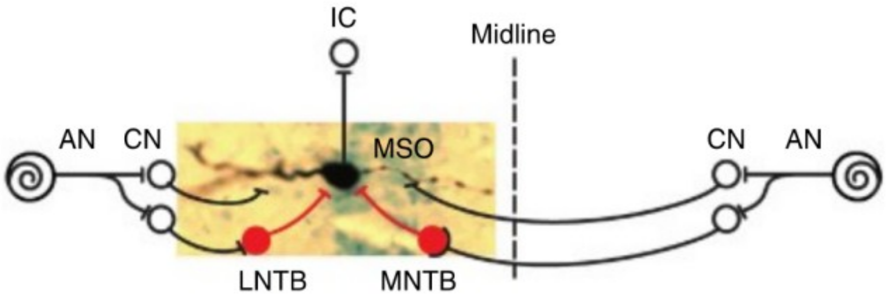
The Jeffress model

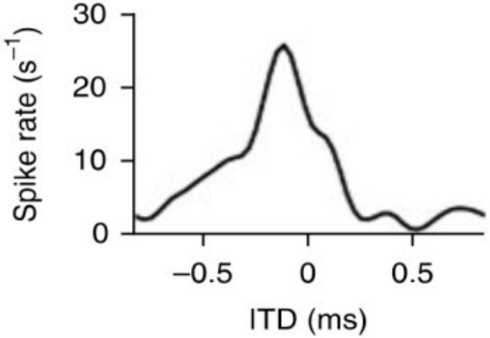


Interaural time delay
(ITD)

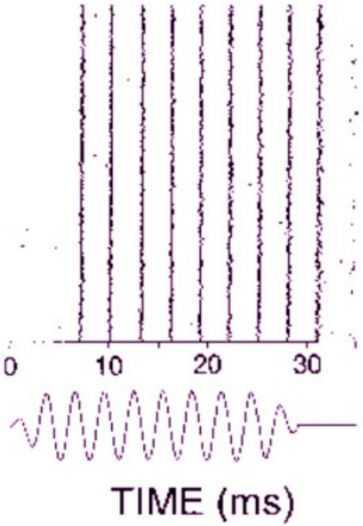
Binaural sound localisation

Anatomical structures from the ear to the brainstem





Franken et al. (2015)



Louage et al. (2005)

Let's try with

BRIAN