Spike-timing dependent plasticity in balanced random networks

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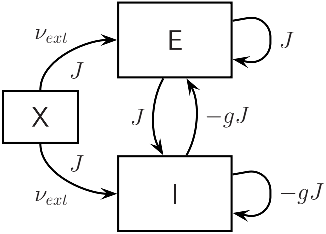
- Abigail Morrison
- Ad Aertsen
- Guo-qiang Bi   (for providing original data)
- NEST Initiative

A. Morrison, A. Aertsen, & M. Diesmann (2005)
Spike-timing dependent plasticity in balanced random networks
Neural Computation, *under review*

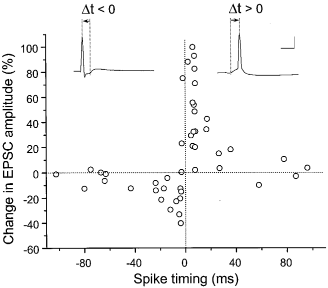
Consistency of cortical network model

model



(Brunel, 2000)

data



(Bi & Poo, 1998)

Is the network model compatible with the data?

Outline

Choice of STDP model

Plastic Networks

Development of structure

Robustness

Synchronous stimulation

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Outline

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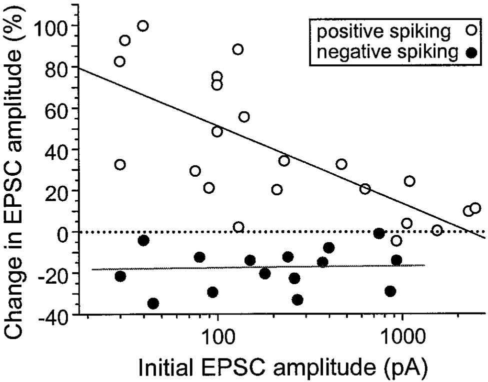
Choice of STDP model

- Additive, multiplicative, ... ?
- All to all, nearest neighbor, ... ?

Can the existent experimental data help to reduce the plethora of possible models?

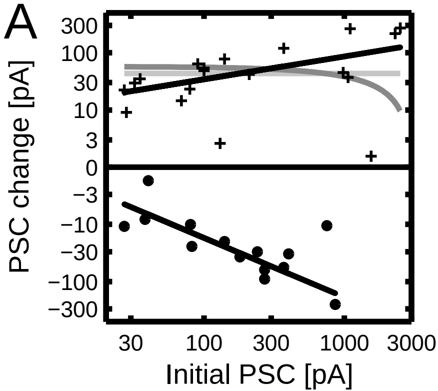
Back to the original data



(Bi & Poo, 1998)

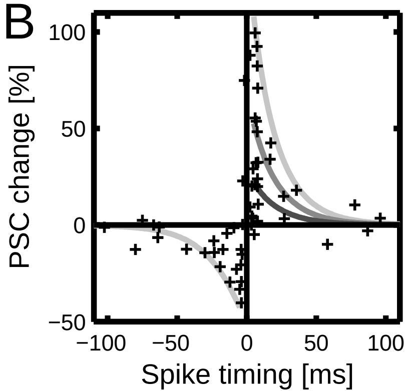
What, if anything, does this tell us about the weight dependency of the STDP update?

Weight dependency of STDP



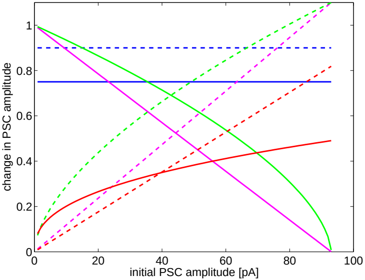
- pale gray additive
- dark gray multiplicative
- power law with $\mu = 0.4$
- depression multiplicative

Weight dependency of STDP



- darker for higher initial w
- variability may result from different initial w
- depression multiplicative $\rightarrow$ no dependence on w

Weight dependency of STDP



additive (Song, Miller, & Abbott)

multiplicative (Rubin, Lee, & Sompolinsky)

in between (Gütig, Aharonov et al.)

$$
\begin{aligned}
\Delta w_- (w, t) &= -\lambda \alpha w^\mu K(t, \theta_{\text{post}}) \\
\Delta w_+ (w, t) &= \lambda (1 - w)^\mu K(t, \theta_{\text{pre}}) \\
K(T, \theta_x) &= \sum_{t_x \in \theta_x : t_x < T} e^{-(T - t_x)/\tau}
\end{aligned}
$$

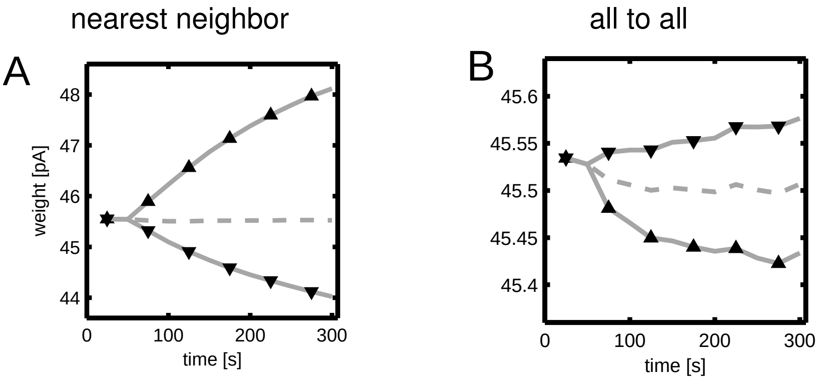
power law

$$
\begin{aligned}
\Delta w_- (w, t) &= -\lambda \alpha w K(t, \theta_{\text{post}}) \\
\Delta w_+ (w, t) &= \lambda w^\mu K(t, \theta_{\text{pre}})
\end{aligned}
$$

solid: potentiation

dashed: depression

Spike pairing scheme



- self-consistent rate necessary for stability
- nearest neighbor scheme amplifies rate disparity
- all to all spike scheme counteracts rate disparity

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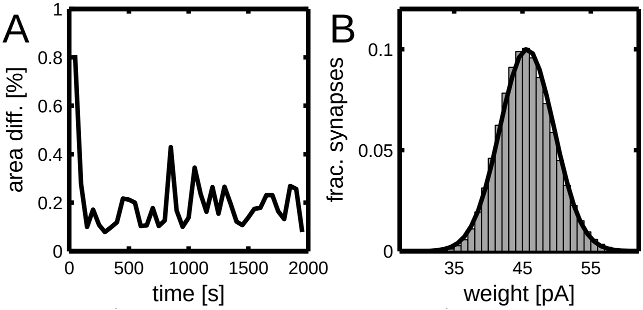
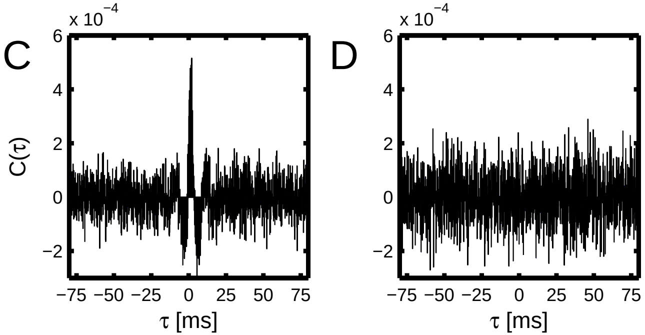
Weight distribution in a fully plastic network



Given a desired w^* of a static BRN, α_{p} can be calculated.

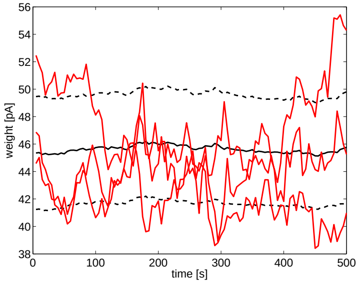
- $\alpha = 1.057\alpha_{\mathrm{p}}$ to compensates for correlation
- weight distribution settles to Gaussian within 200 s

Activity in a fully plastic network



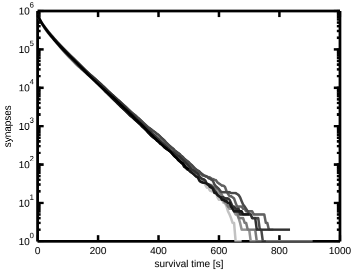
- AI dynamics
- rate slightly higher (8.8 Hz) than in static network (7.7 Hz)
- similar Fano factor and coefficient of variation

Individual weight trajectories



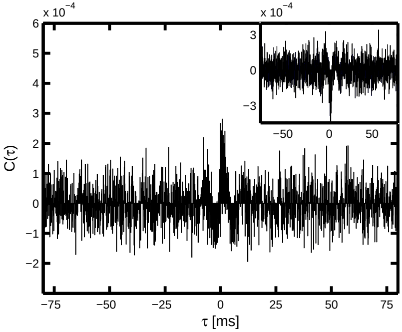
- weight distribution settles fairly quickly ...
- ... but individual weight trajectories remain dynamic
- neither spontaneous development of structure nor withering

Survival time of strong synapses



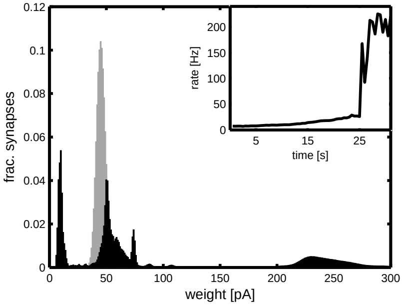
- exponential decay with $\tau \approx 55$s of top 10%
- time shift invariant statistics, steps of 200s shown
- no development of structure

Sensitivity to scaling of depression



- at higher α (stronger depression), here 2%, a new stable state emerges at a lower rate
- but, if α chosen 2% too low, the network explodes
- new regime displays strongly patterned activity interspersed with silence

Sensitivity to scaling of depression



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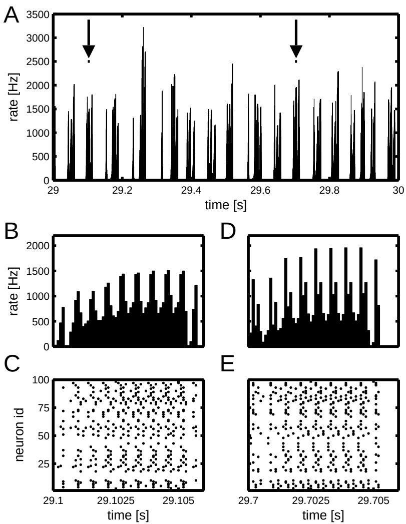

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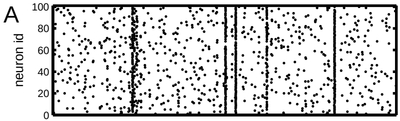
Synchronous stimulation



- current injected into 500 neurons irregularly at 3 Hz
- injection times for each neuron drawn from Gaussian ($\sigma = 0.5$ ms)
- moderate effect on high-connectivity group ($K_{\text{synch}} \geq 69$)
- weak effect on rest of network

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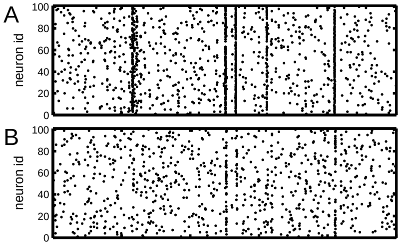

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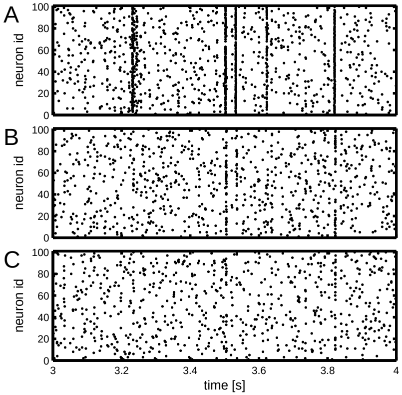

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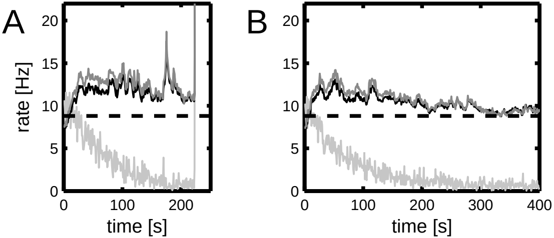
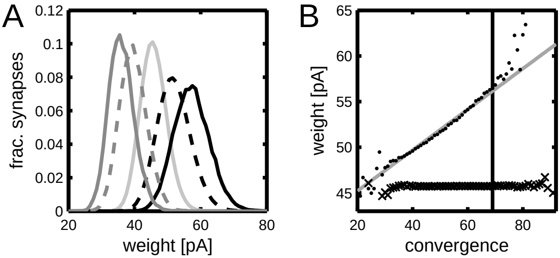
Development of activity during stimulation



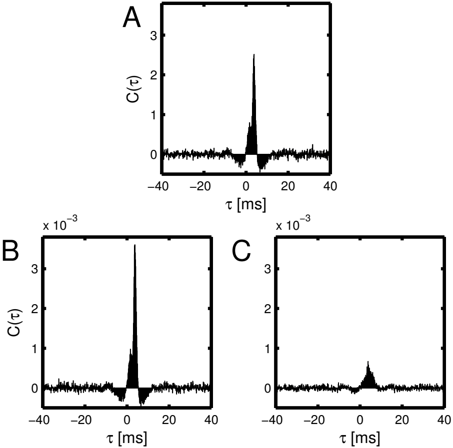
- intra-group connections amplify stimulus
  $\rightarrow$ explosion
- removing intra-group connections permits stable network activity for $N_{\text{synch}} = 500$
- rate of stimulated group plummets

Development of weights



- incoming synapses to stimulated group decrease $\rightarrow$ rate drop
- outgoing synapses increase as K_{synch} increases
- effect does not transfer to high connectivity group

Development of correlation



- expect increase in correlation due to weight increase (A→B)
- decrease in correlation observed (A→C)
- reduction of input to stimulated group lowers responsiveness to stimulus
- development of structure counteracted

Summary

- power law description fits STDP data
- predicts small changes for small weights
- compatible with balanced random networks
- equilibrium weight distribution is unimodal
- weights fluctuate on time scale of minutes
- no spontaneous development of structure
- stimulation creates structure, but (oversimplified?) network counteracts