Rate vs temporal code – about synchrony

Learning objectives:

To understand how synchrony can be measured
To gain an understanding of a simple neural model of synchronization

Announcement:

NO 4 credit section meeting this week

We will resume NEXT week after fall break to talk about phase-precession

Previous lectures

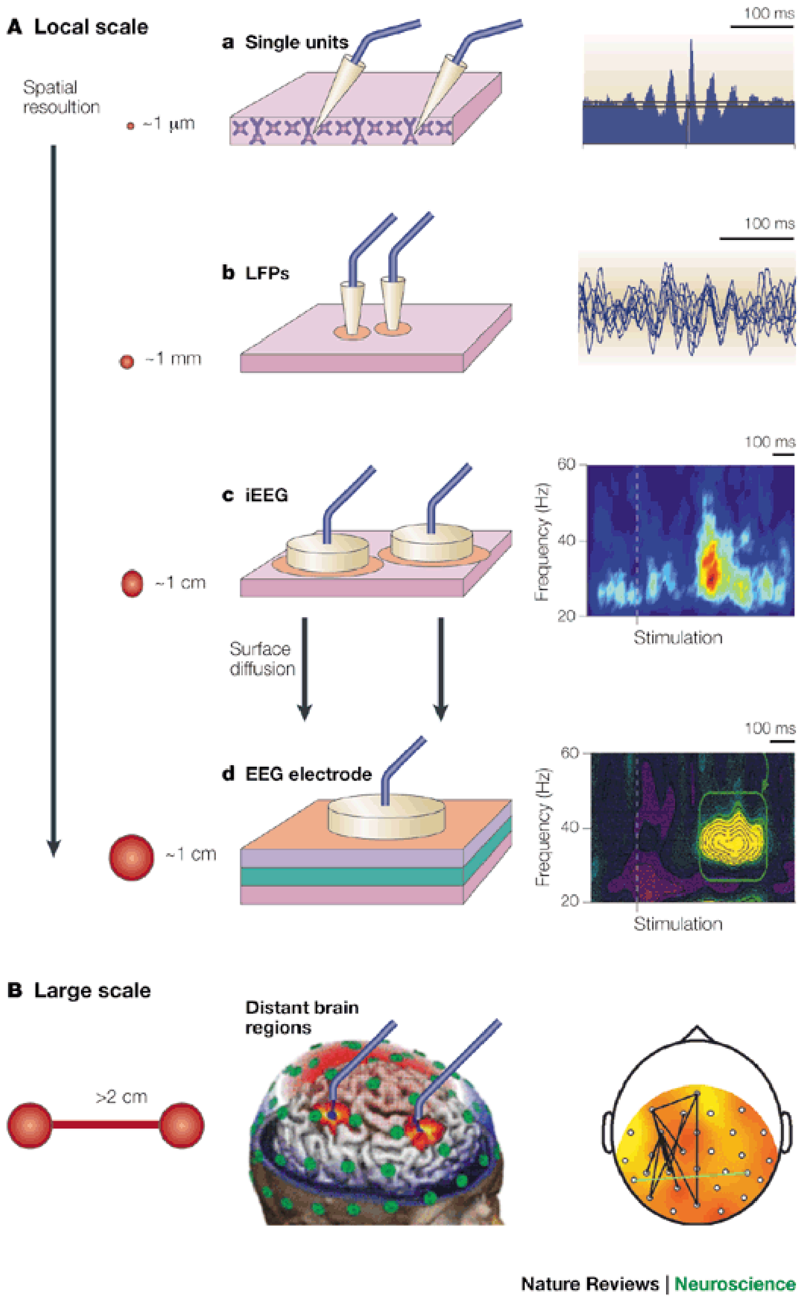
- Receptive fields
- Coding
- Tuning receptive fields
- Beyond receptive fields: oscillations, synchrony and temporal codes
- Oscillations and synchrony in the insect antennal lobe
- Rate and temporal code in the hippocampus

Today

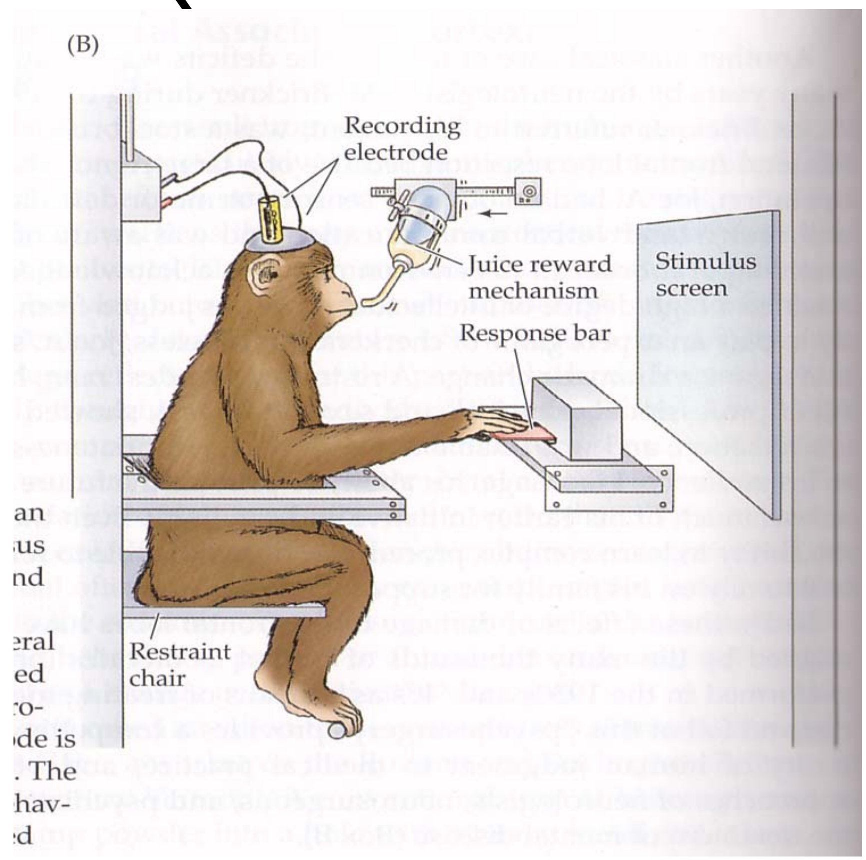
Synchronization properties of neurons in the absence of oscillations
A simple model for propagation of synchronous events

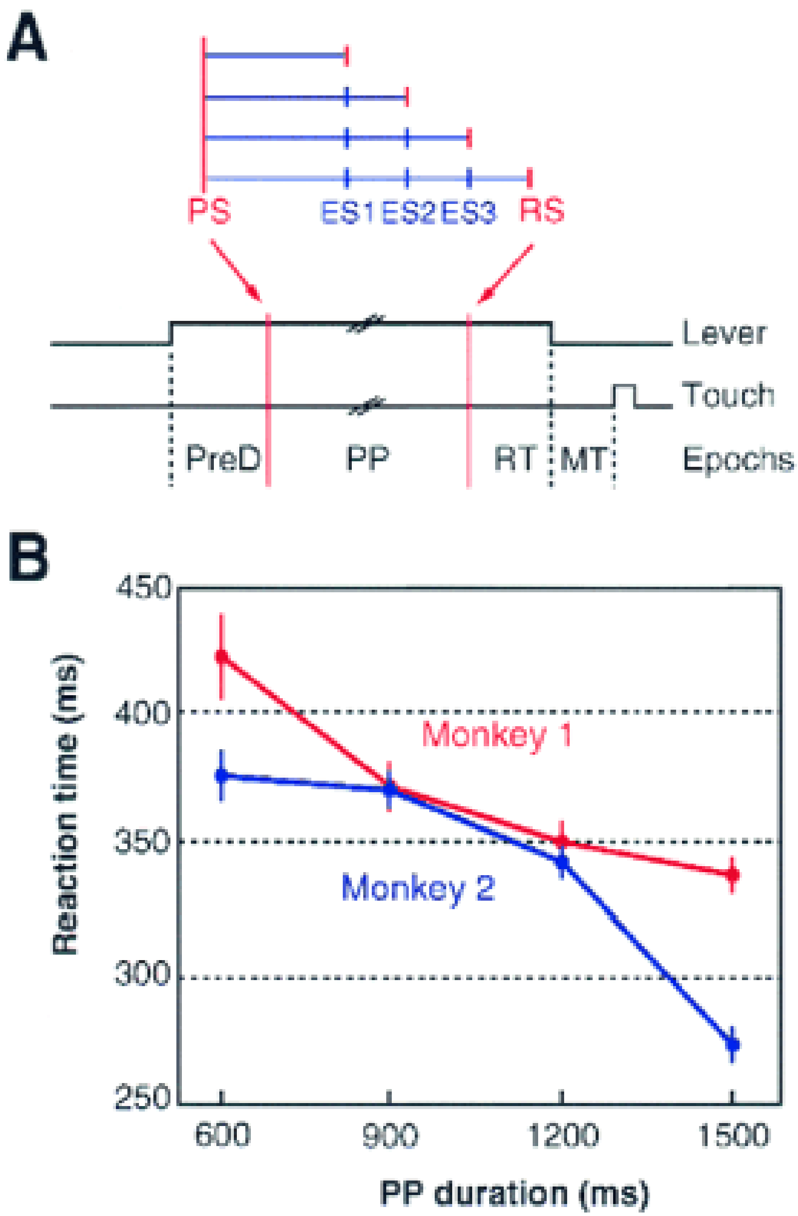
Spike Synchronization and Rate Modulation Differentially Involved in Motor Cortical Function

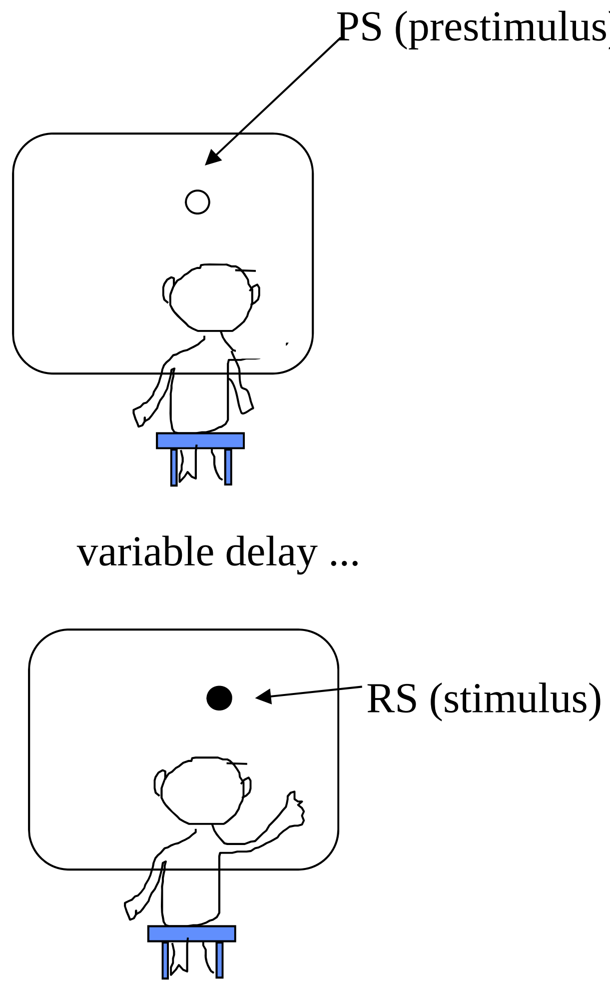
Alexa Riehle, * Sonja Grün, Markus Diesmann, Ad Aertsen

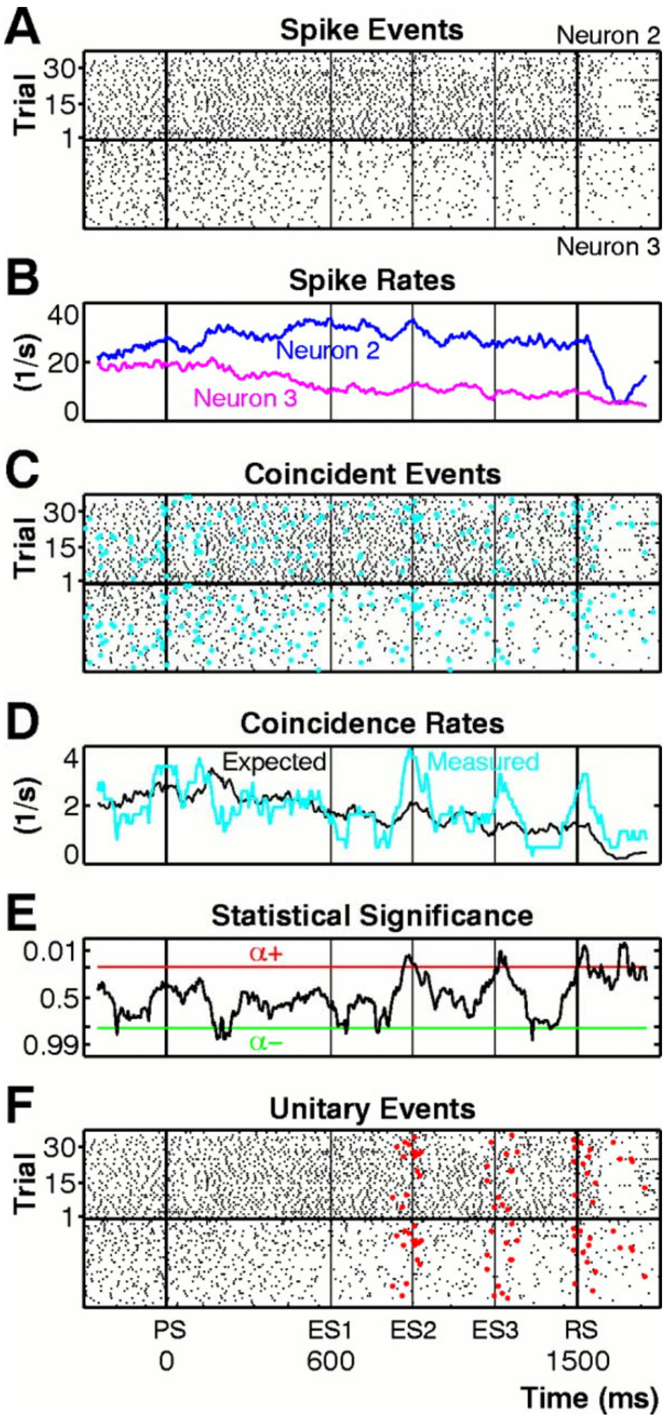


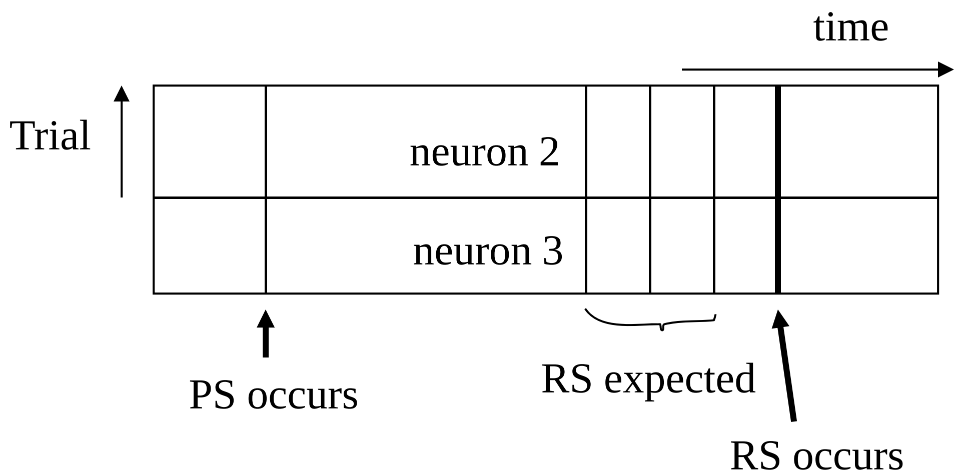
Level of analysis used in this paper!




A
PS
ES1 ES2 ES3
RS
Lever
Touch
PreD
PP
RT
MT
Epochs
B
450
400
350
300
250
Reaction time (ms)
Monkey 1
Monkey 2
600
900
1200
1500
PP duration (ms)

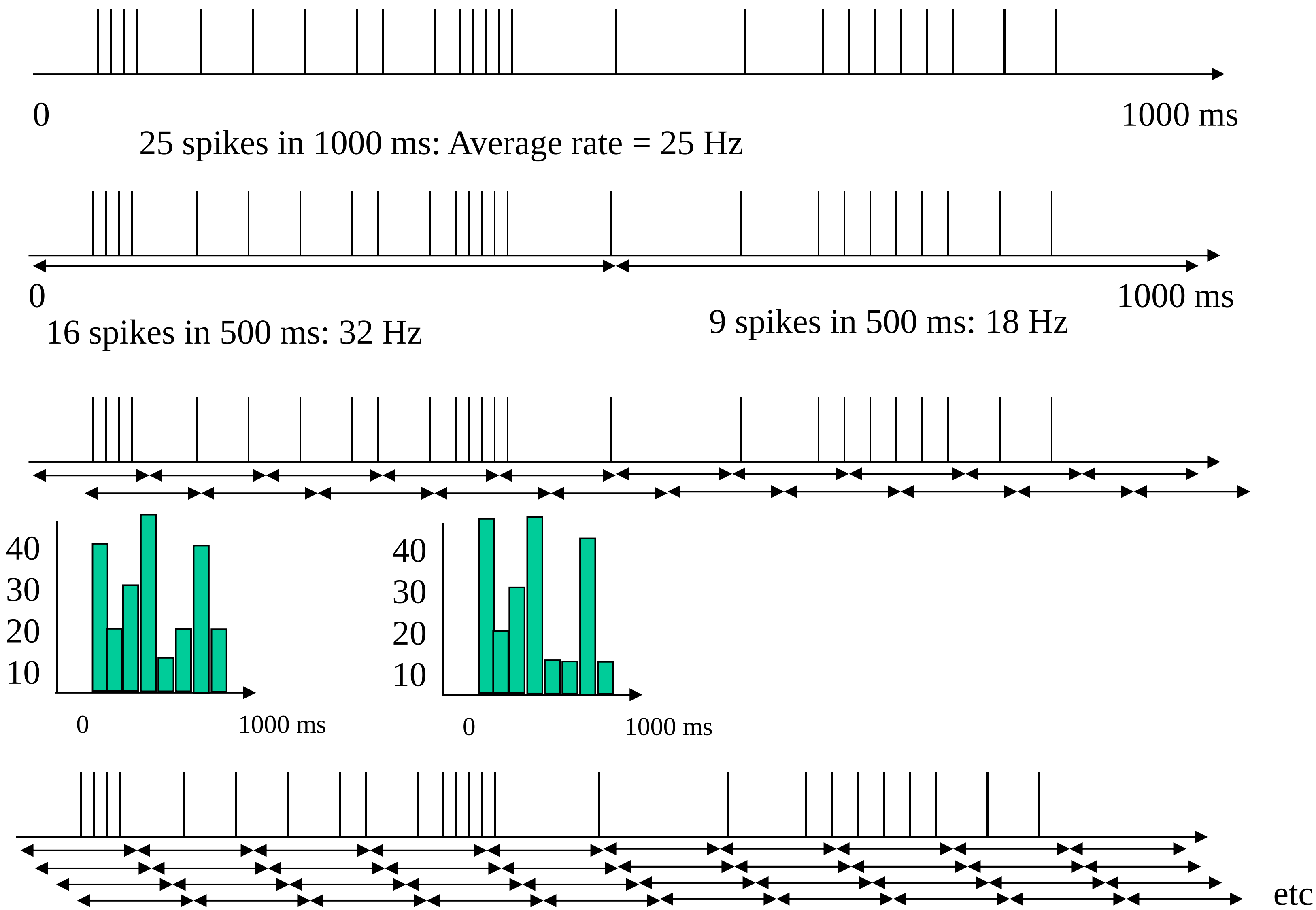

PS (prestimulus)
variable delay ...
RS (stimulus)



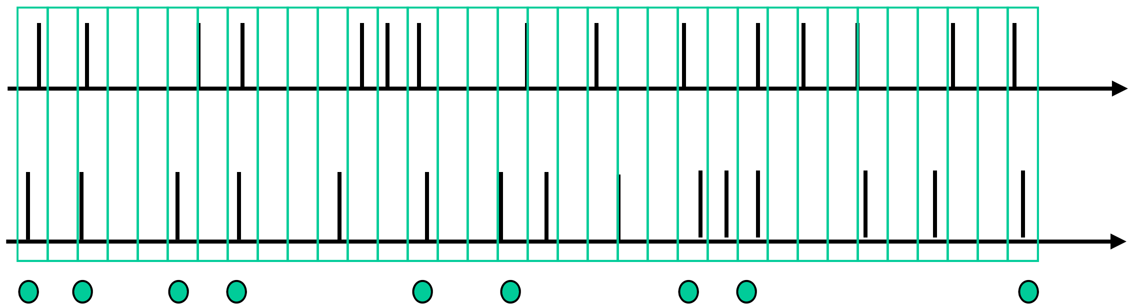


Each dot represents an action potential

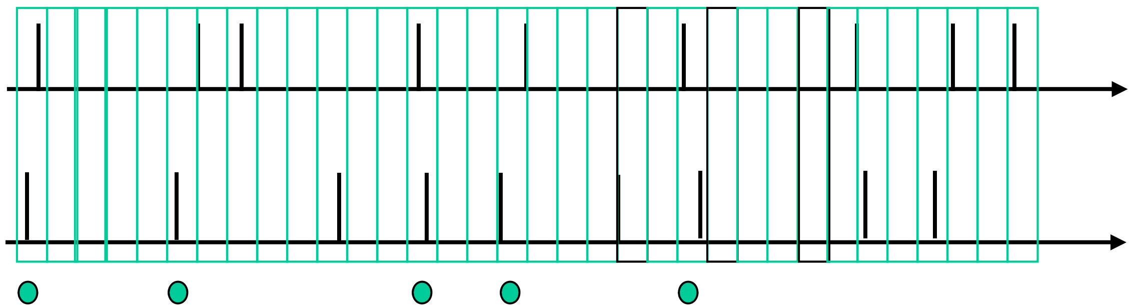
Aside: To measure the mean firing rate, a sliding window of 100 ms was used in 5 ms steps.

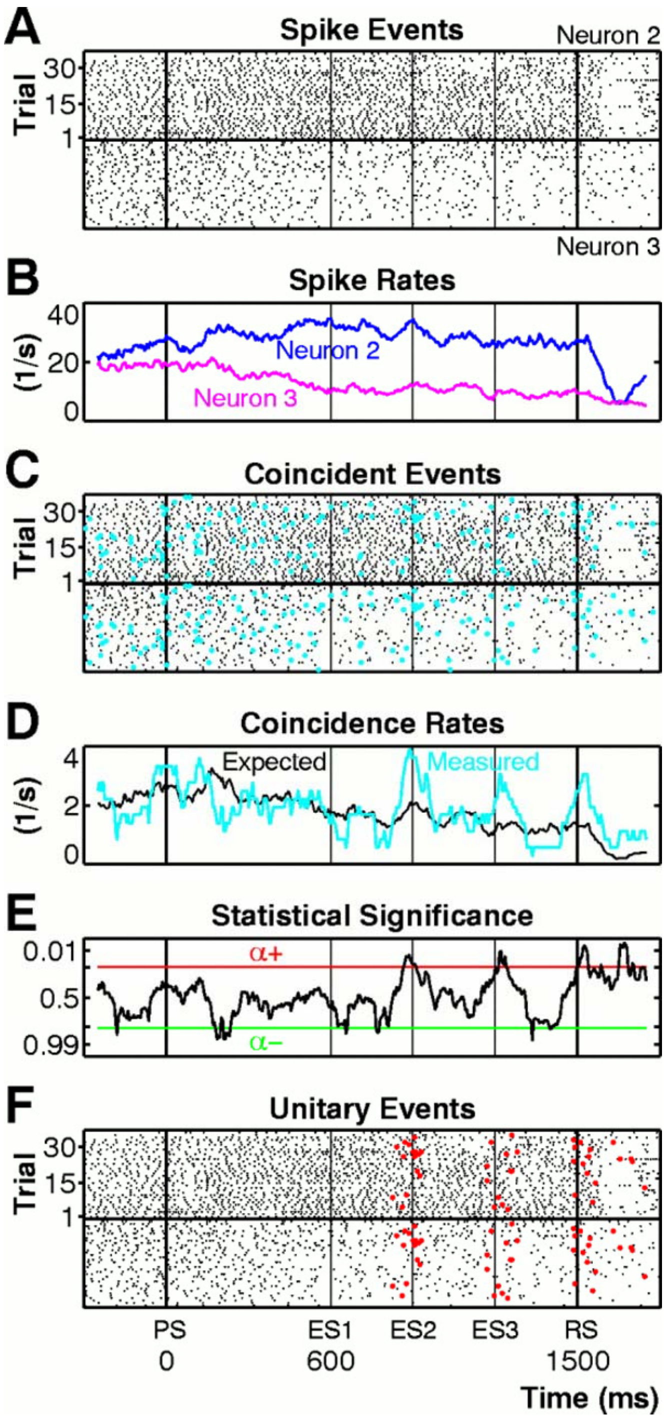


For each point in time, average results and divide by #of 100 ms windows



How many synchronous events can be expected depends on rate



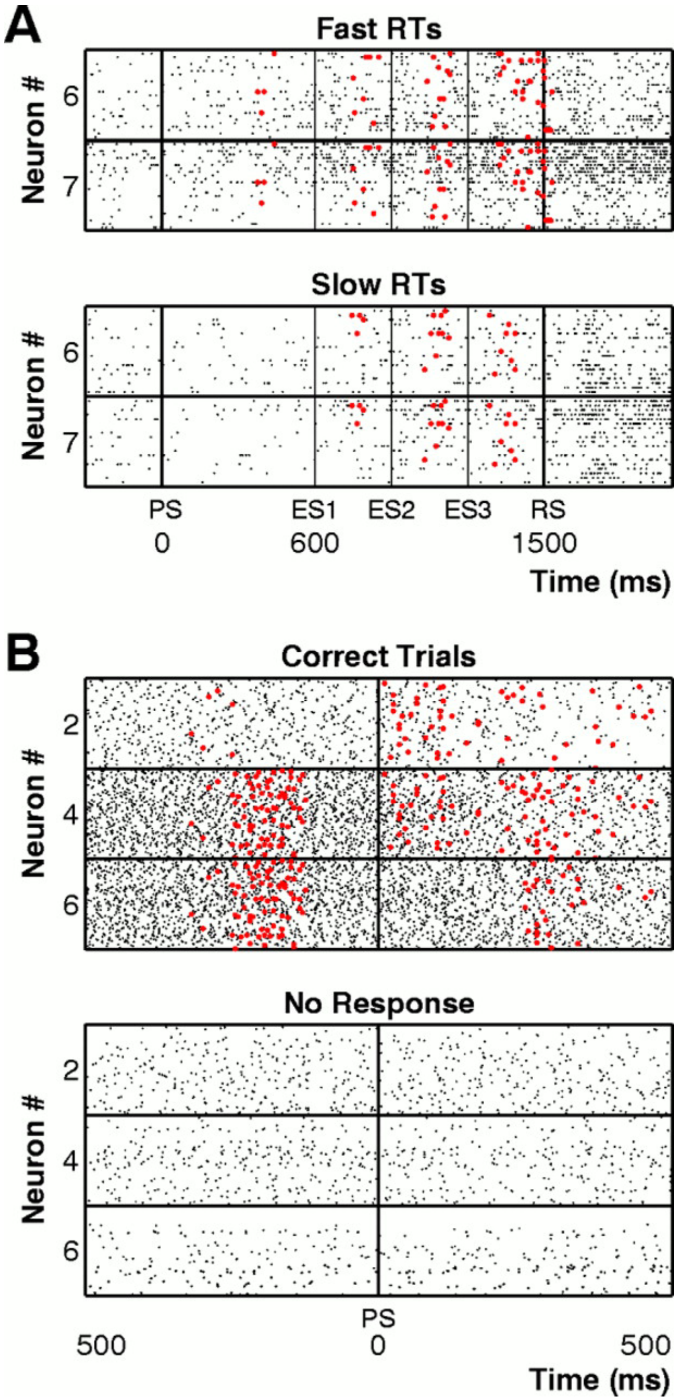


obtained with sliding window

calculated from average spike rates
assuming Poisson Processes

statistics check whether measured #of synchronous events is significantly higher than that expected from two independent Poisson Processes driven by measured mean firing rates.

Results indicate that as expectation of stimulus increases, #of coincidendent spikes increases around time for which stimulus is expected



# of coincident spikes increases only in trials in which animal makes correct response!

If precise firing and synchrony is important for neural coding, can it
be maintained within a relatively noisy environment?

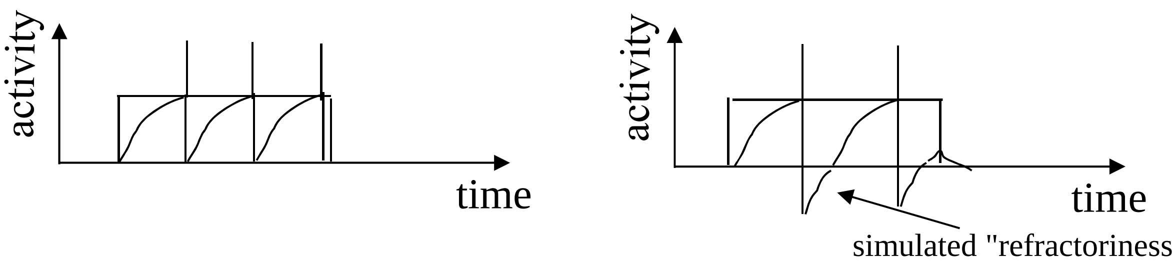
What is meant by noise: synapses are not absolutly reliable, neurons receive inputs from other neurons than the ones of interest etc.

Stable propagation of synchronous spiking in cortical neural networks

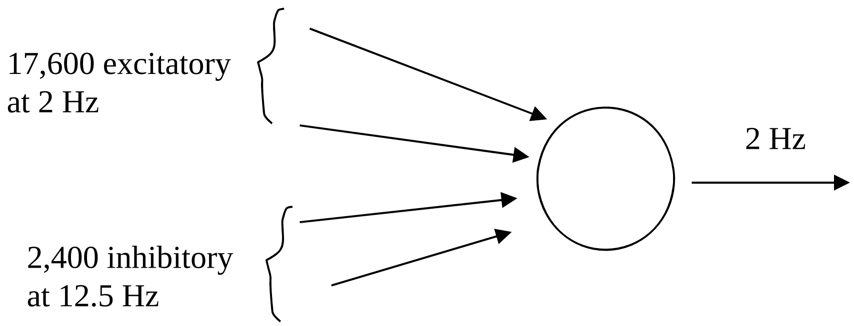
MARKUS DIESMANN*, MARC-OLIVER GEWALTIG* & AD AERTSEN

Model neuron Simulations were performed using a leaky-integrator with voltage-threshold model[13, 14], with physiological and anatomical parameters taken from experimental literature.

Reminder: Leaky-integrate and fire neuron simulates the membrane time constant τ; action potentials are
emitted when the membrane voltage exceeds a given threshold.

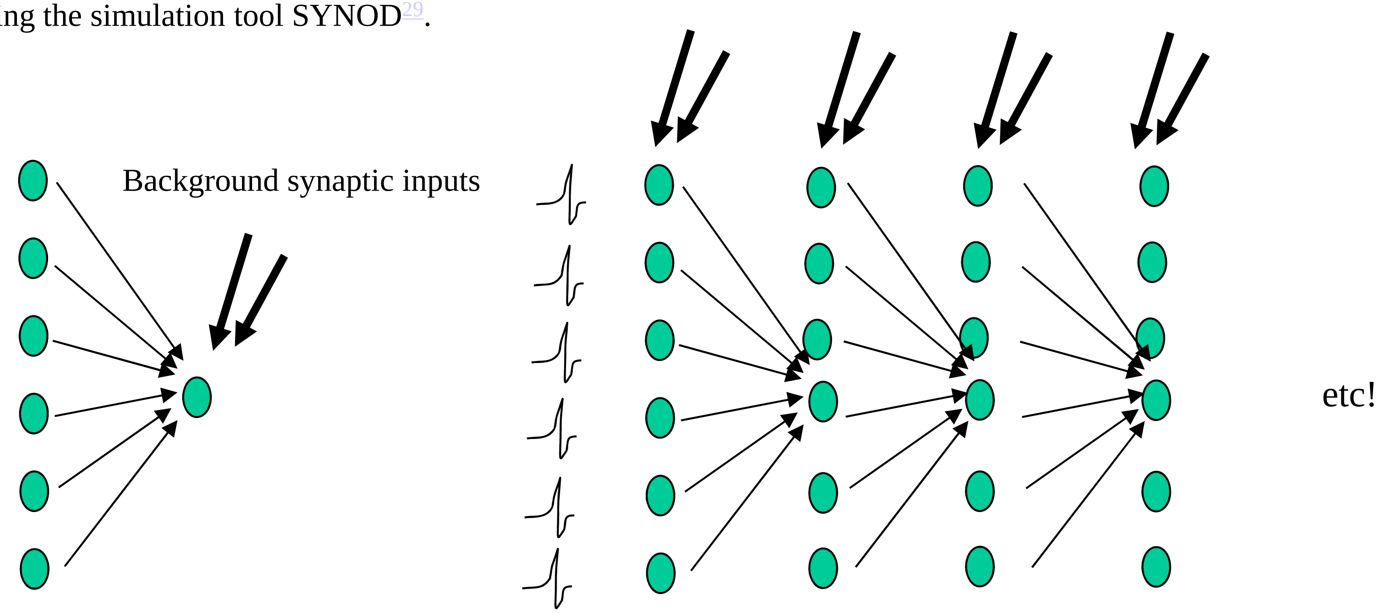


The model neuron (membrane time constant 10 ms, resting potential -70 mV, spike threshold -55 mV, absolute refractoriness 1 ms, relative refractoriness (15 ms) modelled by K-conductances) was supplied with synaptic noise input, reflecting on-going activity in the cortical network (20,000 synapses: 88% excitatory, 12% inhibitory)[26].



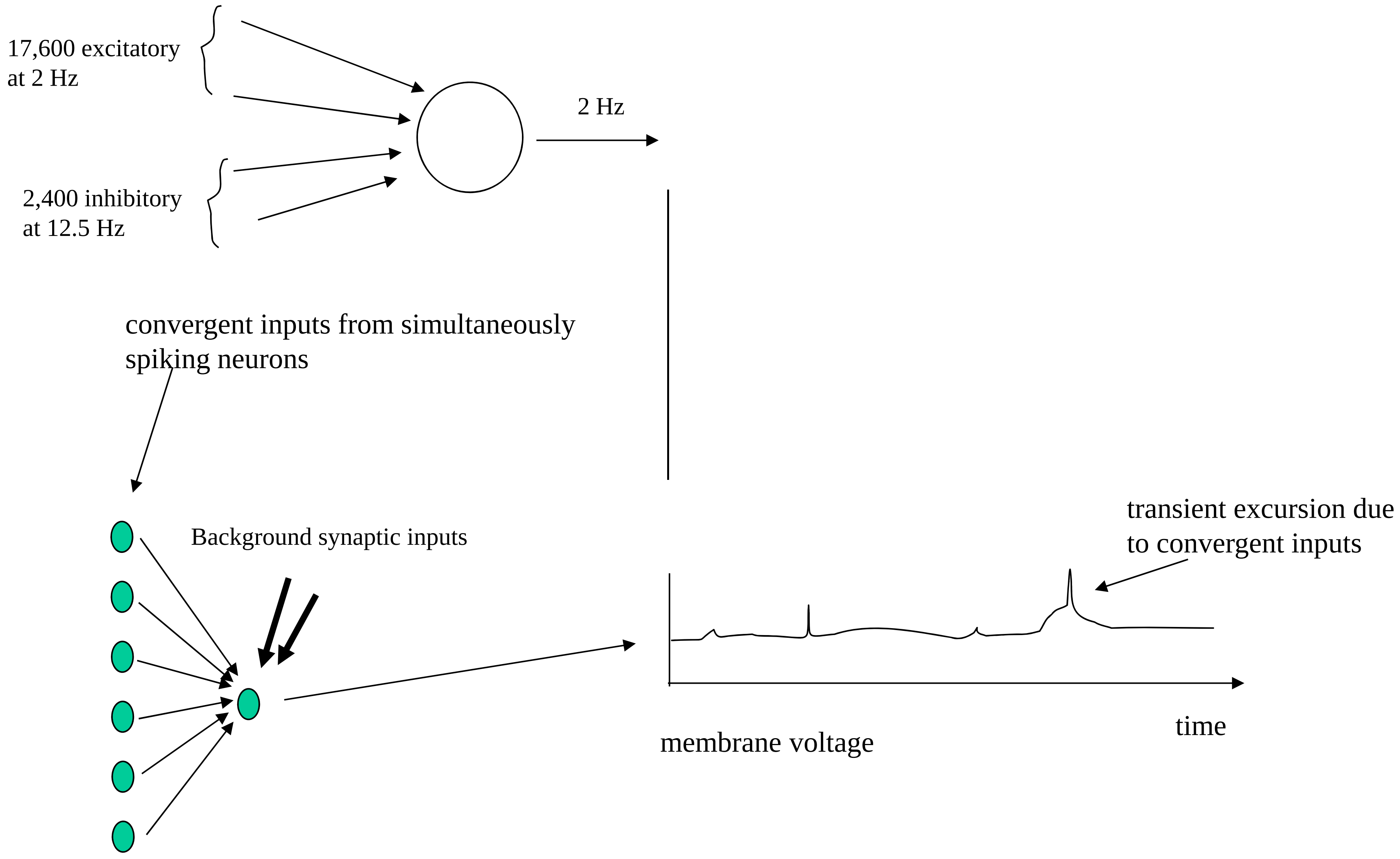
"background" synaptic input is random (Poisson) and balanced such that mean output rate is 2 Hz.

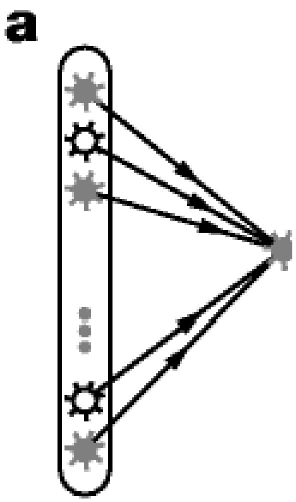
Postsynaptic currents (PSCs) were modelled by an α -function to yield realistic PSPs (peak amplitude 0.14 mV, time-to-peak 1.7 ms, half-width 8.5 ms)[27]. Identical values were used for intergroup and background connections; excitatory and inhibitory PSPs only differed in sign. Background firing rates (excitatory, 2 Hz; inhibitory, 12.5 Hz; all uncorrelated stationary Poisson) were chosen to yield an output rate of 2 Hz. At this consistency condition, output statistics were approximately Poisson, membrane potential shot noise (mean 8.25 mV, s.d. 2.85 mV) was close to 'balanced' excitation/inhibition[28]. It can be shown that details of the construction of background fluctuations are not essential. Simulations were performed in 0.1 ms time steps using the simulation tool SYNOD[29].

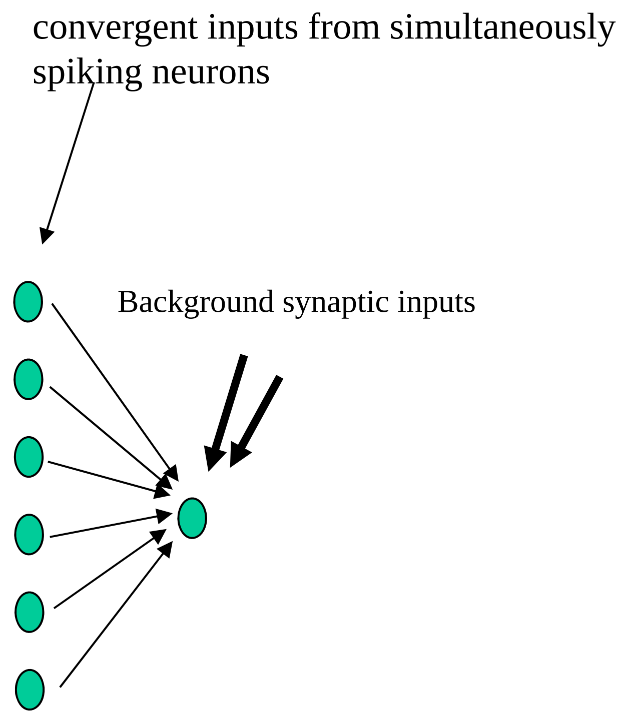


Synchronized volley

Authors focus on "transient membrane potential excursions" , which are explained by convergent inputs from simultaneous neurons onto a target neuron.



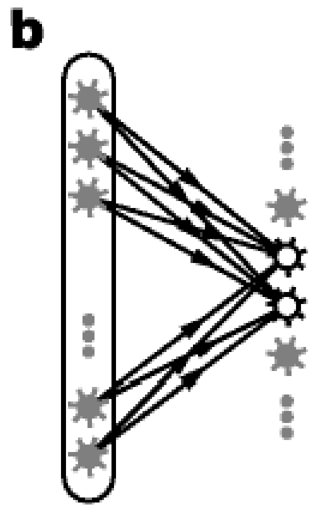




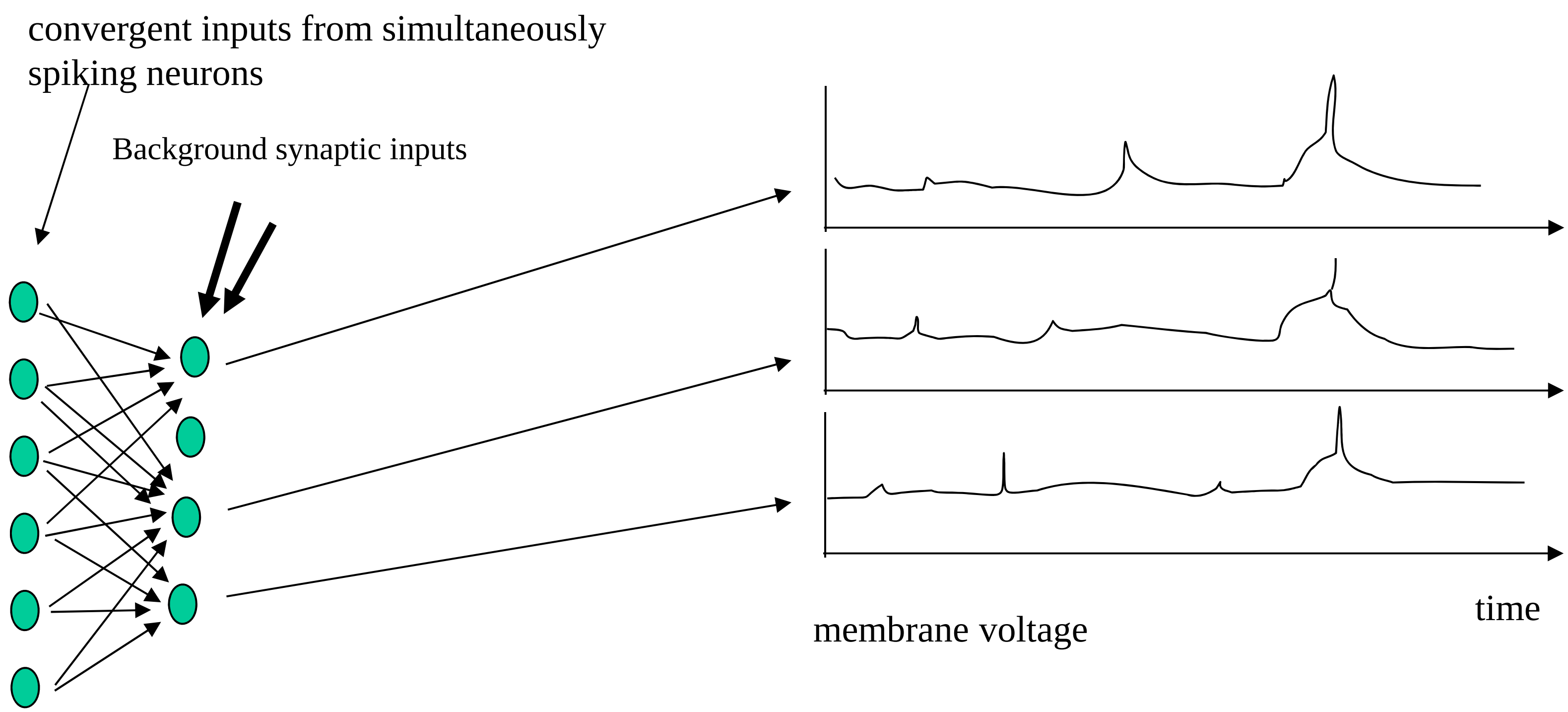
Let I_i be the activity of the inhibitory background neurons and w_i their synaptic weight onto our neuron N,
E_e be the activity of the excitatory background neurons and w_e their synaptic weight onto our neuron N,
O_o be the activity of the input neurons to our neuron N,

Then
$$\mathrm{Input}(N(t)) = \sum_{e=1}^{17600} w_e E_e(t) + \sum_{i=1}^{2400} w_i I_i(t) + \sum_{o=1}^{N} w_o O_o(t)$$

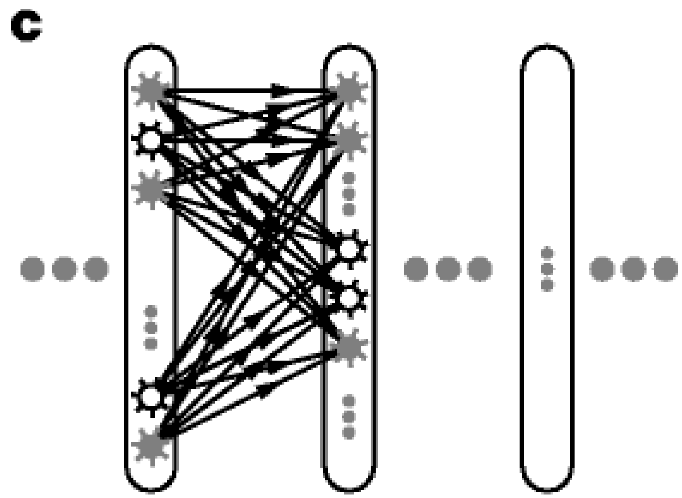
and Output (N(t)) = F(Input(N(t)))



Neurons that share a large enough pool of presynaptic neurons tend to align their spikes with each other



Quality of timing is judged on whether synchronous spiking is sustained or not.
The degree of temporal accuray of spike times among the members of each group (layer) determines whether subsequent groups can reproduce this accuracy.



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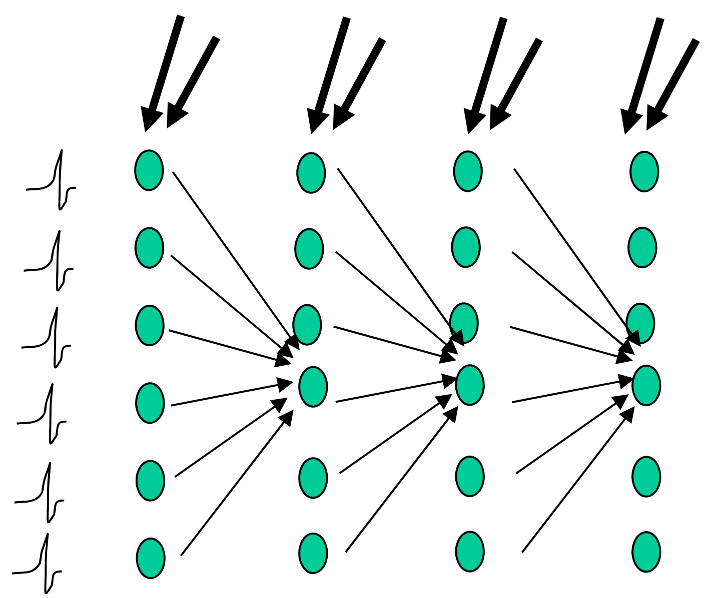
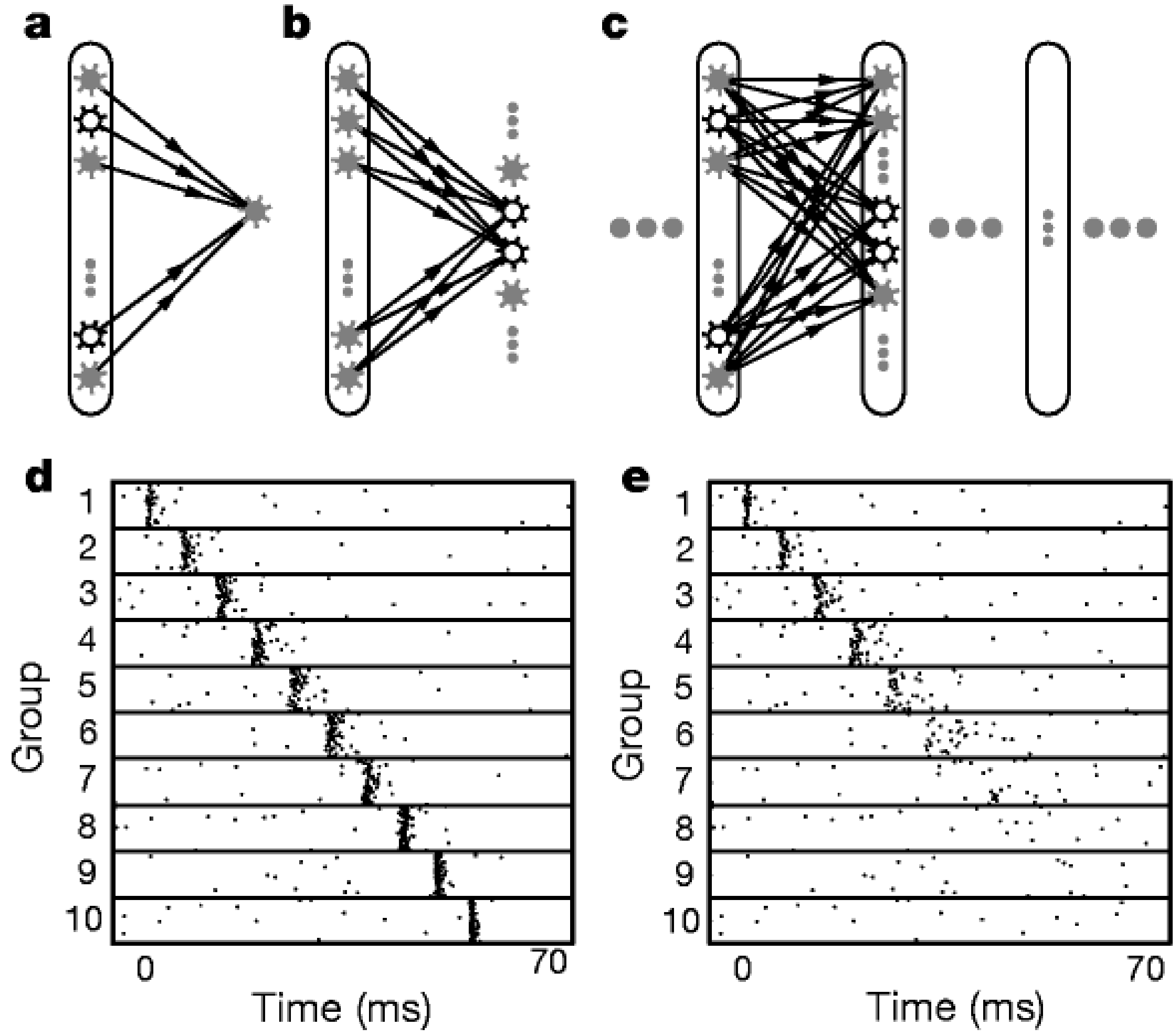
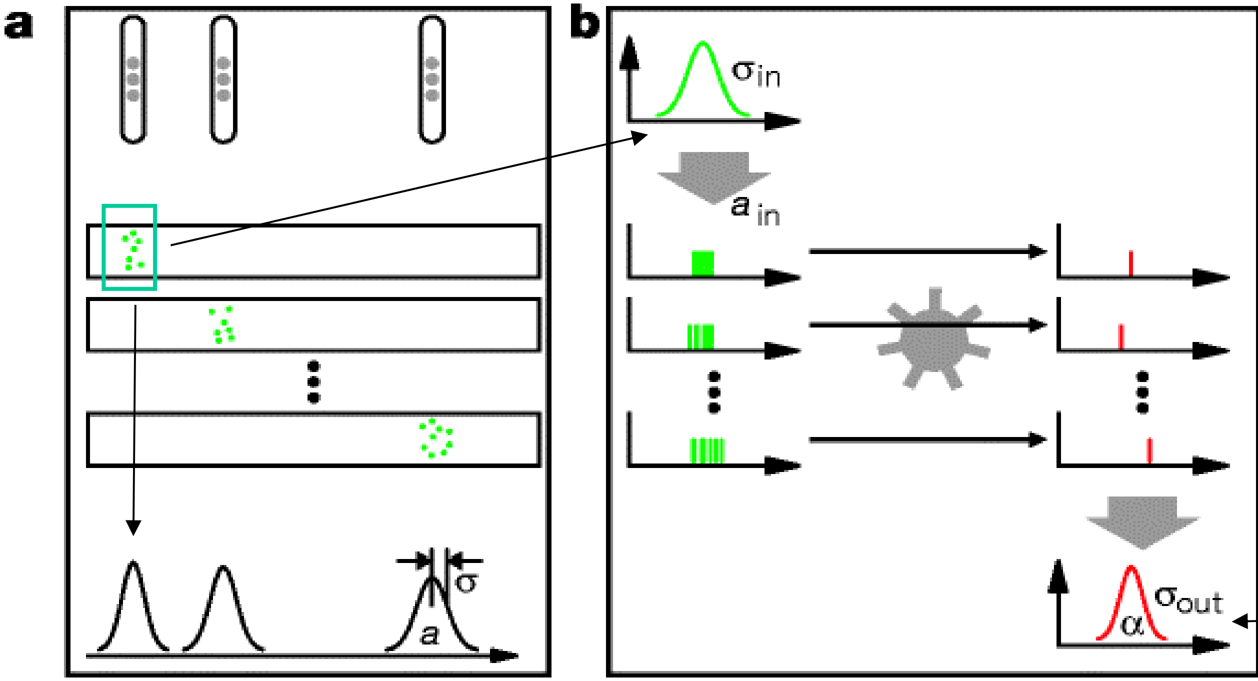


etc!


a
b
c
d
e
Group
1
2
3
4
5
6
7
8
9
10
0
70
Time (ms)
Group
1
2
3
4
5
6
7
8
9
10
0
70
Time (ms)



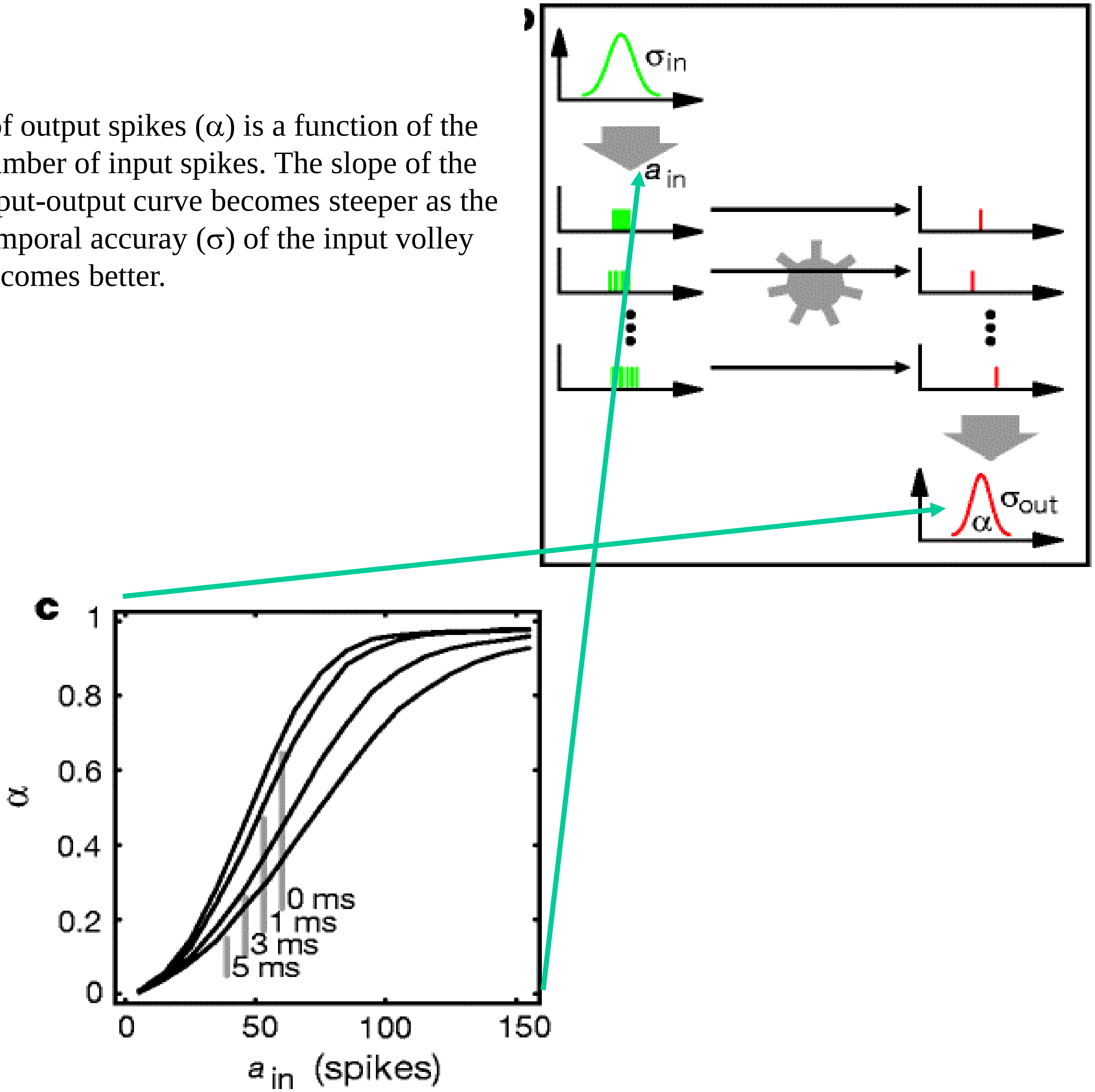
Trials

Individual output spike

Pulse density of output spikes accumulated over many trials; characterized by α, σ_{out}

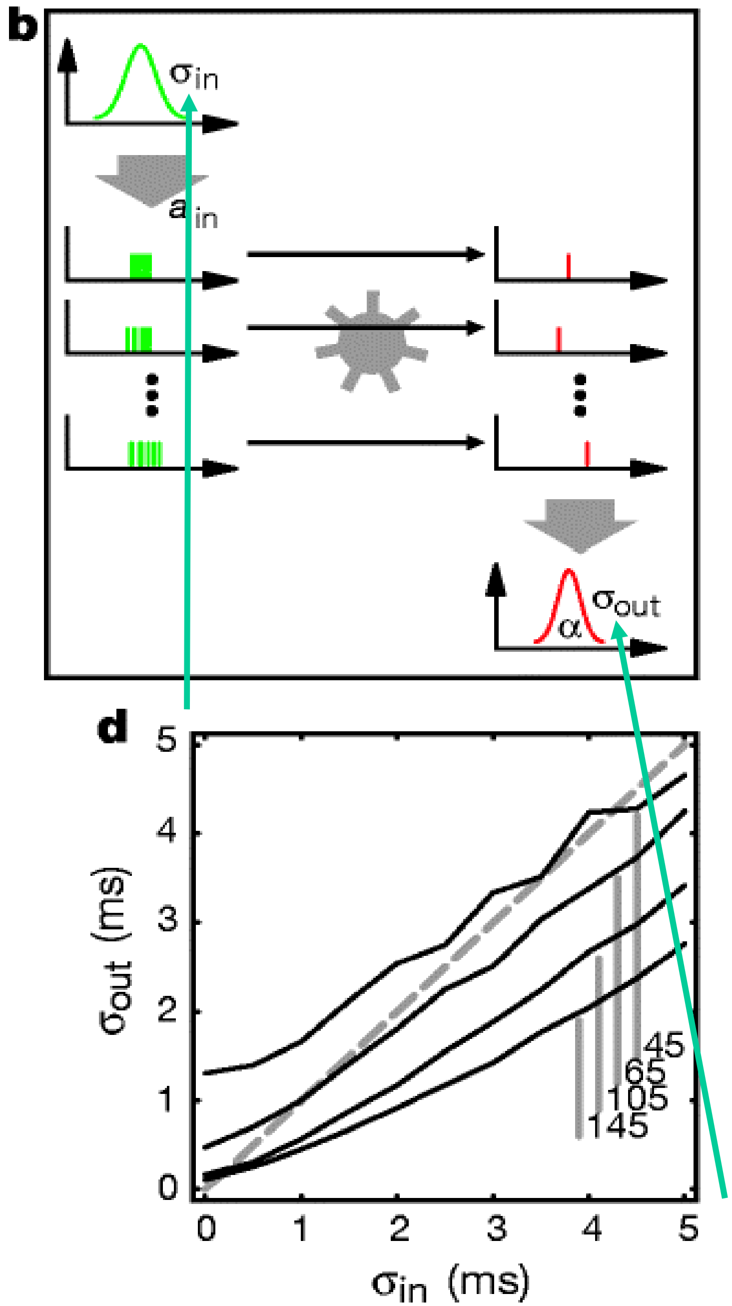
Measure : the pulse packet characterizes a spike volley by two parameters: a (activity or #of spikes) and σ (temporal dispersion or standard deviation of underlying pulse density).

#of output spikes (α) is a function of the number of input spikes. The slope of the input-output curve becomes steeper as the temporal accuray (σ) of the input volley becomes better.



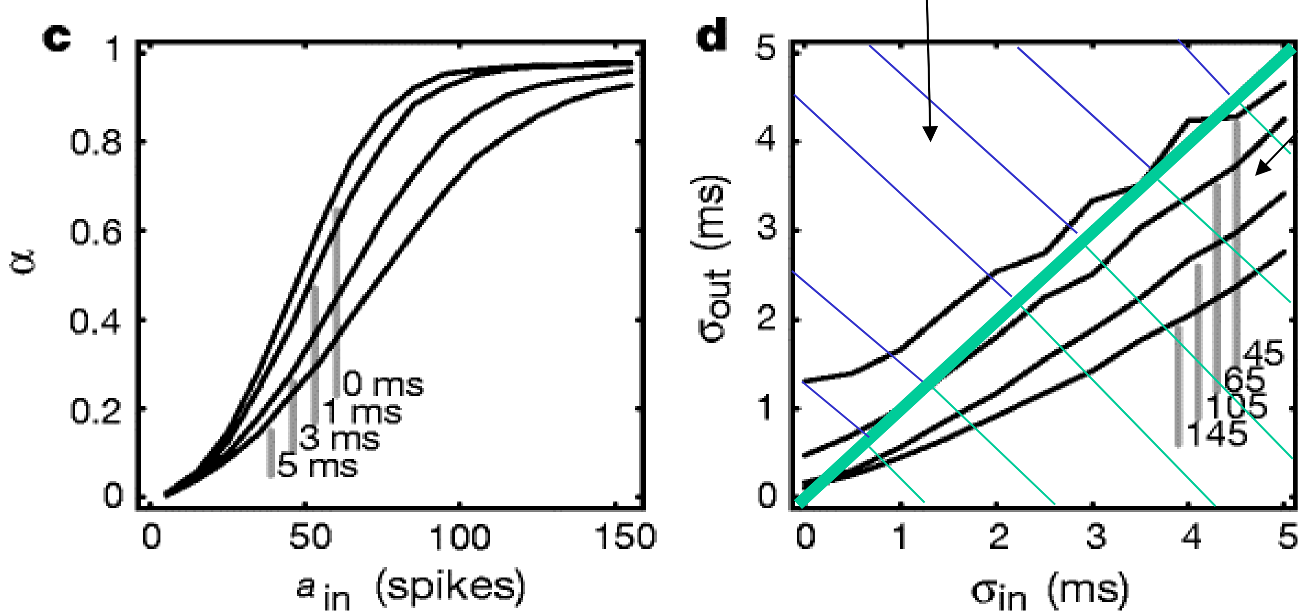
As expected, the spread of the output distribution σ_{out} increases with the spread of the input distribution σ_{in}. However, the slope is < 1, hence the output spread increases slower than the input spread.

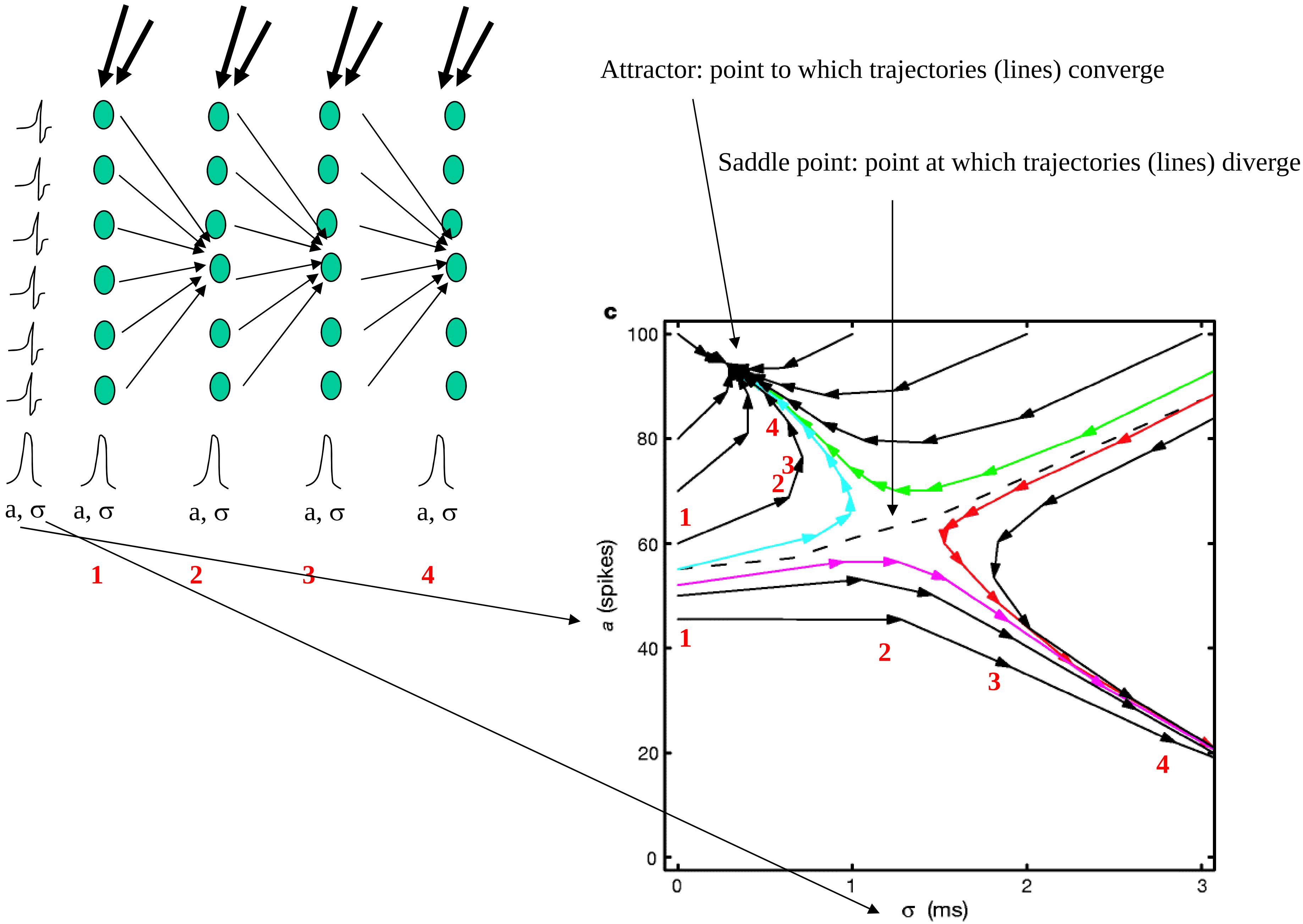
Even for fully synchronized input volleys ($\sigma_{in} = 0$), some jitter in the output spikes remains, reflecting the influence of the background activity.



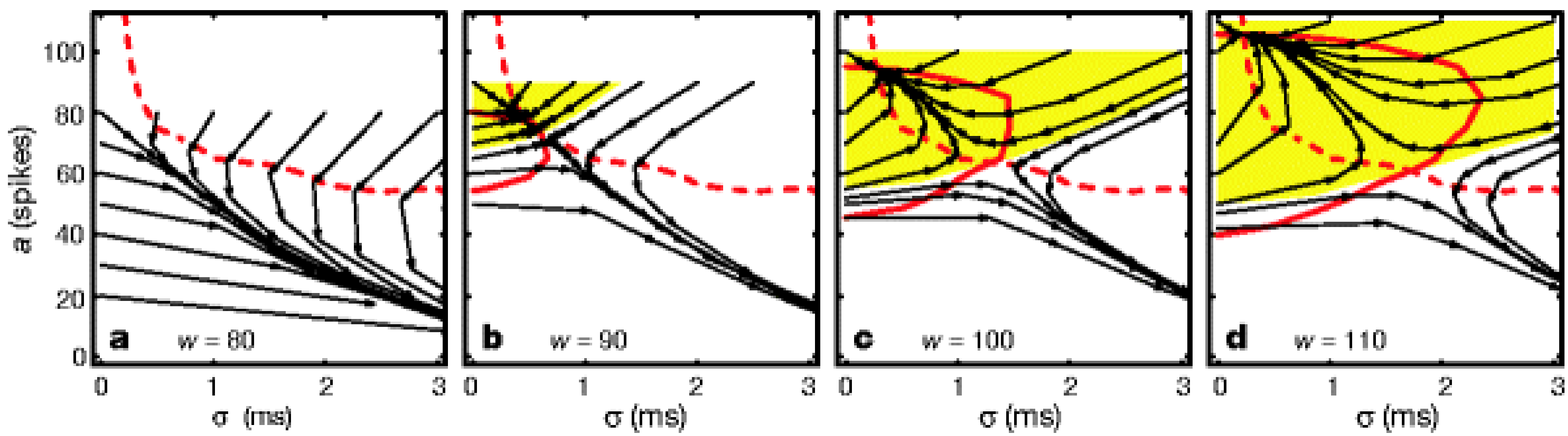
Above diagonal: Output spread is larger than input spread, input becomes "desynchronized".

Below diagonal: output spread is smaller than input spread, input is "synchronized"





Attractor: point to which trajectories (lines) converge
Saddle point: point at which trajectories (lines) diverge
a, σ
a, σ
a, σ
a, σ
a, σ
1
2
3
4
c
a (spikes)
σ (ms)
0
20
40
60
80
100
0
1
2
3


a (spikes)
σ (ms)
a w = 80
b w = 90
c w = 100
d w = 110