



Neural Data Science with **Python**

L3 : Wrangling Spike Trains

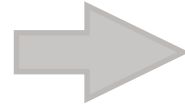
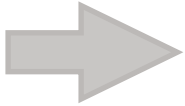
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Université Paris Cité, CNRS

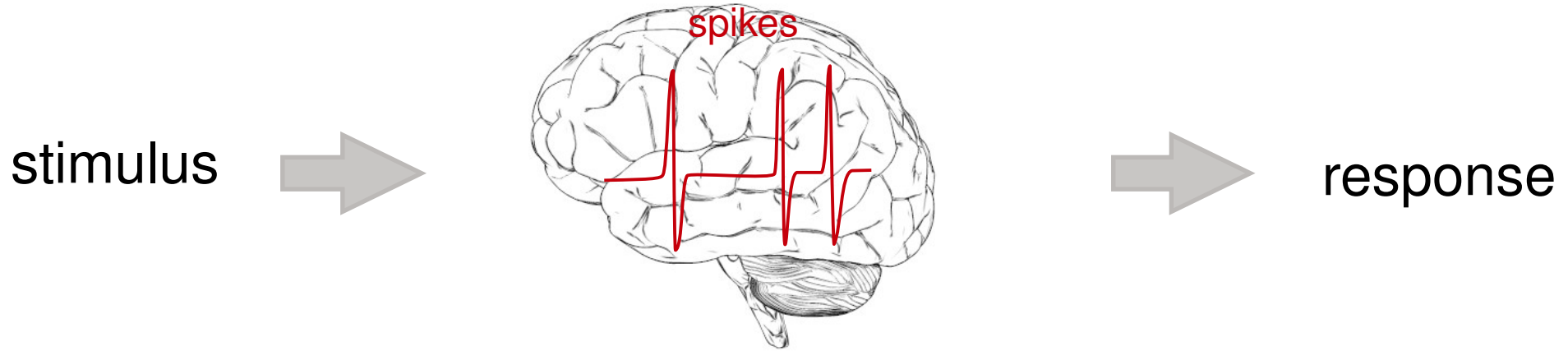
Cognitive processing

stimulus



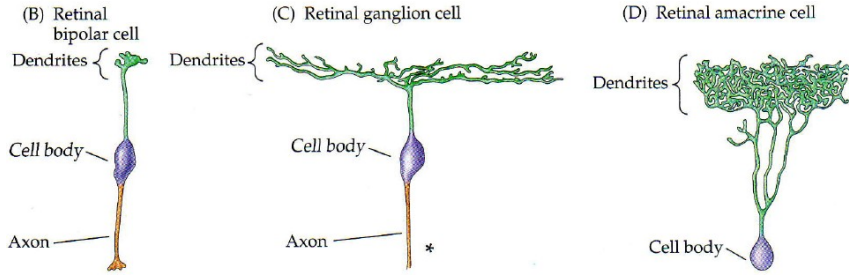
response

The quest for the Neural Code



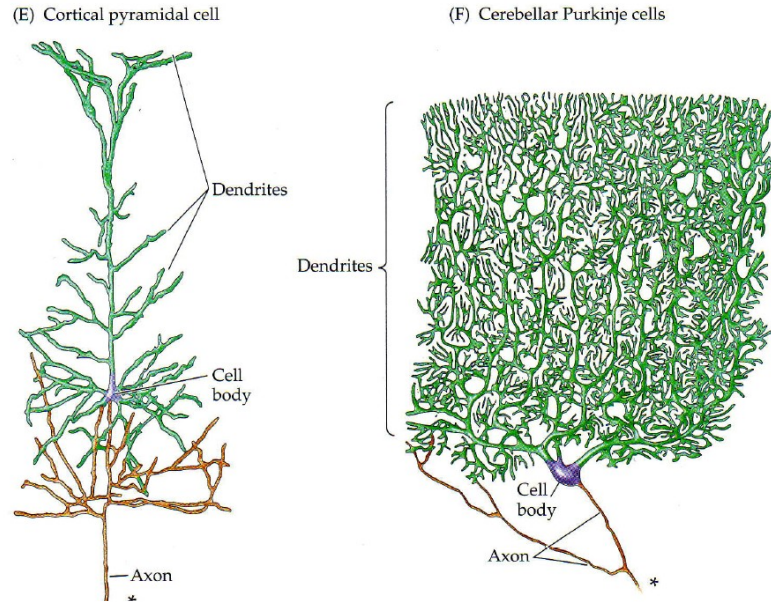
- How is information represented in the brain ?
Is the information carried by the timing of spikes, or in the firing rate
- How much information is carried by neural populations ?
Population codes are complicated, neurons might carry redundant information
- On what time scales is information represented ?
Over which time scale is information integrated ?

Neurons = principal computation units



dendrites

soma

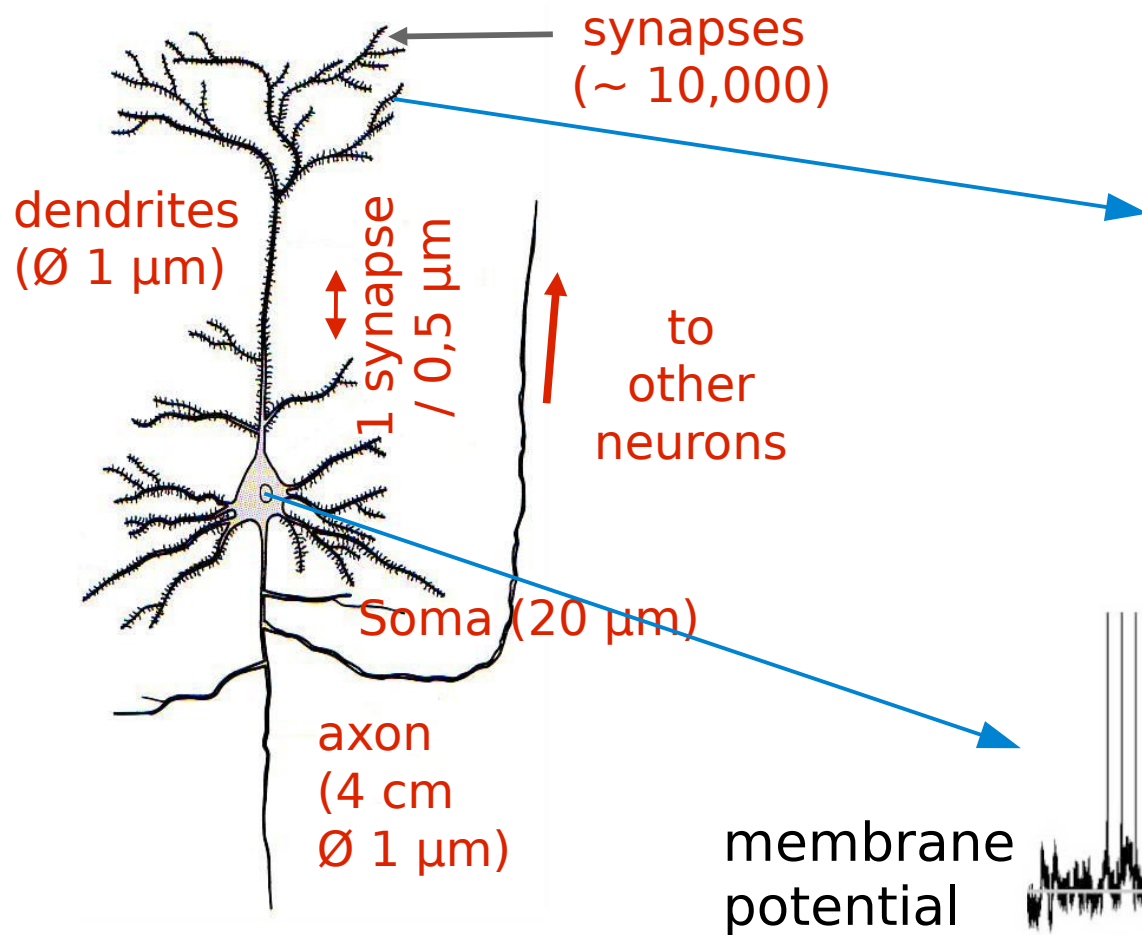


axon

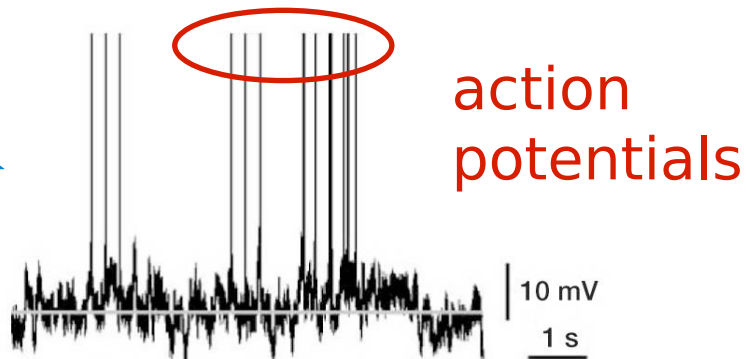
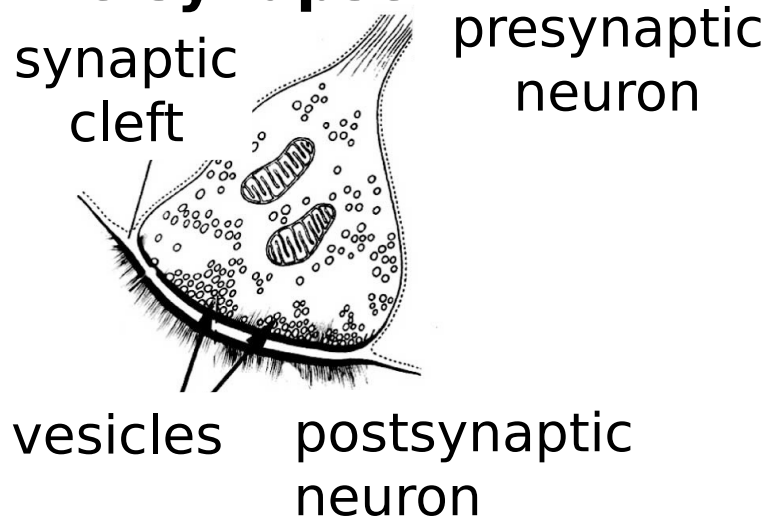
flow of information



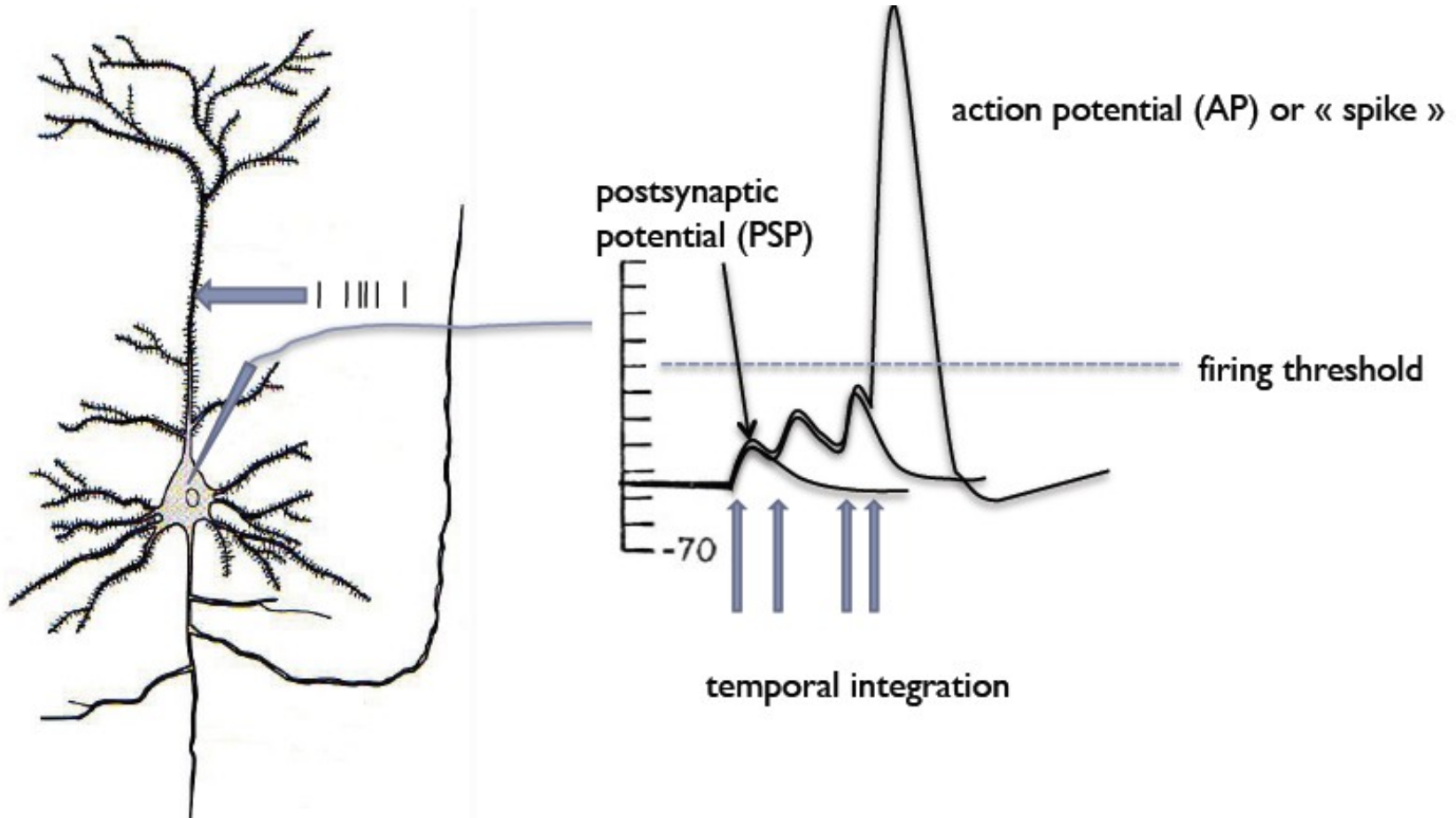
Typical cortical neuron



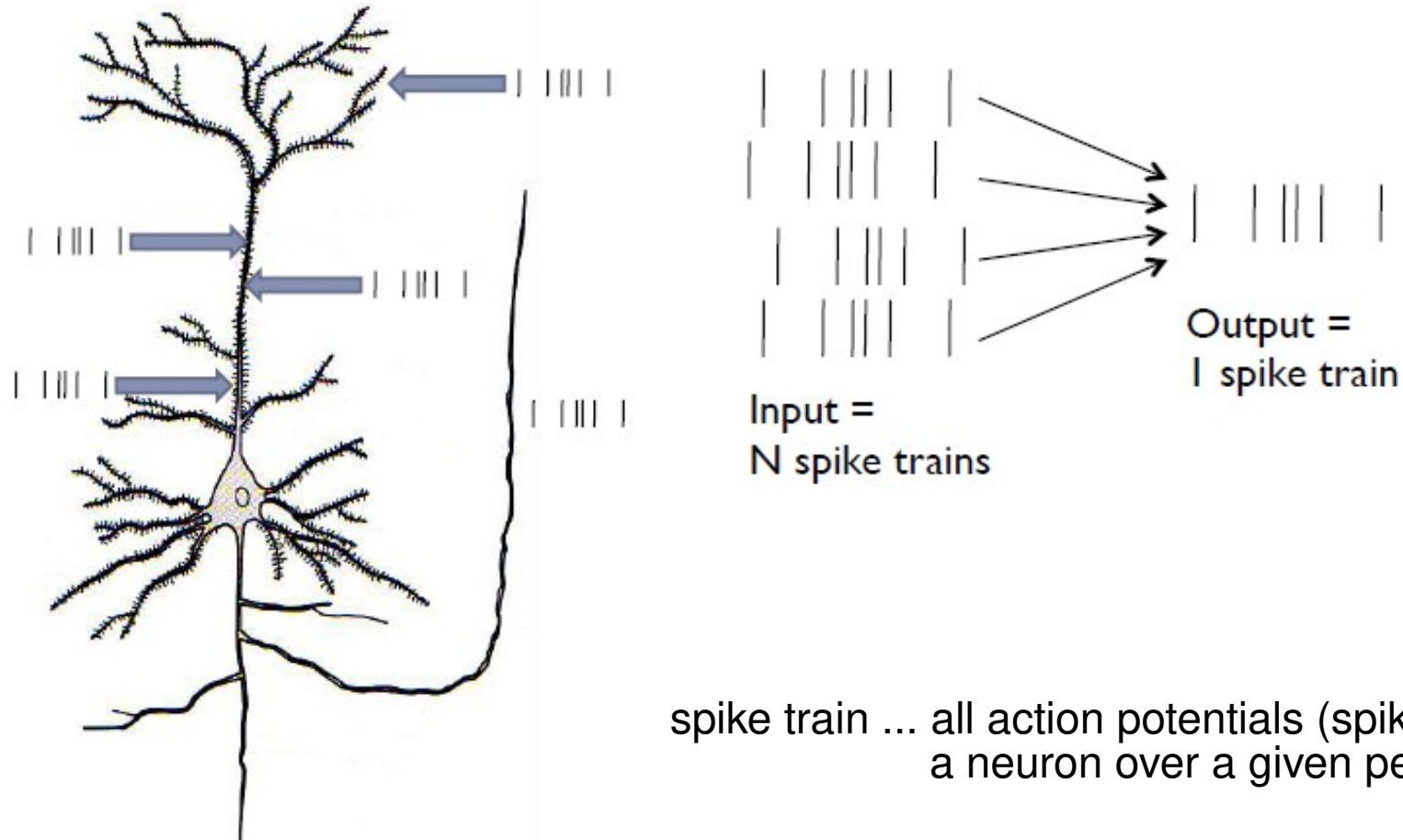
The synapse



Neural integration

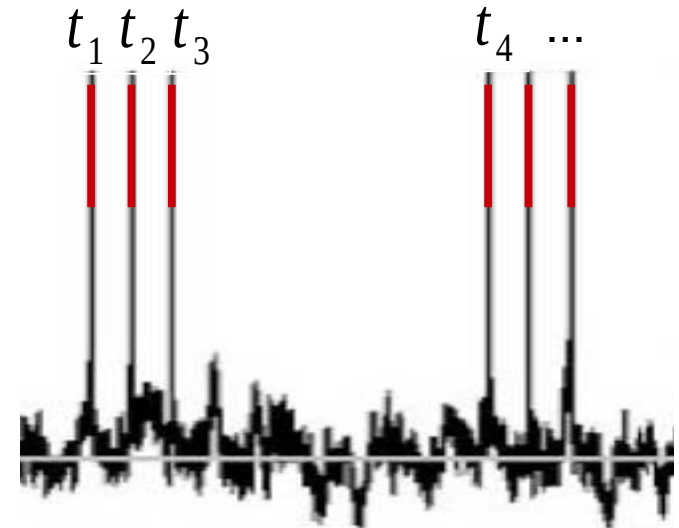


Neural integration



Statistics of trains of action potentials

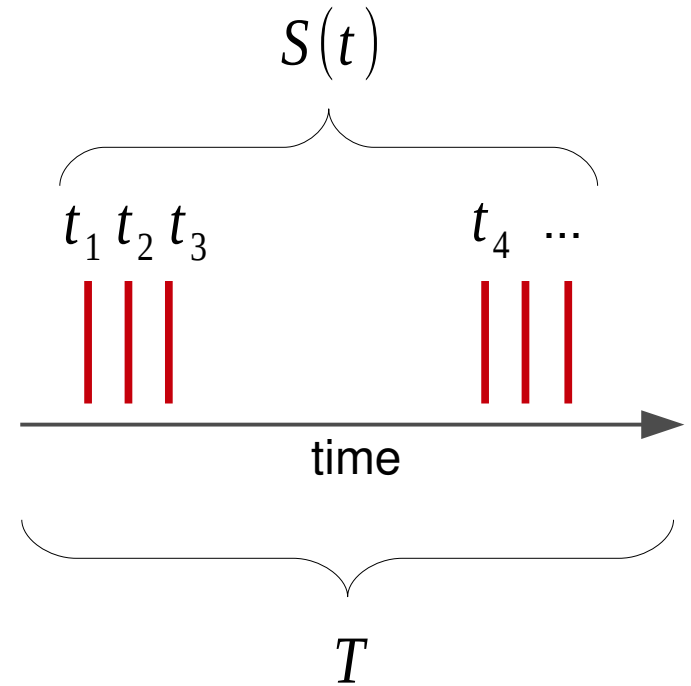
- Spike train (also: discharges, action potentials):
 - a sequence of spike times t^k
 - only the action potential is considered



Statistics of spike-trains: firing rate

- Spike train (also: discharges, action potentials):
 - a sequence of spike times t^k
 - only the action potential is considered
 - a signal $S(t)$
- Firing rate r or ν :
 - number of spikes/time

$$r = \frac{N_{\text{spikes}}}{T}$$



Statistics of spike trains: inter-spike interval

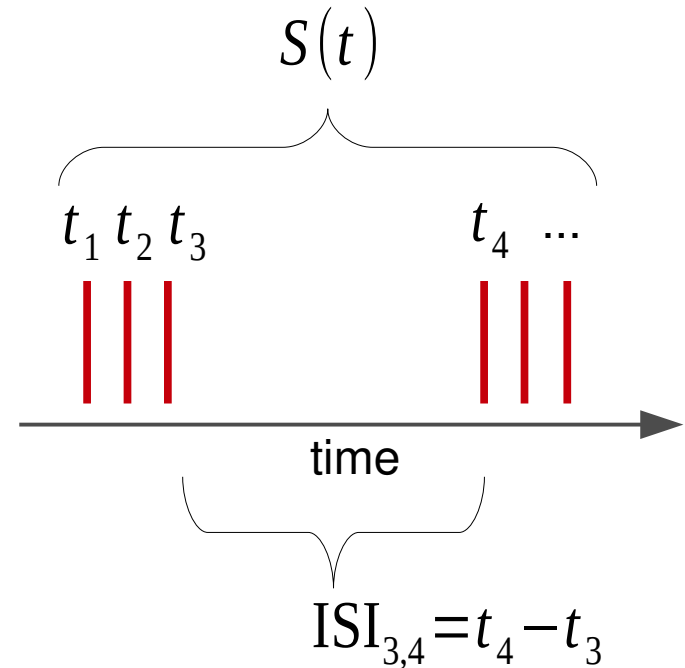
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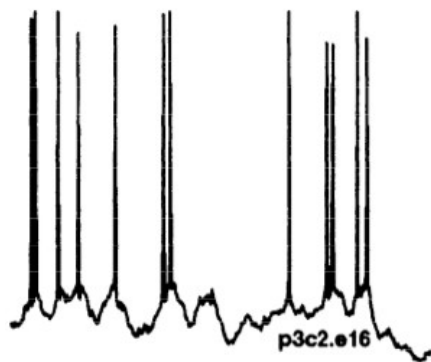
- Inter-spike interval (ISI) :

$$\text{ISI} = t^{n+1} - t^n$$



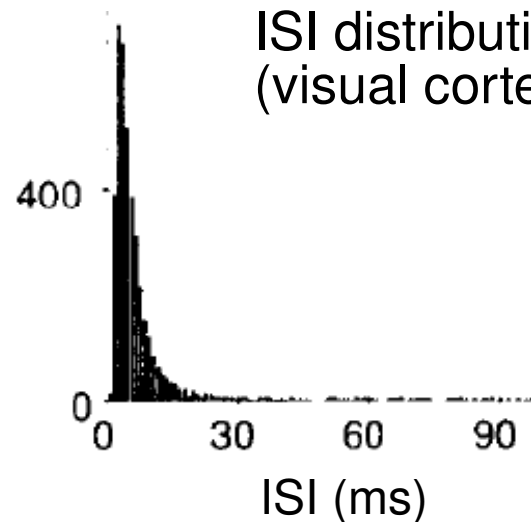
Statistics of spike-trains : inter-spike interval

In Vivo Visual Stimulation



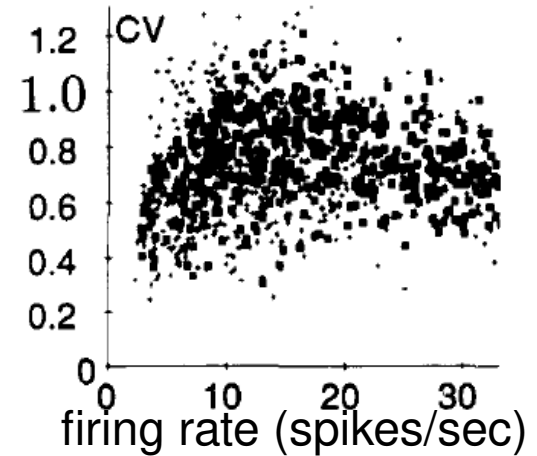
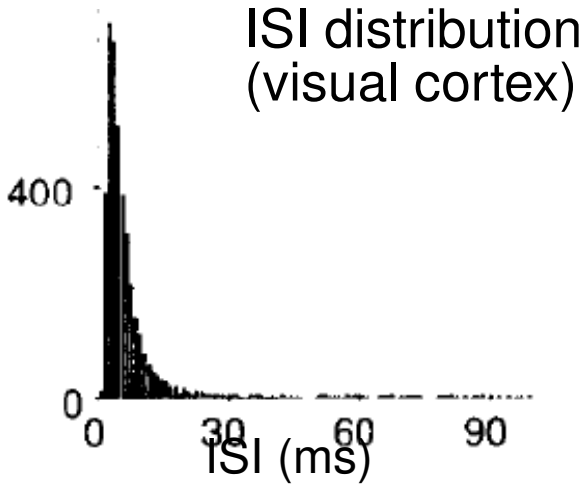
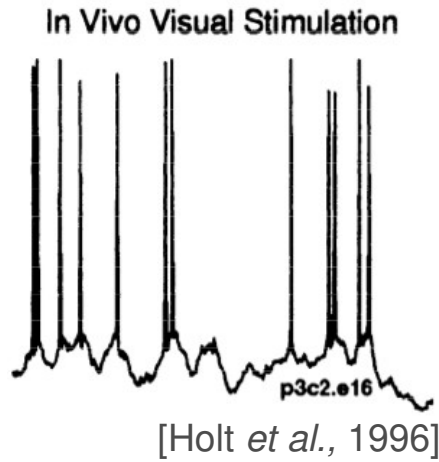
[Holt *et al.*, 1996]

ISI distribution
(visual cortex)



- ISIs of cortical neurons are highly variable
- ISI distribution is highly skewed with a few outliers

Statistics of spike-trains : coefficient of variation

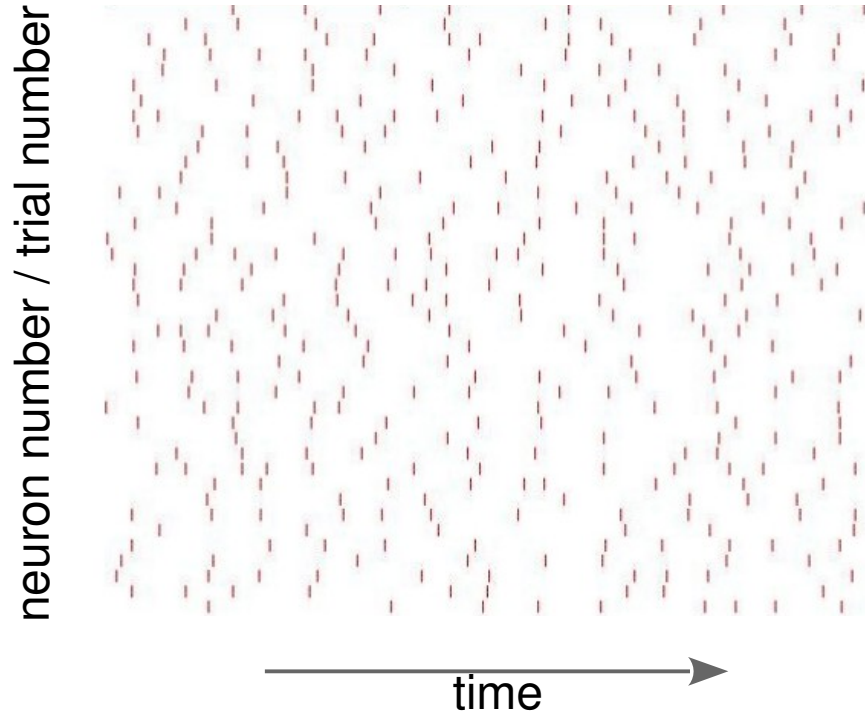


- Coefficient of Variation (CV) :

- ratio between standard-deviation and mean of the inter-spike interval
- measures the irregularity of spike trains
- spike are often irregular (CV~1) and vary from one trial to another

$$CV = \frac{ISI_{\text{standard deviation}}}{ISI_{\text{mean}}}$$

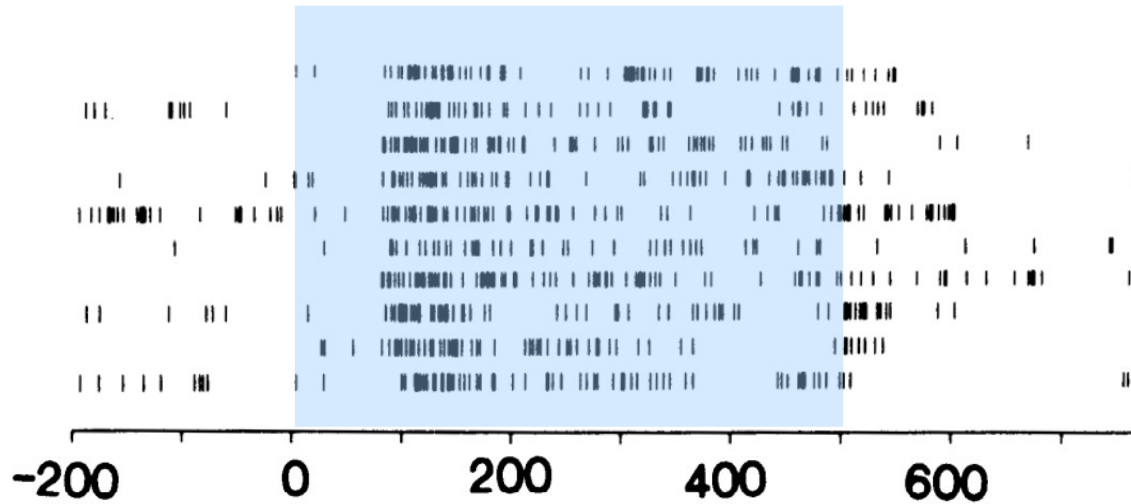
Visualization of spike-trains : raster plot



- provides raw view of spike-times
- each individual vertical line represents an action potential at a specific time of a given neuron, or at a given repetition
- also called **rastergram**

Visualization of spike-trains : PSTH

visual stimuli, duration = 500 ms

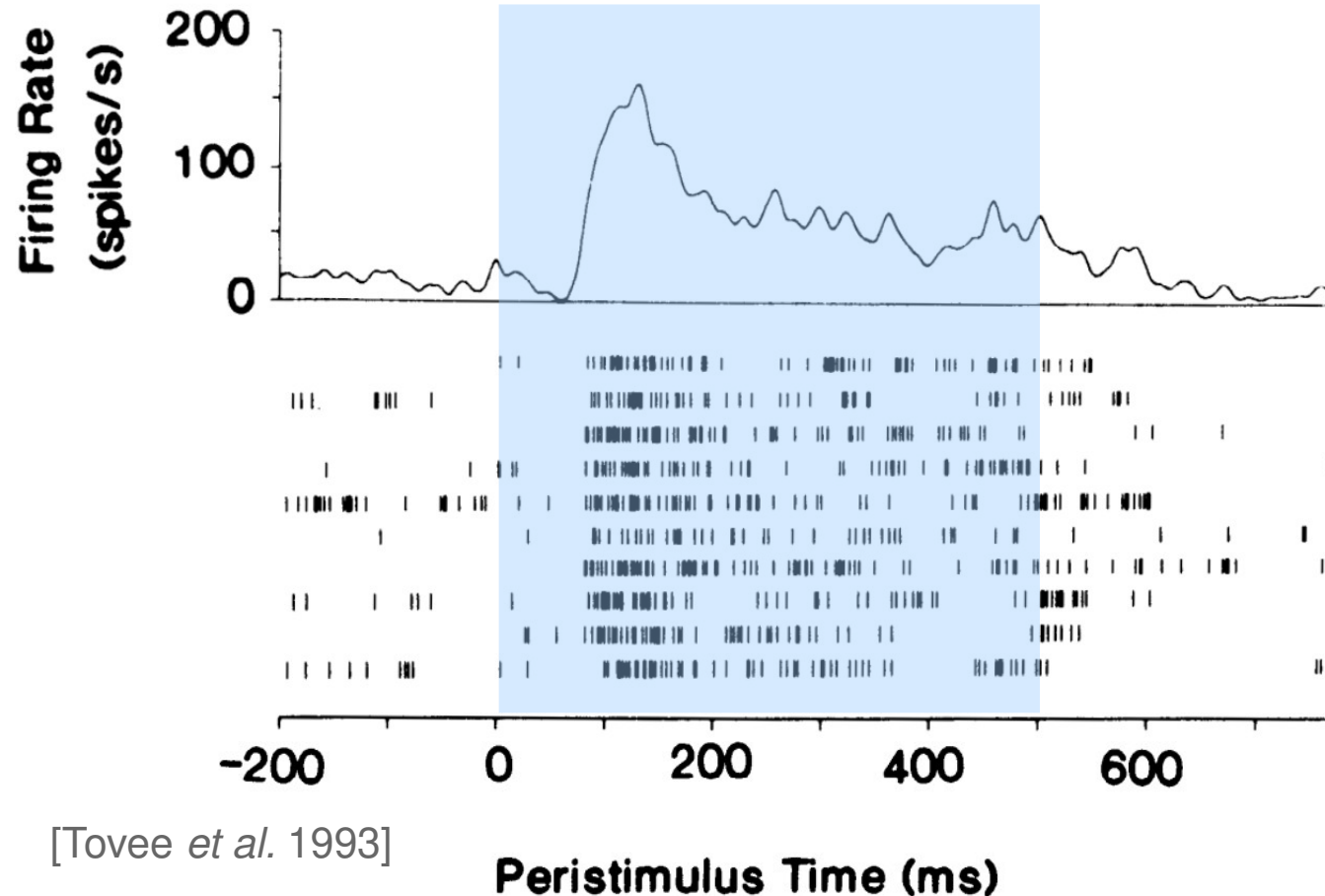


- recording in primate visual cortex
- each line represents a repetition of the same recording

[Tovee *et al.* 1993]

Peristimulus Time (ms)

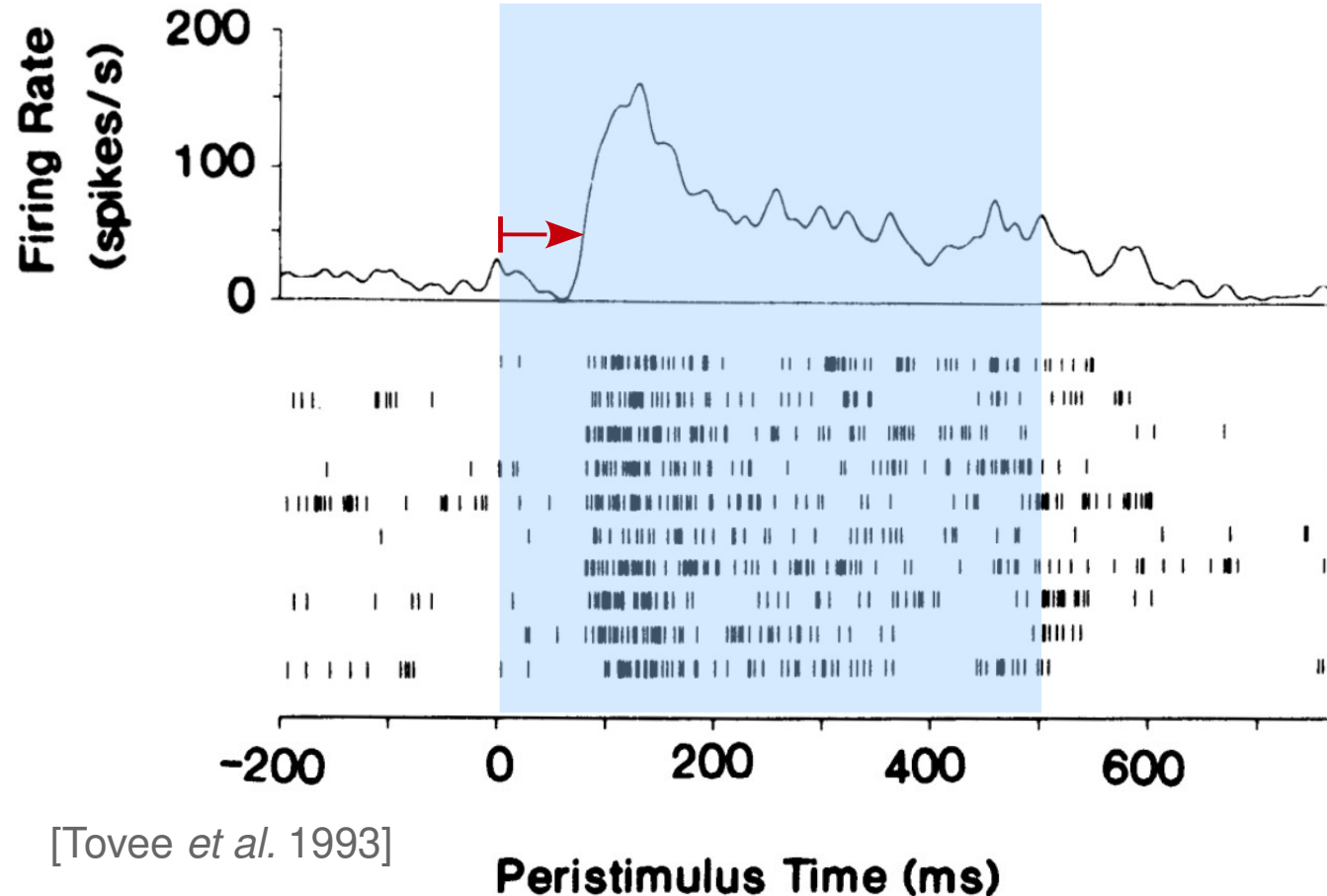
Visualization of spike-trains : PSTH



- the **peri-stimulus time histogram** averages all repetitions of an experiment, showing spike number/firing rate before, during and after a stimulus
- construction : time is binned and responses falling in the same bin are combined

[Tovee *et al.* 1993]

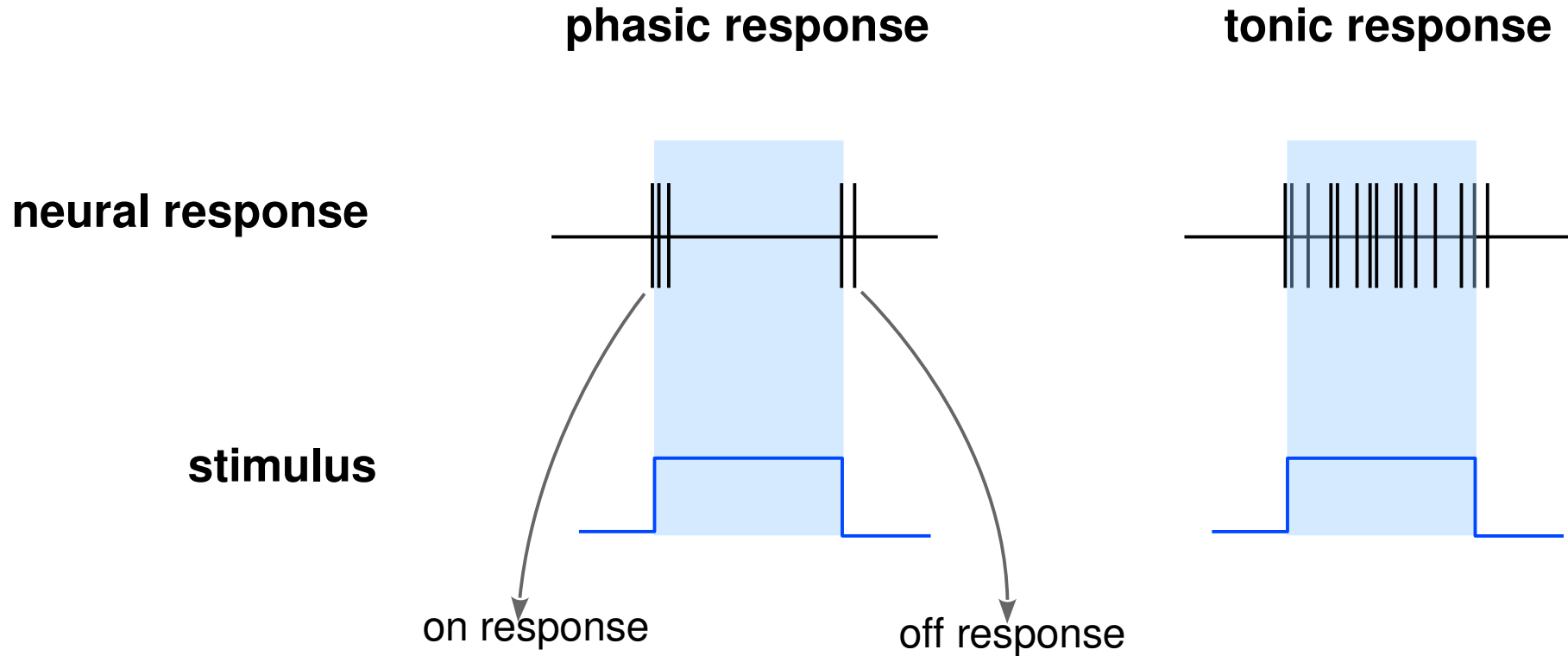
Response latency



- **response latency** : the time it takes a neuron to respond to a stimulus

[Tovee *et al.* 1993]

Neural response behaviors



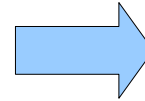
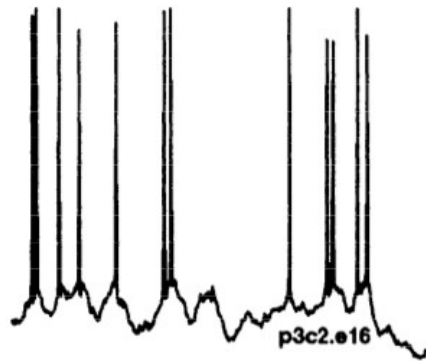
The Poisson process

real neurons

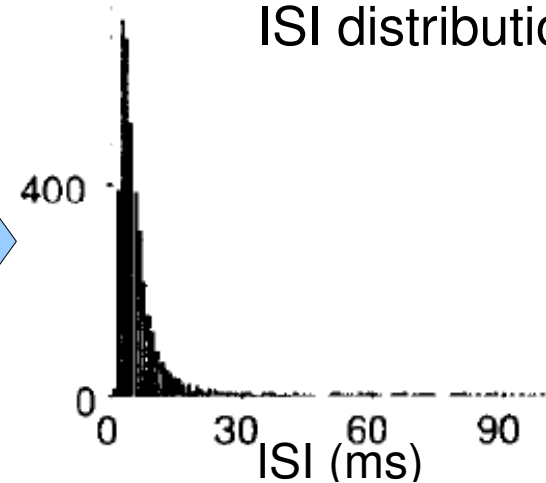
→ highly variable,
maybe spikes don't
matter, only the rate

→ **Poisson process**

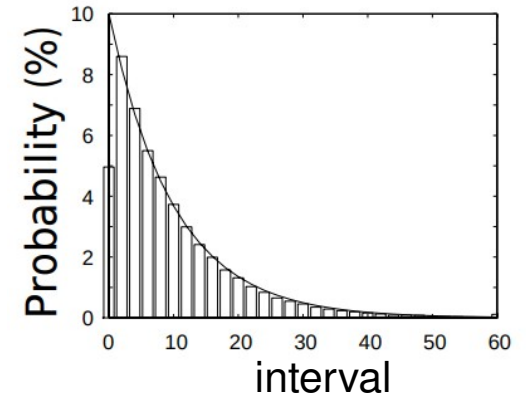
In Vivo Visual Stimulation



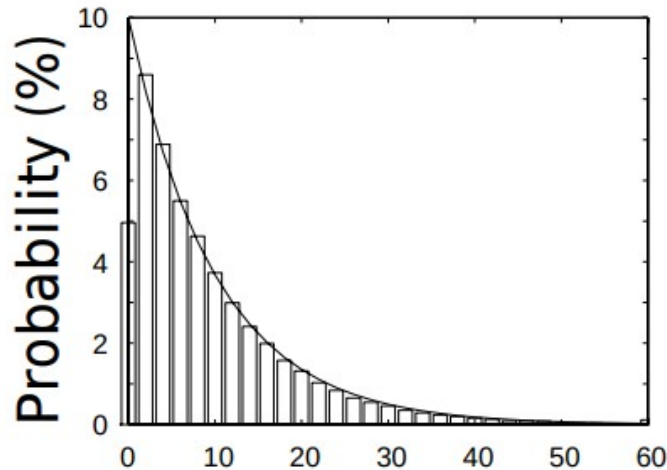
ISI distribution



Poisson processes are used to describe cases with rare, random events in time or space, e.g., radioactive emissions, traffic accidents, earthquakes and action potentials.



The Poisson process



- **Poisson process** : used in scenarios where we are counting the occurrences of certain events that appear to happen at a certain rate r , but completely at random (without a certain structure).
- The **interspike interval (ISI) density (histogram)** for a homogeneous Poisson process (constant rate) is an exponential function. The most likely interspike intervals are short ones and long intervals have a probability that falls exponentially as a function of their duration.

$$p(\tau) = r \exp^{-r\tau}$$

τ ... waiting time for the next spike to occur

r ... rate of the Poisson process