Week 5 – part 3a :Three definitions of rate code

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Neuronal Dynamics:
Computational Neuroscience of Single Neurons

Week 5 – Variability and Noise:
The question of the neural code

Wulfram Gerstner

EPFL, Lausanne, Switzerland

Week 5 – part 3a :Three definitions of rate code

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√ **5.1 Variability of spike trains**
- experiments

√ **5.2 Sources of Variability?**
- Is variability equal to noise?

5.3 Three definitions of Rate code
- Poisson Model

5.4 Stochastic spike arrival
- Membrane potential fluctuations

5.5. Stochastic spike firing
- subthreshold and superthreshold

Neuronal Dynamics – 5.3. Three definitions of Rate Codes

3 definitions

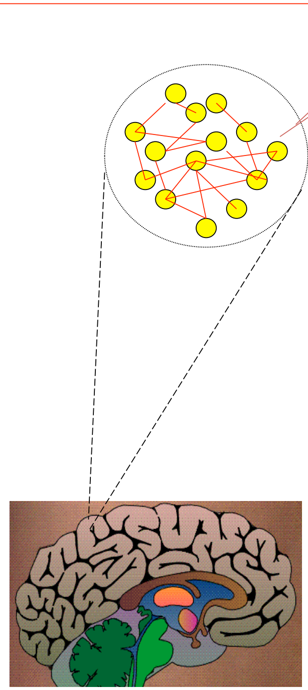
-Temporal averaging

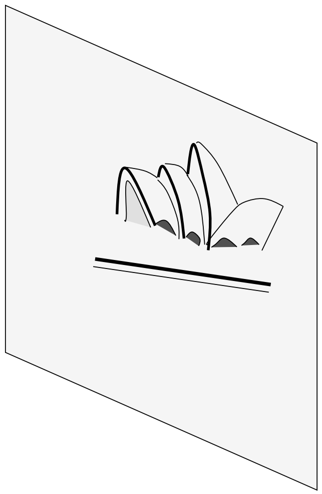
- Averaging across repetitions

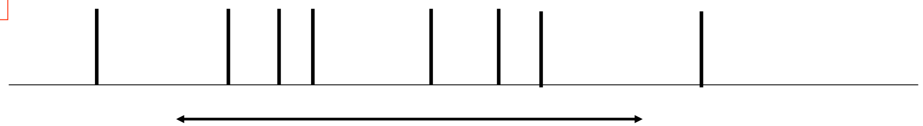
- Population averaging ('spatial' averaging)

Neuronal Dynamics – 5.3. Rate codes: spike count

Variability of spike timing







rate as a (normalized) spike count:

$$\nu(t) = \frac{n^{sp}}{T}$$

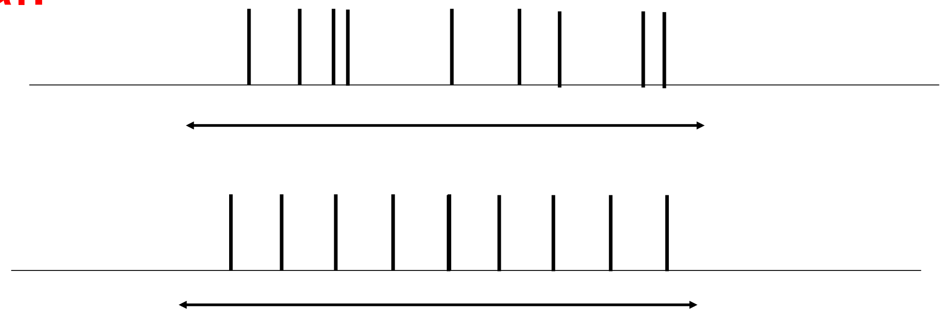
single neuron/single trial:
temporal average

T=1s

stim

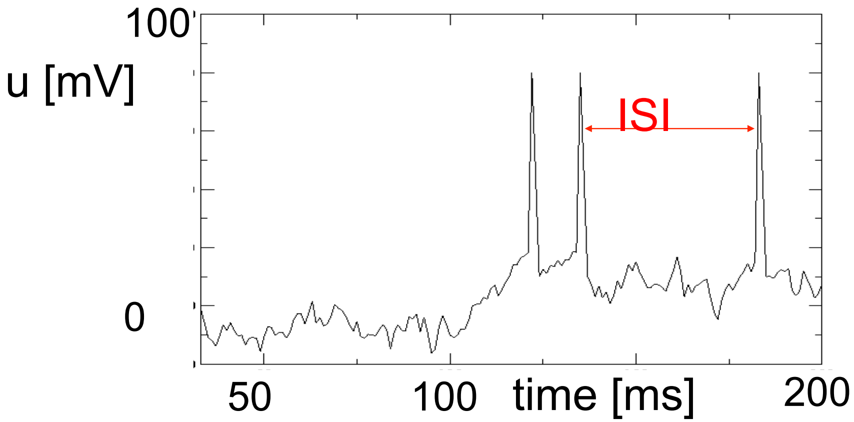
Neuronal Dynamics – 5.3. Rate codes: spike count

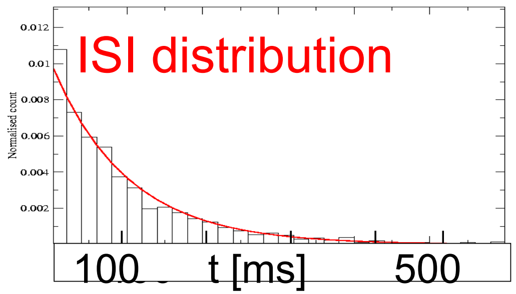
single neuron/single trial:
temporal average



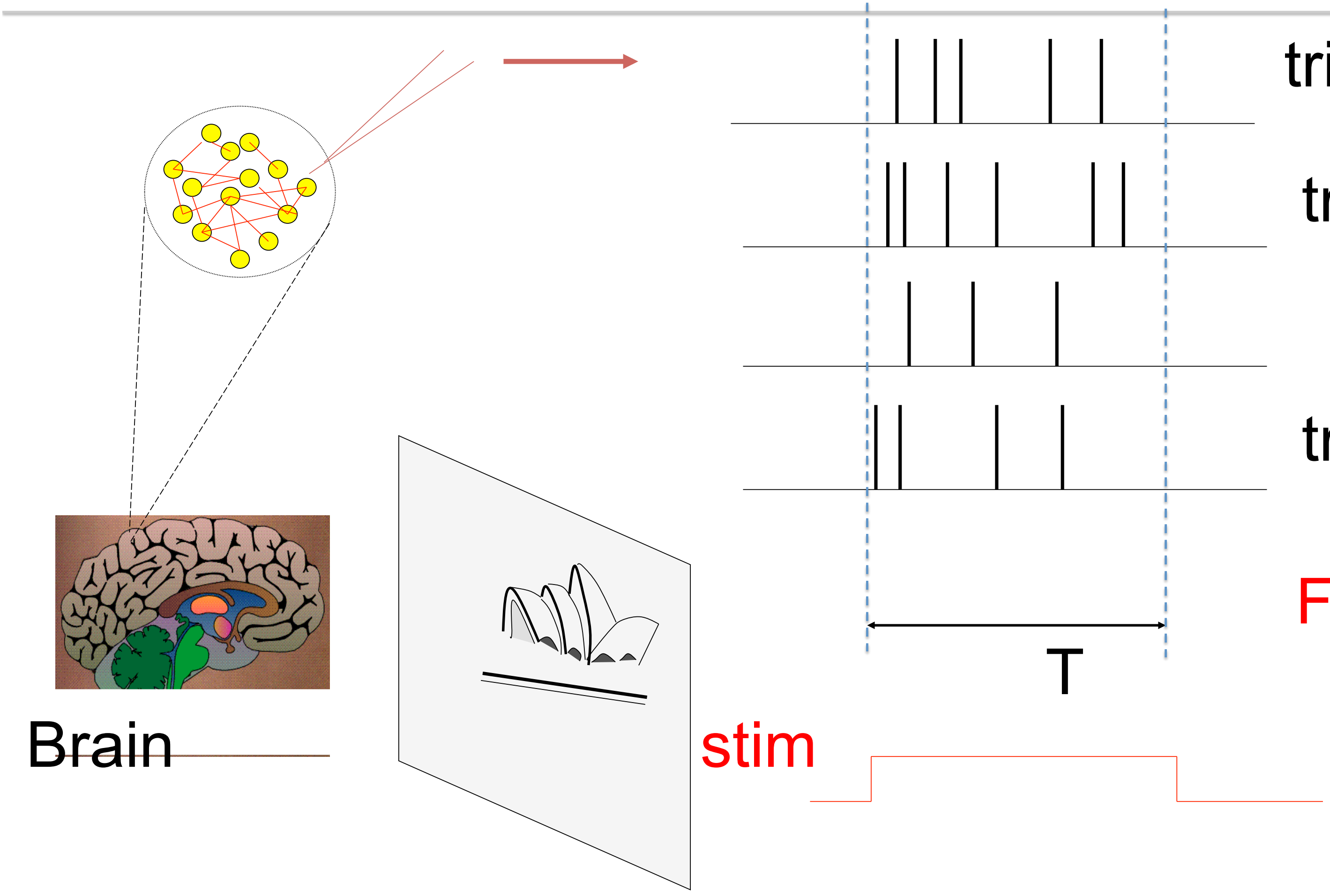
$$\nu(t) = \frac{n^{sp}}{T}$$

Variability of interspike intervals (ISI) measure regularity





Neuronal Dynamics – 5.3. Spike count: FANO factor



trial 1 $n_1^{sp} = 5$

trial 2 $n_2^{sp} = 6$

trial K $n_K^{sp} = 4$

Fano factor

$$F = \frac{\left\langle \left(n_k^{sp} - \left\langle n_k^{sp} \right\rangle \right)^2 \right\rangle}{\left\langle n_k^{sp} \right\rangle}$$

3 definitions

√ -Temporal averaging (spike count)

Problem: slow!!!

ISI distribution (regularity of spike train)

Fano factor (repeatability across repetitions)

- Averaging across repetitions

- Population averaging ('spatial' averaging)

3 definitions

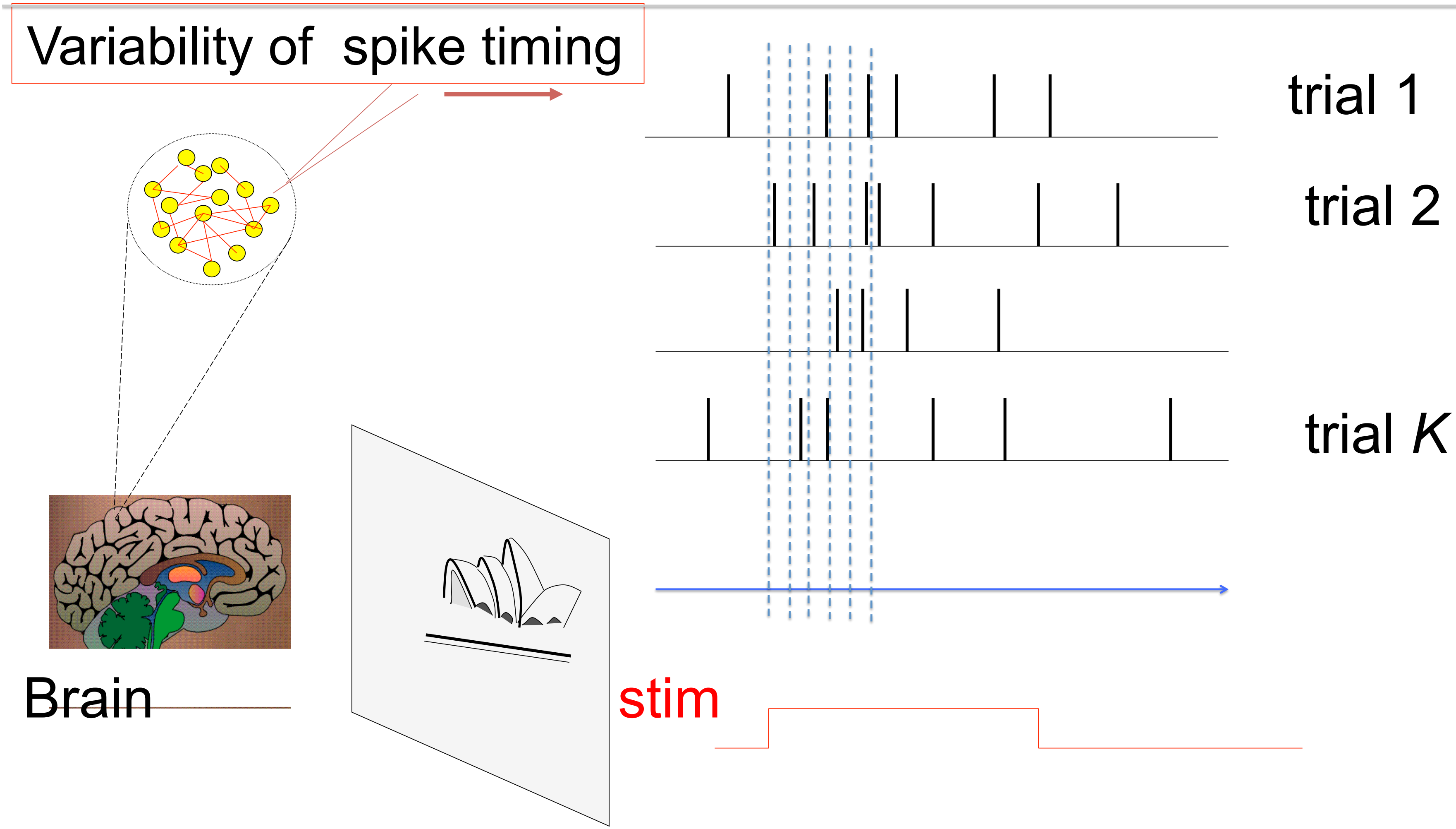
√ -Temporal averaging

Problem: slow!!!

- Averaging across repetitions

- Population averaging

Neuronal Dynamics – 5.3. Rate codes: PSTH

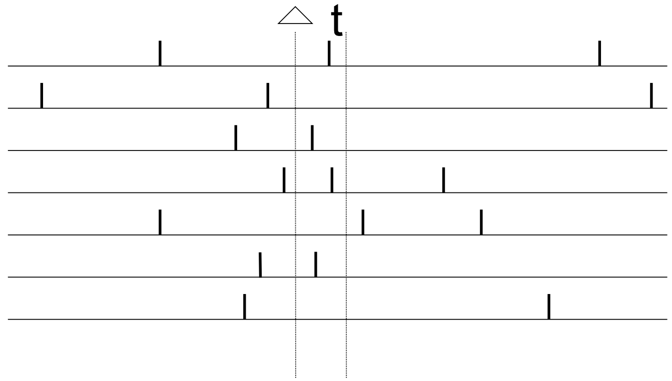


Neuronal Dynamics – 5.3. Rate codes: PSTH

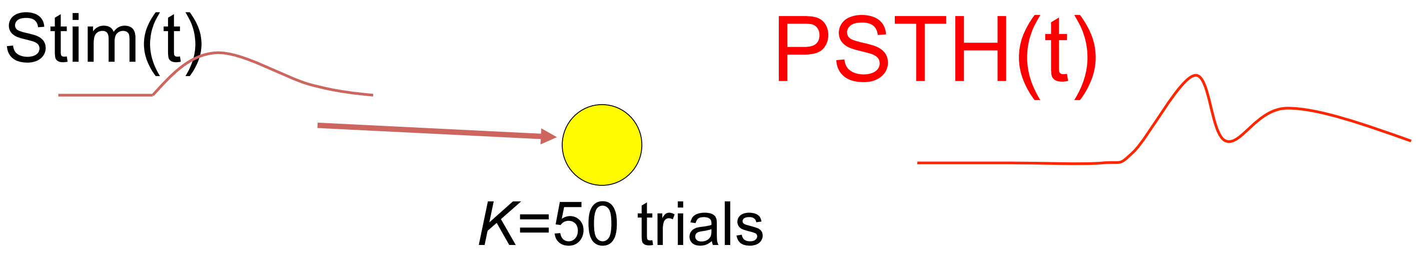
Averaging across repetitions

single neuron/many trials:
average across trials

K repetitions



$$PSTH(t) = \frac{n(t; t + \Delta t)}{K\,\Delta t}$$



3 definitions

√ -Temporal averaging

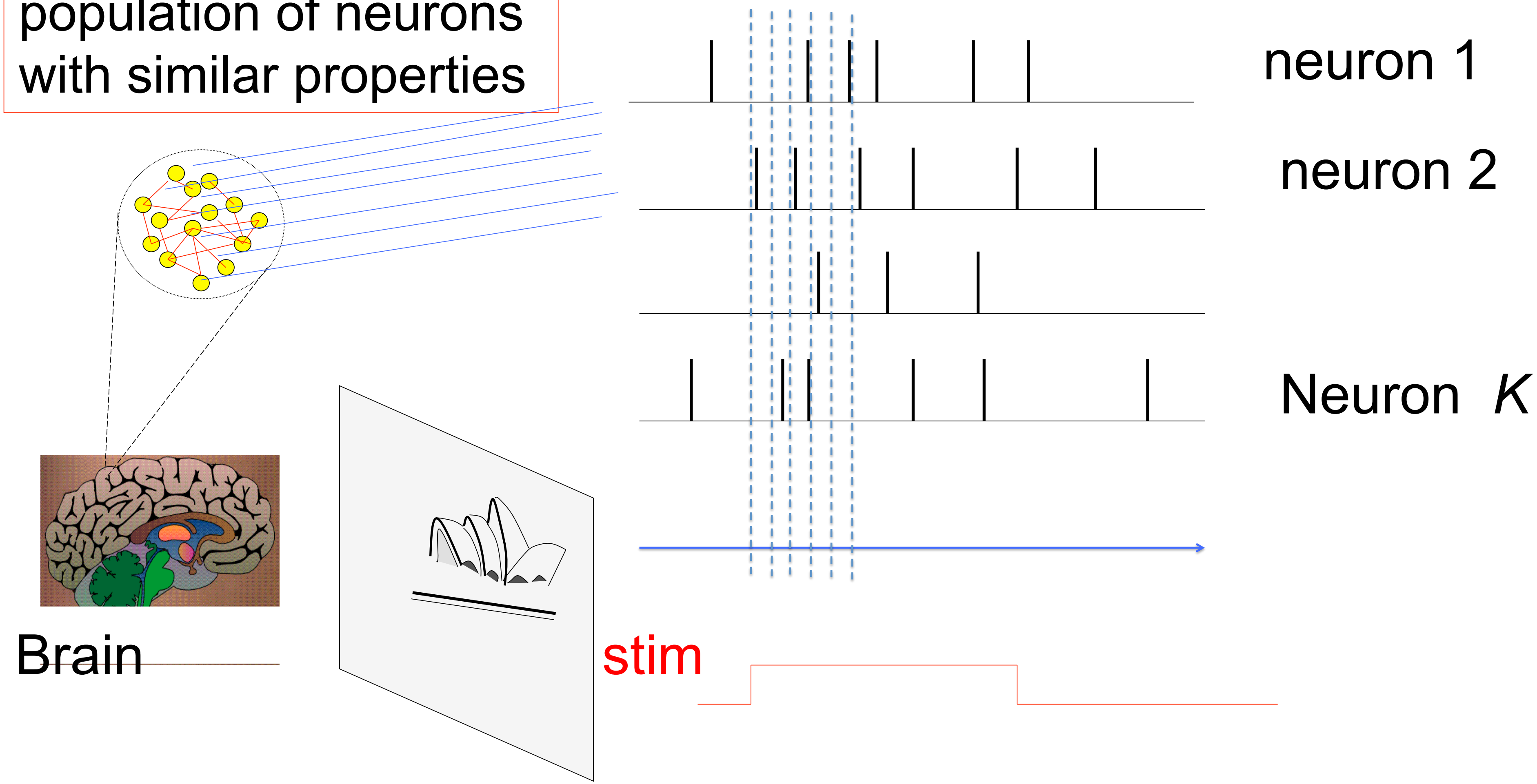
√ - Averaging across repetitions

Problem: not useful for animal!!!

- Population averaging

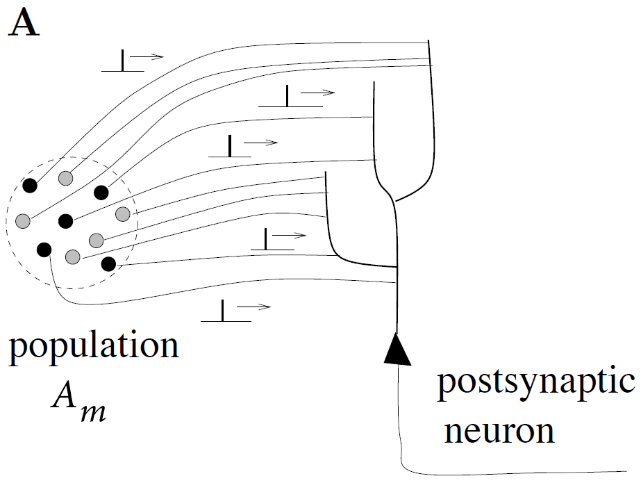
Neuronal Dynamics – 5.3. Rate codes: population activity

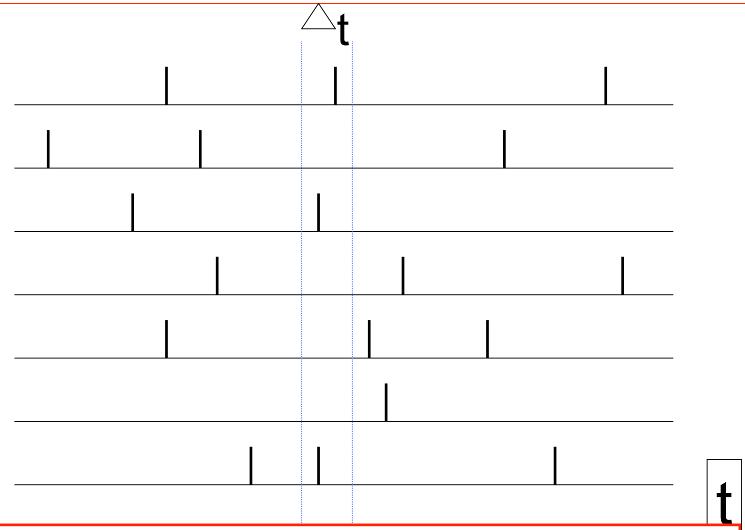
population of neurons
with similar properties



Neuronal Dynamics – 5.3. Rate codes: population activity

population activity - rate defined by population average





‘natural’

population activity

$$A(t) = \frac{n(t;t+\Delta t)}{N\Delta t}$$

Neuronal Dynamics – 5.3. Three definitions of Rate codes

Three averaging methods

-over time

Too slow for animal!!!

- over repetitions

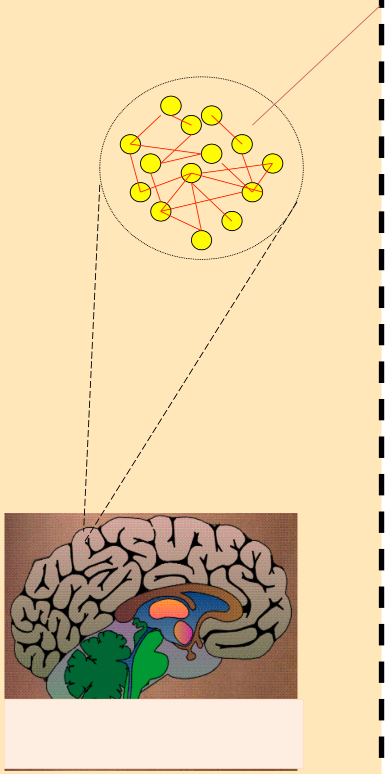
Not possible for animal!!!

- over population (space)

'natural'

Neuronal Dynamics – Quiz 5.2.

Rate codes. Suppose that in some brain area we have a group of 500 neurons. All neurons have identical parameters and they all receive the same input. Input is given by sensory stimulation and passes through 2 preliminary neuronal processing steps before it arrives at our group of 500 neurons. Within the group, neurons are not connected to each other. Imagine the brain as a model network containing 100 000 nonlinear integrate-and-fire neurons, so that we know exactly how each neuron functions.



Experimentalist A makes a measurement in a single trial on all 500 neurons using a multi-electrode array, during a period of sensory stimulation.

Experimentalist B picks an arbitrary single neuron and repeats the same sensory stimulation 500 times (with long pauses in between, say one per day).

Experimentalist C repeats the same sensory stimulation 500 times (1 per day), but every day he picks a random neuron (amongst the 500 neurons).

All three determine the time-dependent firing rate.
[ ] A and B and C are expected to find the same result.
[ ] A and B are expected to find the same result, but that of C is expected to be different.
[ ] B and C are expected to find the same result, but that of A is expected to be different.
[ ] None of the above three options is correct.

Week 5 – part 3b :Poisson Model

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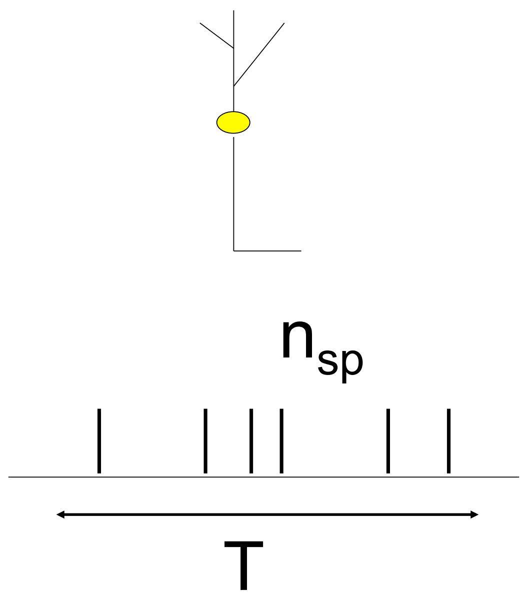
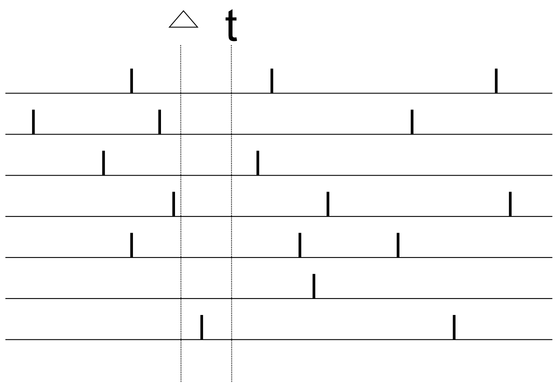
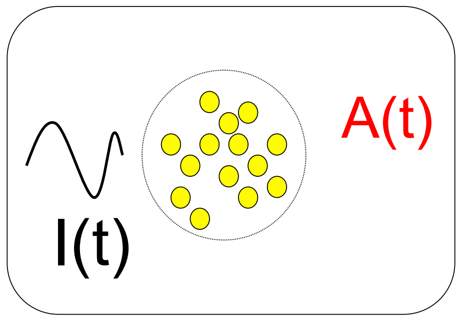
Neuronal Dynamics – 5.3b. Inhomogeneous Poisson Process





$$PSTH(t) = \frac{n(t;t+\Delta t)}{K\,\Delta t}$$



$$A(t) = \frac{n(t;t+\Delta t)}{N\Delta t}$$

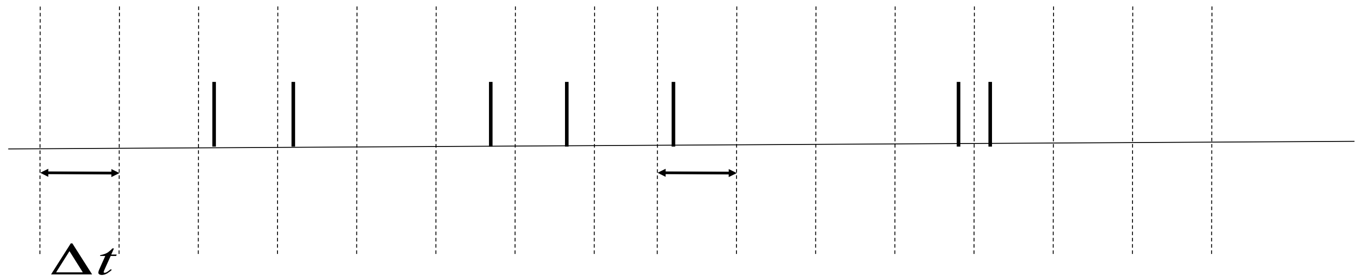
population activity

Pure rate code = stochastic spiking → Poisson model

Neuronal Dynamics – 5.3b. Poisson Model

Homogeneous Poisson model: constant rate

Math detour:
Poisson model



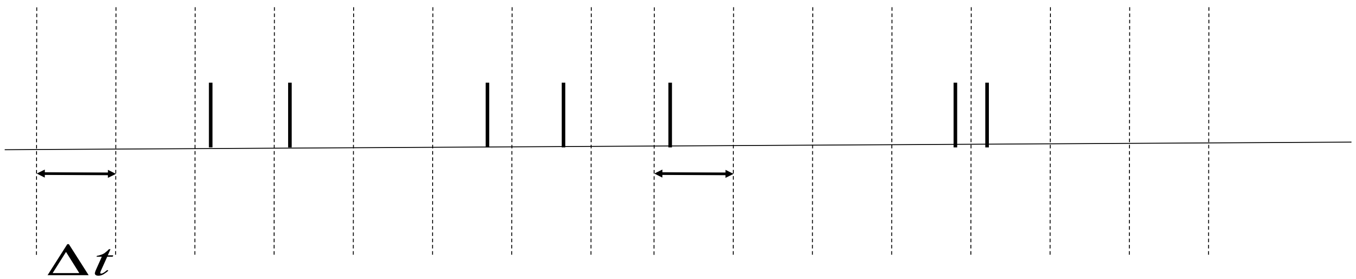
Probability of finding a spike $P_F = \rho_0 \Delta t$

Pure rate code = stochastic spiking → Poisson model

Neuronal Dynamics – 5.3b. Poisson Model

Probability of firing:

$$P_F = \rho_0 \, \Delta t$$

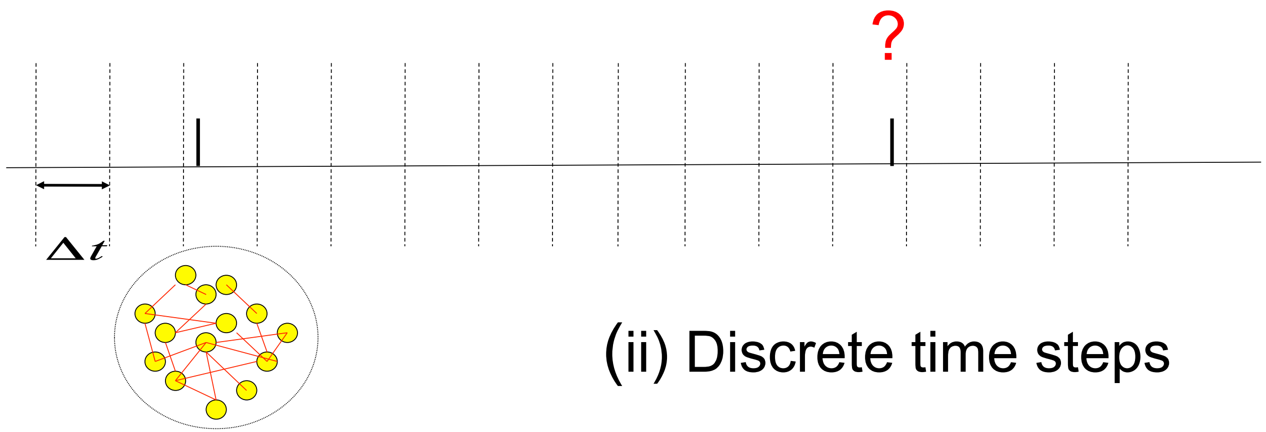


Take $\Delta t \to 0$

Neuronal Dynamics – 5.3b. Interval distribution

Probability of firing:

$$P_F = \rho_0 \, \Delta t$$



(i) Continuous time

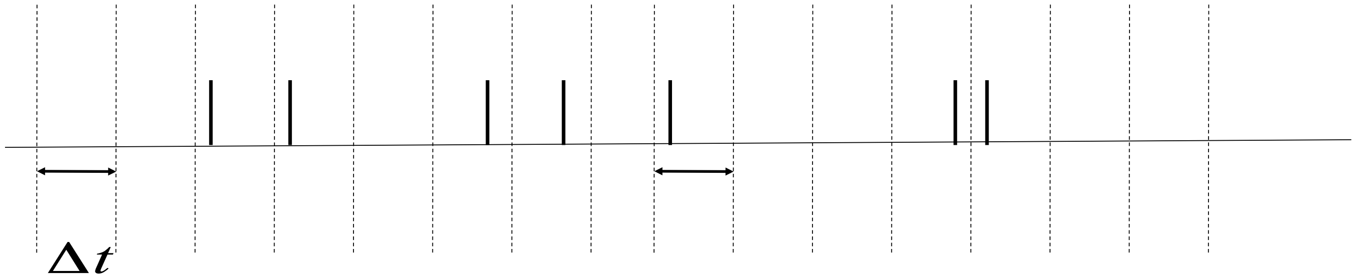
prob to 'survive'

(ii) Discrete time steps

$$\Delta t \rightarrow 0$$

Neuronal Dynamics – 5.3b. Inhomogeneous Poisson Process

rate changes

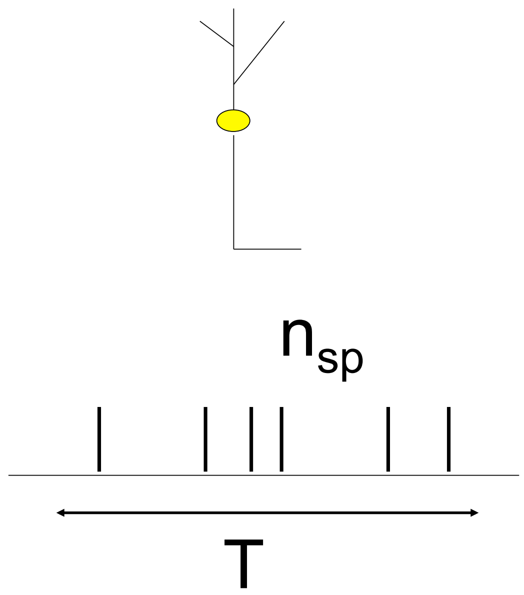


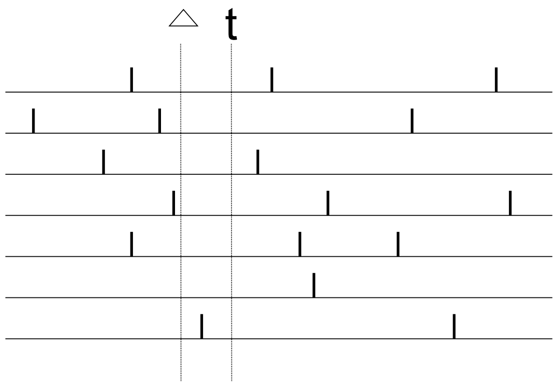
Probability of firing $P_F = \rho(t)\,\Delta t$

Survivor function $S(t\,|\,\hat{t}) = \exp(-\int_{\hat{t}}^{t} \rho(t')\,dt')$

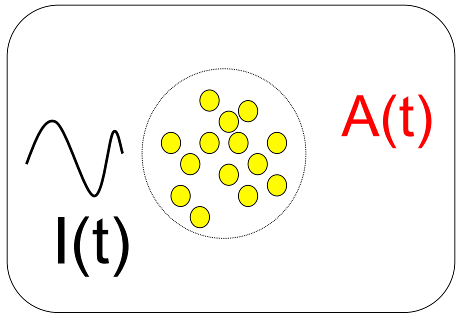
Interval distribution

Neuronal Dynamics – 5.3b. Inhomogeneous Poisson Process





$$PSTH(t) = \frac{n(t;t+\Delta t)}{K\,\Delta t}$$



$$A(t) = \frac{n(t;t+\Delta t)}{N\Delta t}$$

population activity

inhomogeneous Poisson model consistent with rate coding

Probability of firing

$$P_F = \rho(t)\,\Delta t$$

Survivor function

$$S(t\,|\,\hat{t}) = \exp\left(-\int_{\hat{t}}^{t} \rho(t')\,dt'\right)$$

Interval distribution

$$P(t\,|\,\hat{t}) = \rho(t)\exp\left(-\int_{\hat{t}}^{t} \rho(t')\,dt'\right)$$

Neuronal Dynamics – Quiz 5.3.

A Homogeneous Poisson Process:
A spike train is generated by a homogeneous Poisson process with rate 25Hz with time steps of 0.1ms.

[ ] The most likely interspike interval is 25ms.
[ ] The most likely interspike interval is 40 ms.
[ ] The most likely interspike interval is 0.1ms
[ ] We can't say.

B Inhomogeneous Poisson Process:
A spike train is generated by an inhomogeneous Poisson process with a rate that oscillates periodically (sine wave) between 0 and 50Hz (mean 25Hz). A first spike has been fired at a time when the rate was at its maximum. Time steps are 0.1ms.

[ ] The most likely interspike interval is 25ms.
[ ] The most likely interspike interval is 40 ms.
[ ] The most likely interspike interval is 0.1ms.
[ ] We can't say.