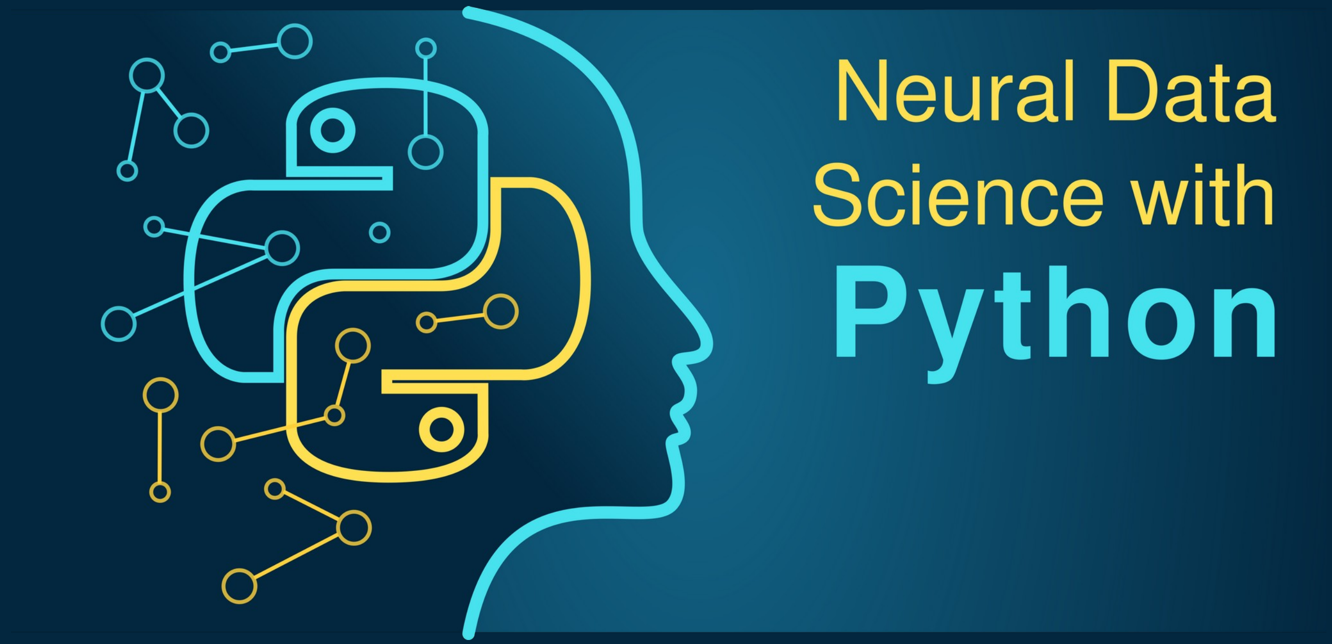


L4 : Wrangling Spike Trains

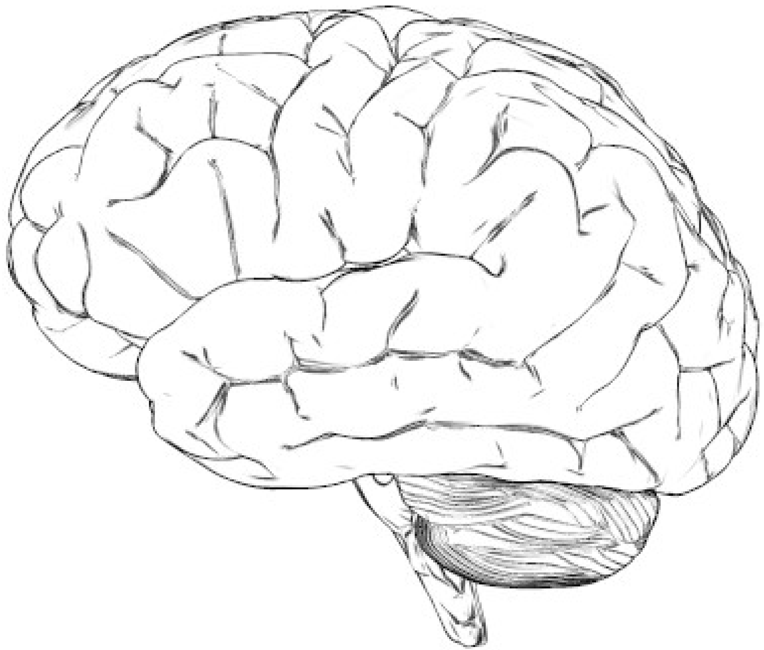
Michael Graupner

SPPIN – Saint-Pères Institute for the Neurosciences

Université Paris Cité, CNRS

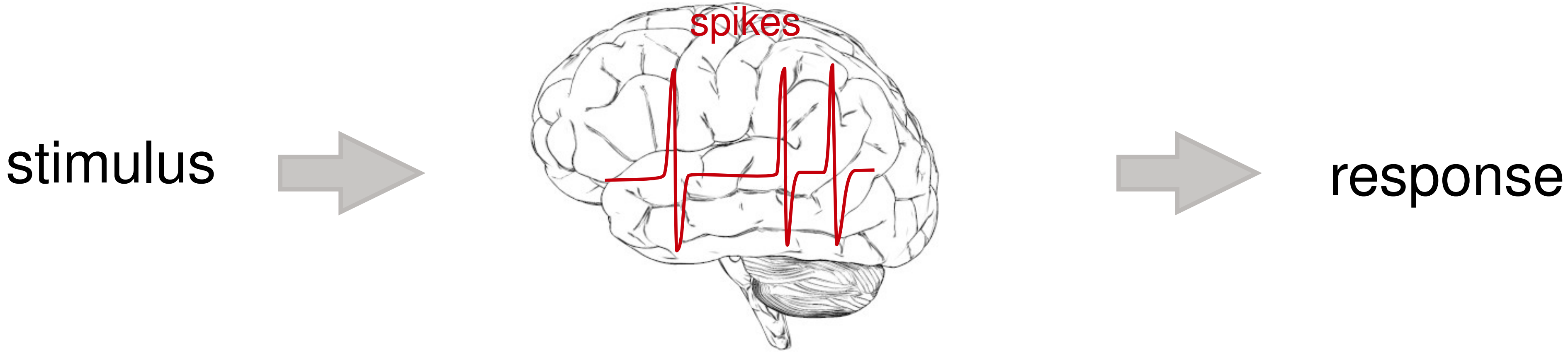
Cognitive processing

stimulus



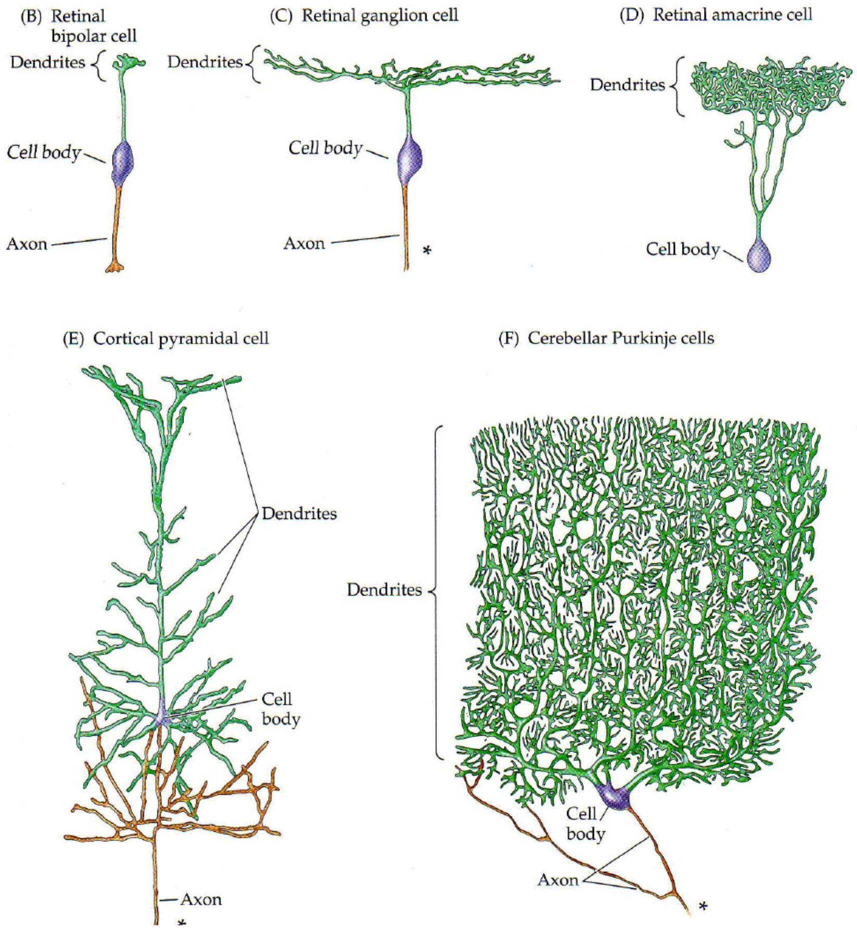
response

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



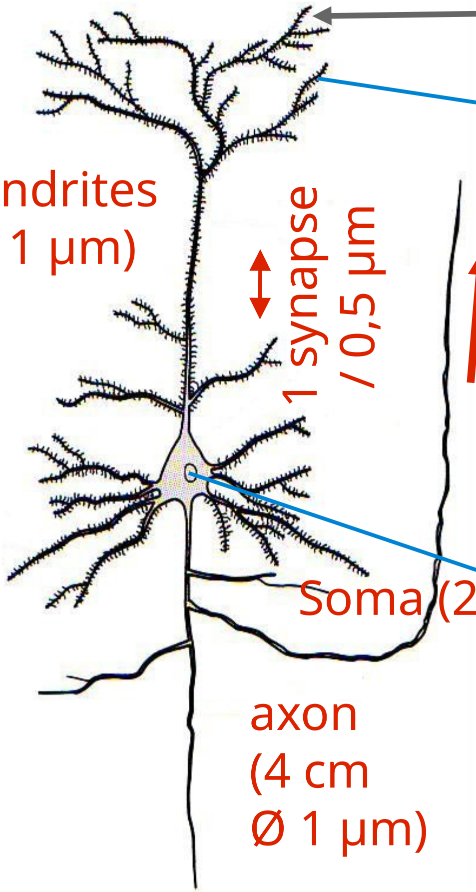
dendrites

soma

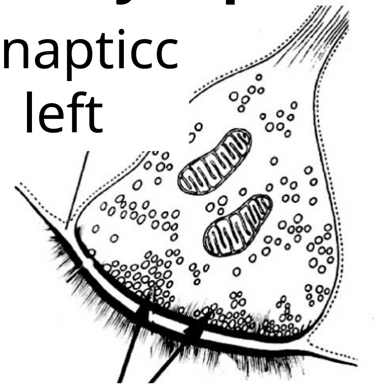
axon

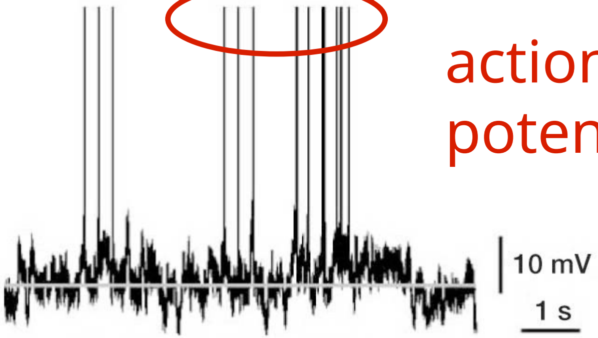
flow of information

Typical cortical neuron

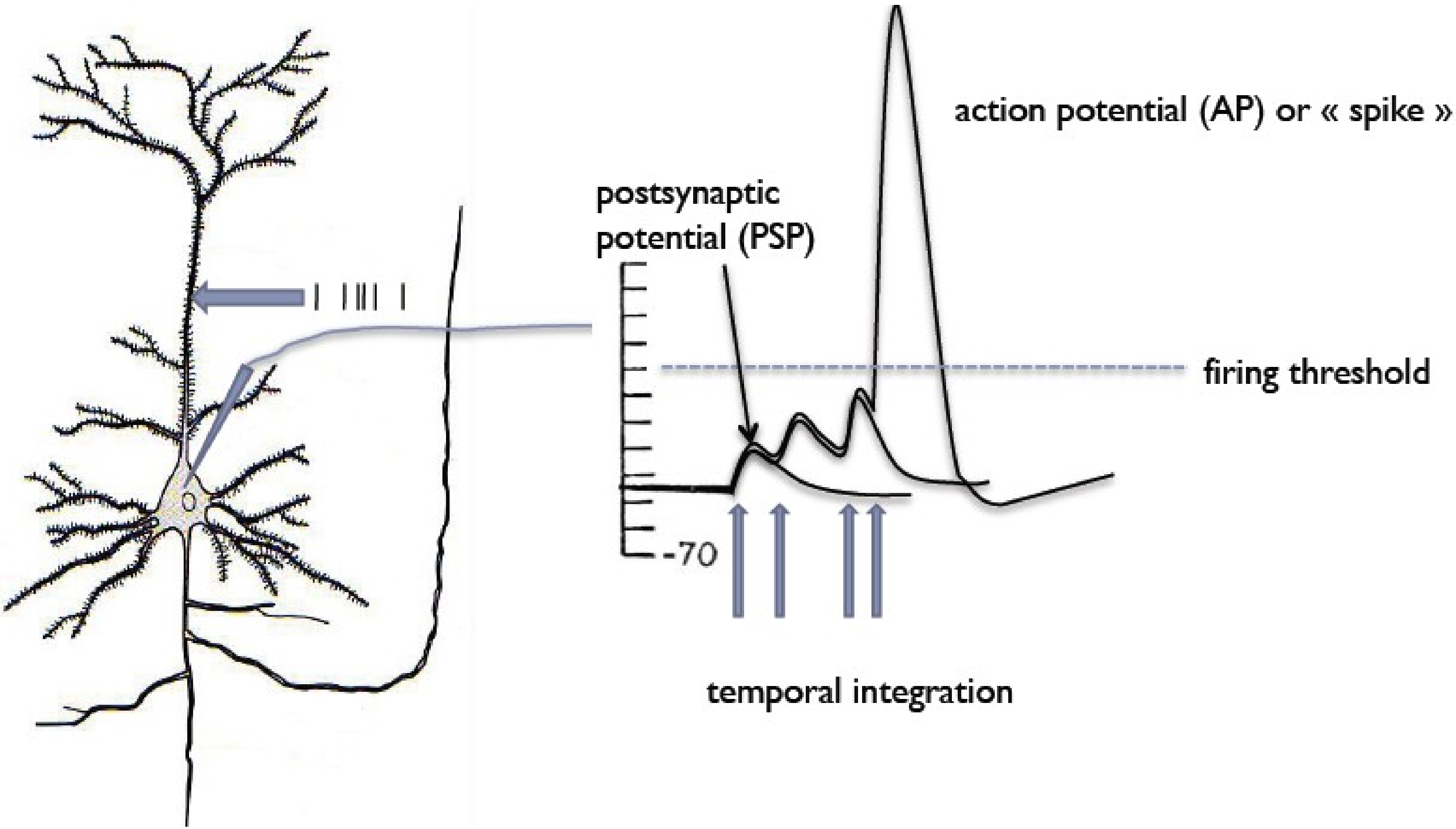


The synapse

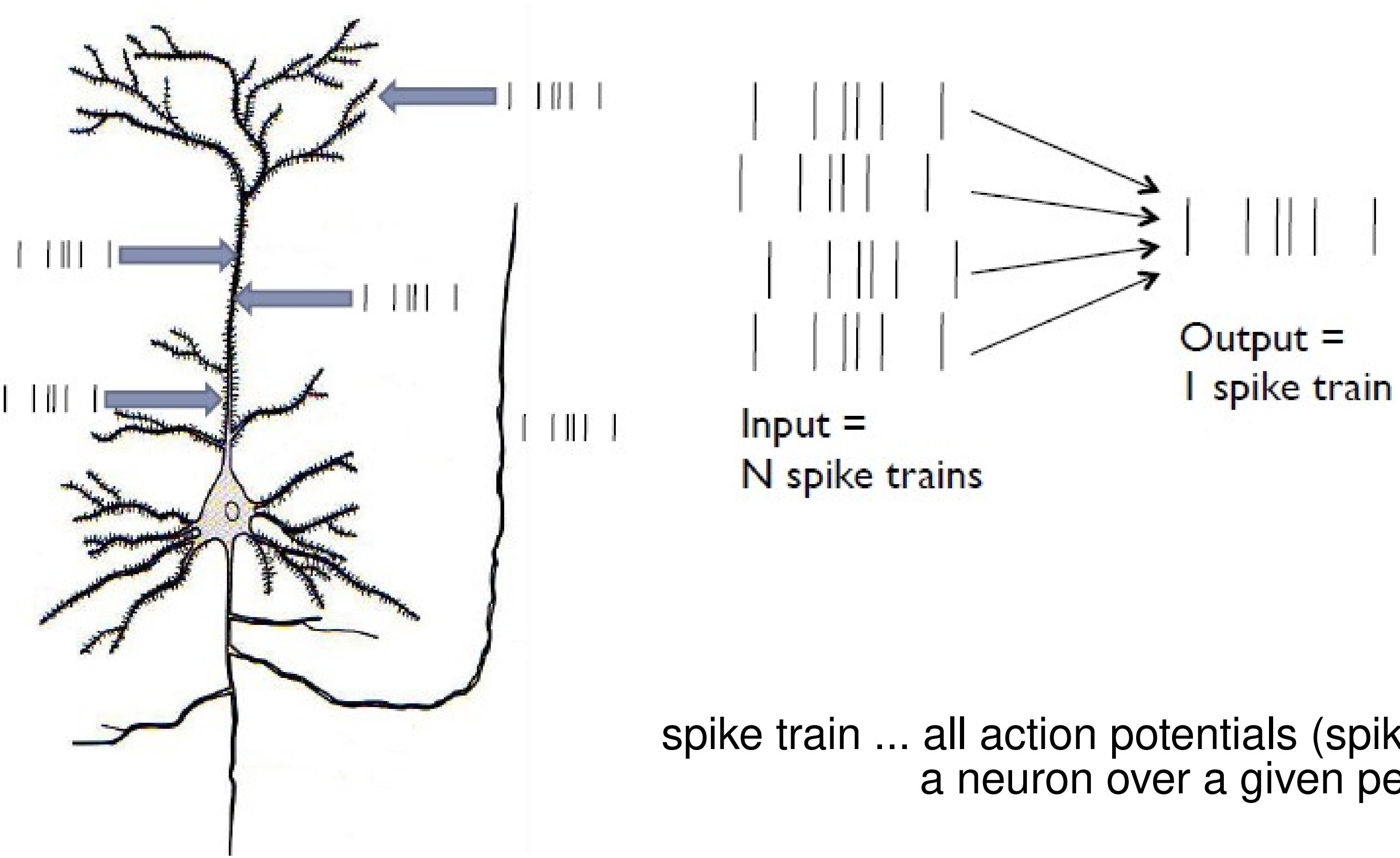




Neural integration



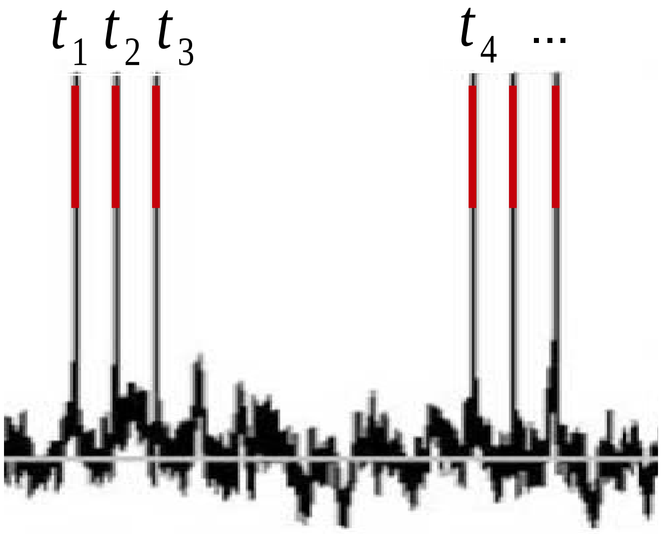
Neural integration



spike train ... all action potentials (spikes) emitted by a neuron over a given period of time

Statistics of trains of action potentials

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

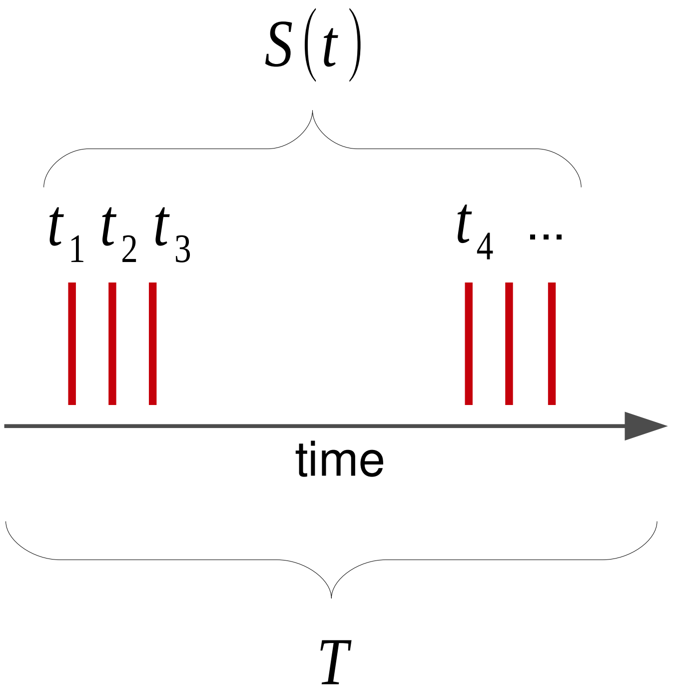


Statistics of spike-trains: firing rate

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

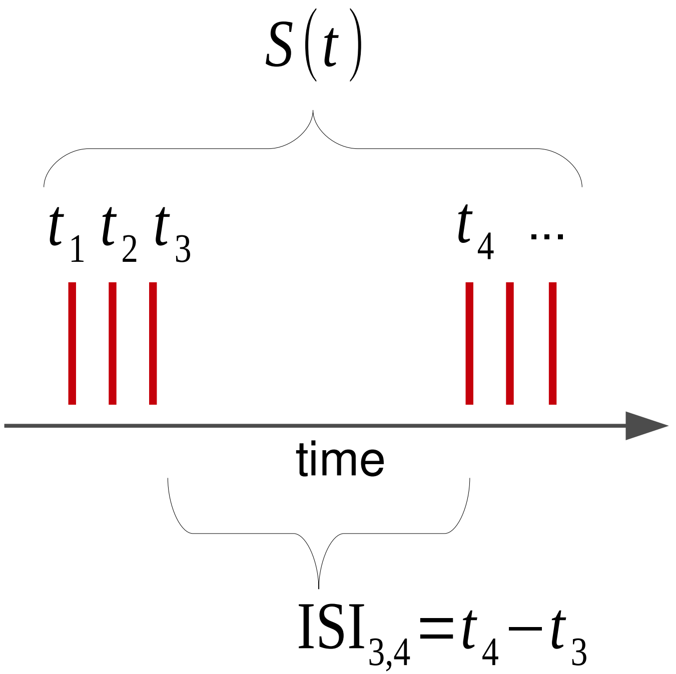
- Firing rate r or ν:
  $\rightarrow$ number of spikes/time

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



Statistics of spike trains: inter-spike interval

- 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

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

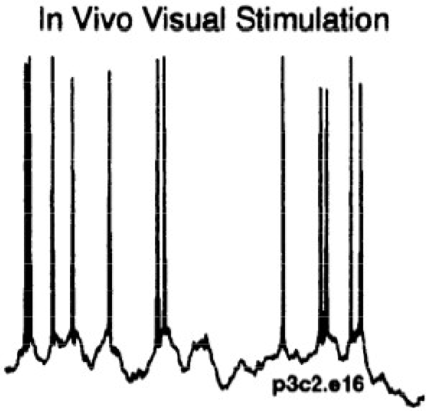
- Inter-spike interval (ISI) :

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

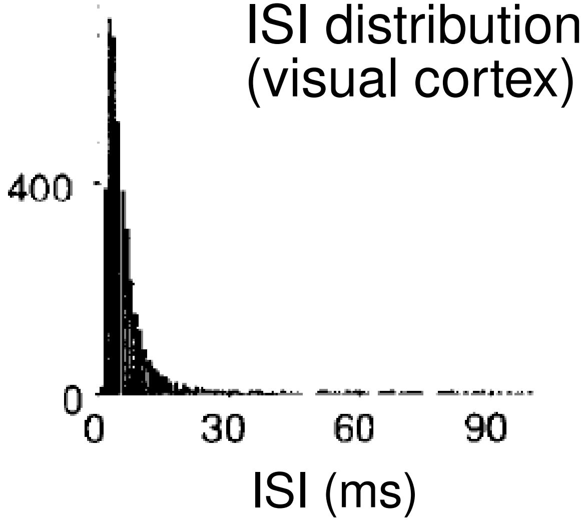
- Firing rate from ISI :

$$r = \frac{1}{ISI_{mean}}$$

Statistics of spike-trains : inter-spike interval

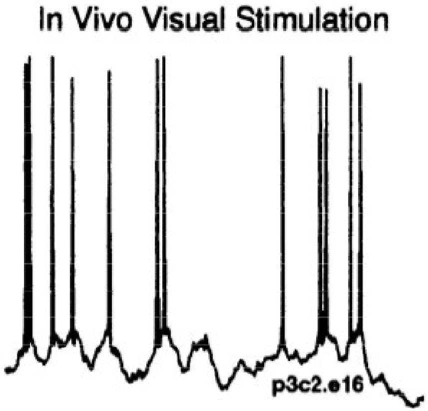


[Holt *et al.*, 1996]



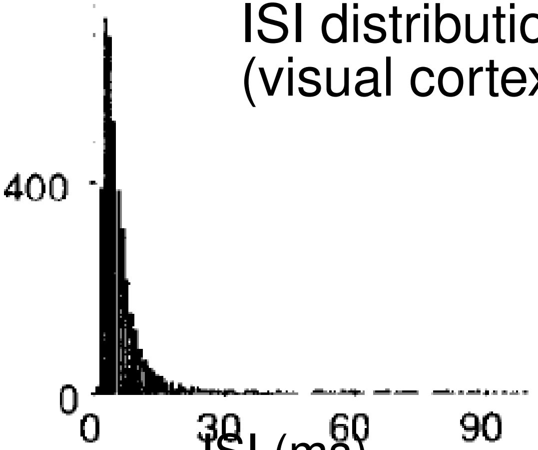
- ISIs of cortical neurons are highly variable
- ISI distribution is highly skewed with a few outliers

Statistics of spike-trains : coefficient of variation

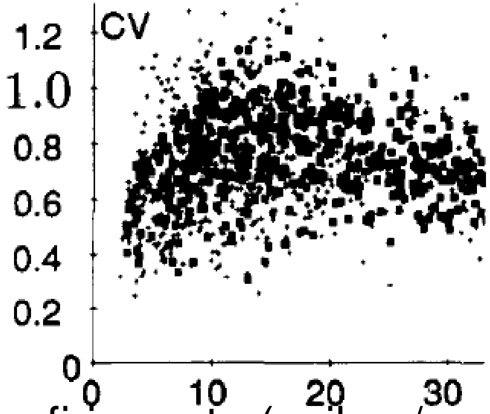


[Holt *et al.*, 1996]

ISI distribution
(visual cortex)



ISI (ms)

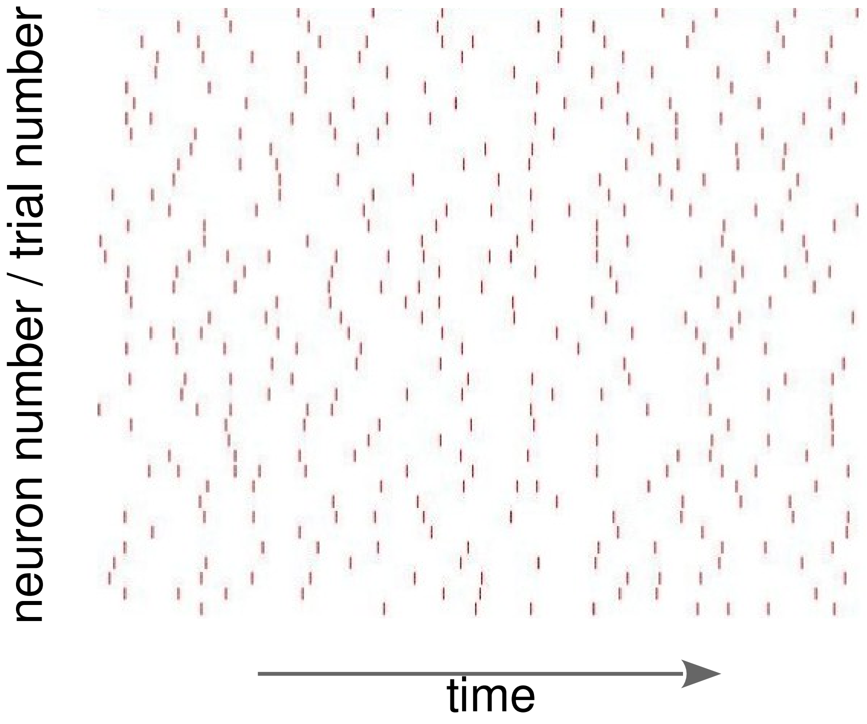


firing rate (spikes/sec)

- 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

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

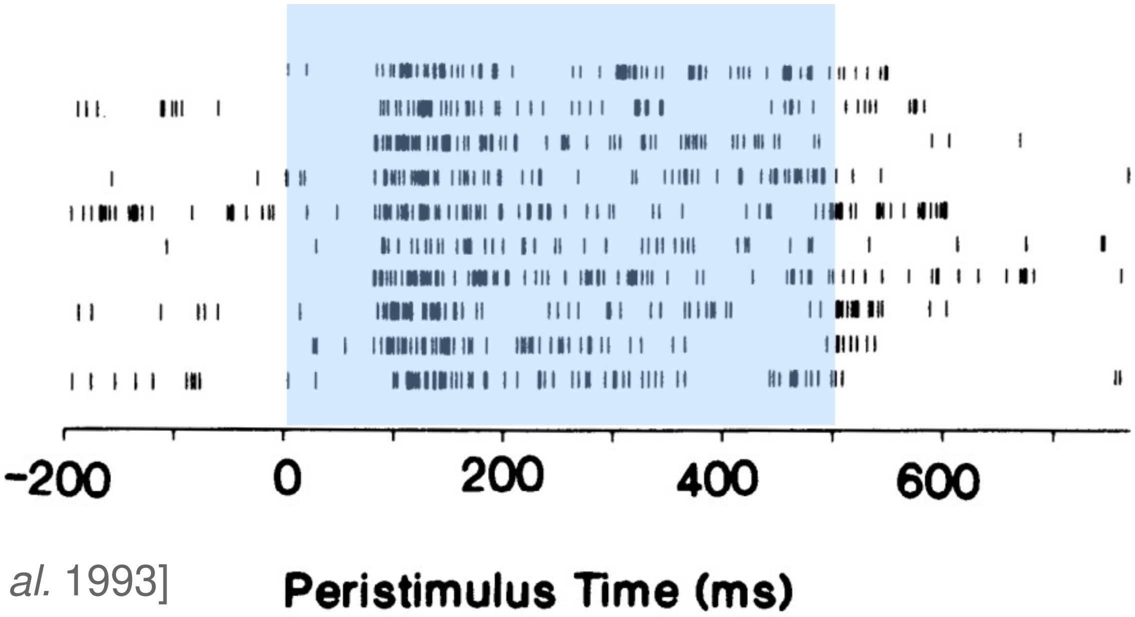
Visualization of spike-trains : raster plot



- 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

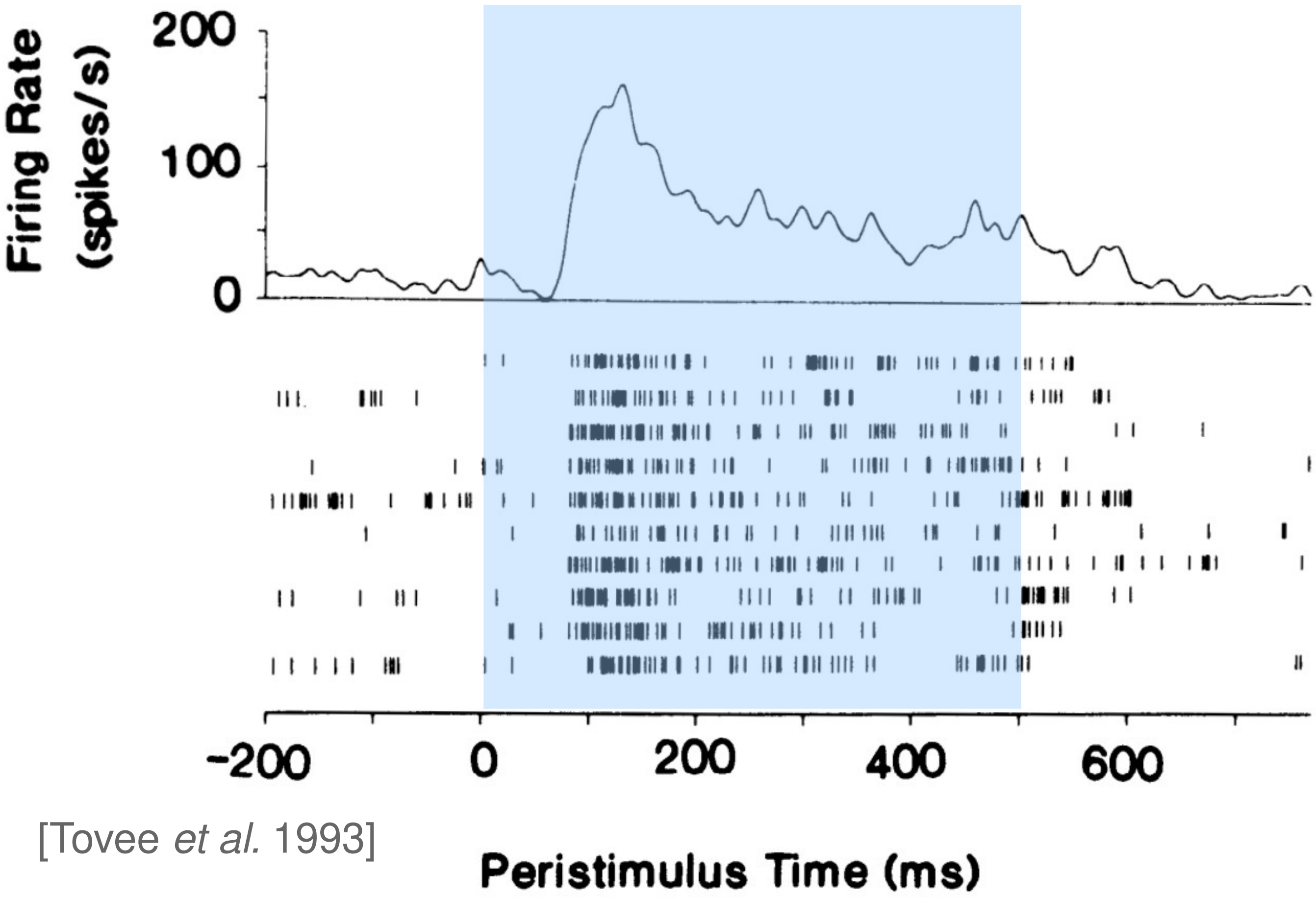
visual stimuli, duration = 500 ms



[Tovee *et al.* 1993]

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

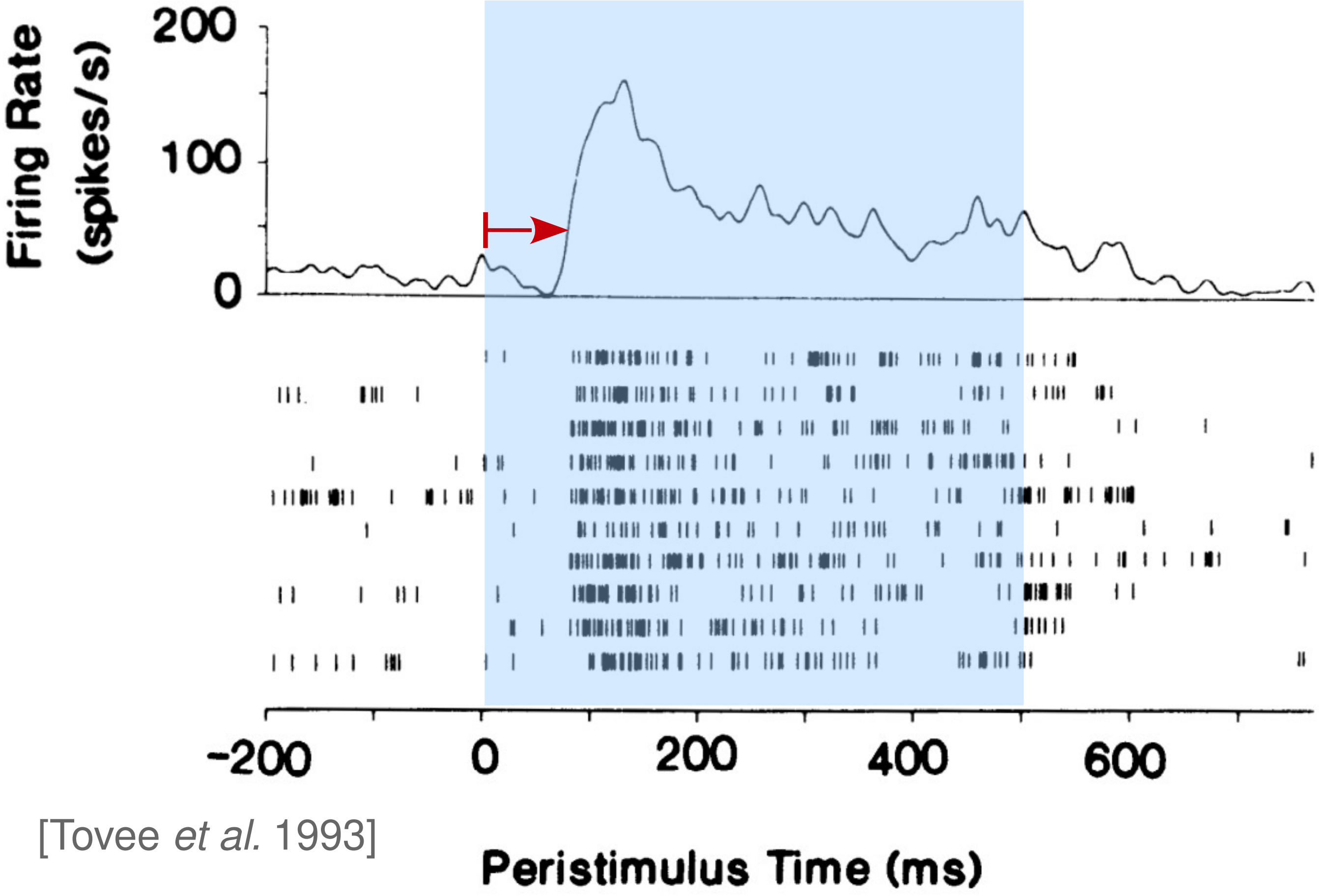
Visualization of spike-trains : PSTH



[Tovee *et al.* 1993]

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

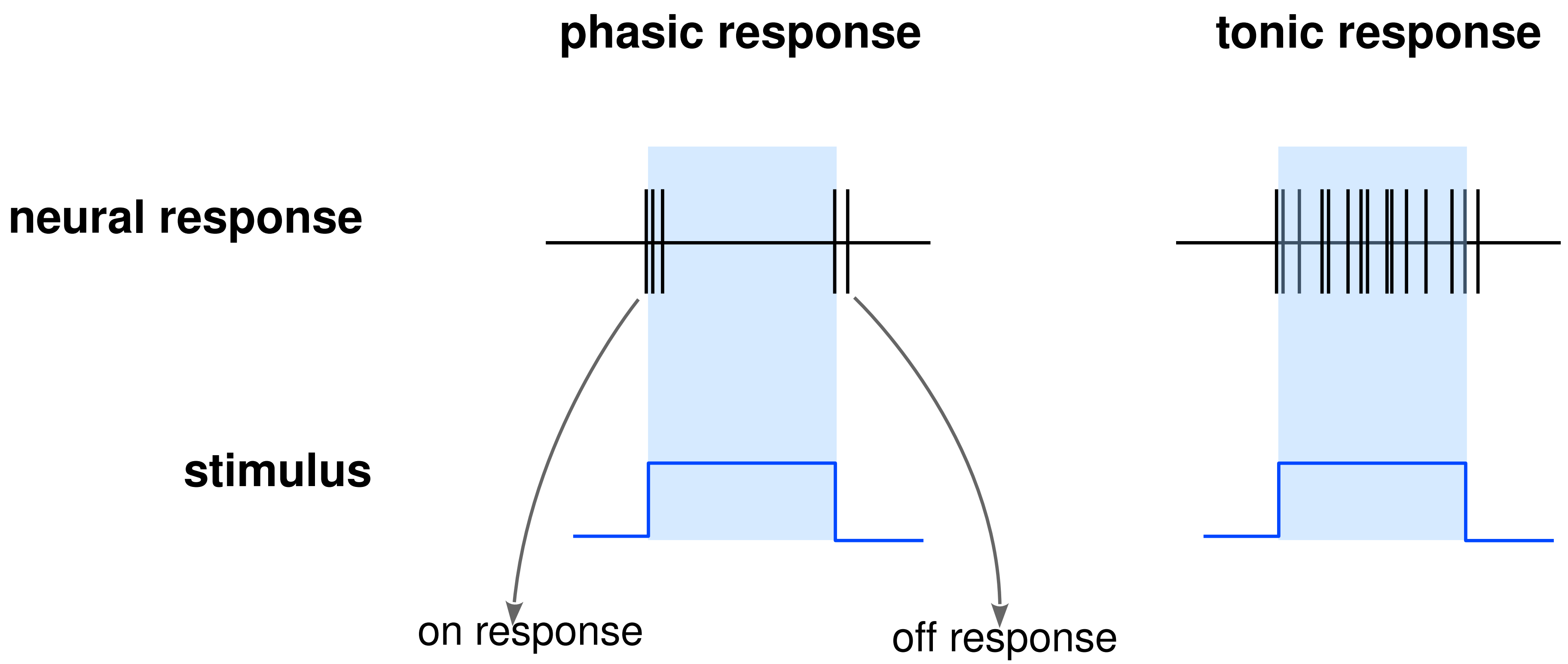
Response latency



[Tovee *et al.* 1993]

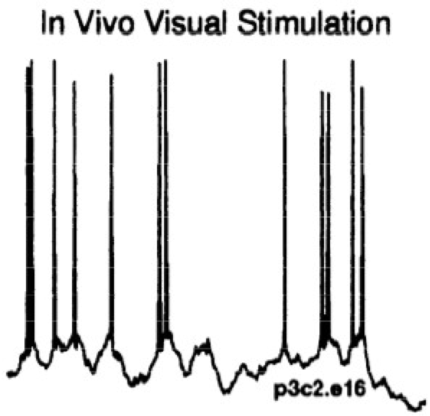
- **response latency** : the time it takes a neuron to respond to a stimulus

Neural response behaviors

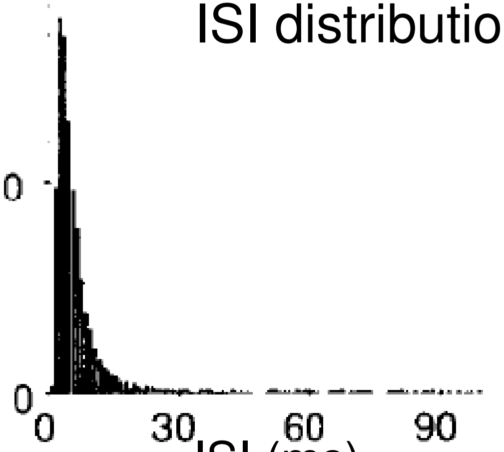


The Poisson process

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



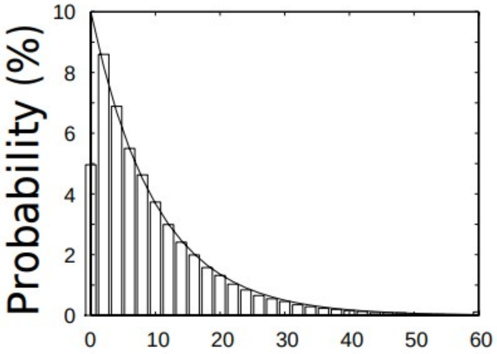
ISI distribution



ISI (ms)

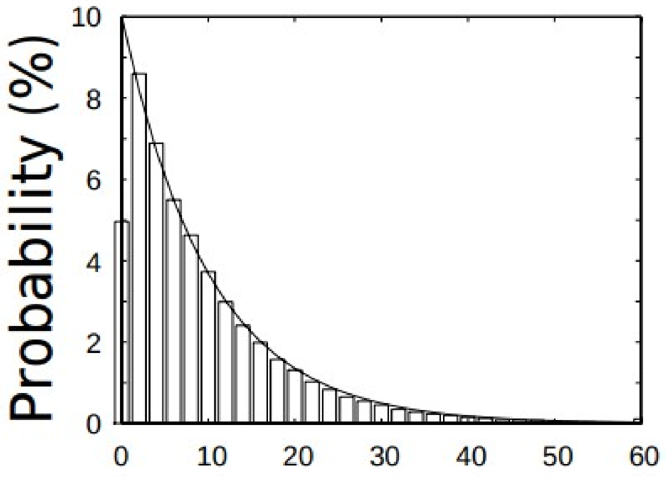
→ **Poisson process**

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.



interval

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