Emergence of Oriented Circuits driven by Synaptic Pruning associated with Spike-Timing-Dependent Plasticity (STDP)

Javier Iglesias[1,2]

under the supervision of

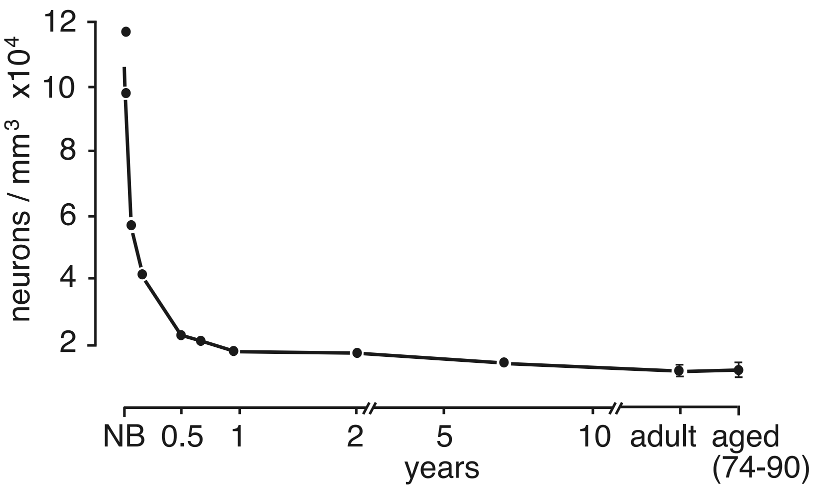
Alessandro E.P. Villa[2] and Marco Tomassini[1]

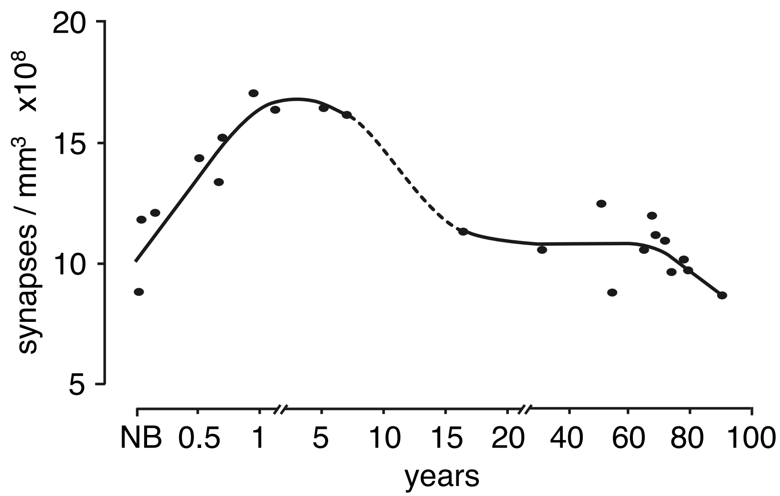
[1] Information Systems Department, University of Lausanne, Switzerland

[2] Laboratory of Neurobiophysics, University Joseph-Fourier, France

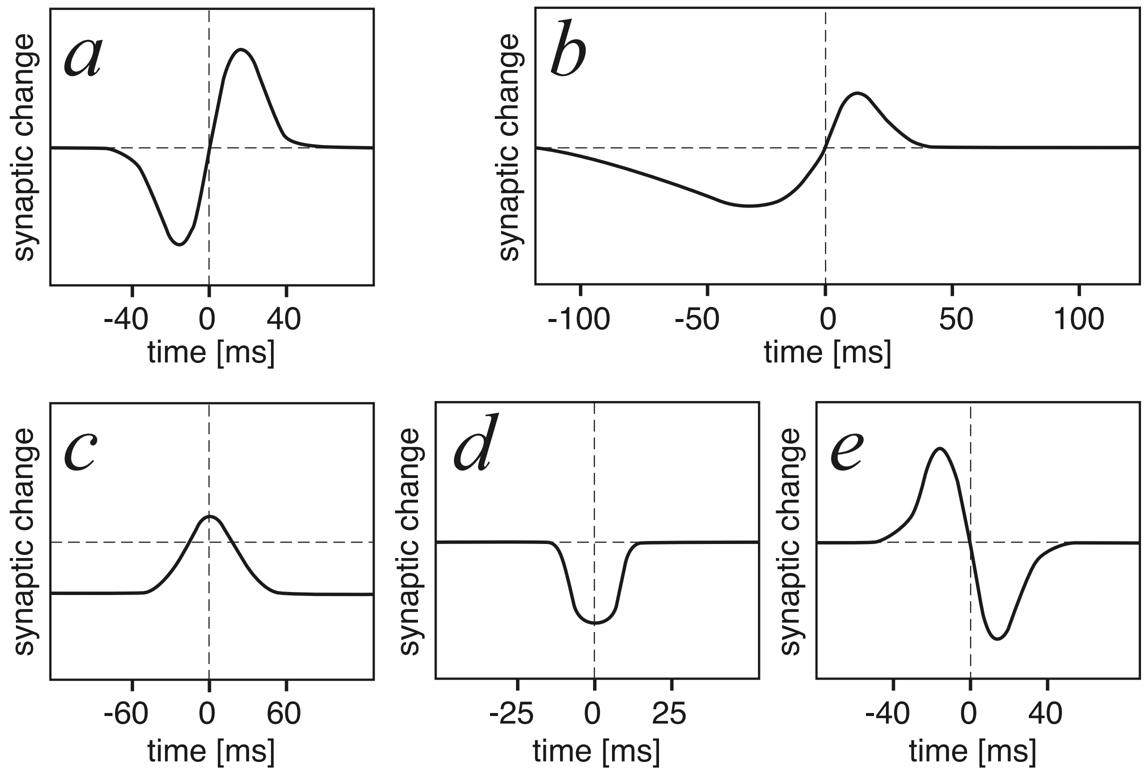
<javier.iglesias@unil.ch>

introduction: synaptogenesis and synaptic pruning





modified from Huttenlocher, *Synaptic density in human frontal cortex – developmental changes and effects of aging*, Brain Research, 163:195–205, 1979



modified from Roberts and Bell, *Spike timing dependent synaptic plasticity in biological systems*, Biol. Cybern., 87:392–403, 2002

- The memory performance of a network is optimally maximized if, under limited metabolic energy resources restricting their number and strength, synapses are first overgrown and then pruned.

Chechik *et al.*, *Synaptic pruning in development: A computational account*, Neural Computation, 10(7):1759–77, 1998

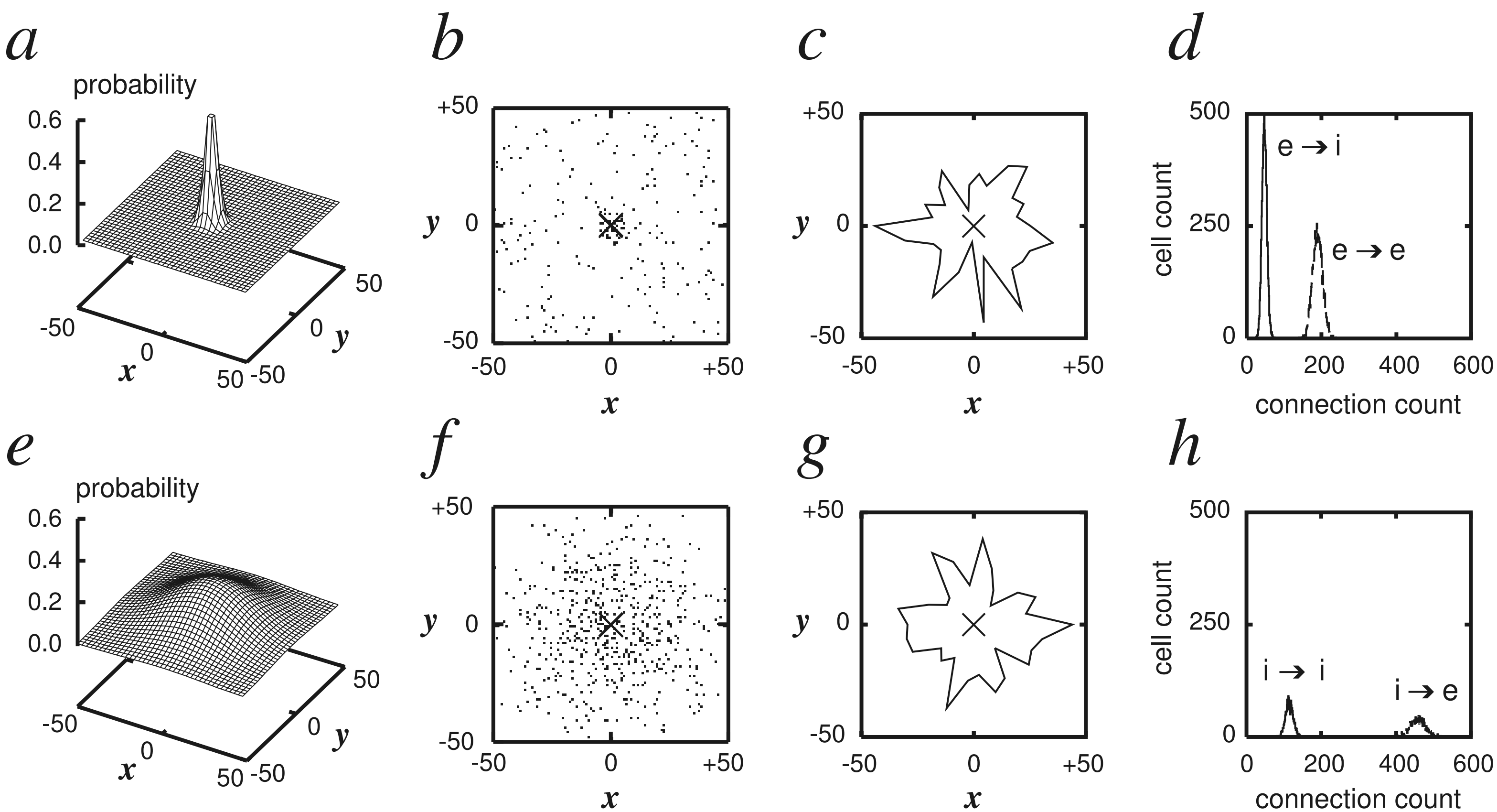
- Neuronal regulation might maintain the memory performance of networks undergoing synaptic degradation.

Horn *et al.*, *Memory maintenance via neuronal regulation* Neural Computation, 10(1):1–18, 1998

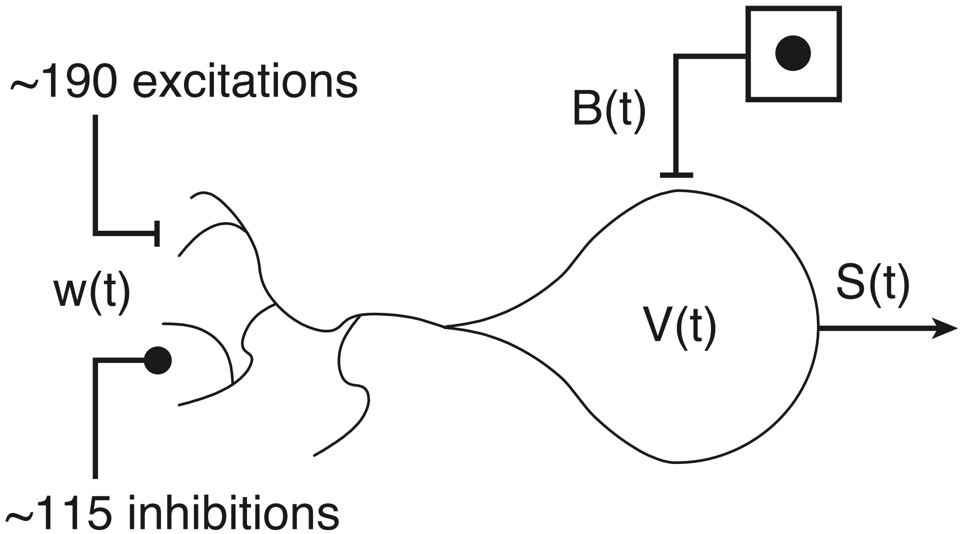
- STDP has been shown to maintain the postsynaptic input field.

Abbott *et al.*, *Synaptic plasticity: taming the beast* Nature Neuroscience, 3:1178–83, 2000

model: network



Iglesias *et al.*, *Dynamics of Pruning in Simulated Large-Scale Spiking Neural Networks*, Biosystems, 79(1-3):11-20, 2005



Type I	=	excitatory 80%	
Type II	=	inhibitory 20%	
V_{rest}	=	-76	[mV]
θ_i	=	-40	[mV]
τ_{mem}	=	8	[ms]
t_{refract}	=	1	[ms]
λ_i	=	10	[spikes/s]
n	=	50	

$$V_i(t{+}1) = V_{\text{rest}[q]} + (1 - S_i(t)) \cdot ((V_i(t) - V_{\text{rest}[q]}) \cdot k_{\text{mem}[q]}) + \sum_j w_{ji}(t) + B_i(t)$$

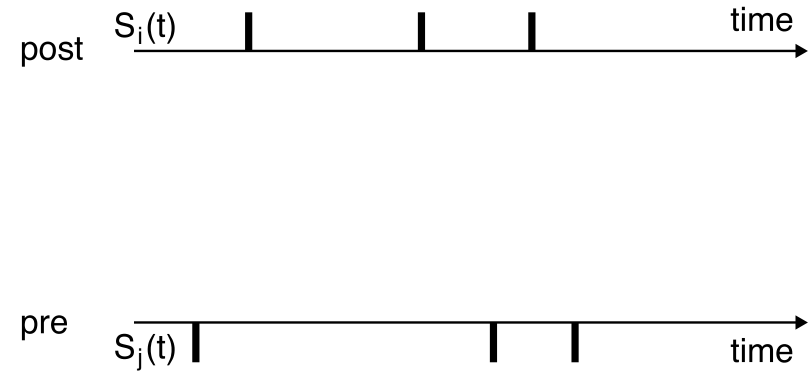
$$S_i(t) = \mathcal{H}(V_i(t) - \theta_{q_i})$$

$$w_{ji}(t+1) = S_j(t) \cdot A_{ji}(t) \cdot P_{[q_j, q_i]}$$

$$B_i(t+1) = \mathcal{P}_{reject}(\lambda_{q_i}) \cdot n \cdot P_{[q_1, q_i]}$$

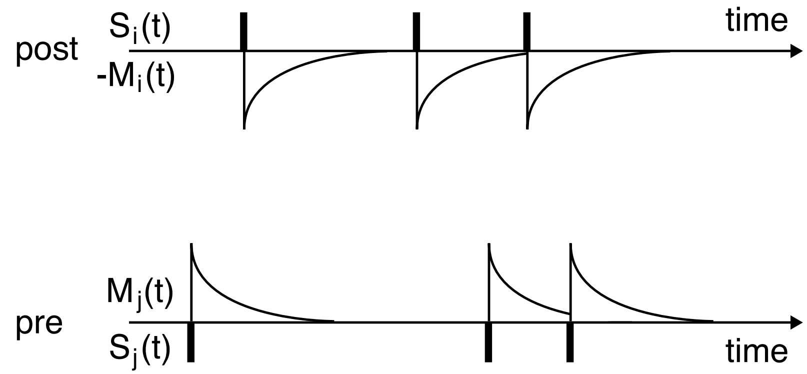
model: STDP and pruning

$$
\begin{aligned}
L_{ji}(t+1) = \quad & L_{ji}(t) \cdot k_{\mathrm{act}[q_j,q_i]} \\
& +(S_i(t) \cdot M_j(t)) \\
& -(S_j(t) \cdot M_i(t))
\end{aligned}
$$



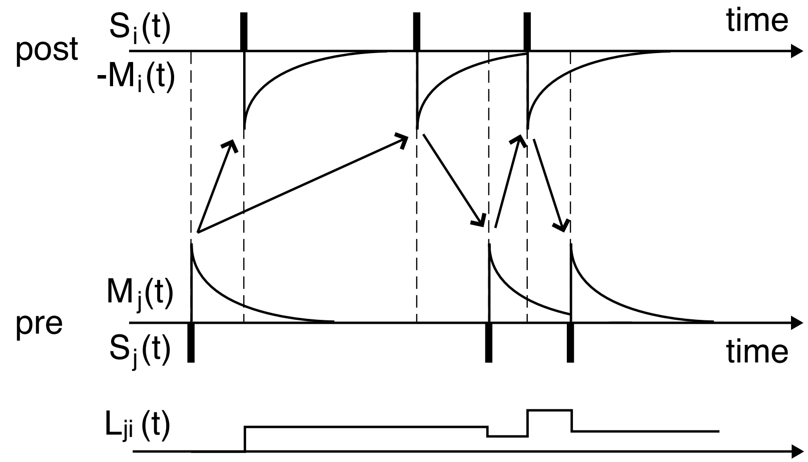
model: STDP and pruning

$$L_{ji}(t+1) = L_{ji}(t) \cdot k_{\mathrm{act}[q_j,q_i]} + (S_i(t) \cdot M_j(t)) - (S_j(t) \cdot M_i(t))$$



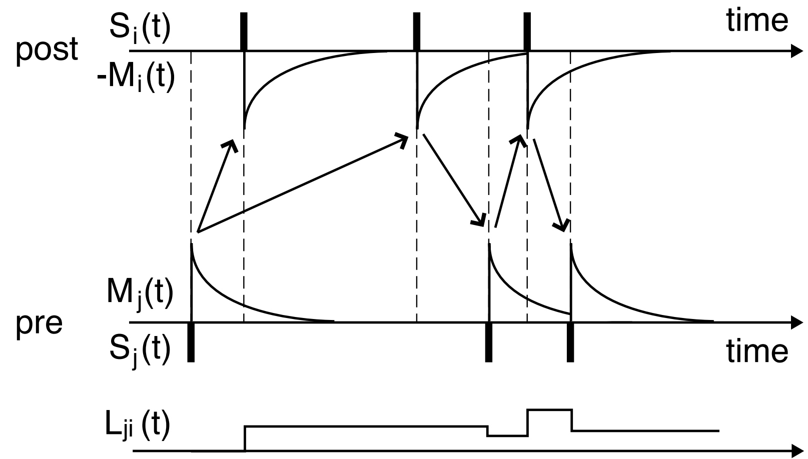
model: STDP and pruning

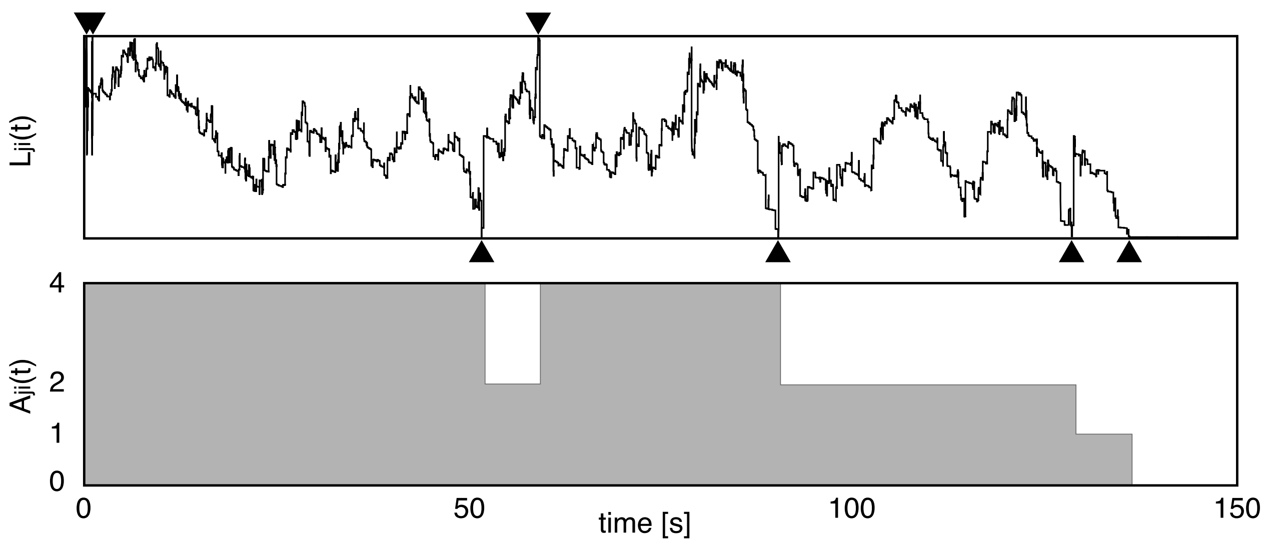
$$L_{ji}(t+1) = L_{ji}(t) \cdot k_{\mathrm{act}[q_j,q_i]} + (S_i(t) \cdot M_j(t)) - (S_j(t) \cdot M_i(t))$$



model: STDP and pruning

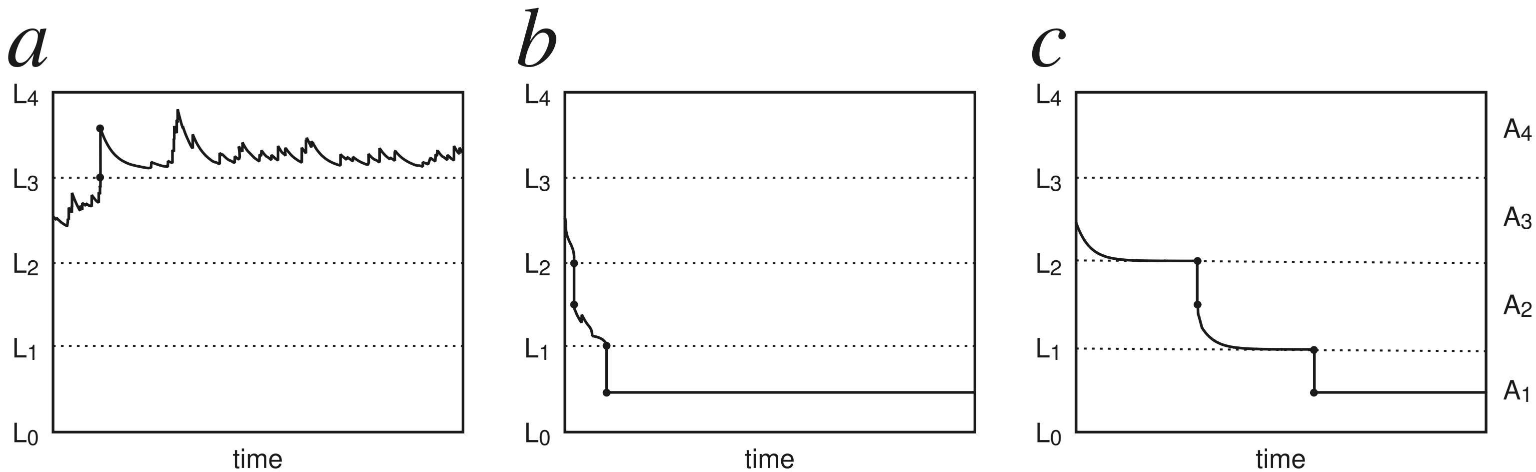
$$L_{ji}(t+1) = L_{ji}(t) \cdot k_{\mathrm{act}[q_j,q_i]} + (S_i(t) \cdot M_j(t)) - (S_j(t) \cdot M_i(t))$$



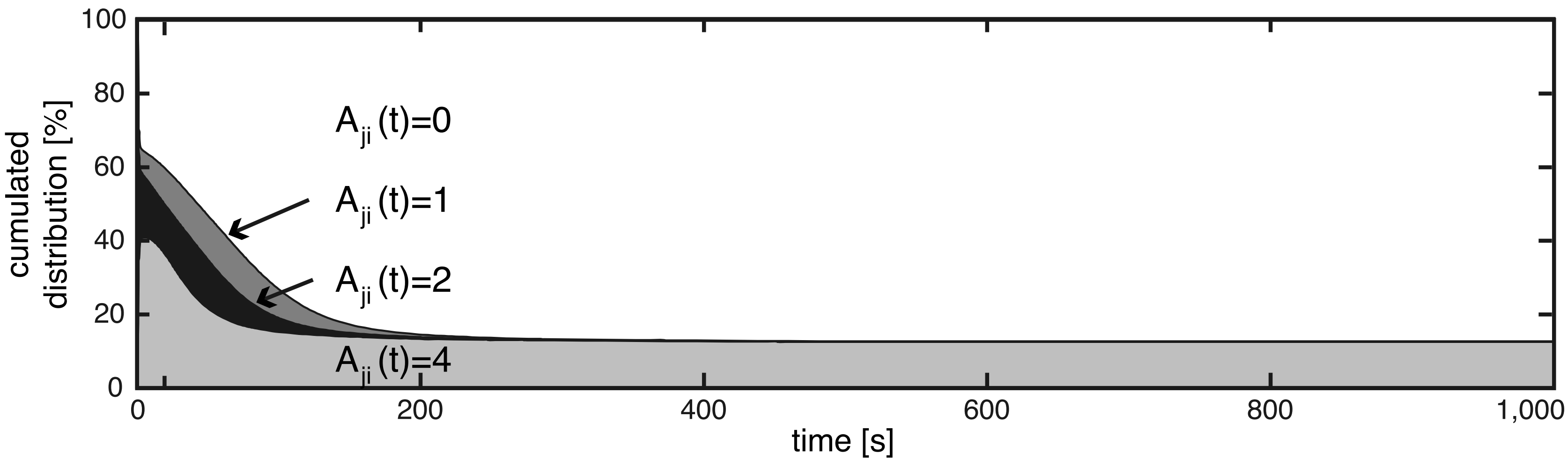


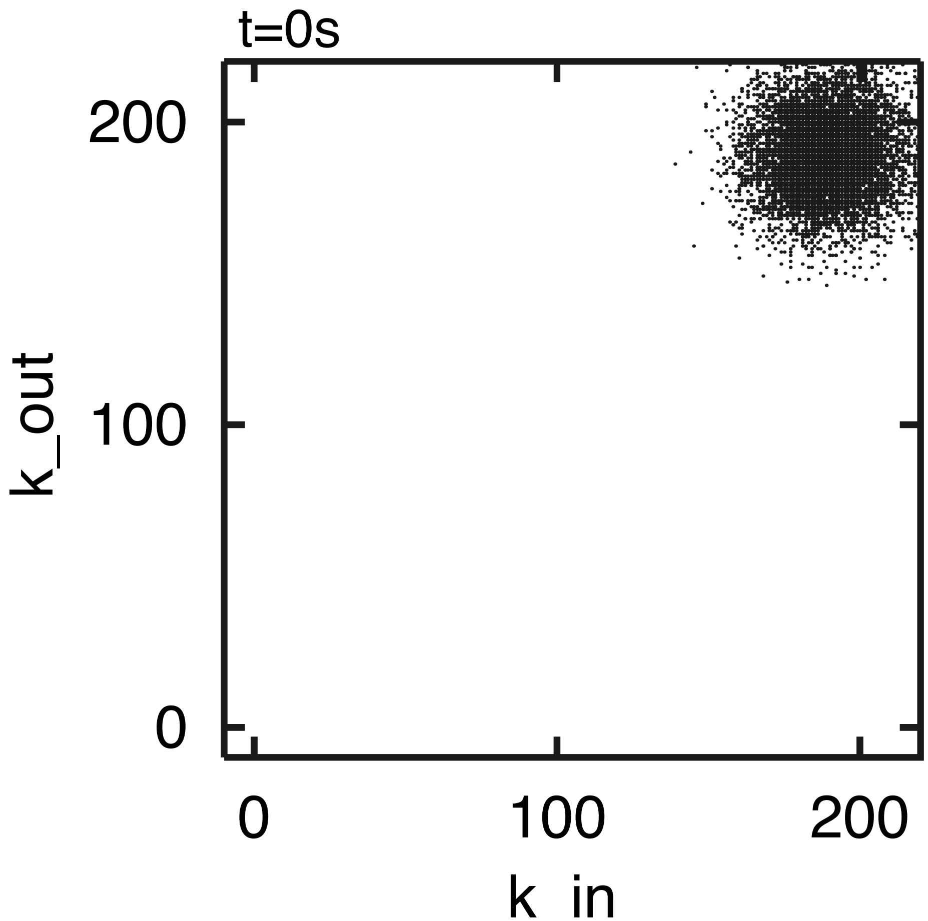
$$w_{ji}(t+1) = S_j(t) \cdot A_{ji}(t) \cdot P_{[q_j,q_i]}$$

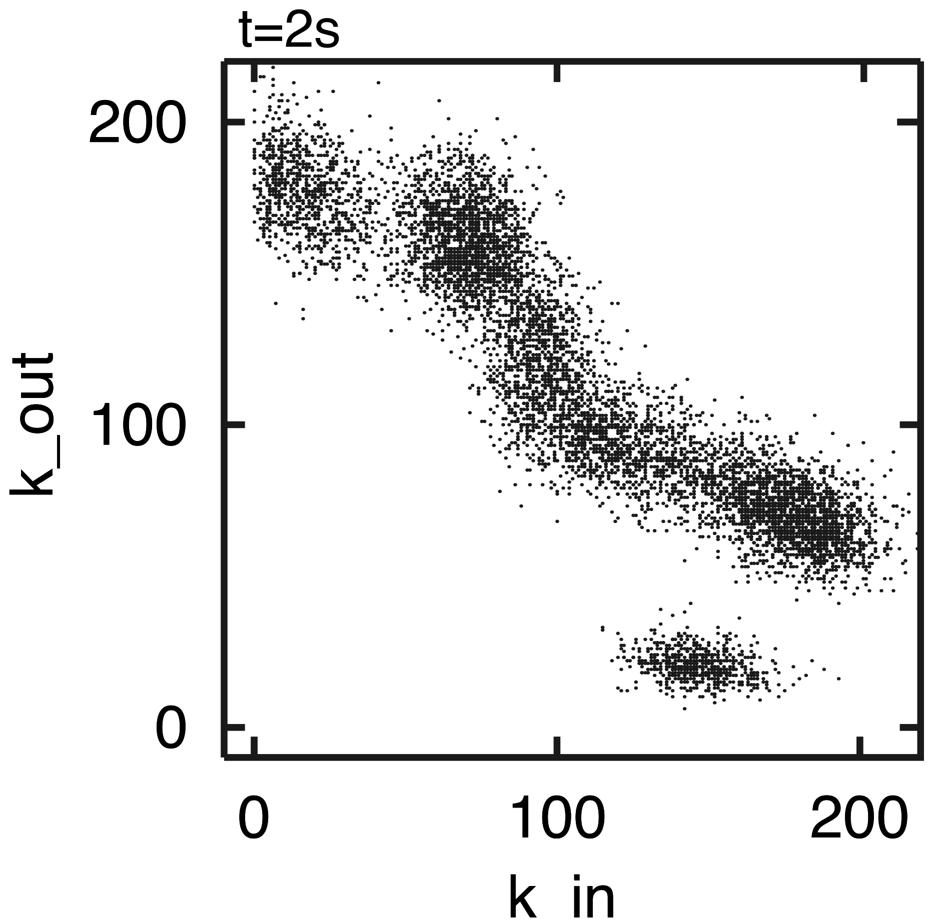
model: synaptic adaptation examples

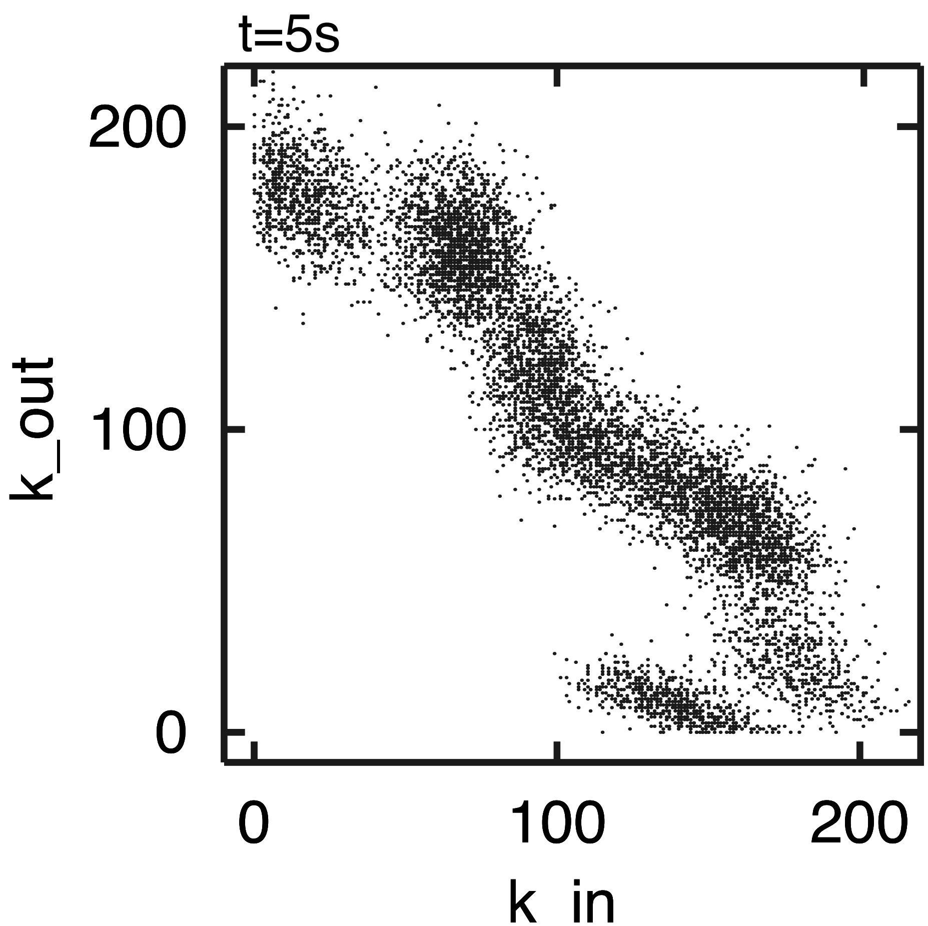


results: simulation evolution

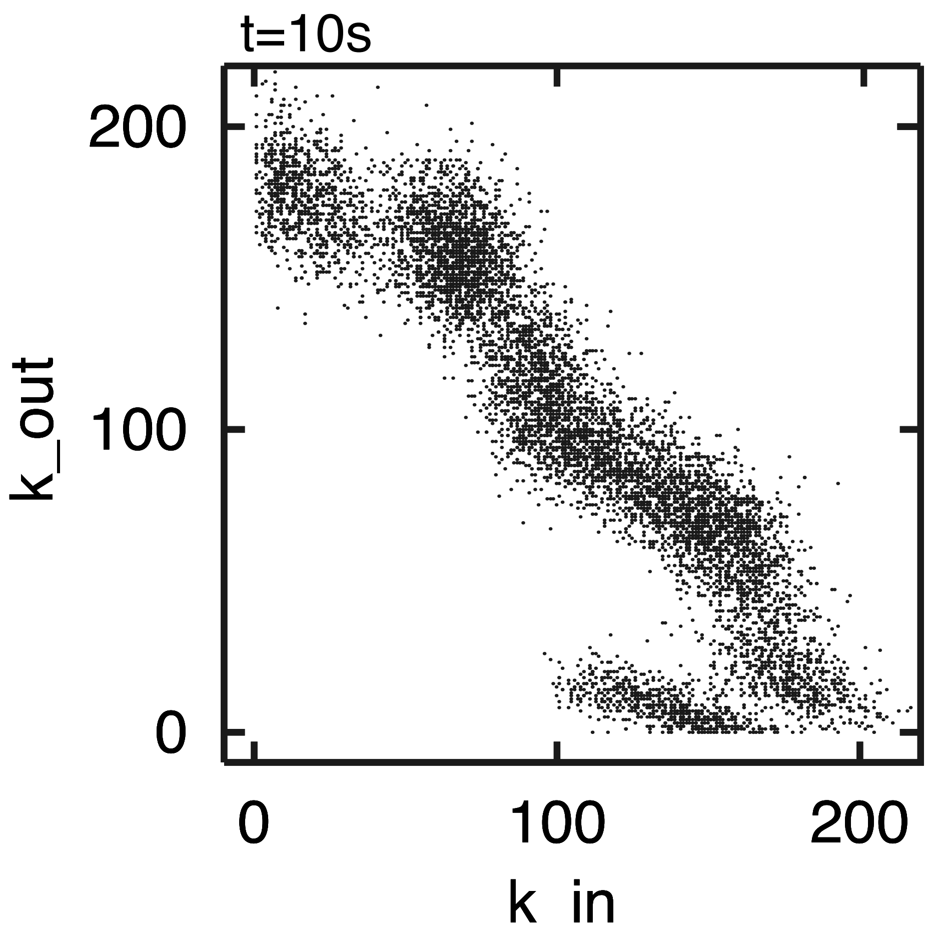


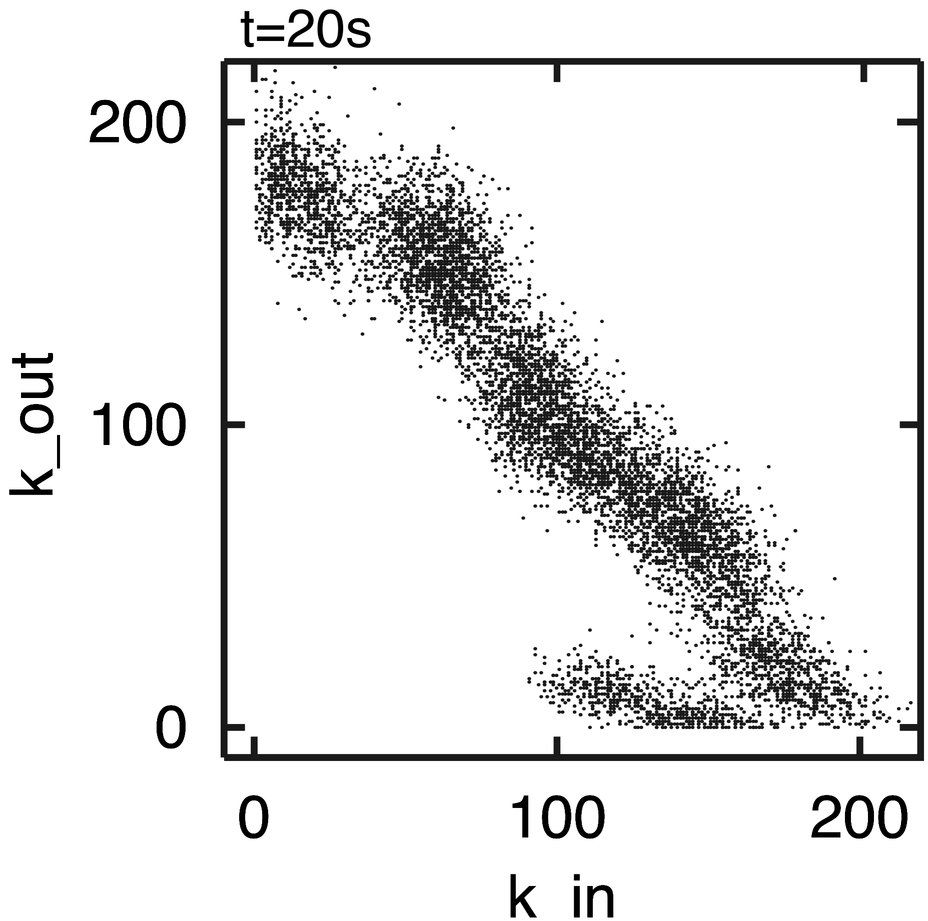

t=0s
200
100
0
k_out
0
100
200
k_in

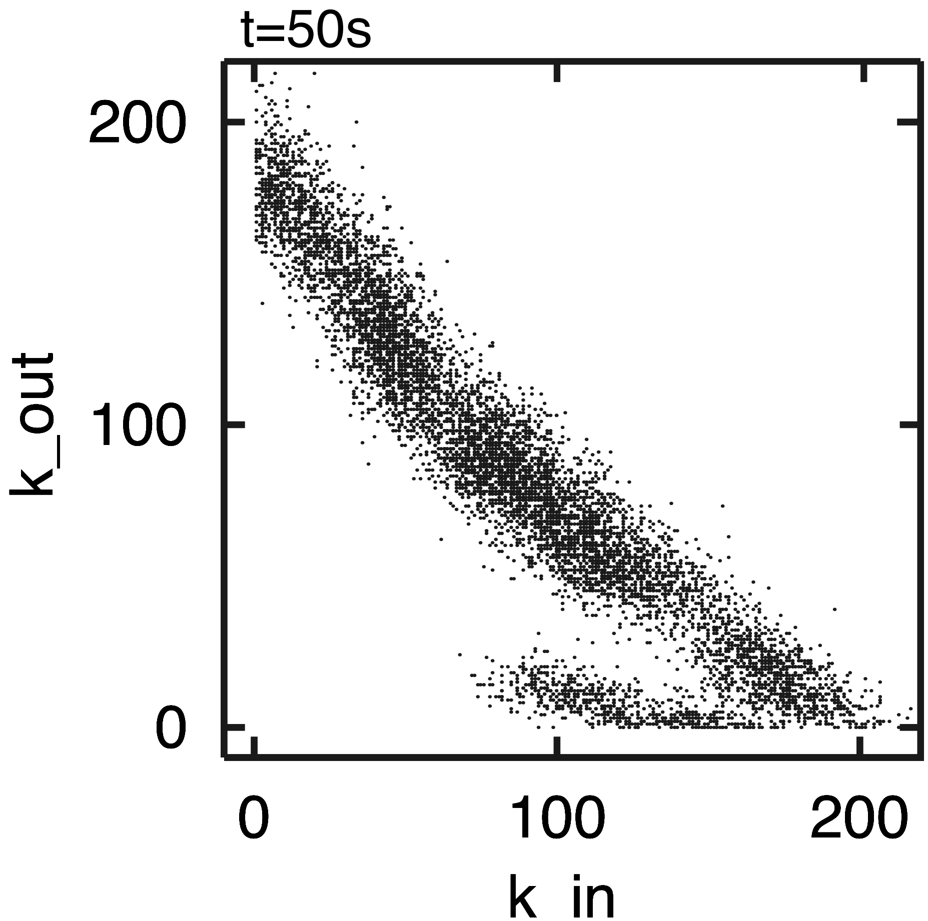

t=2s
k_out
200
100
0
0
100
200
k_in

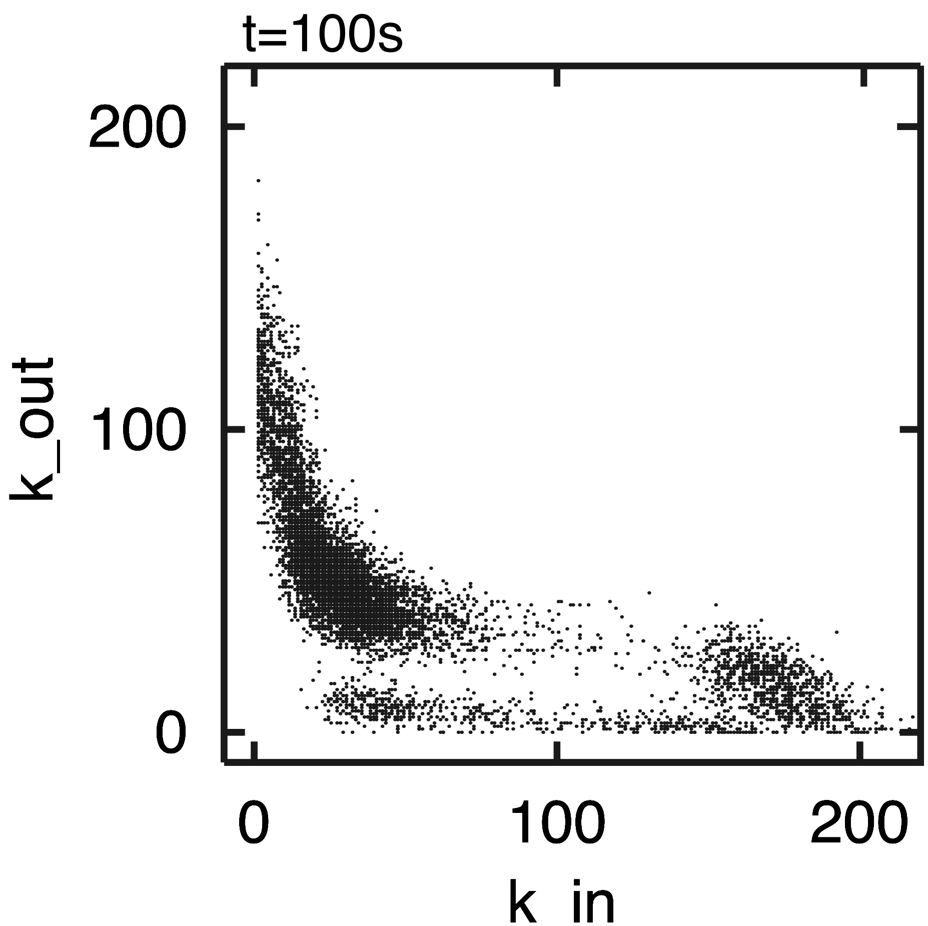


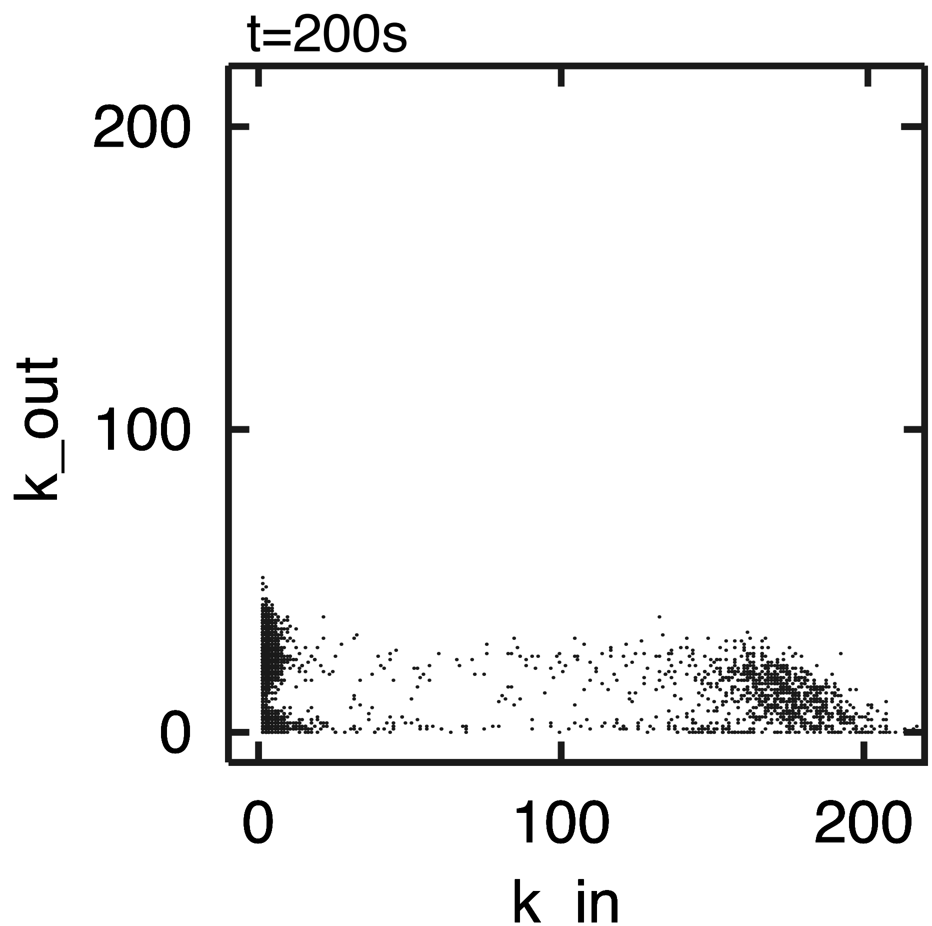
t=5s
k_out
k_in
0
100
200
0
100
200

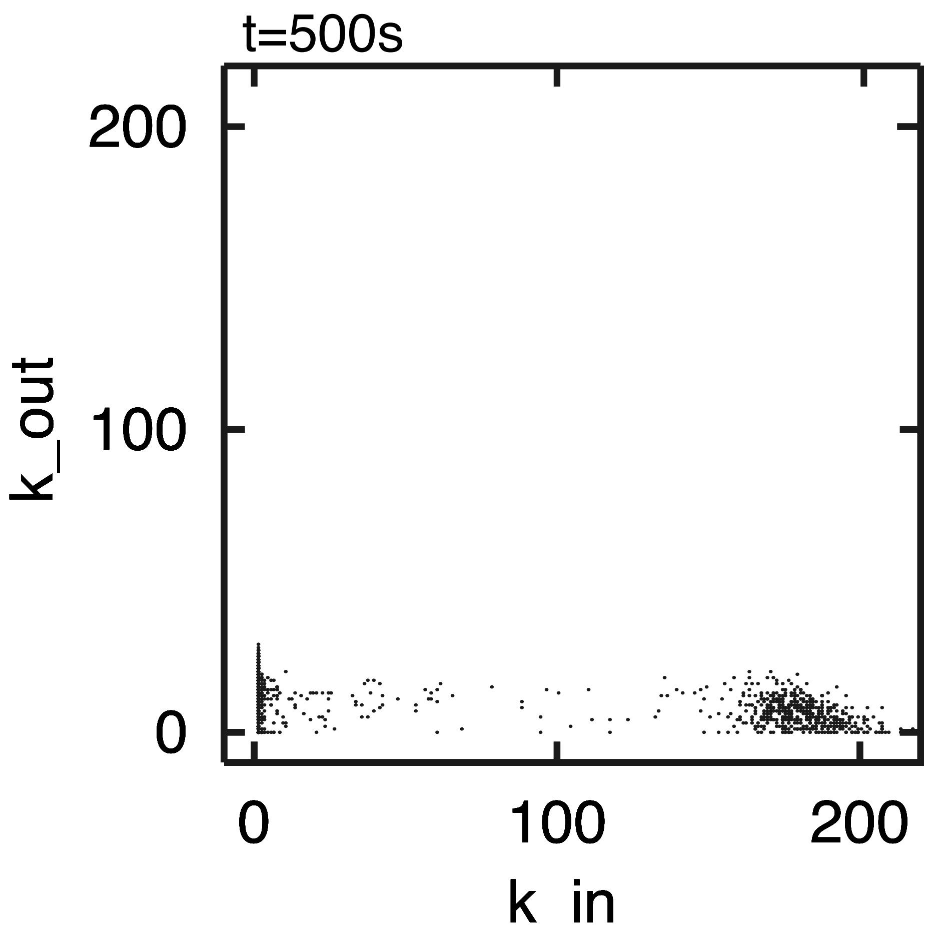

t=10s
200
100
0
k_out
0
100
200
k_in


t=20s
200
100
0
k_out
0
100
200
k_in


t=50s
200
100
0
k_out
0
100
200
k_in


t=100s
200
100
0
k_out
0
100
200
k_in


t=200s
200
100
0
k_out
0
100
200
k_in


t=500s
200
100
0
k_out
0
100
200
k_in

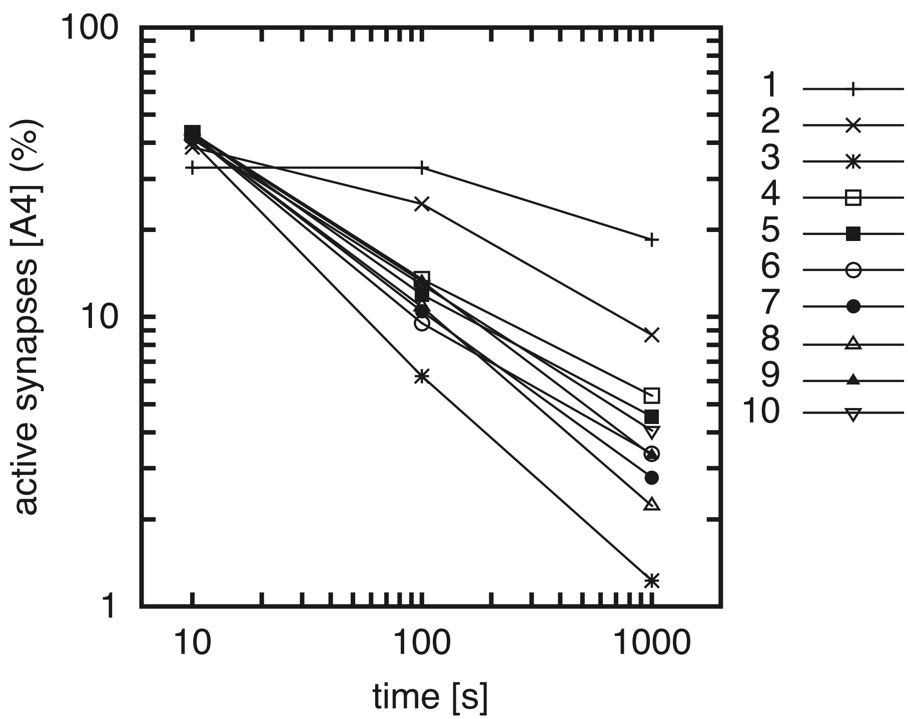
results: scaling factor

$$f = \sqrt[3]{\frac{10^4}{(10 \cdot N)^2}}$$

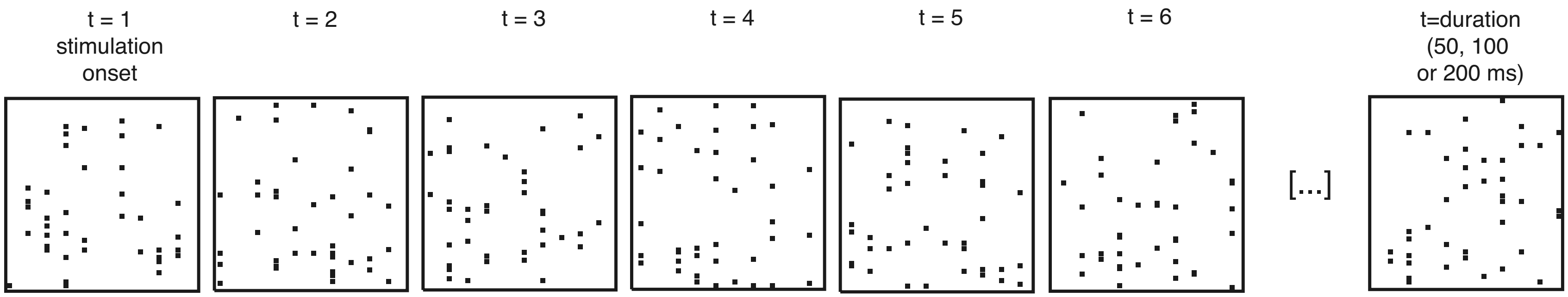
$$\phi^*_{[exc]} = f \cdot \phi_{[exc]}$$

$$P^*_{[\mathrm{exc,exc}]} = \left(1 + \frac{f-1}{2}\right) \cdot P_{[\mathrm{exc,exc}]}$$

network size
is defined as
$(10 \times N)^2$



model: simple stimulus



every 2 seconds
N vertical bars moving to the right
during 50, 100, or 200 time steps.

input units ratio: 3, 5, 7, or 10% excitatory units.
randomly selected before stimulation or in the beginning

See an animated sequence.

Strongly Interconnected (SI) units

at the end of the simulation
set of cells (discarding input units)
maintaining $k_{out} \geq 3$ and $k_{in} \geq 3$
with strongest activation level ($A_{ji}(t) = 4$)
with units with the same properties.

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Neighbourhood

all excitatory units (including input units)
with at least one projection to or from SI-units.

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set of cells (discarding input units)
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with units with the same properties.

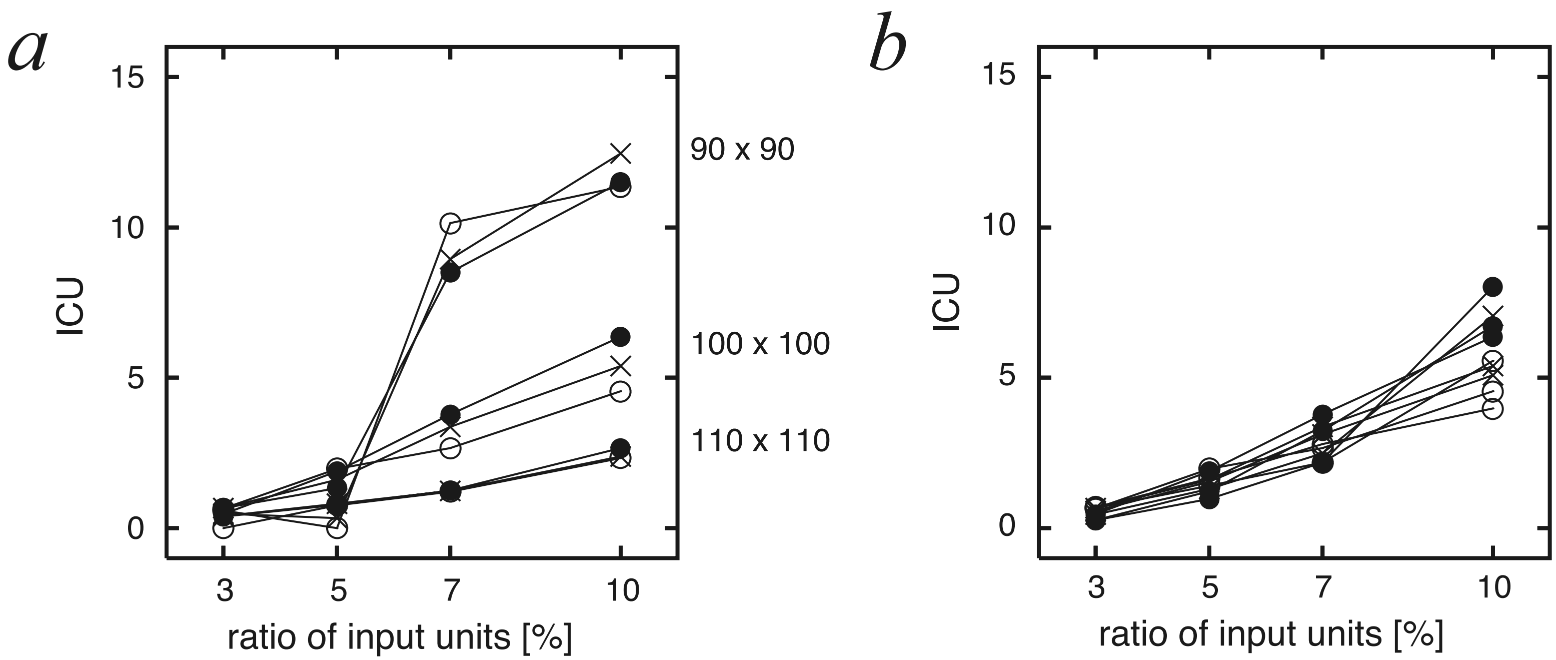
Neighbourhood

all excitatory units (including input units)
with at least one projection to or from SI-units.

index of connected units (ICU)

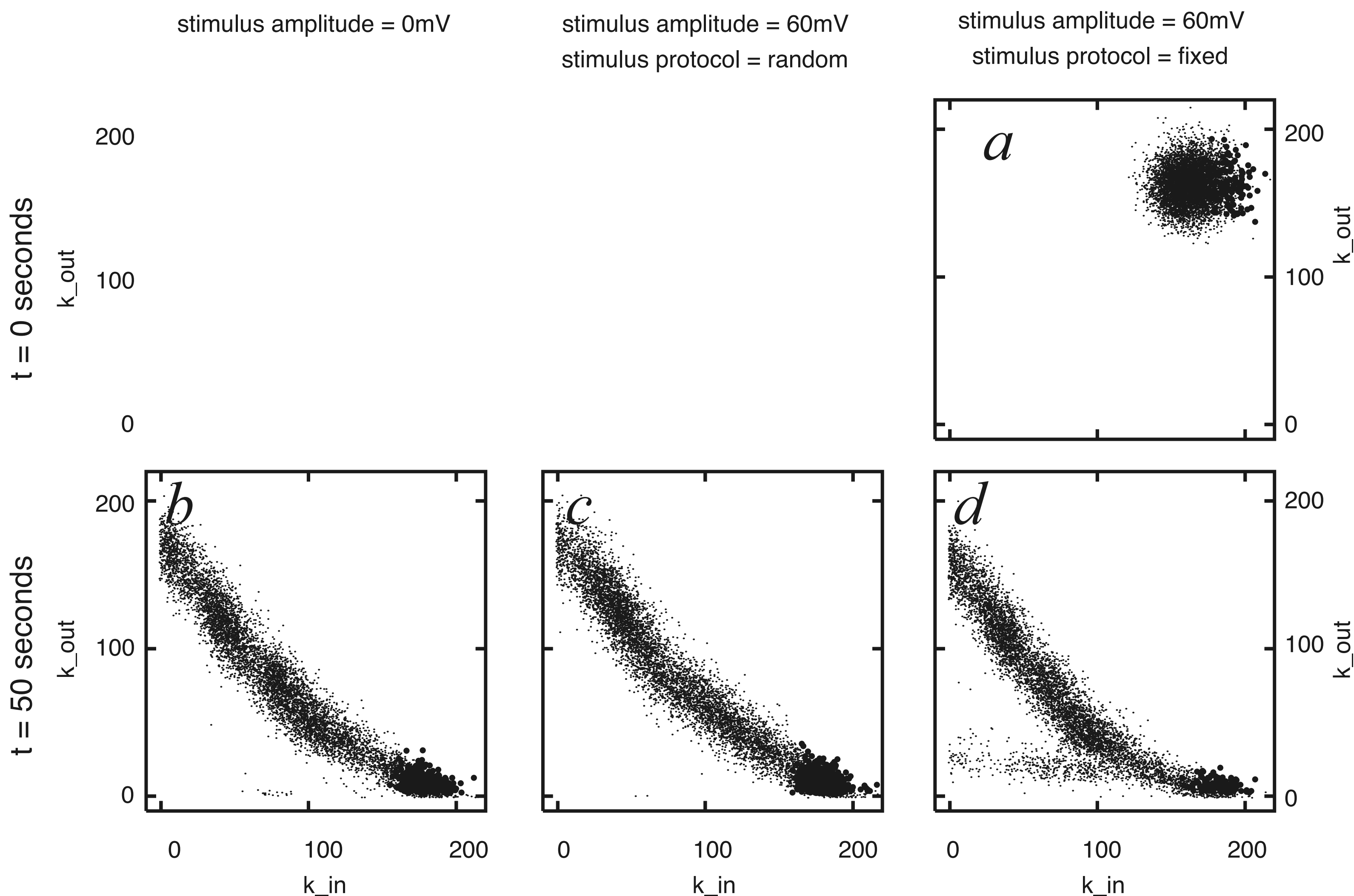
$$\frac{\#\text{input units in neighbourhood}}{\#\text{SI}-\text{units}}$$

results: with and without scaling factor

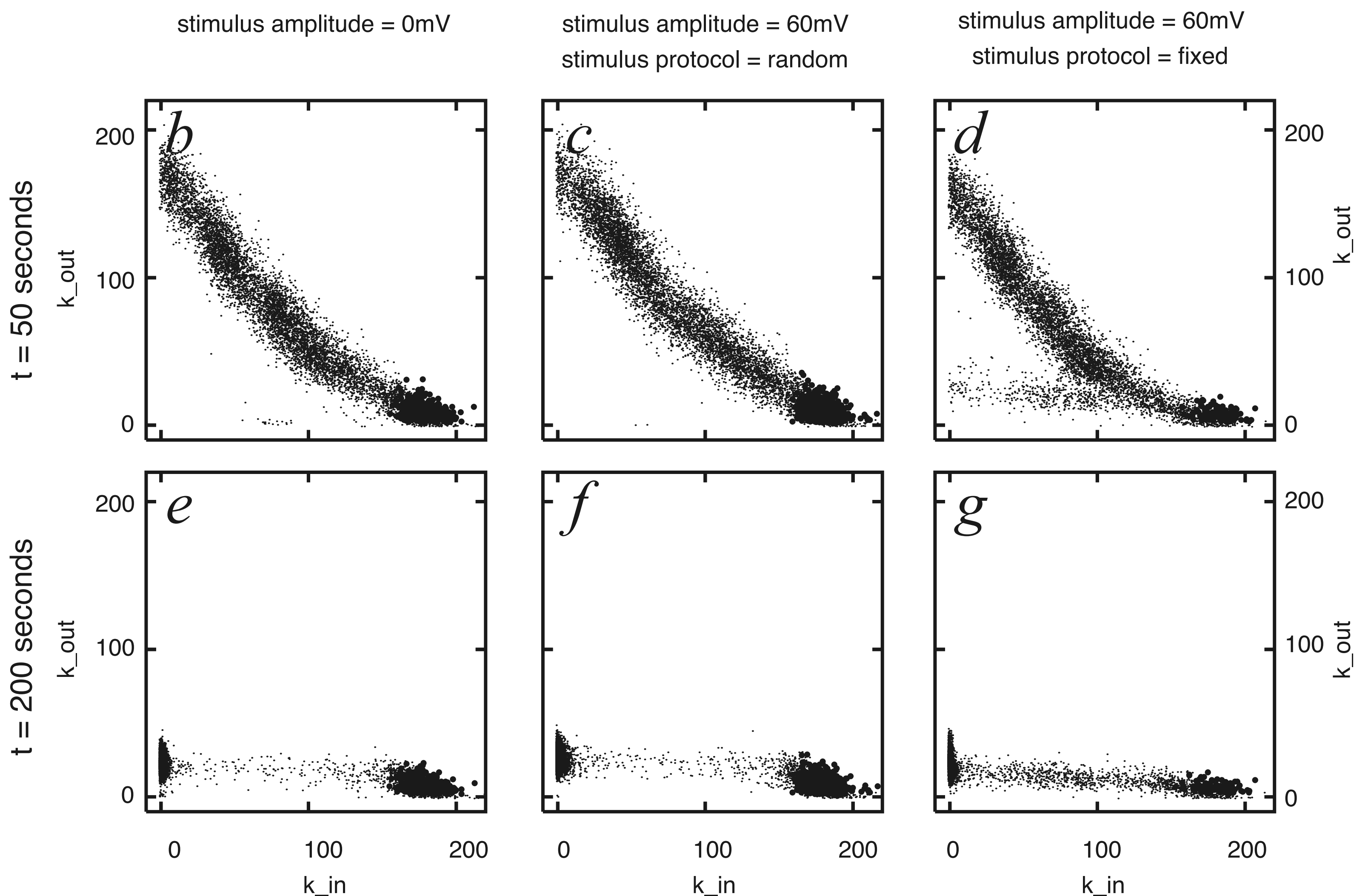


Iglesias *et al.*, *Stimulus-Driven Unsupervised Pruning in Large Neural Networks*, LNCS (*in press, October 2005*)

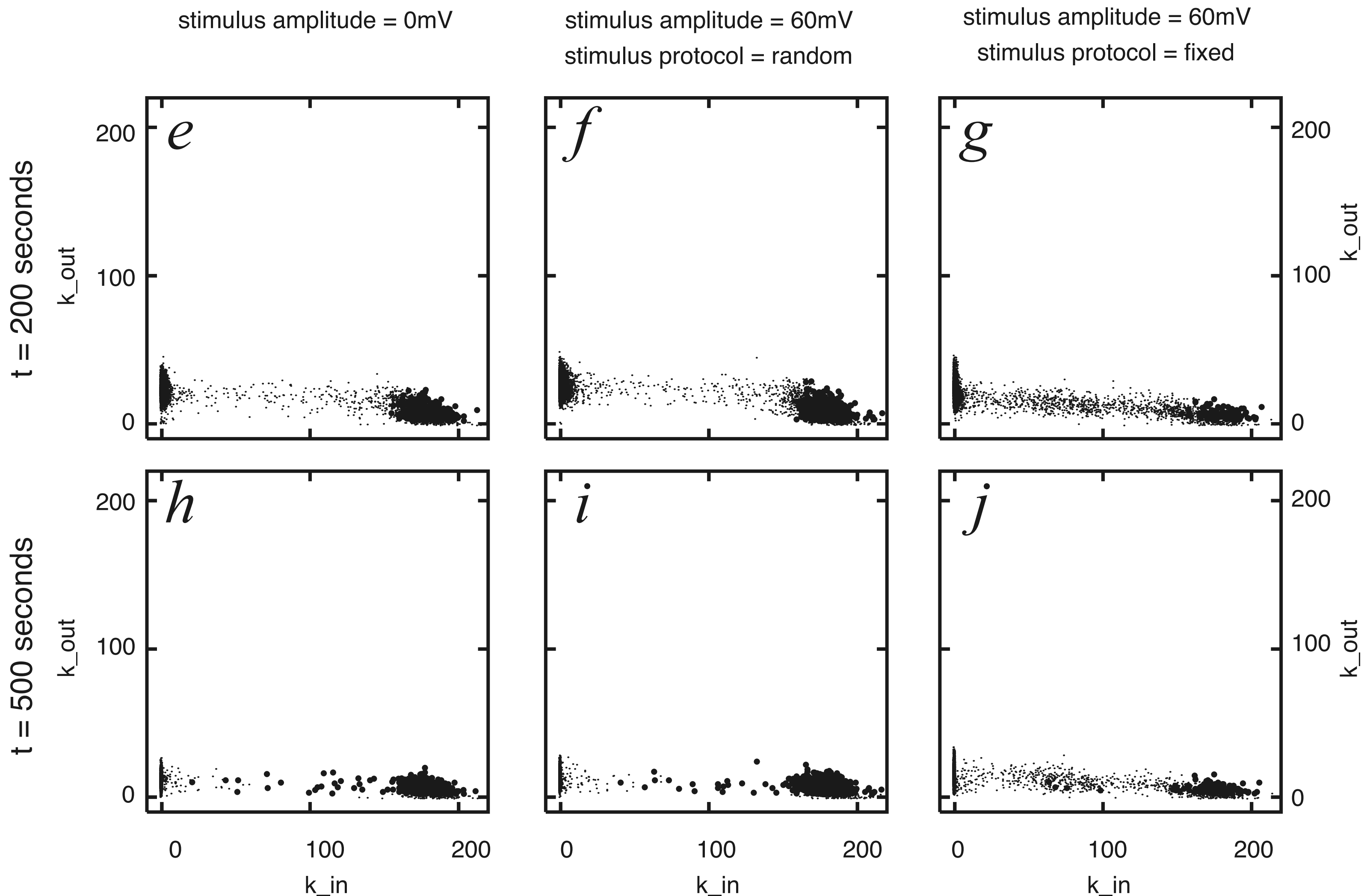
results: emergence of circuits from t=0 to t=50s



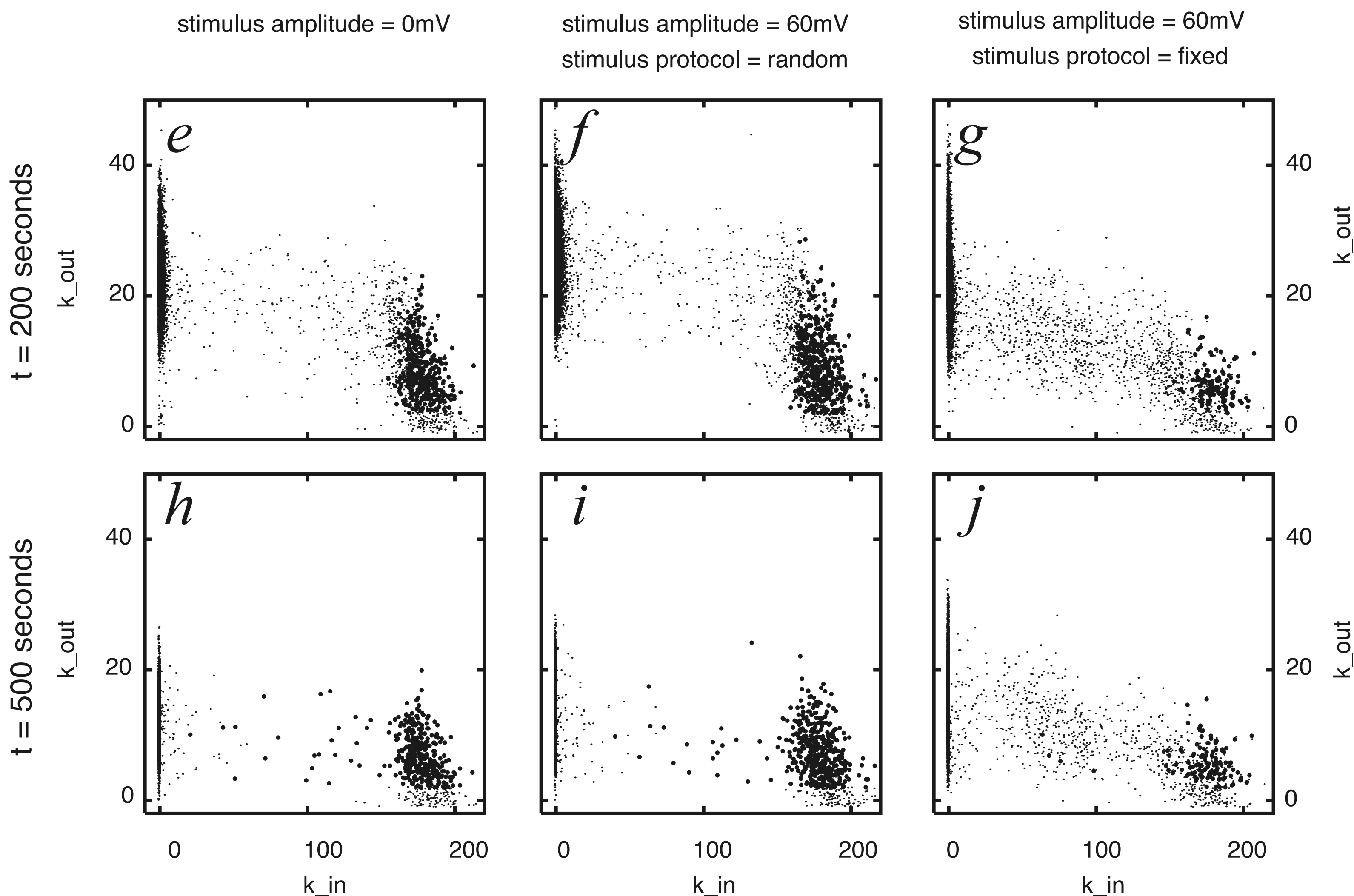
results: emergence of circuits from t=50 to t=200s



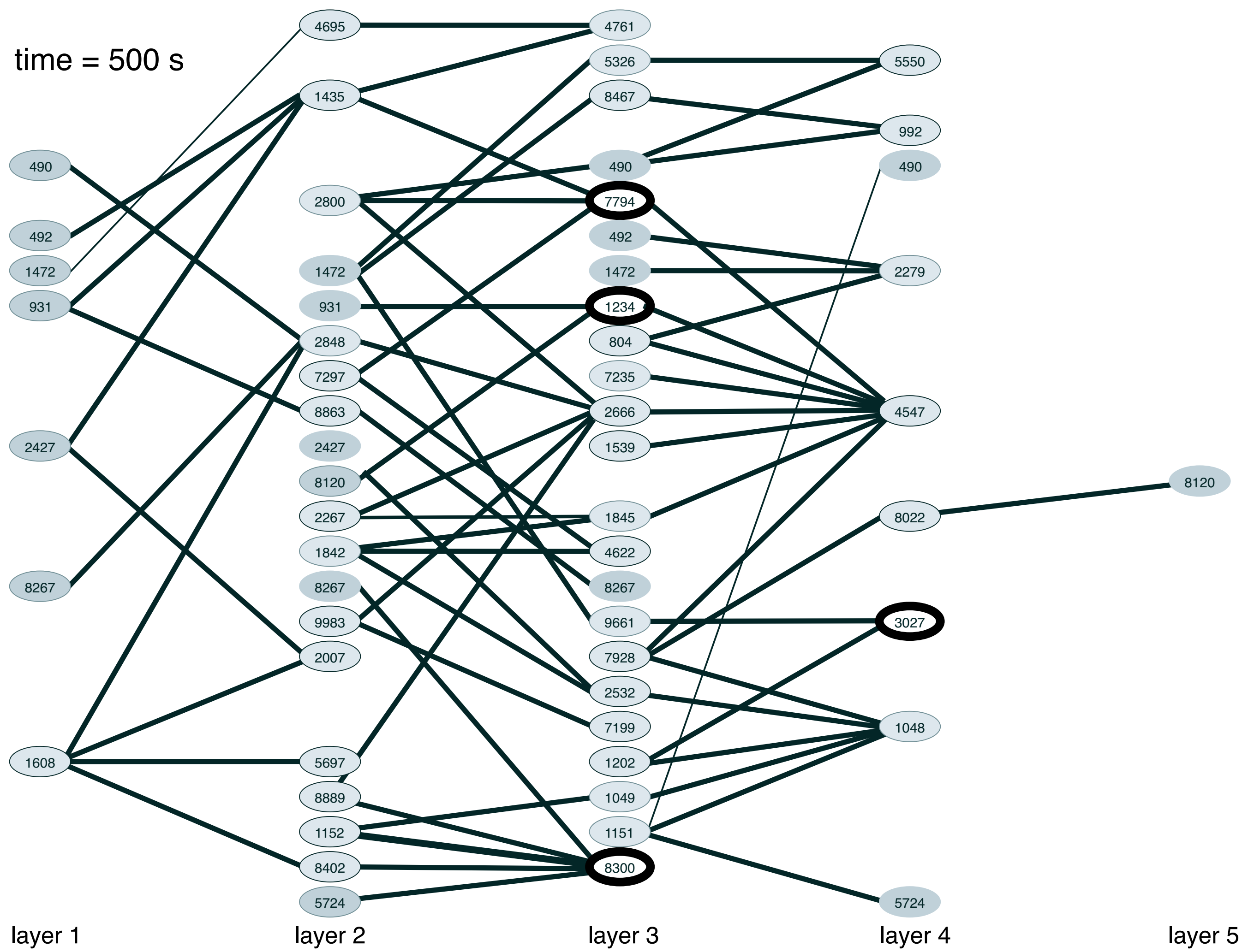
results: emergence of circuits from t=200 to t=500s



results: emergence of circuits from t=200 to t=500s (cont.)

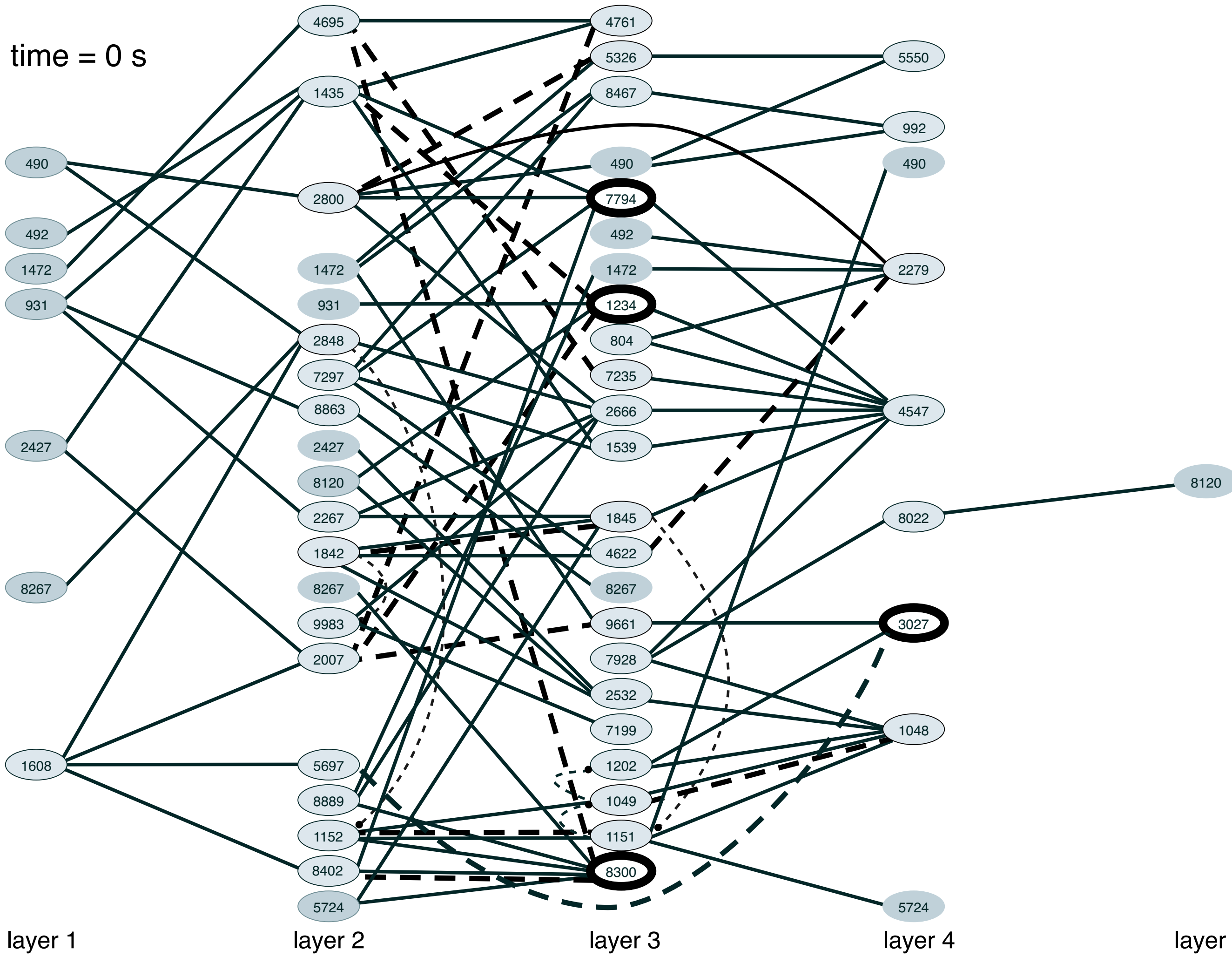


Iglesias *et al.*, *Emergence of Oriented Cell Assemblies Associated with Spike-Timing-Dependent Plasticity*, LNCS 3696:127-132, 2005

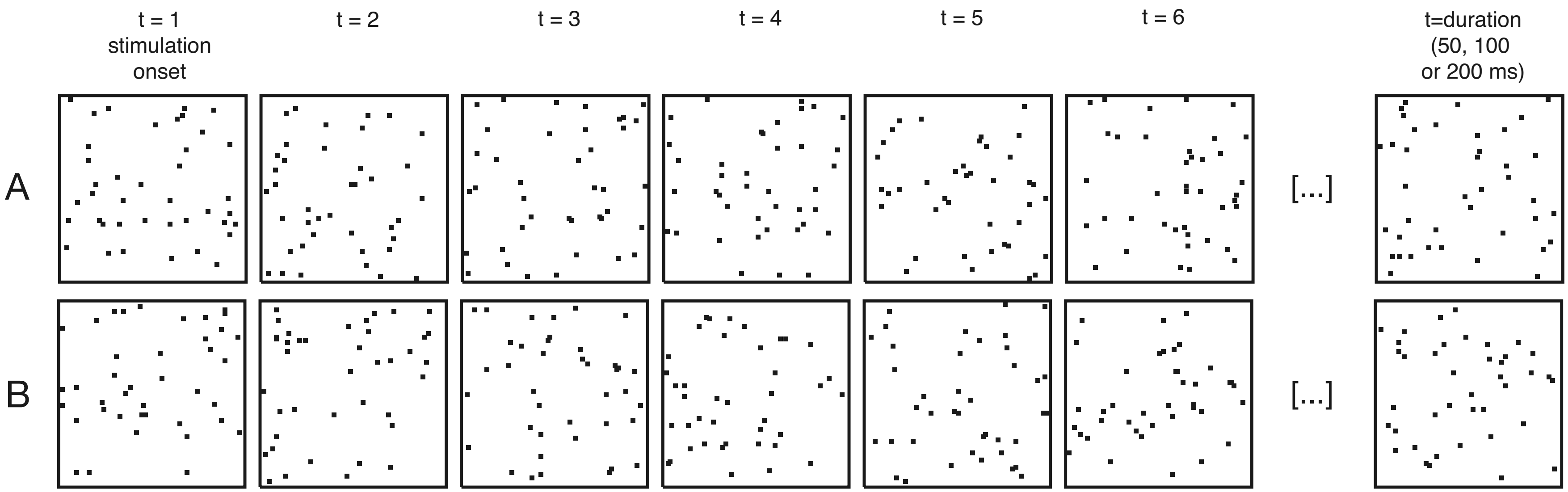


results: circuit

Iglesias *et al.*, *Emergence of Oriented Cell Assemblies Associated with Spike-Timing-Dependent Plasticity*, LNCS 3696:127-132, 2005



model: complex stimulus



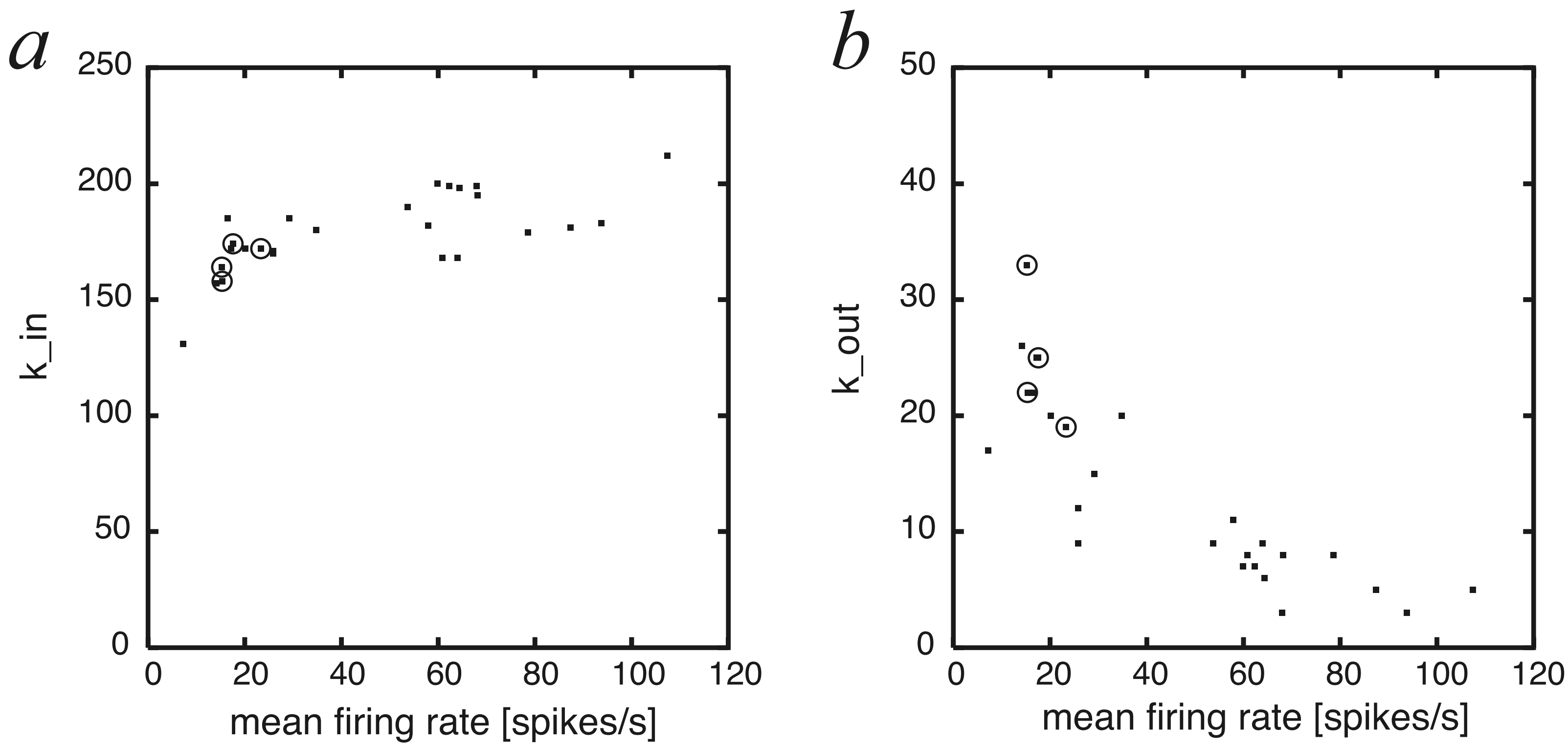
every 2 seconds
10 groups of 40 units activated in sequence (5% input units)
during 200 time steps (AA, BB, AB, BA, AB|BA)

continuous and interrupted pruning

Animated sequences are available for both stimuli A and B.

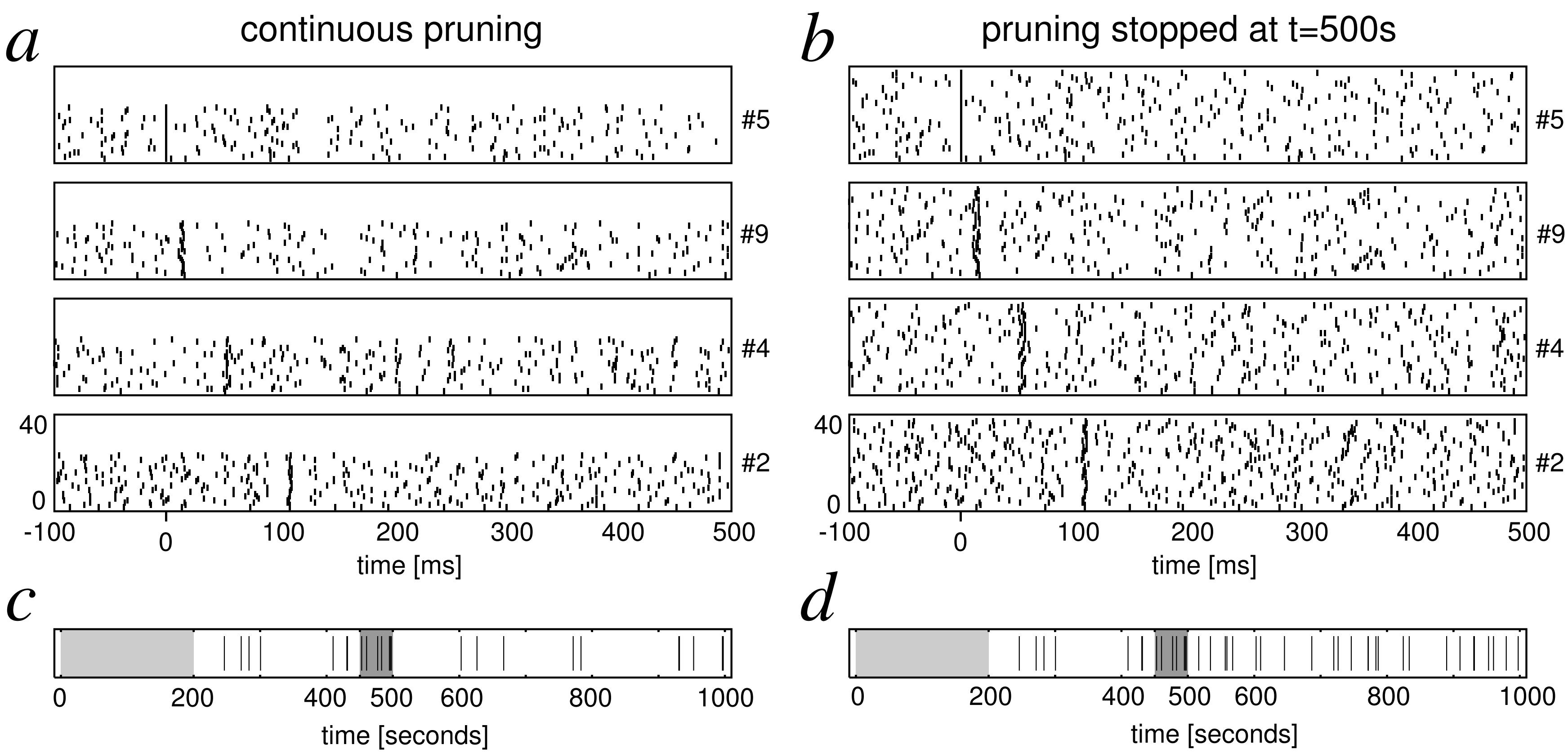
results: firing rates *vs.* connection degrees

26 units with $k_{in} = k_{out} = 0$ in absence of stimulation
and $k_{in} > 0$ and $k_{out} > 0$ with all other stimuli (AA, BB, ...)



results: spatio-temporal pattern of activity

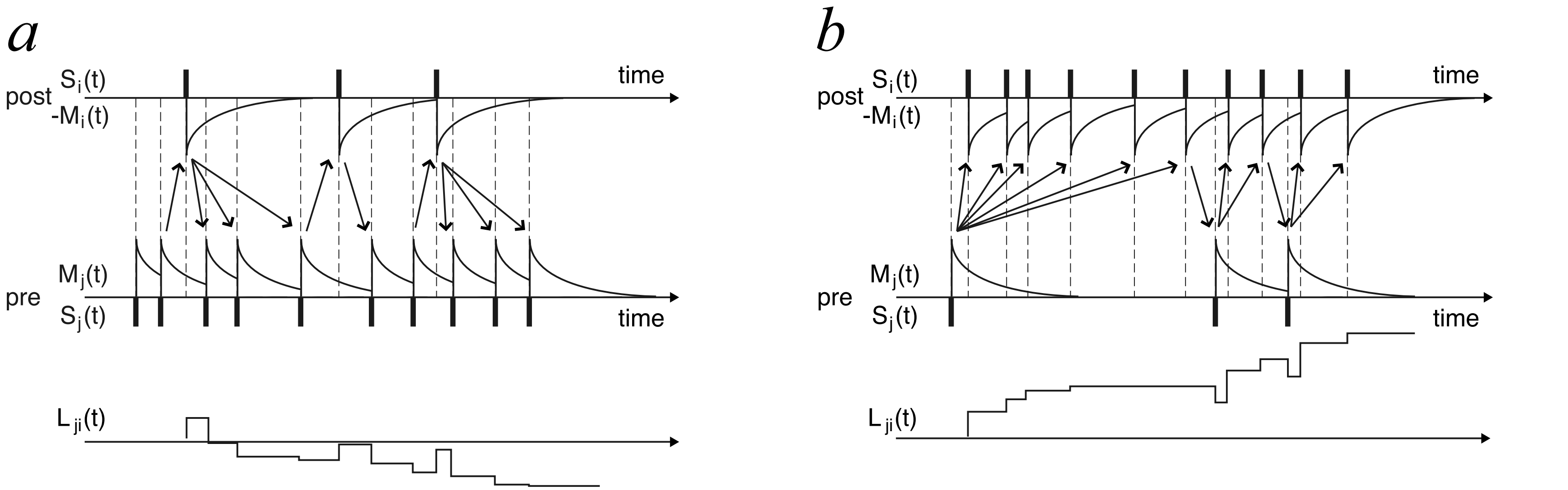
<5, 9, 4, 2; 13, 53, 109>



for methods, see Villa *et al.*, 1999; Tetko and Villa, 2001

- network size effect
- emergence of oriented circuits
  by synaptic pruning associated with STDP
- circuits are able to produce
  spatiotemporal patterns of activity
- role of firing rate

discussion: firing rates *vs.* connection degrees (cont.)



discussion: firing rates *vs.* connection degrees (cont.)