

Effect of Stimulus-Driven Pruning on the Detection of Spatio-Temporal Pattern of Activity in Large Neural Networks

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6th Neural Coding Workshop
Marburg, 2005-08-27

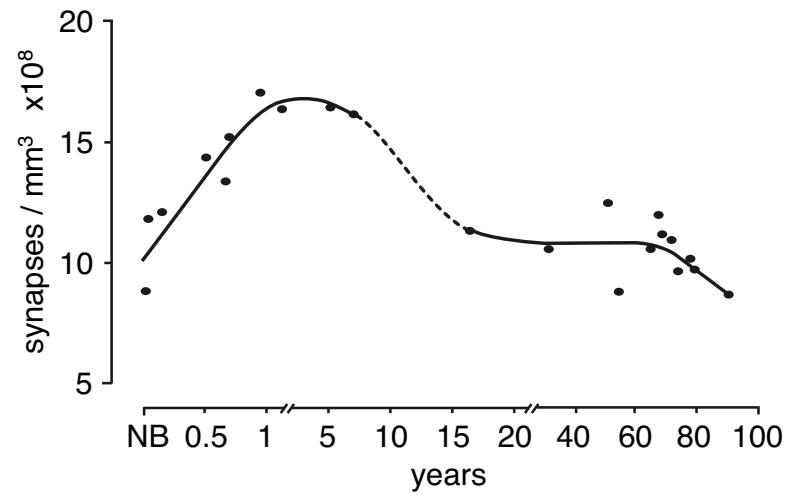
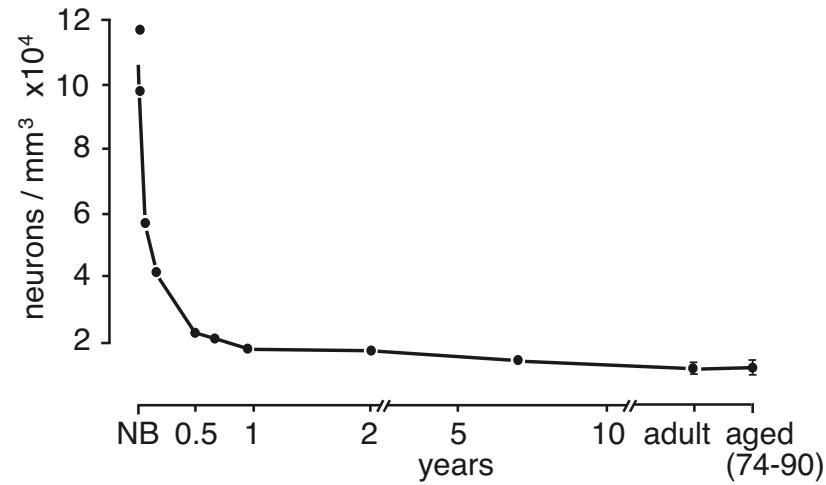
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introduction: synaptogenesis and synaptic pruning

1



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

- 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.

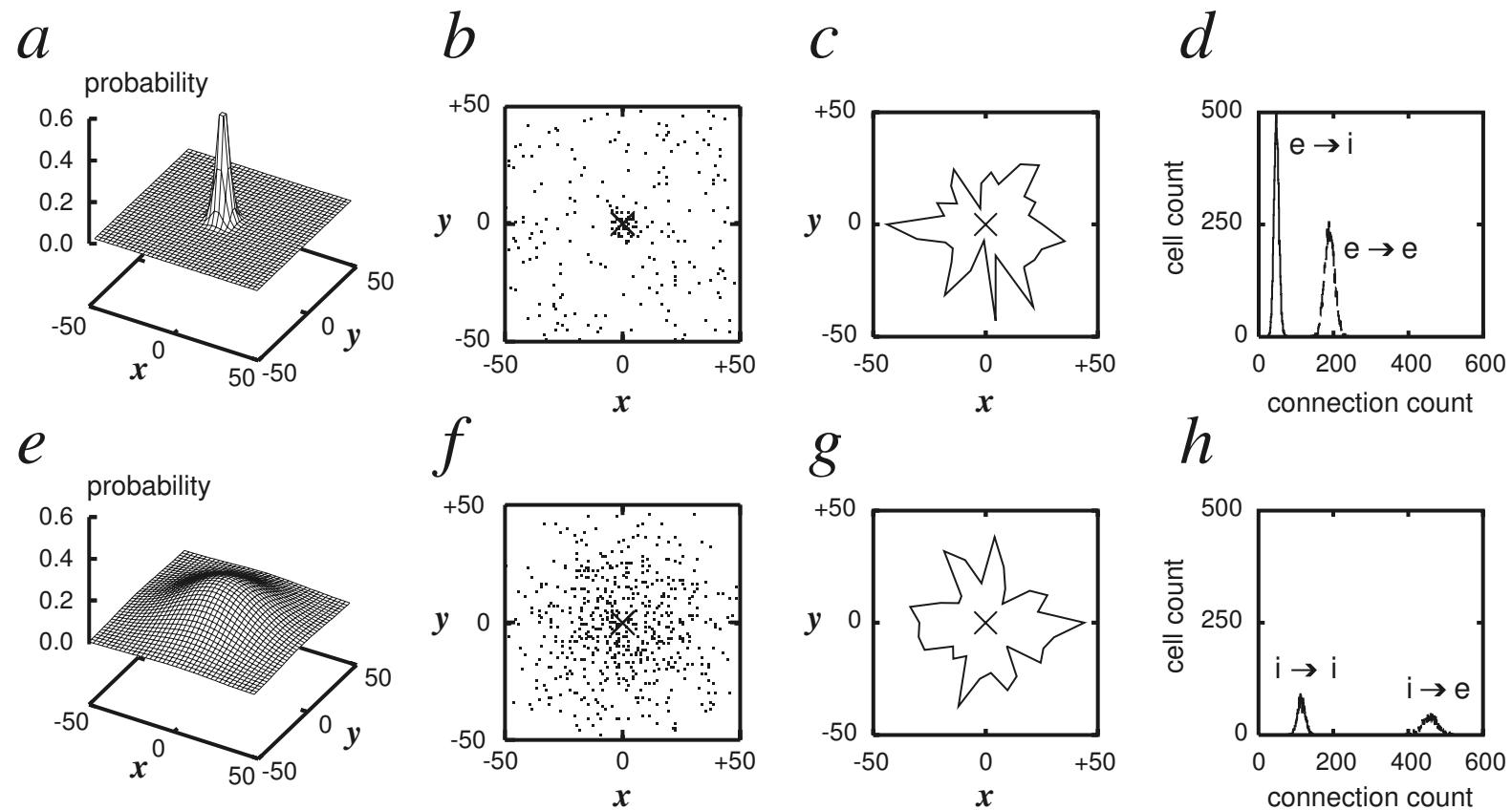
Chechik *et al.*, *Synaptic pruning in development: A computational account*, Neural Computation, 10(7):1759–77, 1998

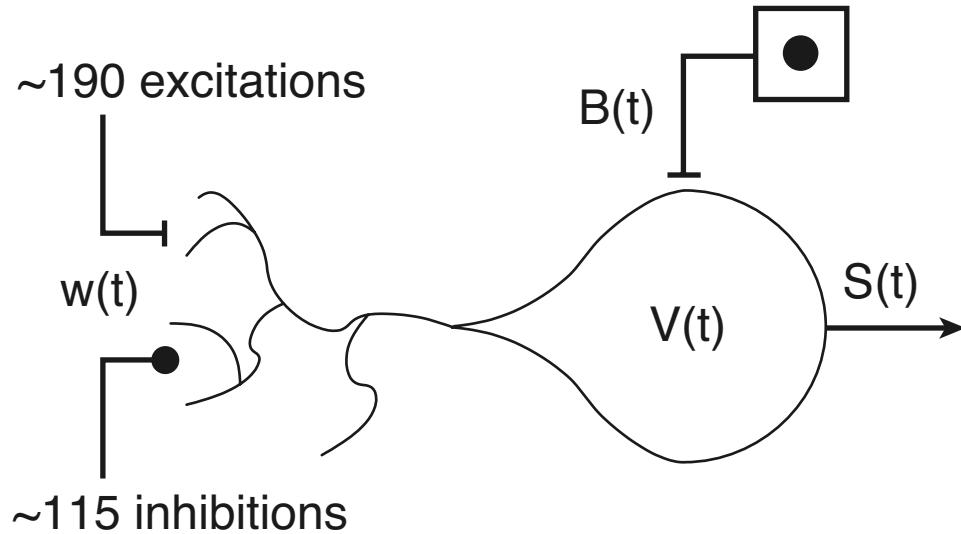
- Neuronal regulation might maintain the memory performance of networks undergoing synaptic degradation.

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





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	

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

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

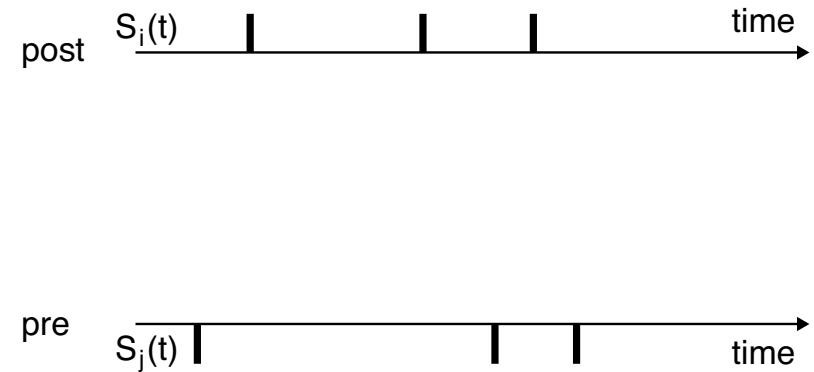
$$w_{ji}(t+1) = S_j(t) \cdot A_{ji}(t) \cdot P_{[q_j, q_i]}$$

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

model: STDP and pruning

5

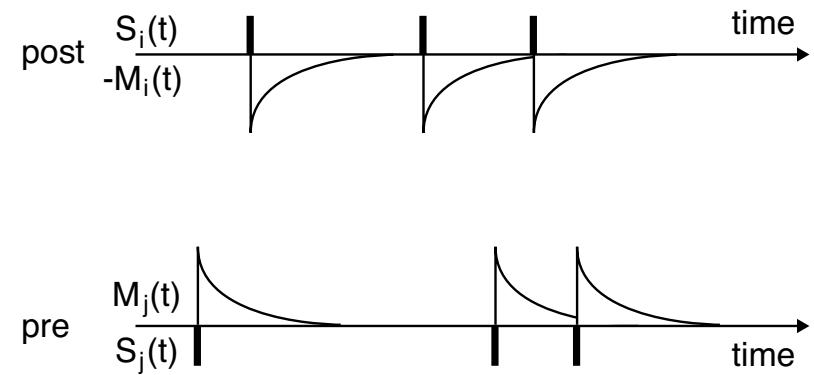
$$\begin{aligned} L_{ji}(t+1) = & \quad L_{ji}(t) \cdot k_{\text{act}}[q_j, q_i] \\ & + (S_i(t) \cdot M_j(t)) \\ & - (S_j(t) \cdot M_i(t)) \end{aligned}$$



model: STDP and pruning

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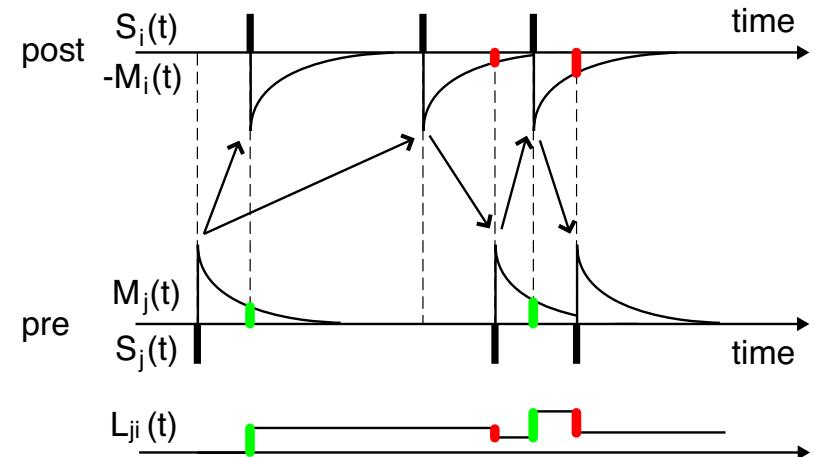
$$L_{ji}(t + 1) = L_{ji}(t) \cdot k_{\text{act}}[q_j, q_i] \\ + (S_i(t) \cdot M_j(t)) \\ - (S_j(t) \cdot M_i(t))$$



model: STDP and pruning

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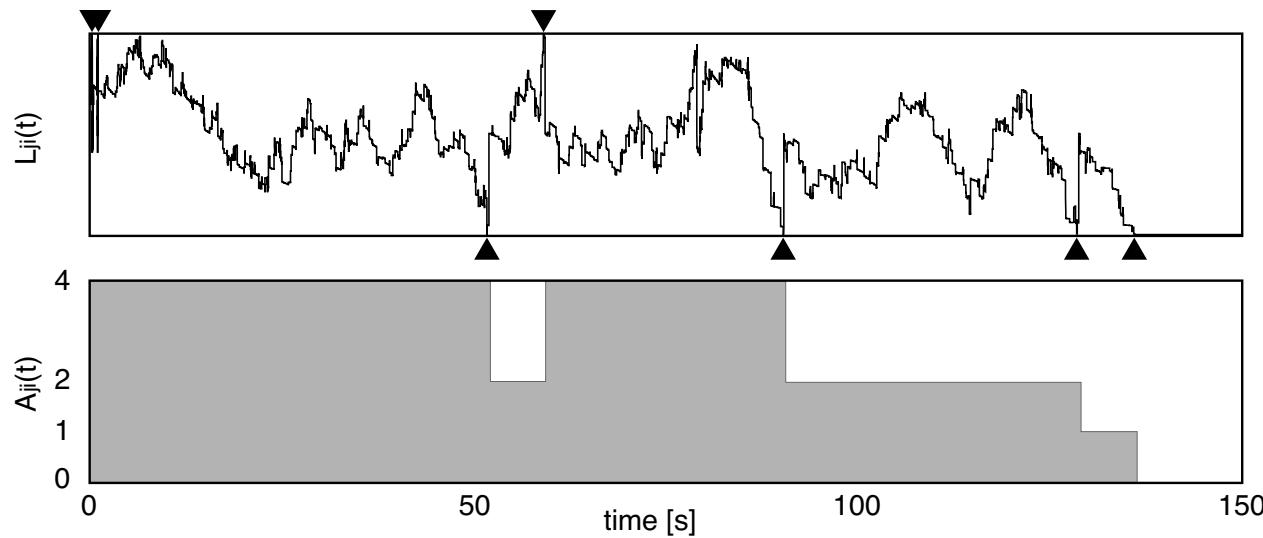
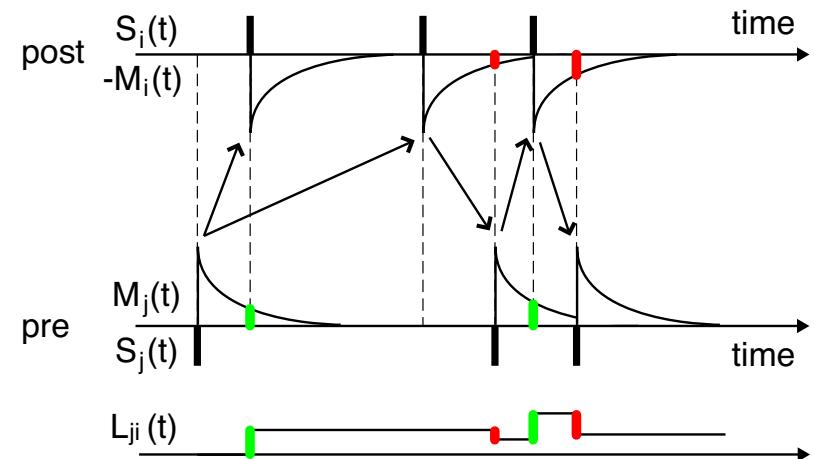
$$L_{ji}(t + 1) = L_{ji}(t) \cdot k_{act[q_j, q_i]} + (S_i(t) \cdot M_j(t)) - (S_j(t) \cdot M_i(t))$$



model: STDP and pruning

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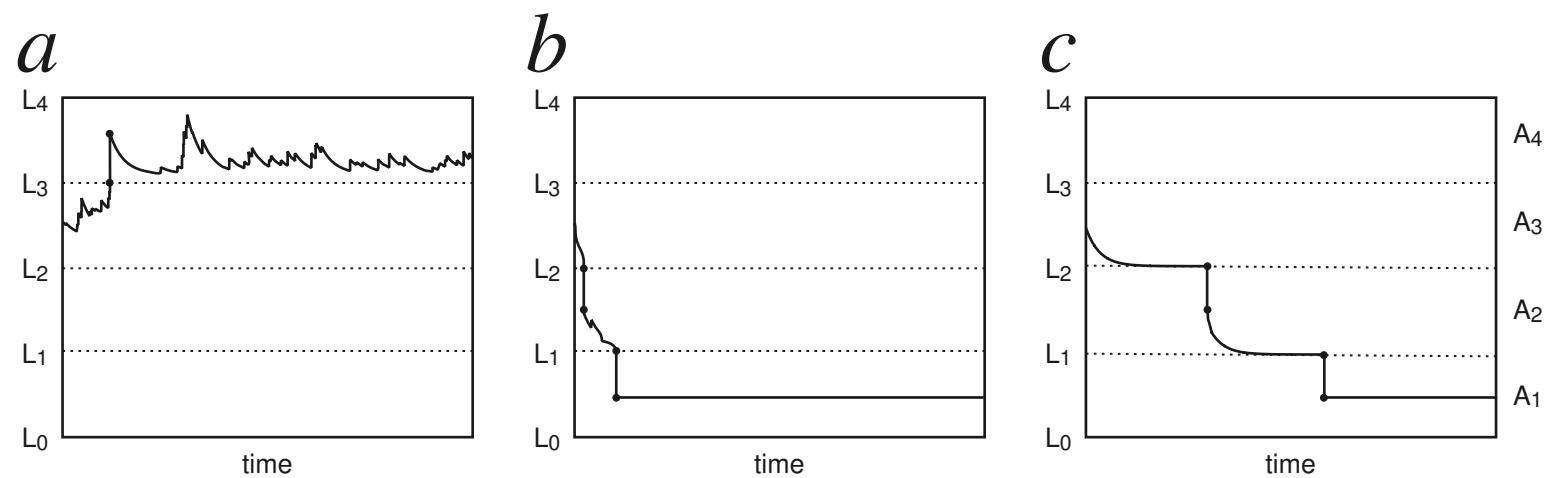
$$L_{ji}(t + 1) = L_{ji}(t) \cdot k_{act[q_j, q_i]} + (S_i(t) \cdot M_j(t)) - (S_j(t) \cdot M_i(t))$$



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

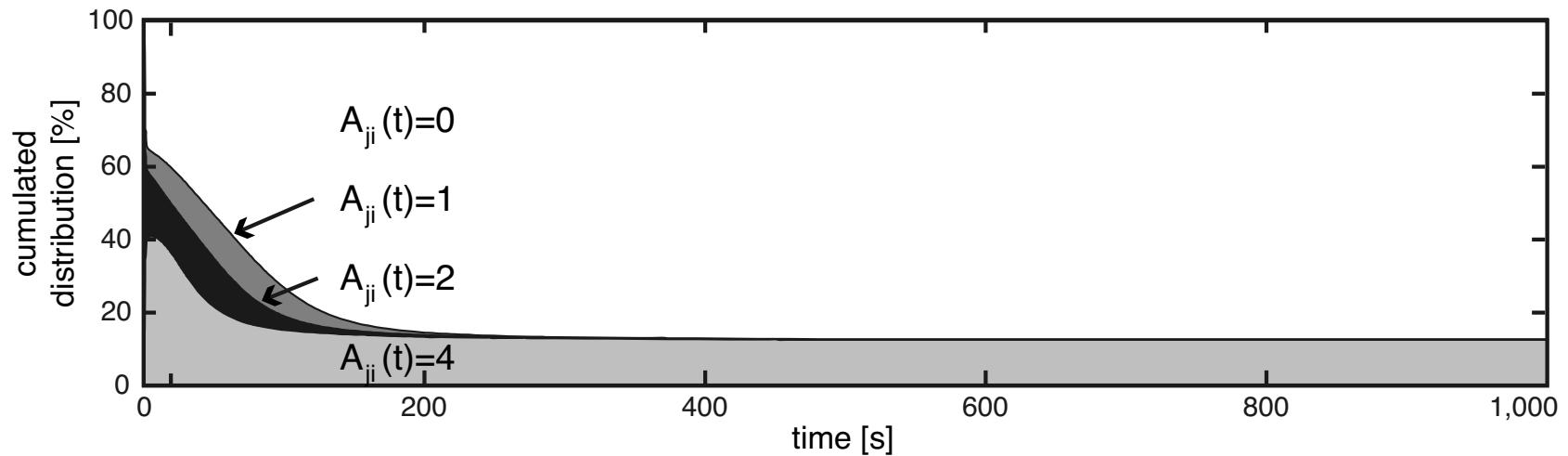
model: synaptic adaptation examples

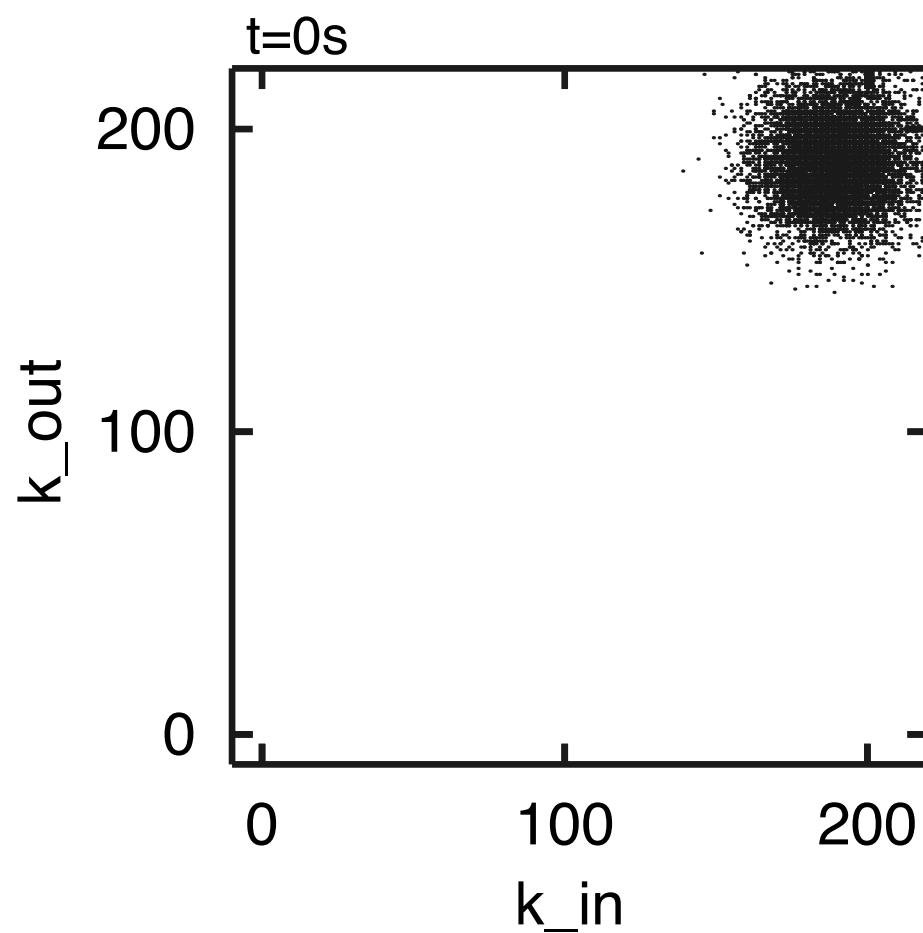
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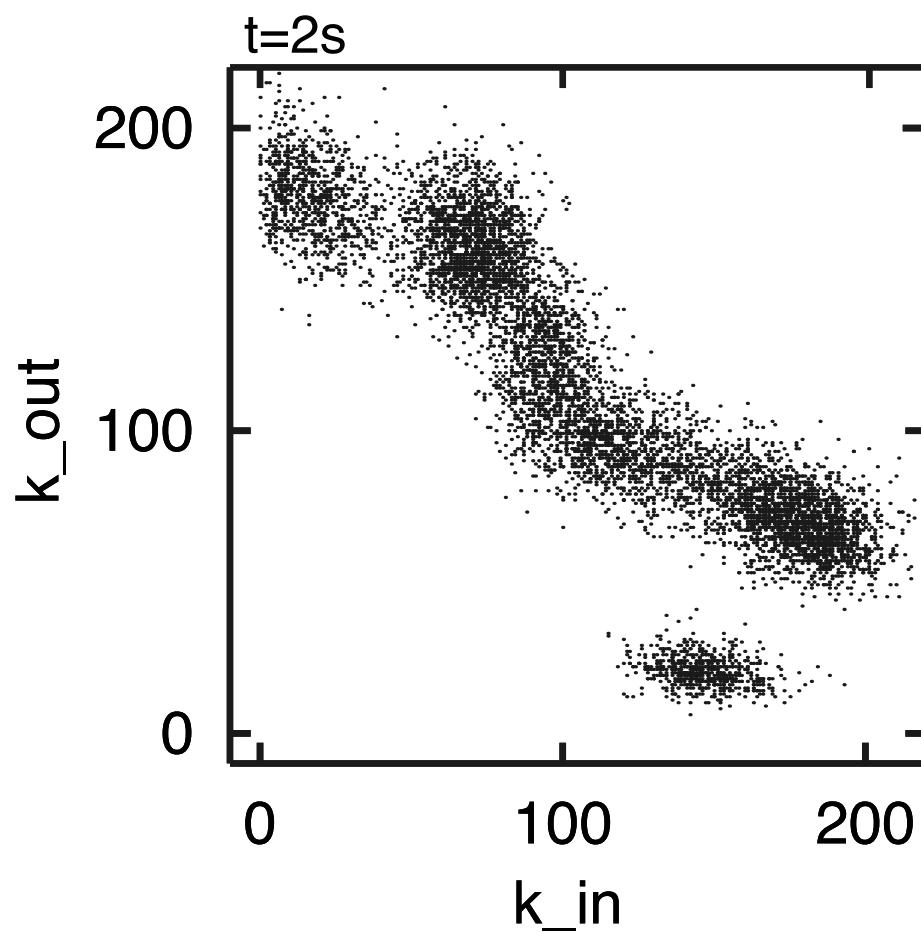


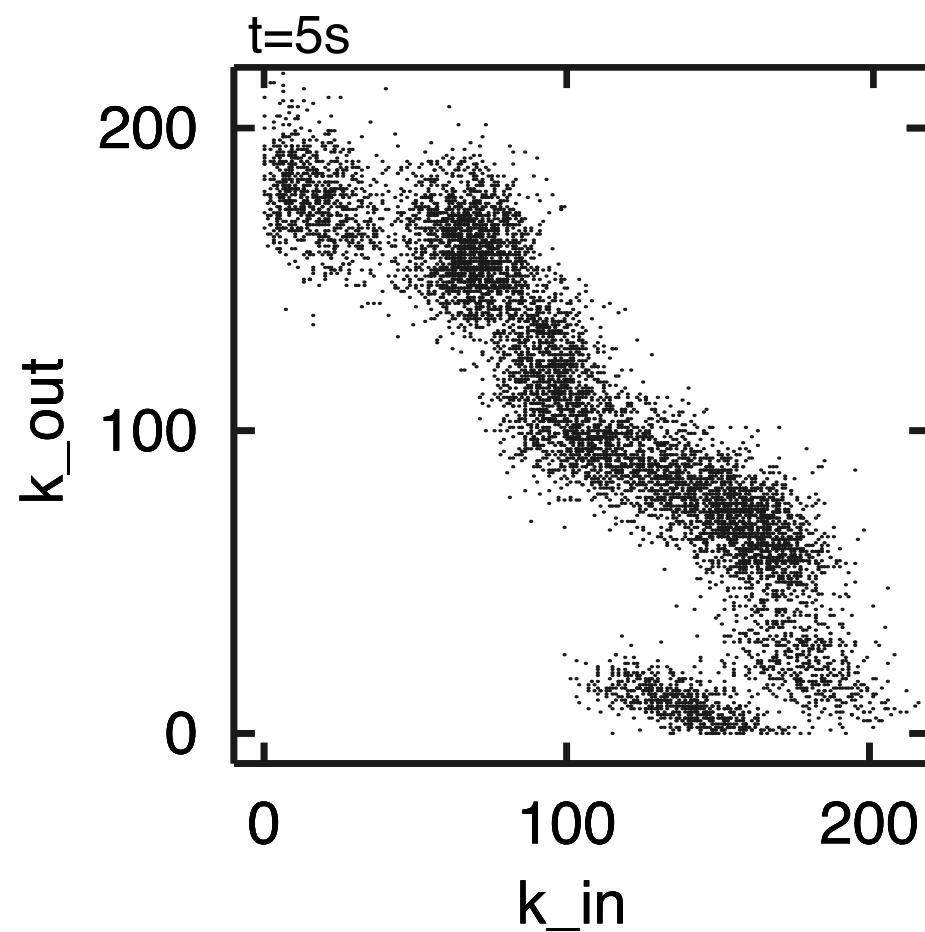
results: simulation evolution

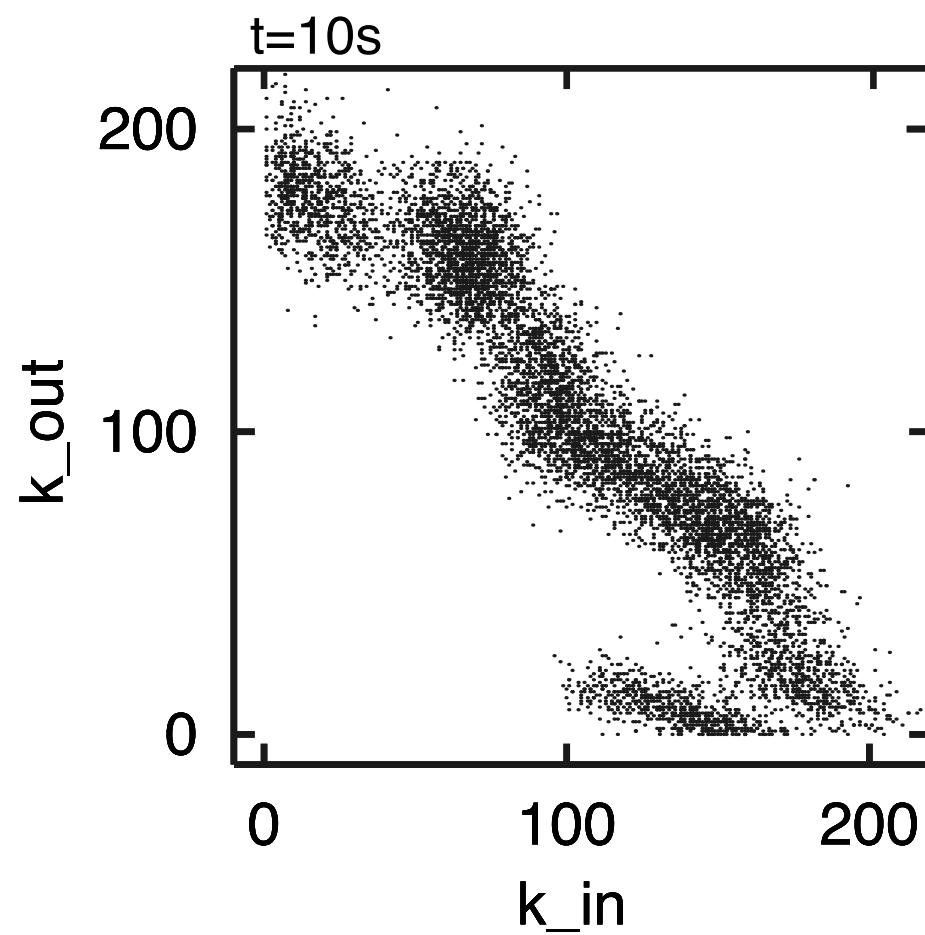
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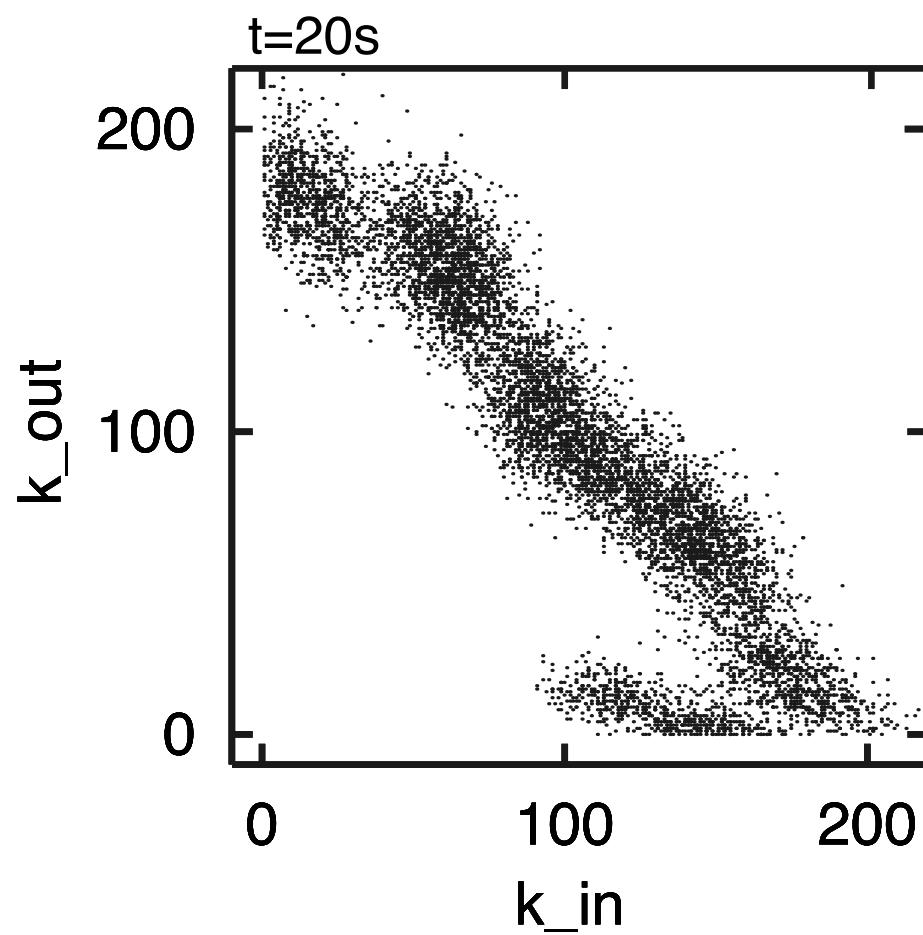


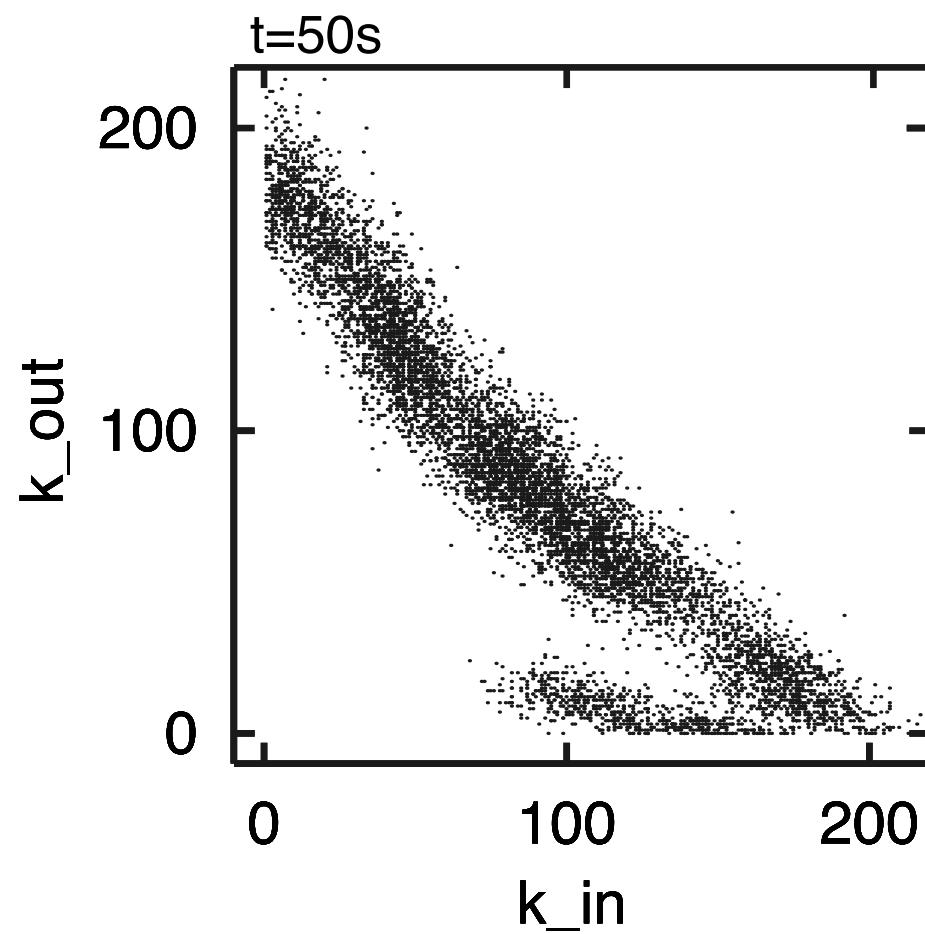


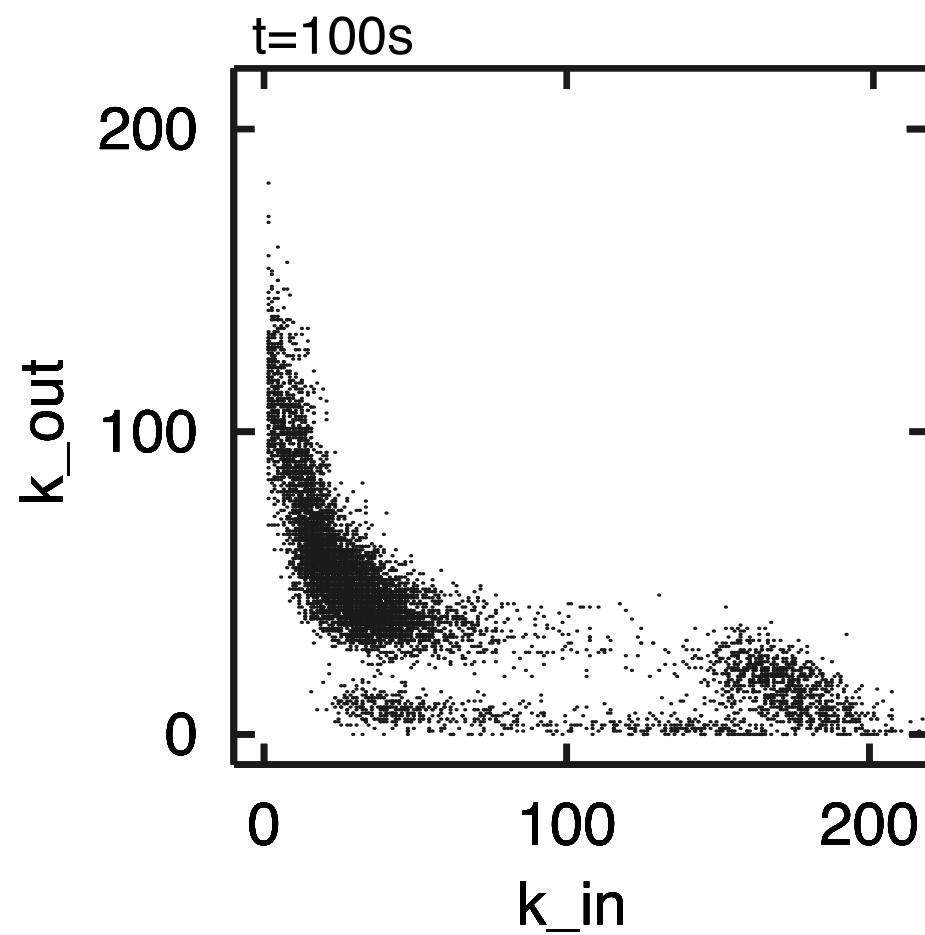


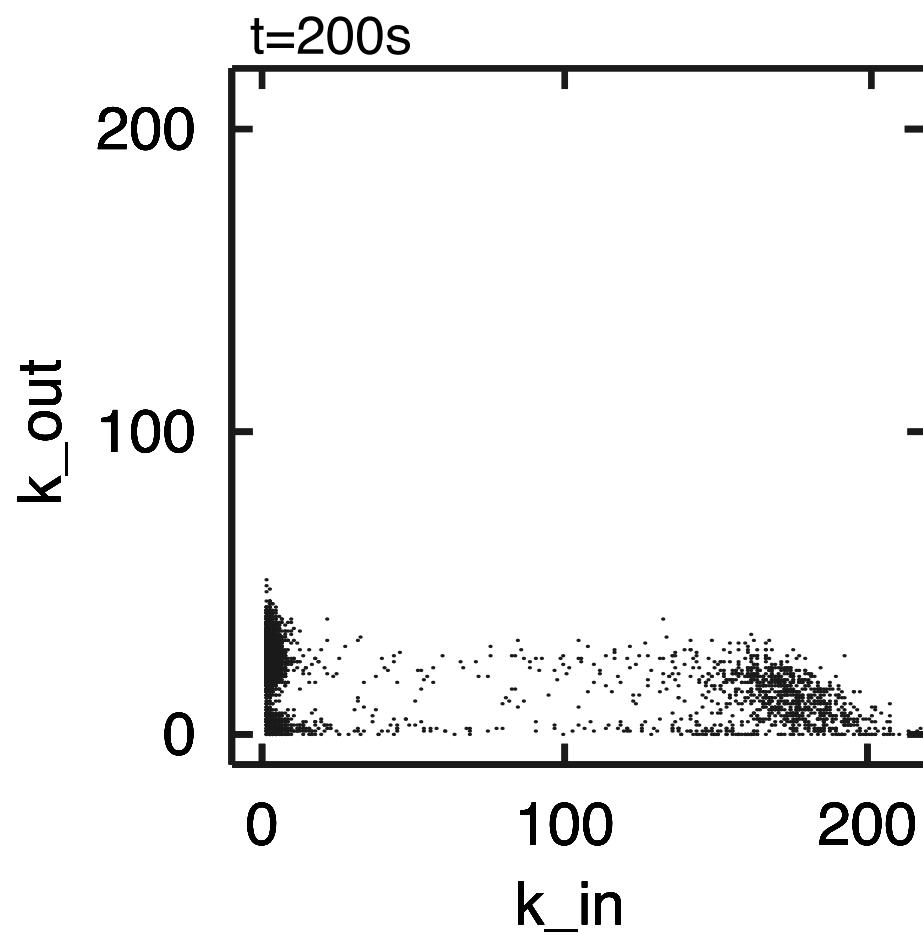


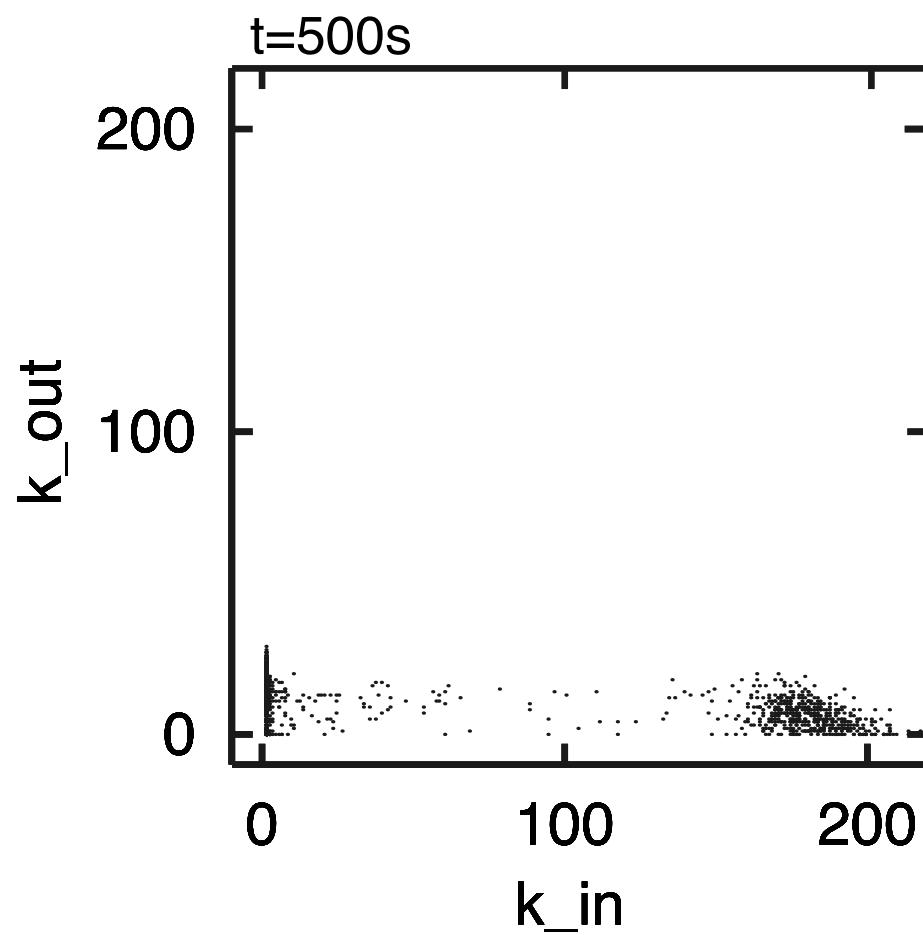


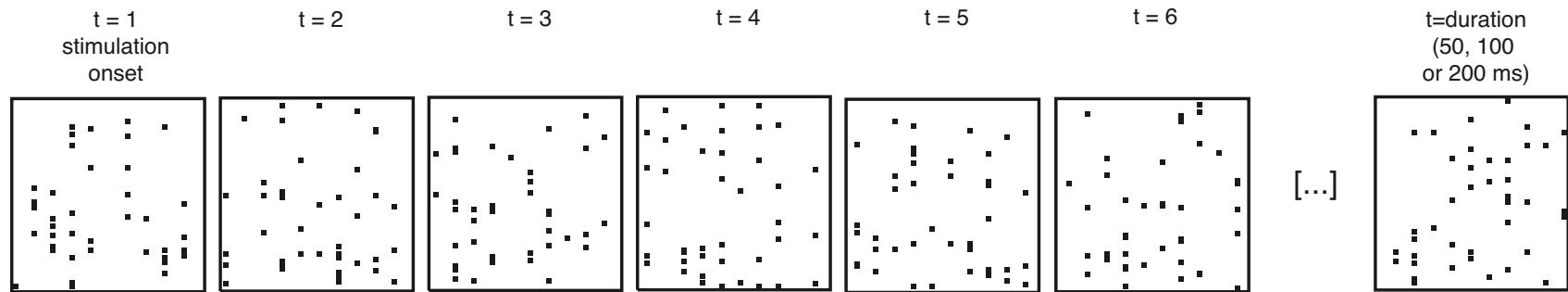












every 2 seconds
10 vertical bars moving to the right
during 200 time steps.

input units ratio: 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.

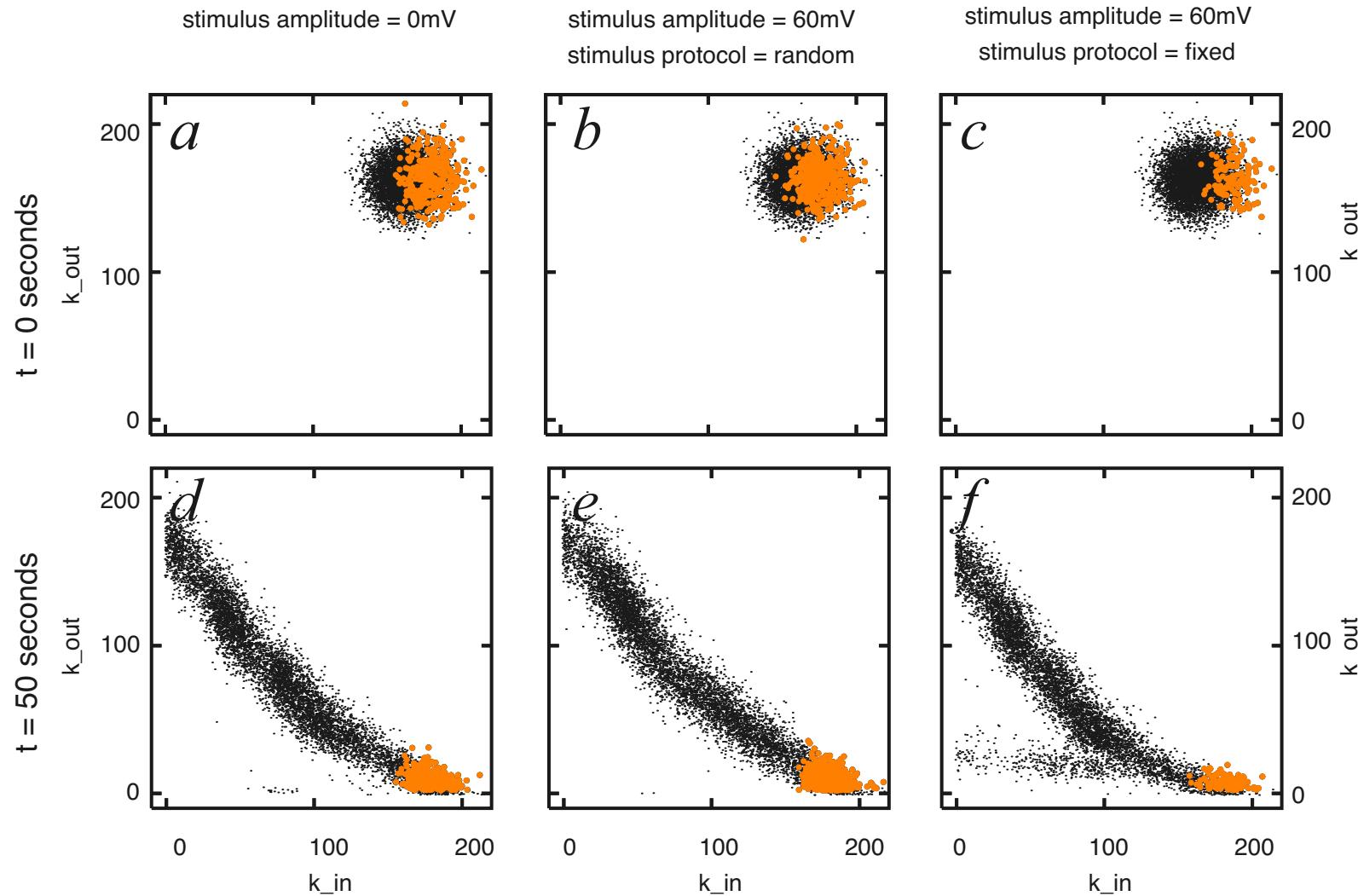
Neighbourhood

all excitatory units (including input units)

with at least one projection to or from SI-units.

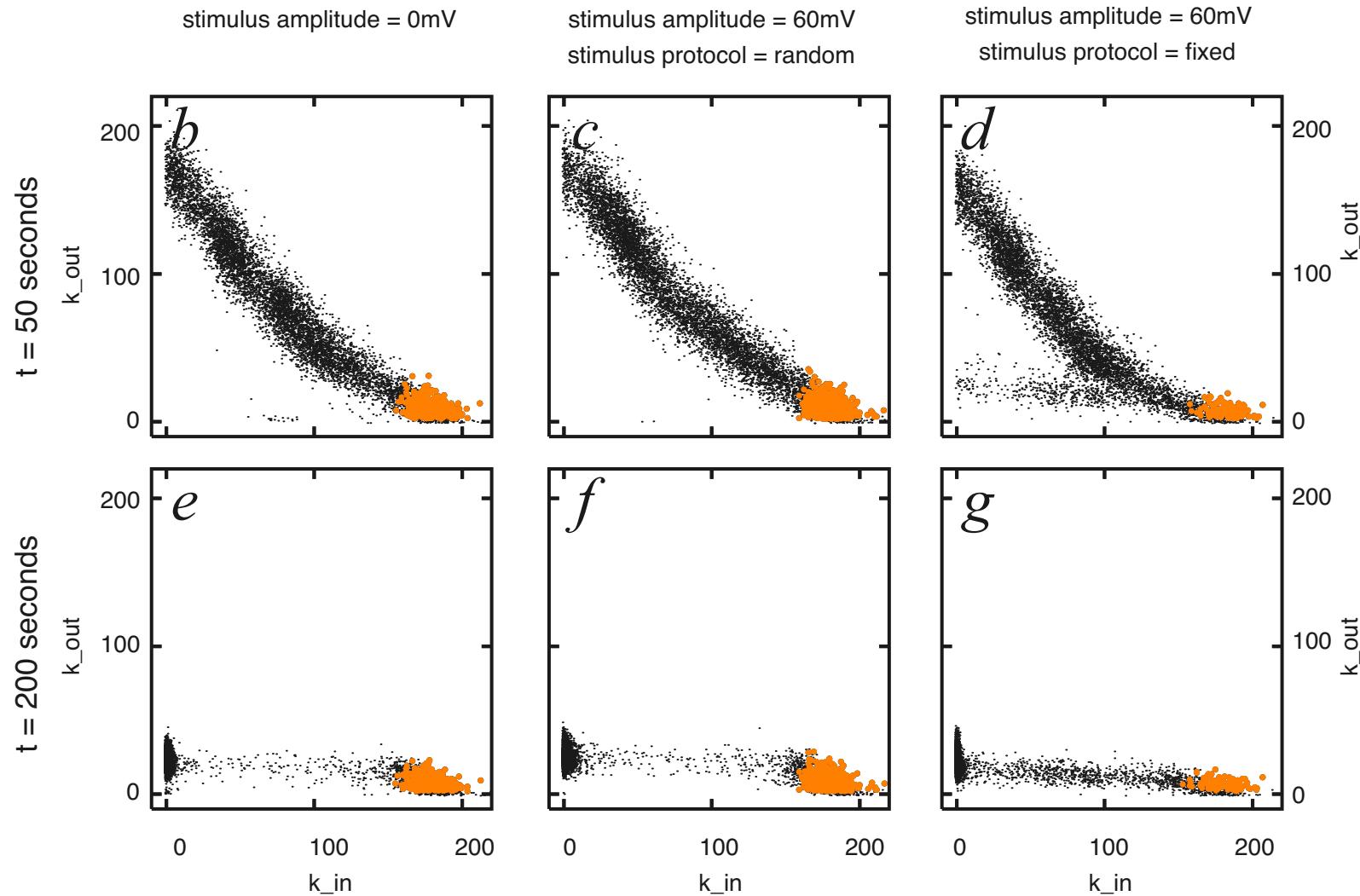
results: emergence of circuits from t=0 to t=50s

11



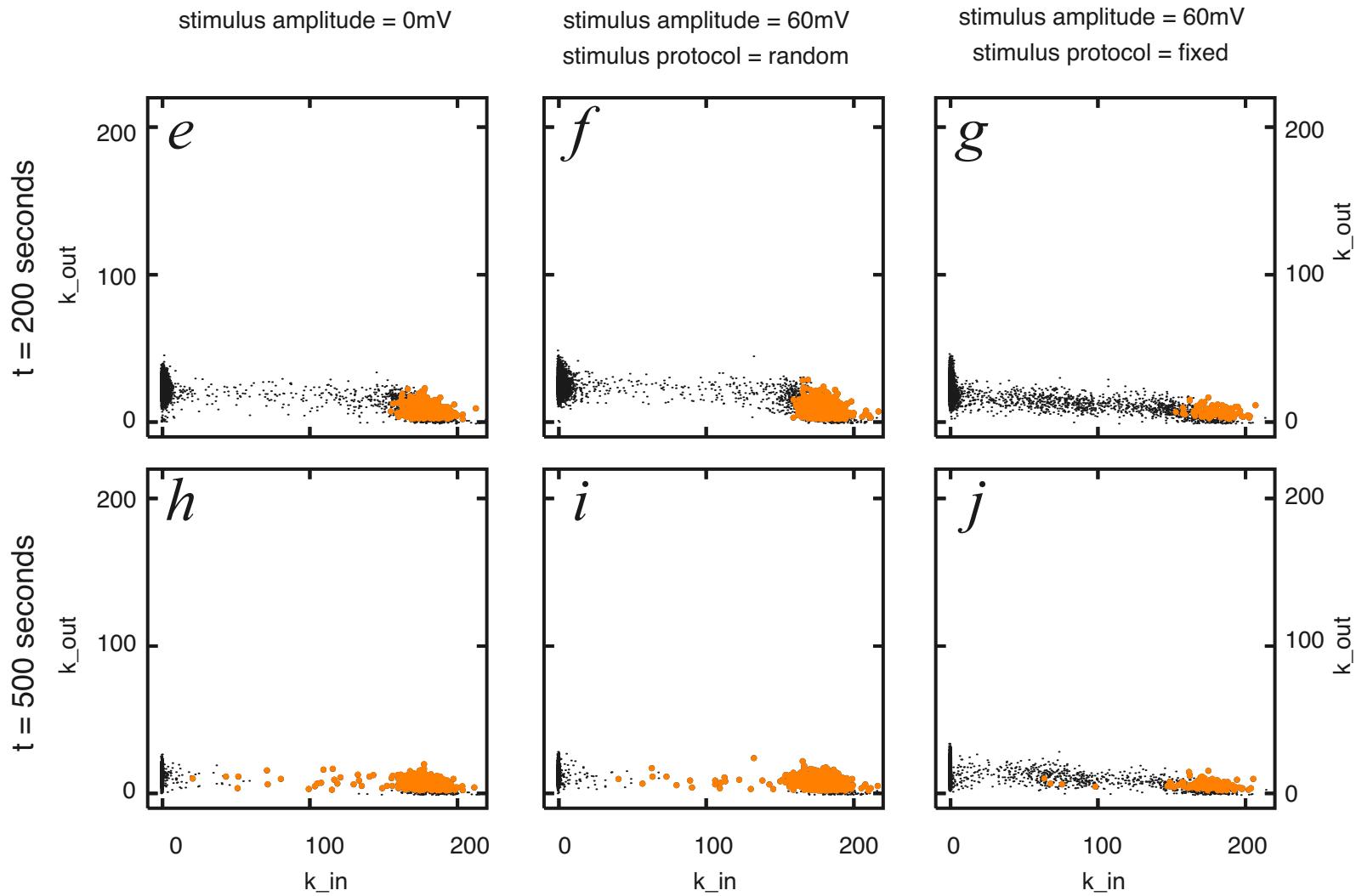
results: emergence of circuits from t=50 to t=200s

12



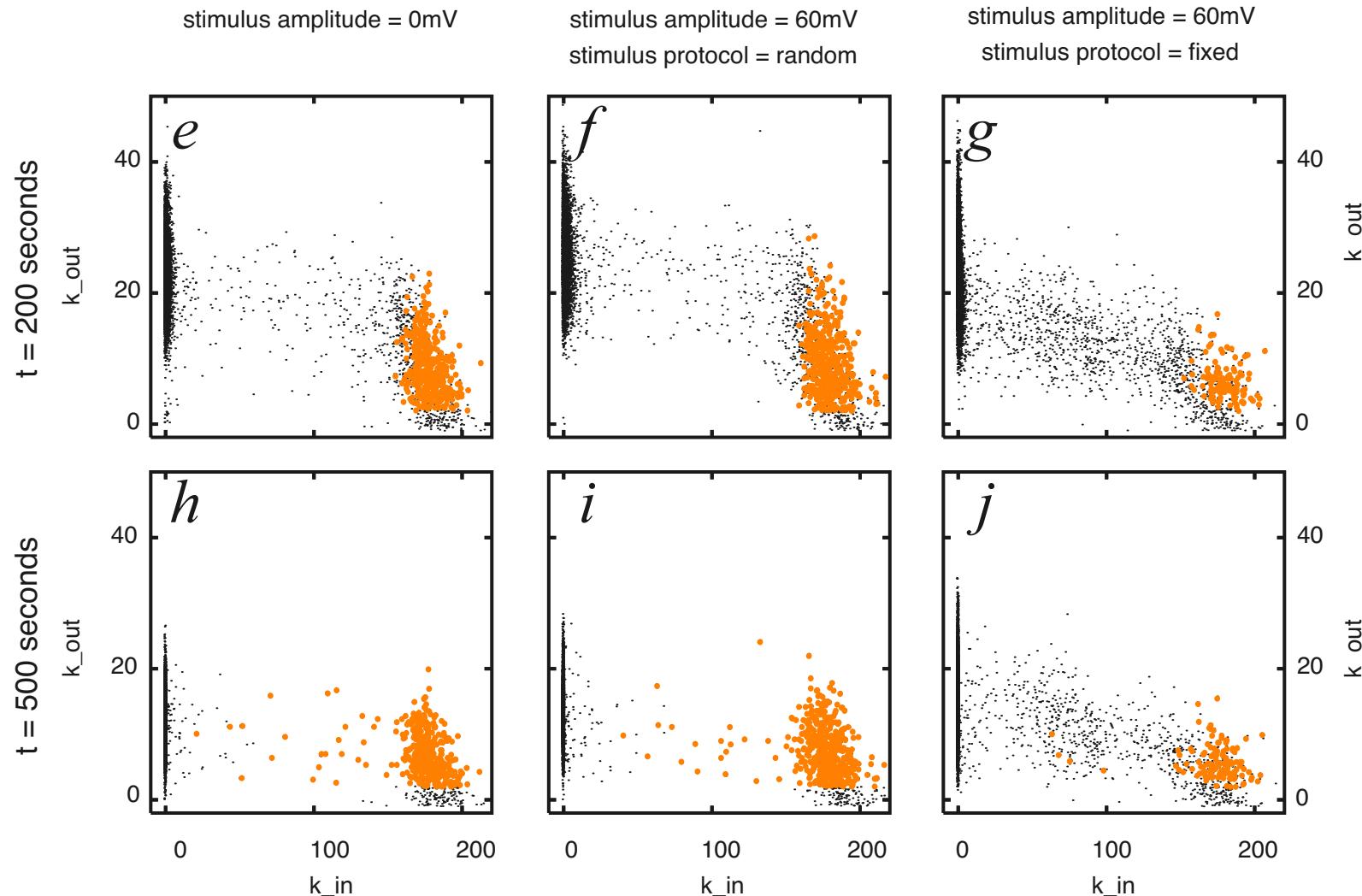
results: emergence of circuits from t=200 to t=500s

13

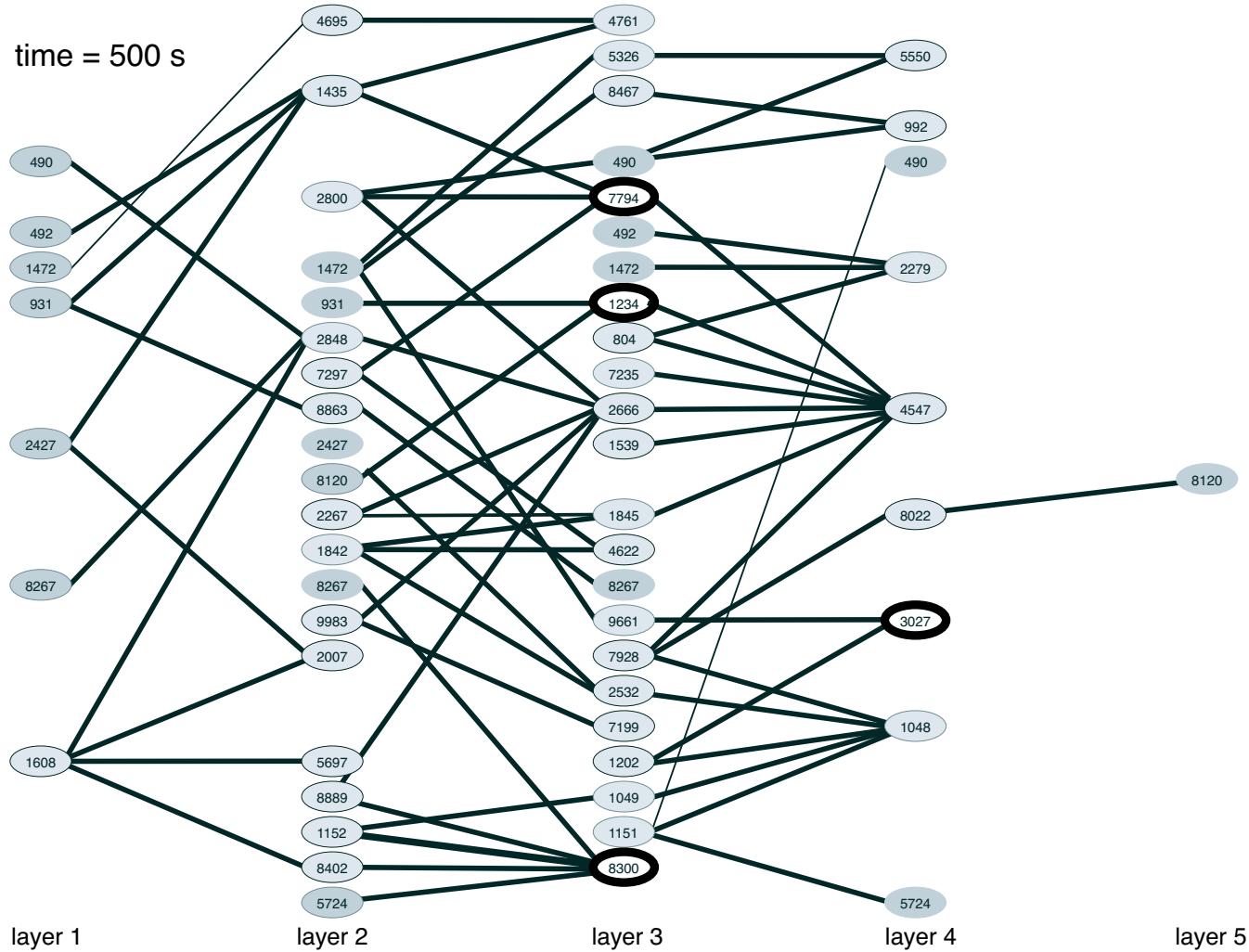


results: emergence of circuits from t=200 to t=500s (cont.)

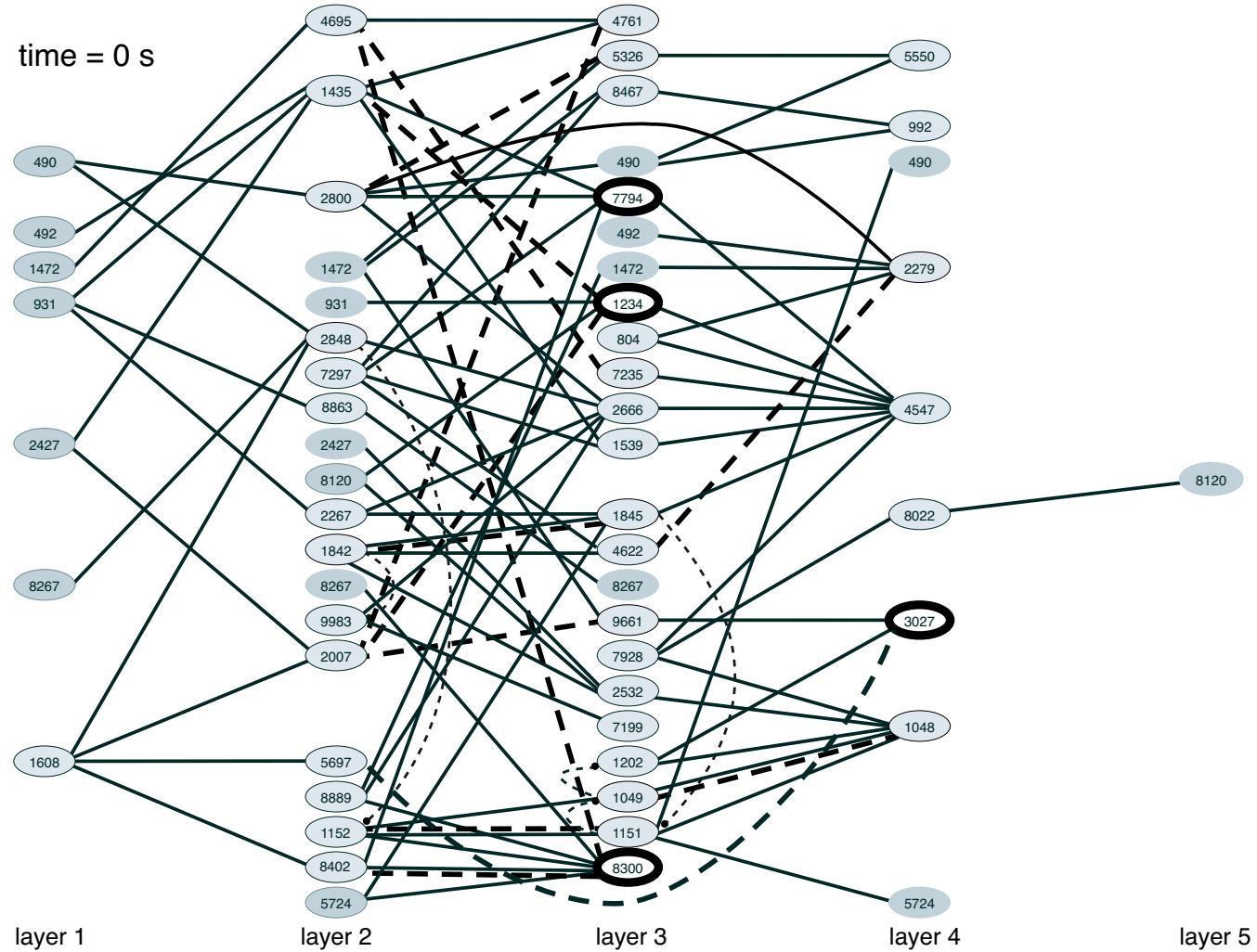
14

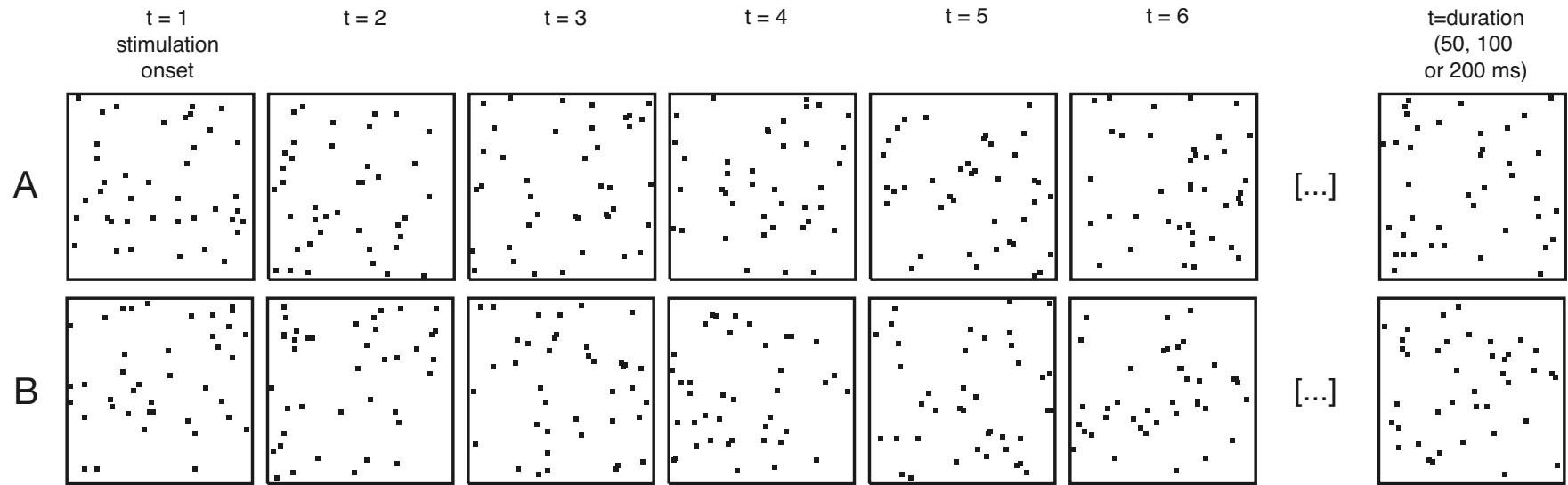


Iglesias et al., Emergence of Oriented Cell Assemblies
Associated with Spike-Timing-Dependent Plasticity, LNCS 3696:127-132, 2005



Iglesias et al., Emergence of Oriented Cell Assemblies
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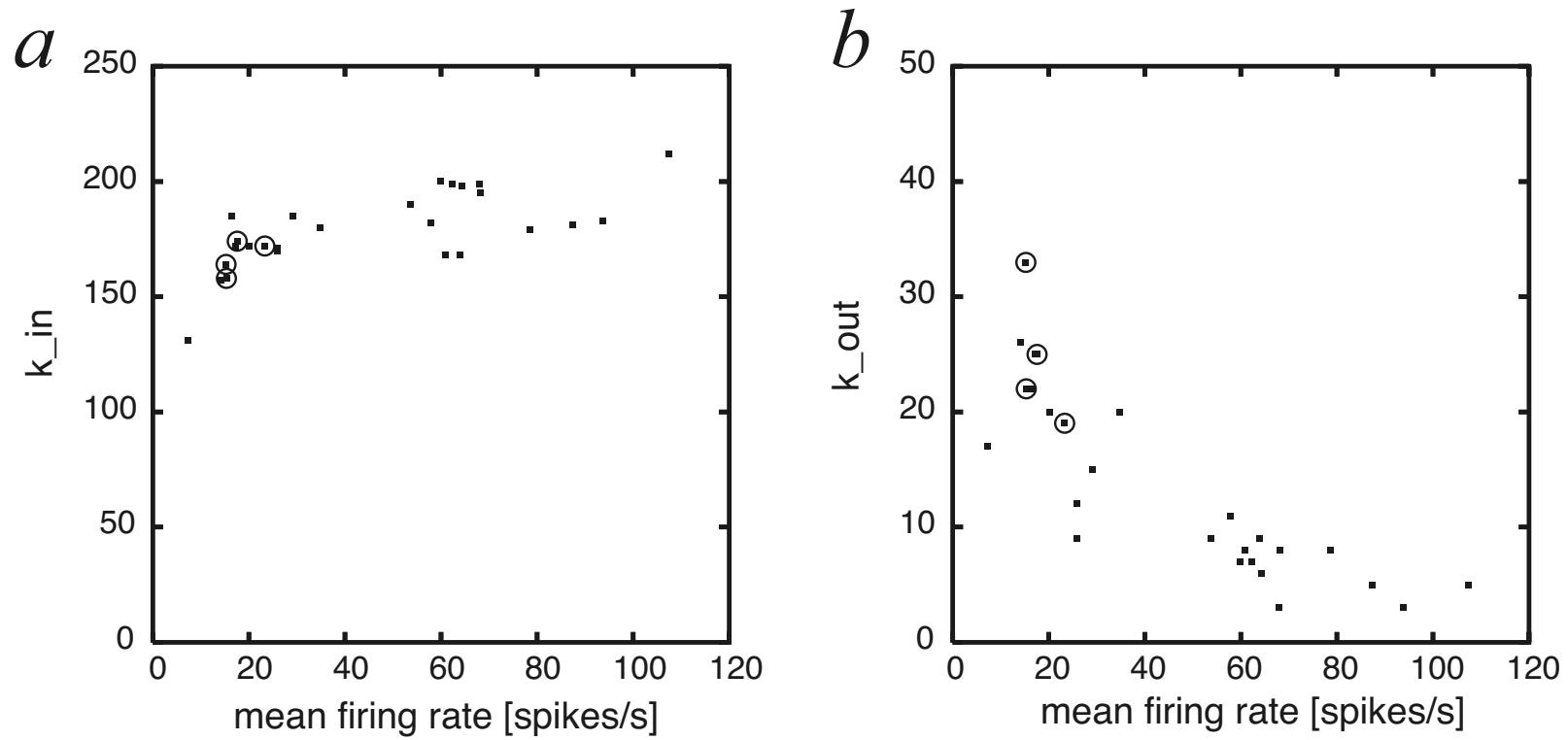
every 2 seconds

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

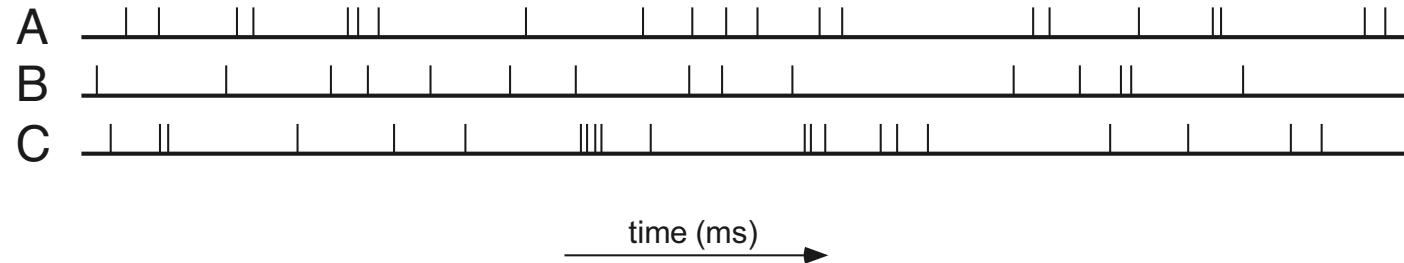
Animated sequences are available for both stimuli [A](#) and [B](#).

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, ...)



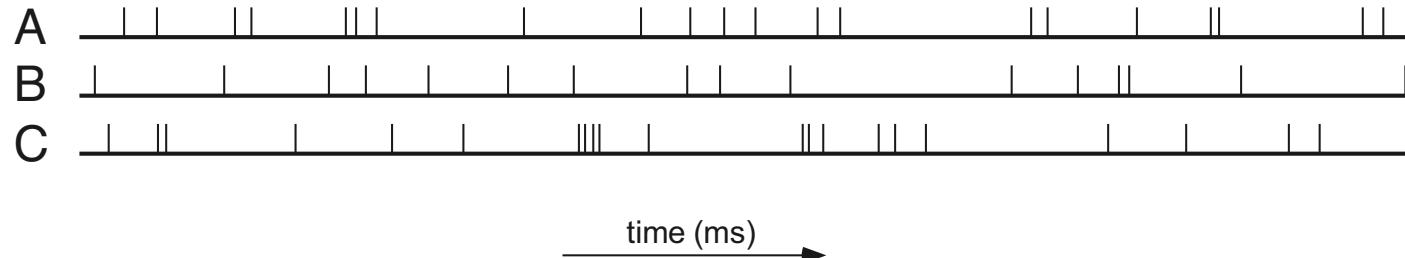
a

simultaneous recording of spike trains



a

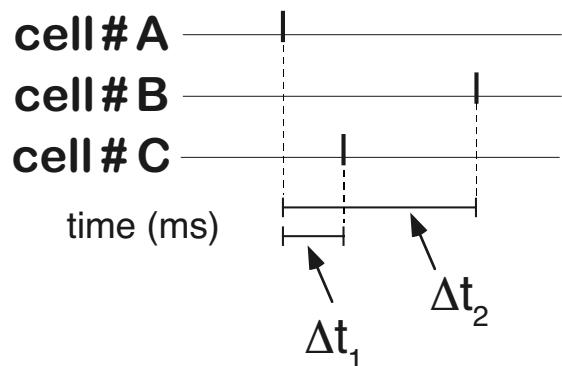
simultaneous recording of spike trains



b

detection of statistically significant spatiotemporal firing patterns

$\langle A, C, B; \Delta t_1, \Delta t_2 \rangle$



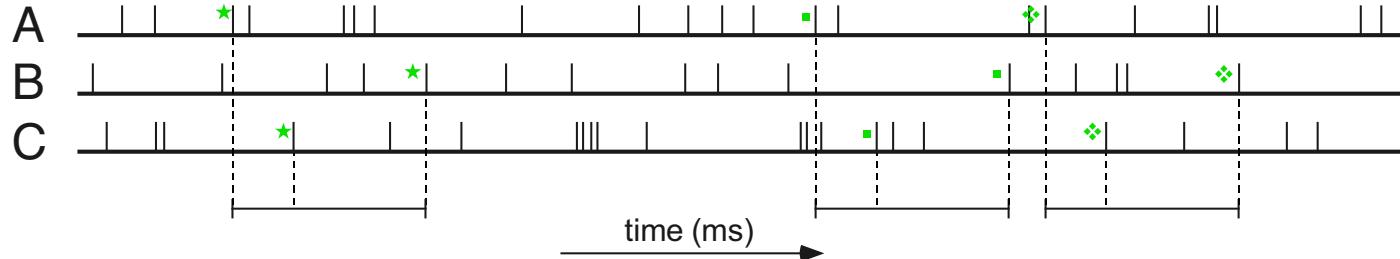
patterns found $n=3$

expected count $N=0.02$

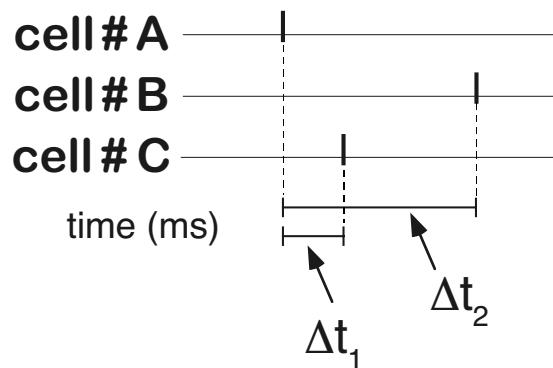
significance of this pattern
 $p(3, 0.02) \approx 1.3 \cdot 10^6 < 0.001$

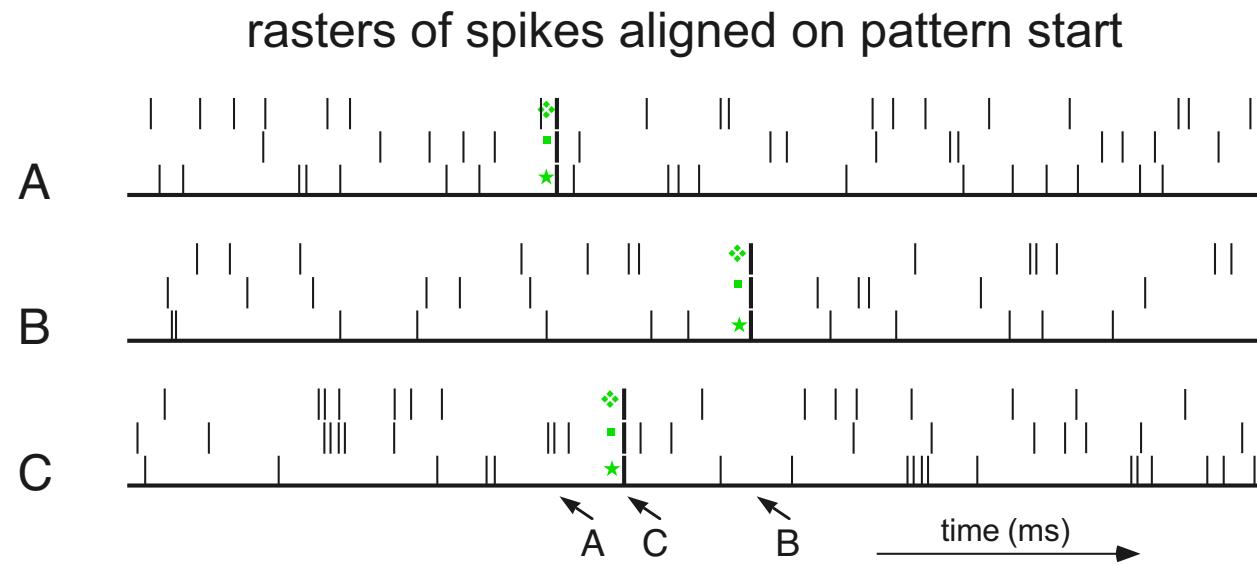
a

simultaneous recording of spike trains

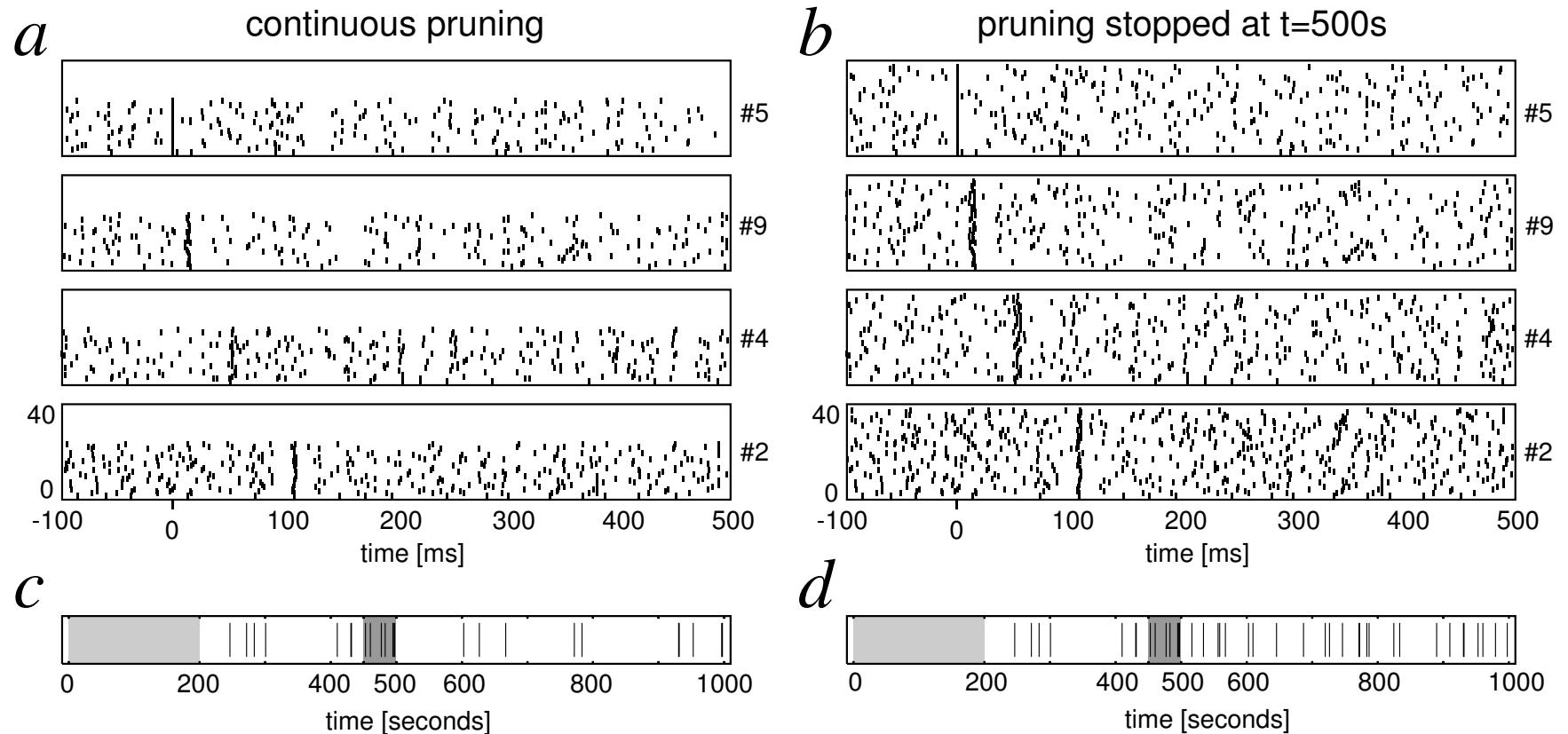
*b*

detection of statistically significant spatiotemporal firing patterns

 $\langle A, C, B; \Delta t_1, \Delta t_2 \rangle$ patterns found $n=3$ expected count $N=0.02$ significance of this pattern
 $p(3, 0.02) \approx 1.3 \cdot 10^6 < 0.001$ for methods, see Villa *et al.*, 1999; Tetko and Villa, 2001



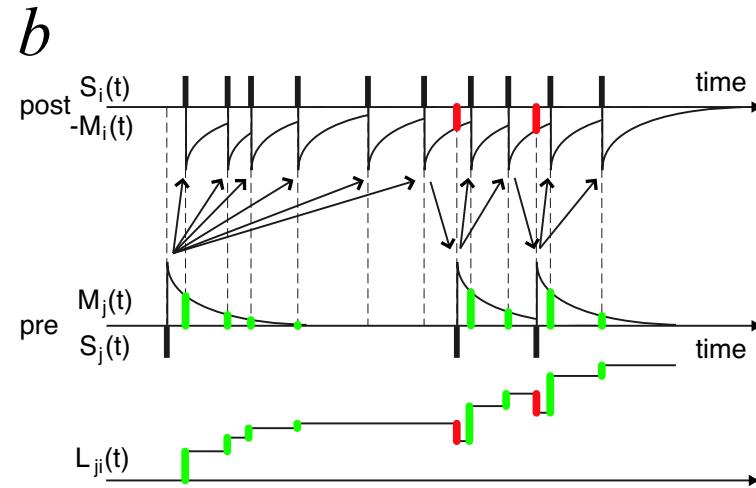
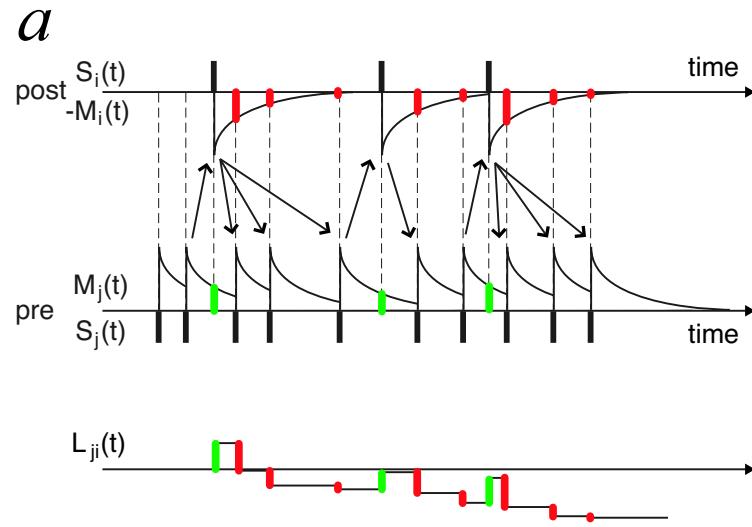
$\langle 5, 9, 4, 2; 13, 53, 109 \rangle$



- emergence of oriented circuits by synaptic pruning associated with STDP
- circuits are able to produce spatiotemporal patterns of activity
- role of pre– vs. postsynaptic firing rate difference on STDP synaptic modification rule

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

22



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

22

