

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/2022-TD-Brian-Sorbonne>

Plan for today

Practical introduction to neural modeling

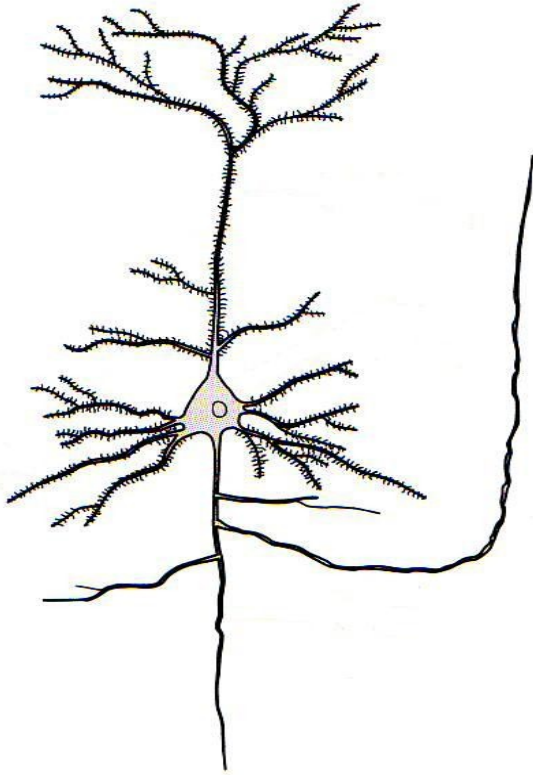
Part 1: neurons

Part 2: networks of neurons

Part 3: case study (binaural sound localisation)

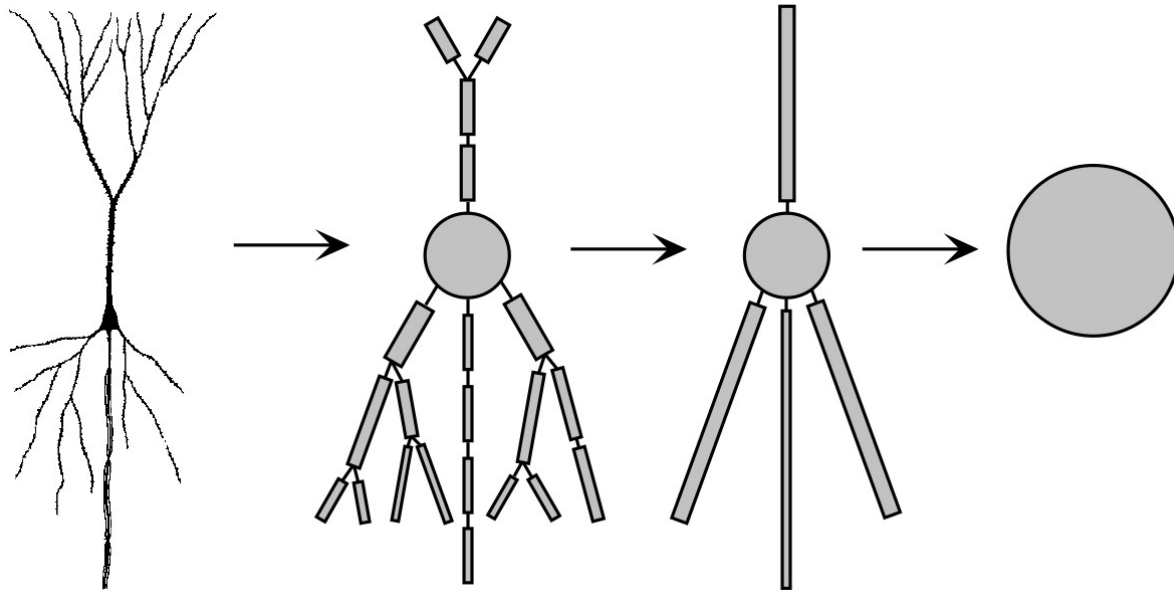
Each part:

some slides + practical simulation in Brian



Part 1: Neurons

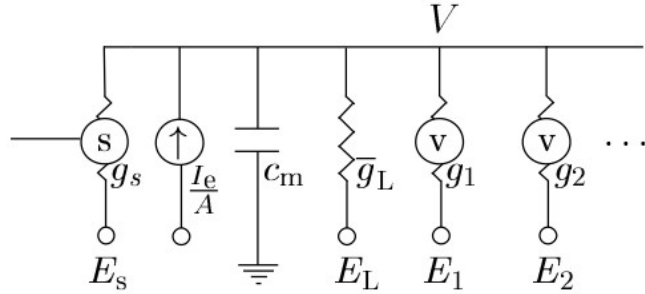
Modelling neurons



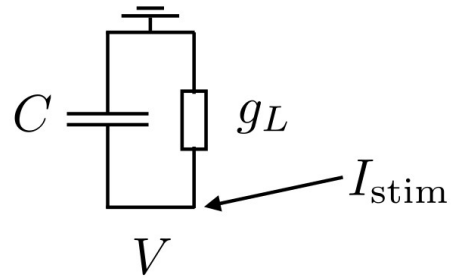
Detailed neuronal morphologies → point-neuron models

Modelling neurons

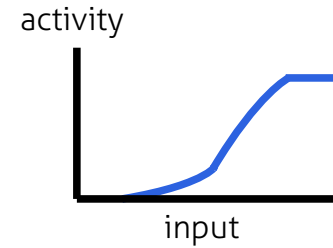
Point-neuron models



Hodgkin-Huxley formalism



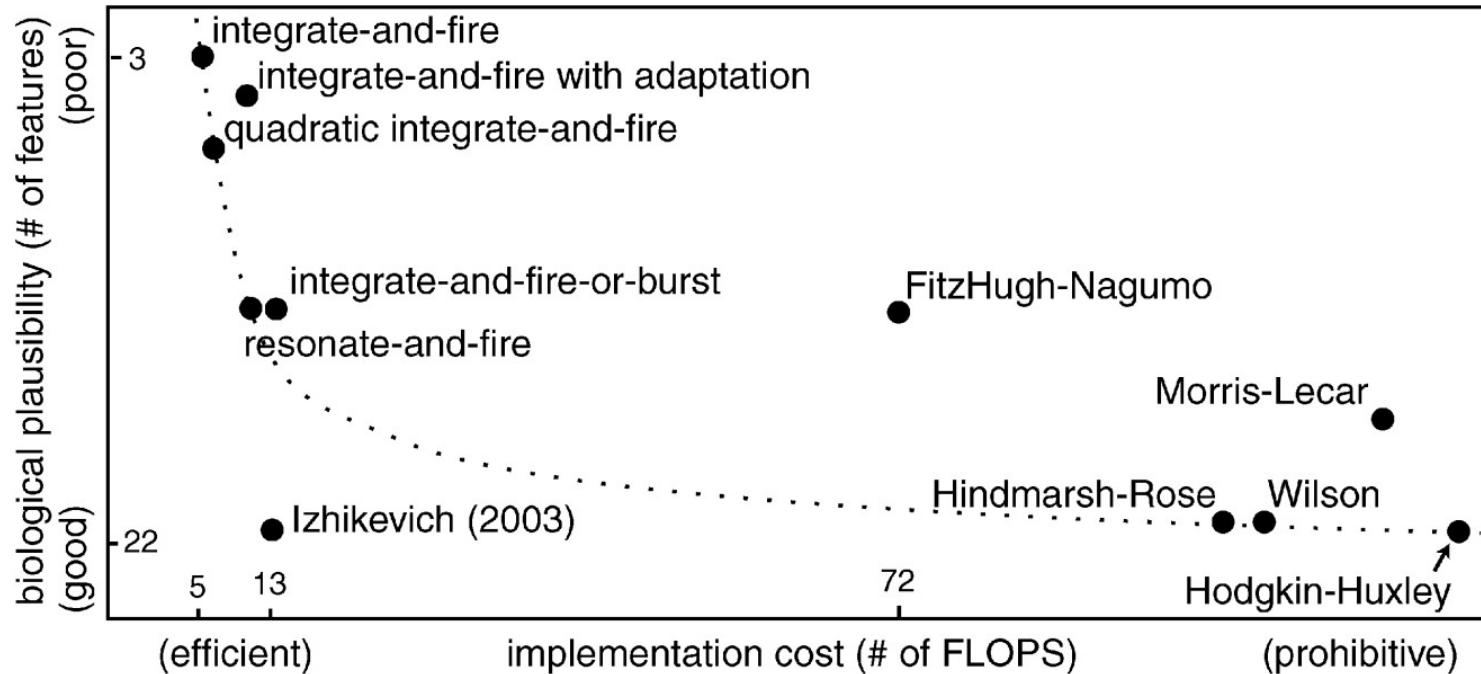
integrate-and-fire model



firing rate models

Modelling neurons

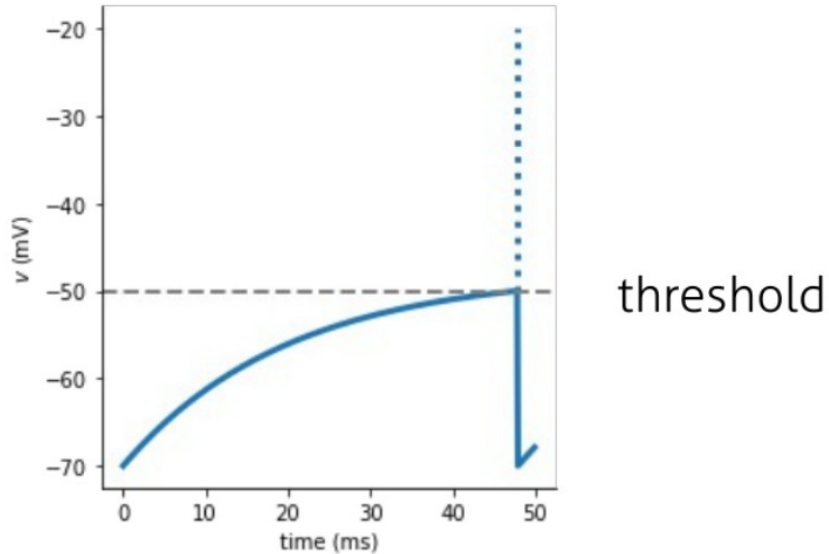
Point-neuron models



Integrate-and-fire neuron

$$C \frac{dV}{dt} = g_L (V_{\text{rest}} - V) + I_{\text{stim}}$$

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

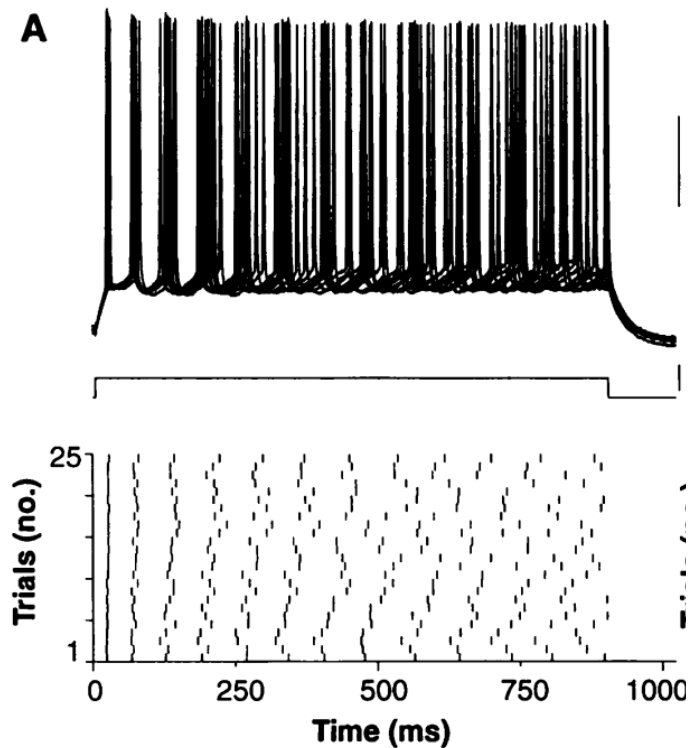


Computing with spikes

- 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

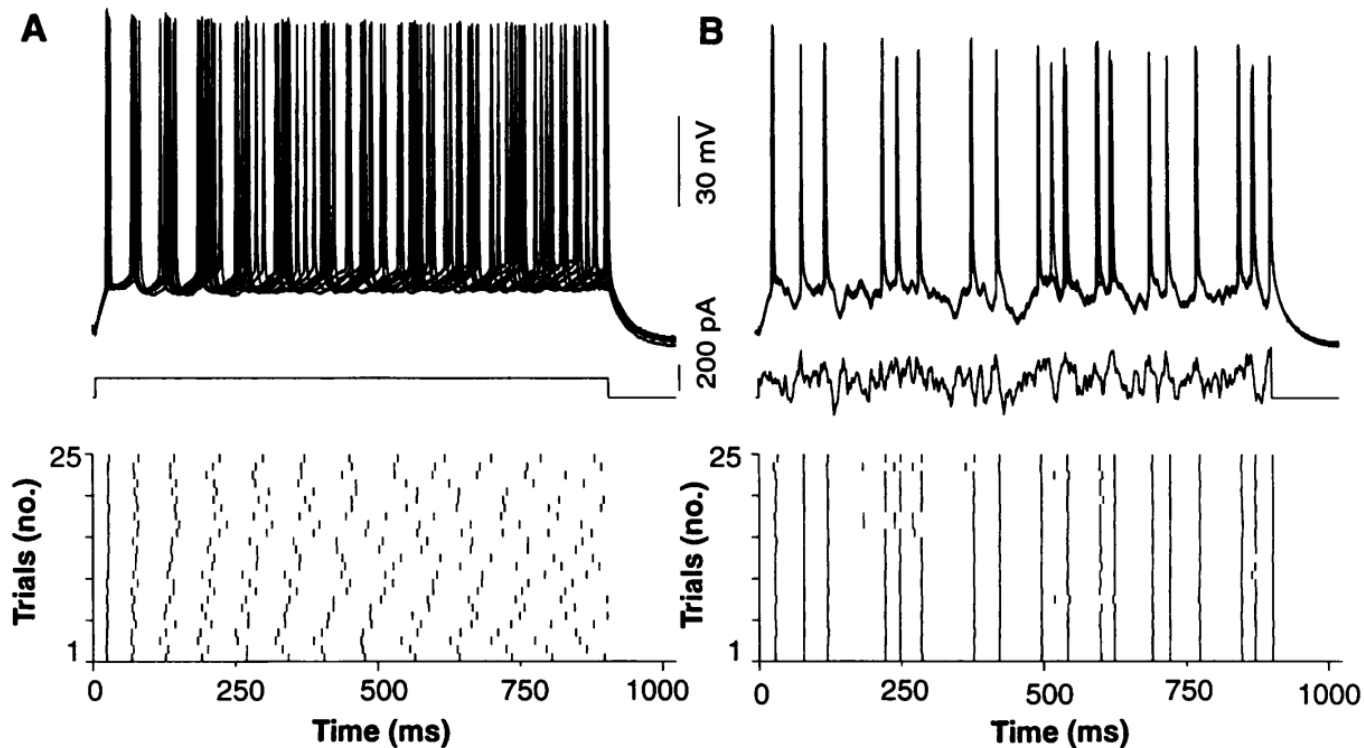
Constant current injection = **unreliable** spike times



Computing with spikes

Constant current injection = **unreliable** spike times

Fluctuating current injection = **reliable** spike times



Let's try with

BRIAN

The

BRIAN

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>

Part 2: Networks

Modelling networks of neurons

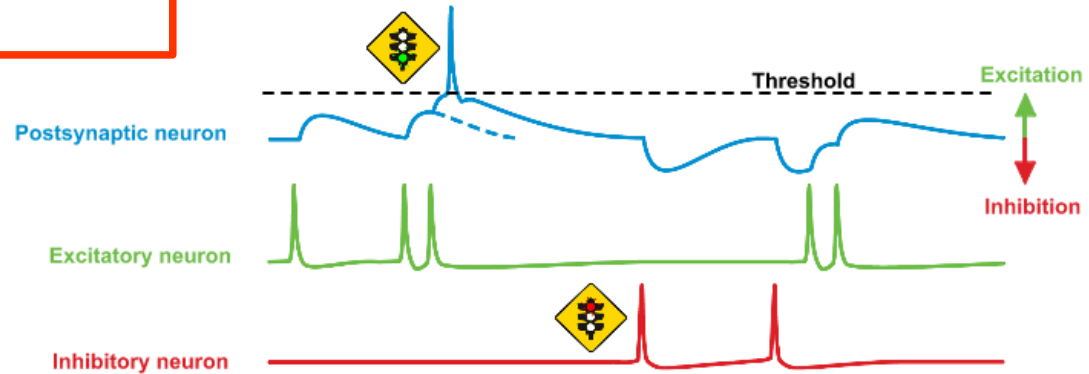
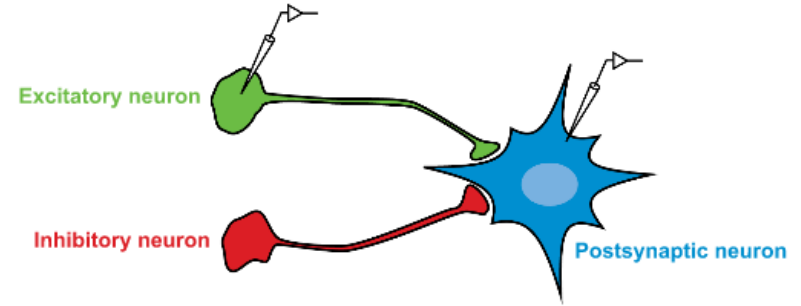
Synapses

?

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

!

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



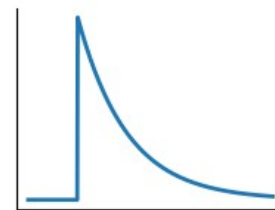
Synaptic models

Synapses

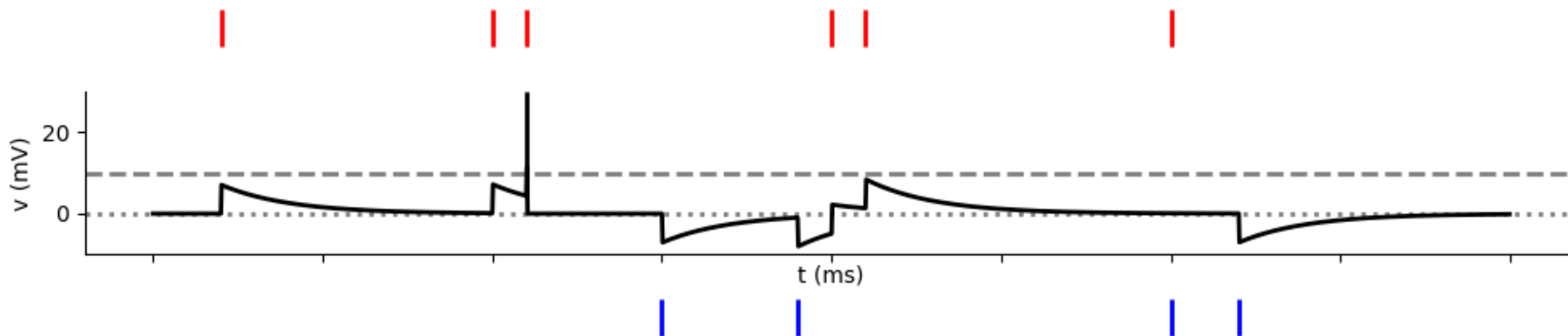
For each spike: increase V_m by J_{ij}

weight from j to i

membrane potential



“delta synapse”

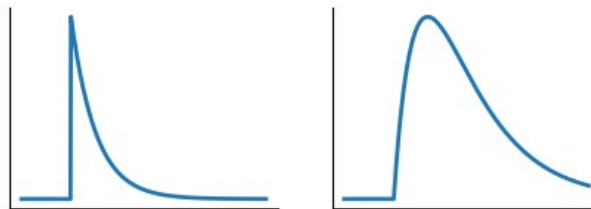


Synaptic models

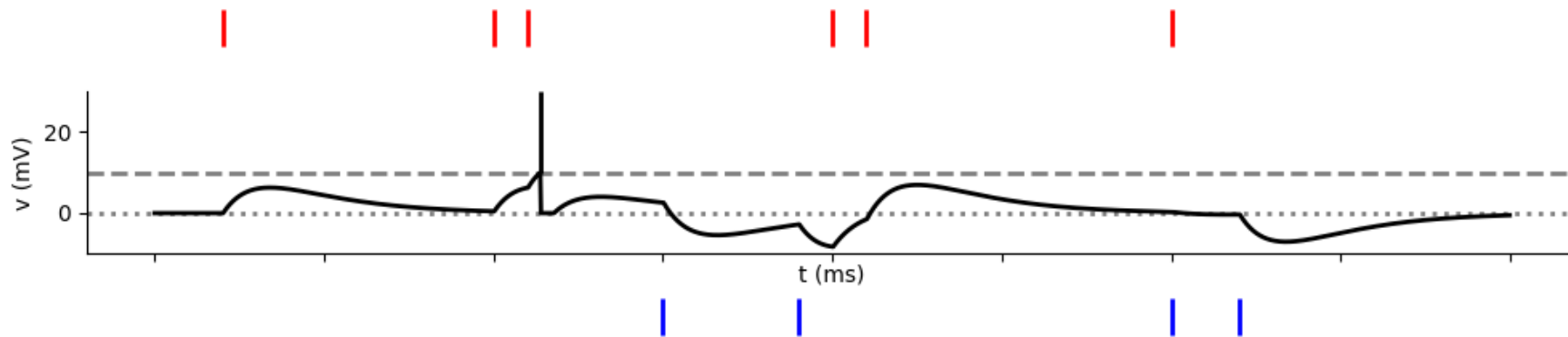
Synapses

For each spike: increase I_{syn} by J_{ij}
Between spikes: I_{syn} exponentially decays to 0

synaptic current membrane potential



Current-based
synapse



Synaptic models

Synapses

$$I_{syn} = g_{syn} (E_{syn} - V_m)$$

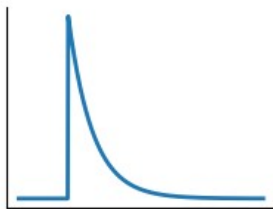
For each spike:

increase g_{syn} by J_{ij}

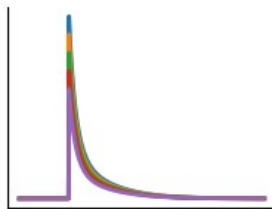
Between spikes:

g_{syn} exponentially decays to 0

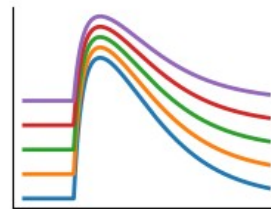
synaptic
conductance



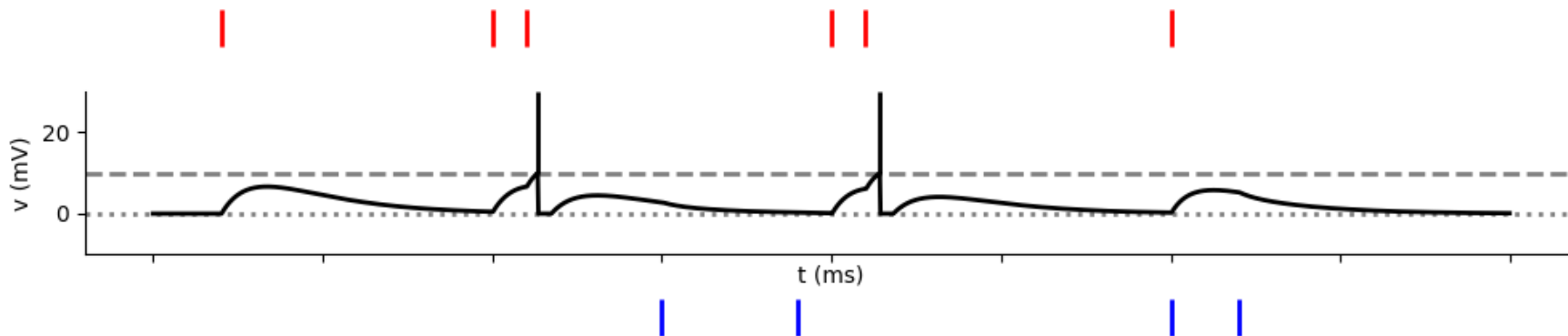
synaptic current



membrane potential



exponential
conductance-based



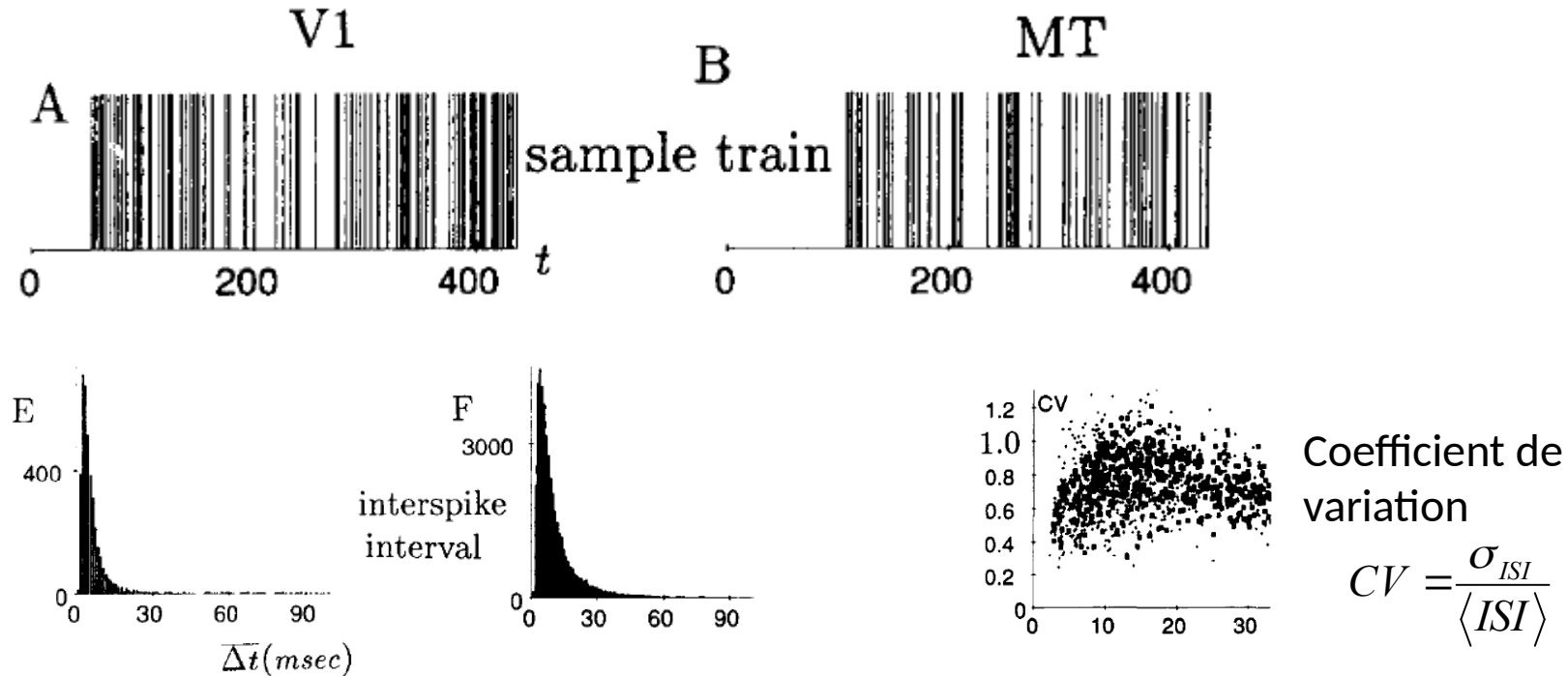
Input integration in neurons

- 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!

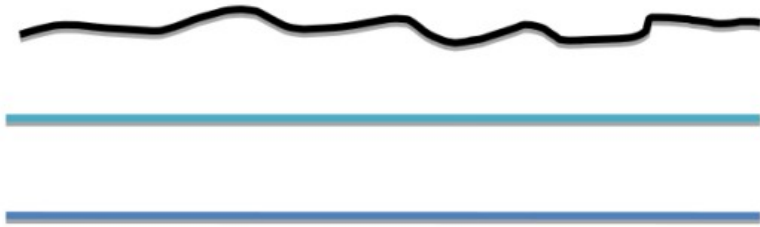
Irregularity of spike trains

Cortical neurons fire irregularly (in vivo)



Mean-driven vs. fluctuation-driven

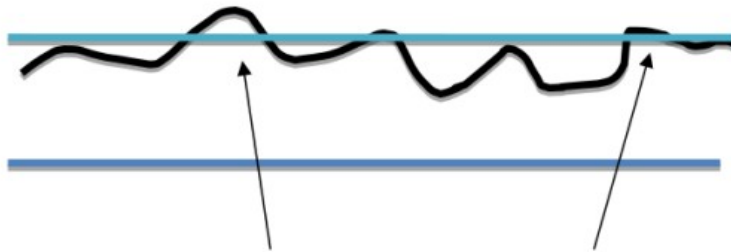
Mean-driven



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

Small variability (average of many inputs)

Fluctuation-driven



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

0

Let's try with

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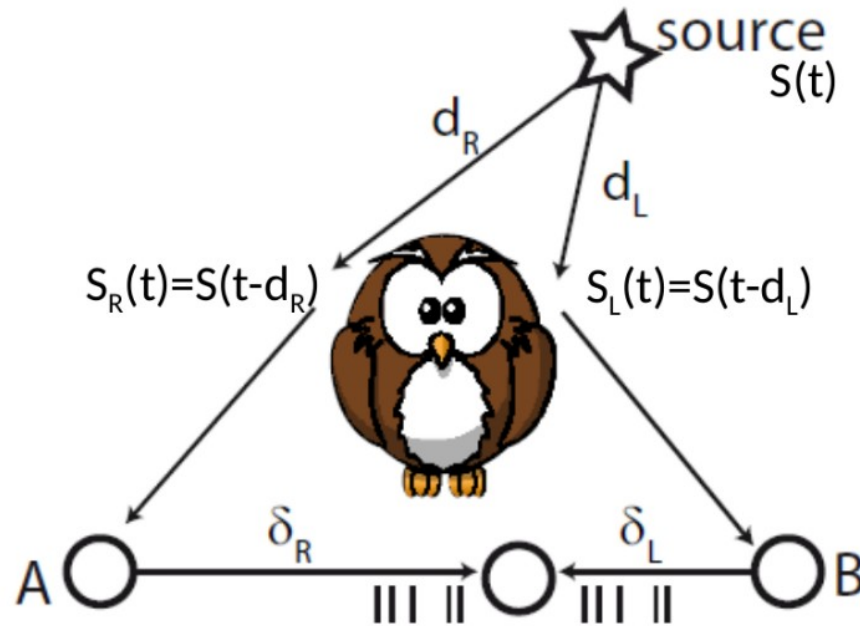
spikes can only occur at times when the input fluctuates above the mean

Part 3: Case study

Binaural sound localisation

Binaural sound localisation

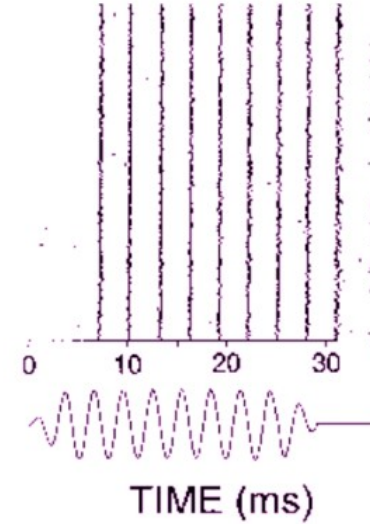
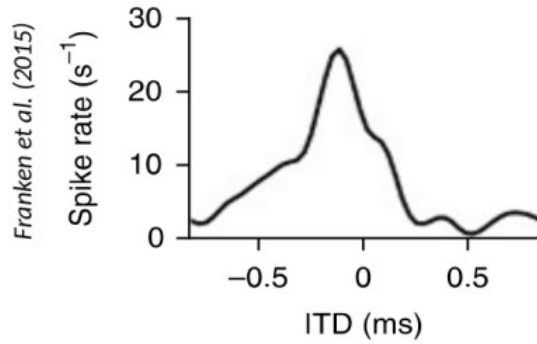
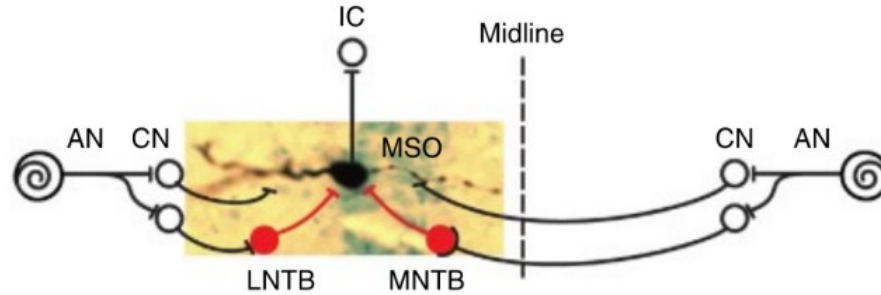
The Jeffress model



Interaural time delay
(ITD)

Binaural sound localisation

Anatomical structures from the ear to the brainstem



Louage et al. (2005)

Let's try with

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