

A forecast-based biologically-plausible STDP learning rule

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and Steve Furber

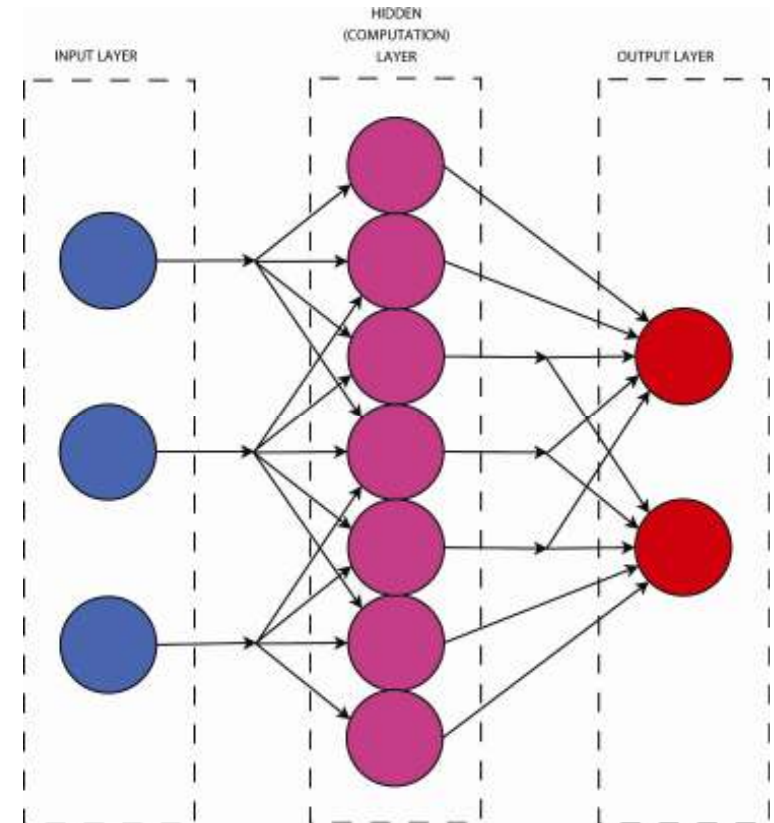
APT group
The University of Manchester

Overview of topics

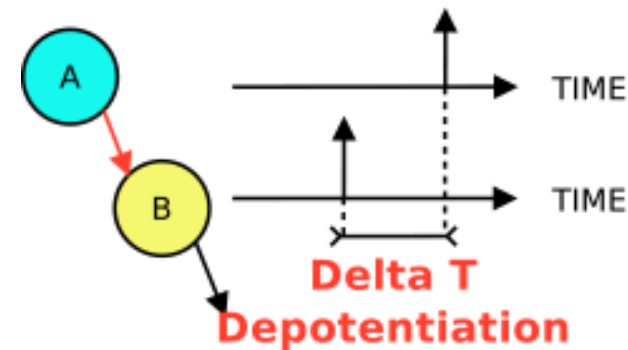
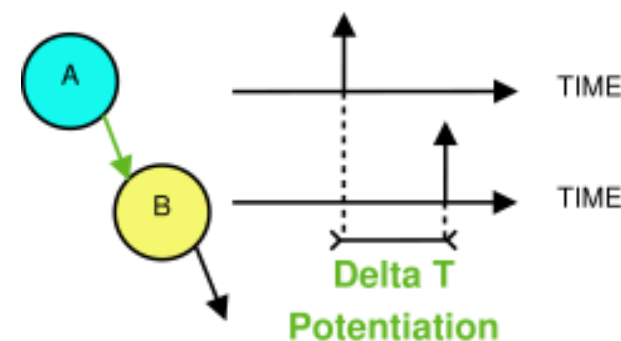
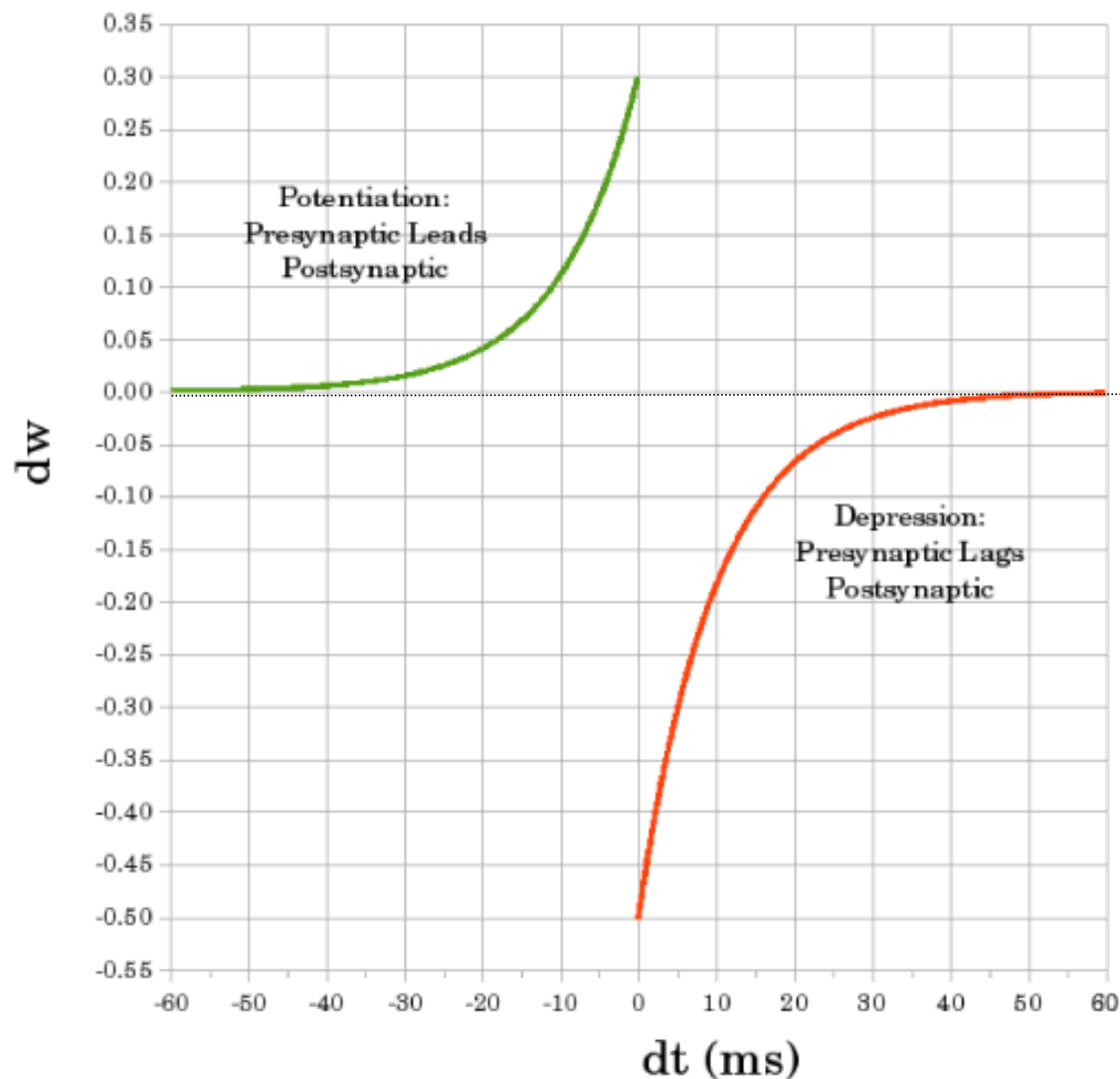
- Basic description of neural networks
- Standard STDP learning rule
- Description of the new approach
- The STDP-TTS
- Test environment
- Learning features

Artificial neural networks

- Are a computational model inspired from the analysis of biological neural networks. A huge number of small units (neurons or cells) interconnected;
- Neurons communicate using spikes;
- Biological neural networks are able to learn and adapt to external stimuli. Can we make artificial neural networks learn from external stimuli?



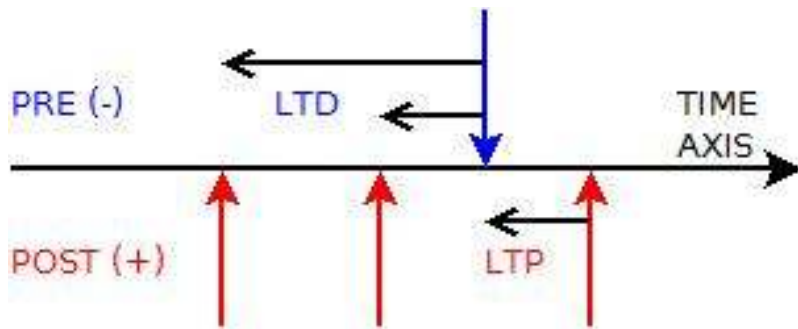
Spike Timing Dependent Plasticity



Implementation

Triggering the STDP algorithm

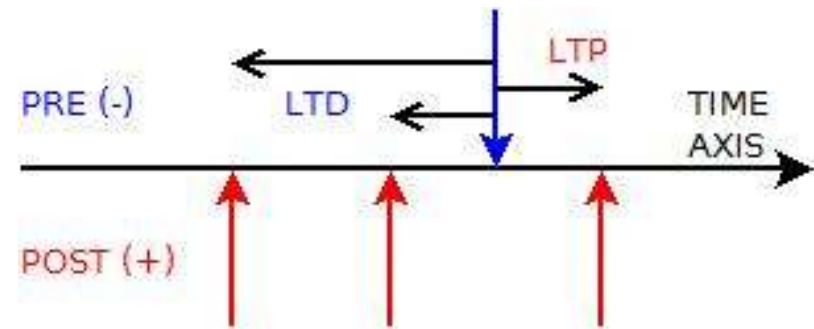
The usual way:



STDP is triggered on:

- Pre-synaptic spike arrival (LTD)
- Post-synaptic spike emission (LTP)

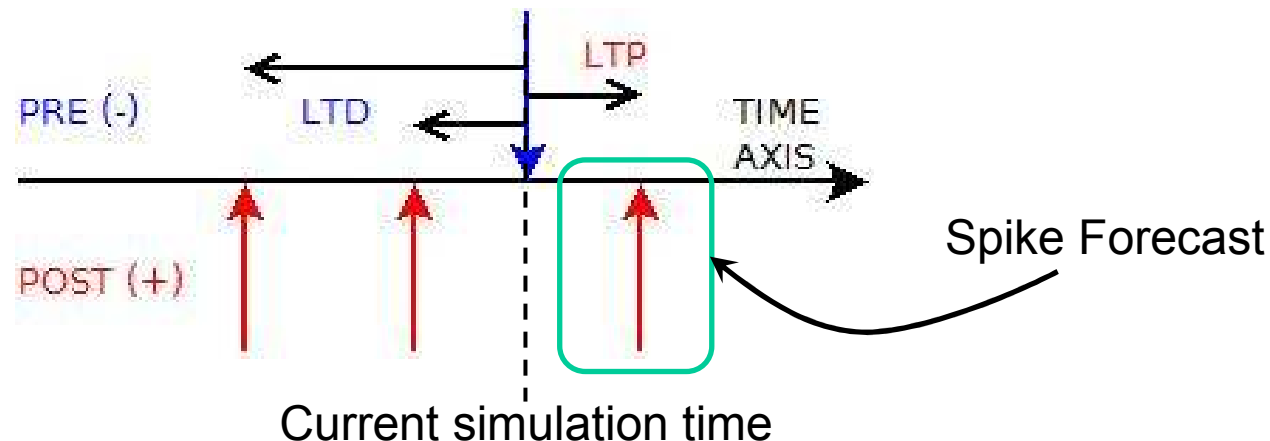
The SpiNNaker way:



- STDP is triggered only on pre-synaptic spike arrival (LTD and LTP)
- Weights are available only at pre-synaptic spike arrival.
- Since LTP needs future information, the algorithm needs to be deferred until the time window is filled

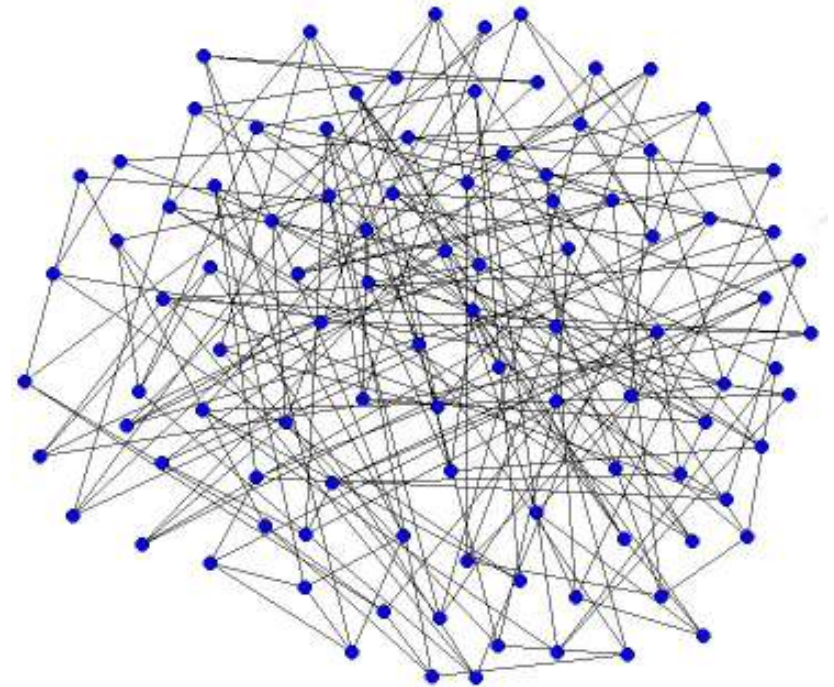
New approach

- Is it possible to simplify the STDP model so that its implementation on SpiNNaker is more performant (from both memory and computational points of view)?
- To avoid the Deferred Event Model, we need to have statistics that tell us when a neuron is going to fire in the future (at least with some probability).



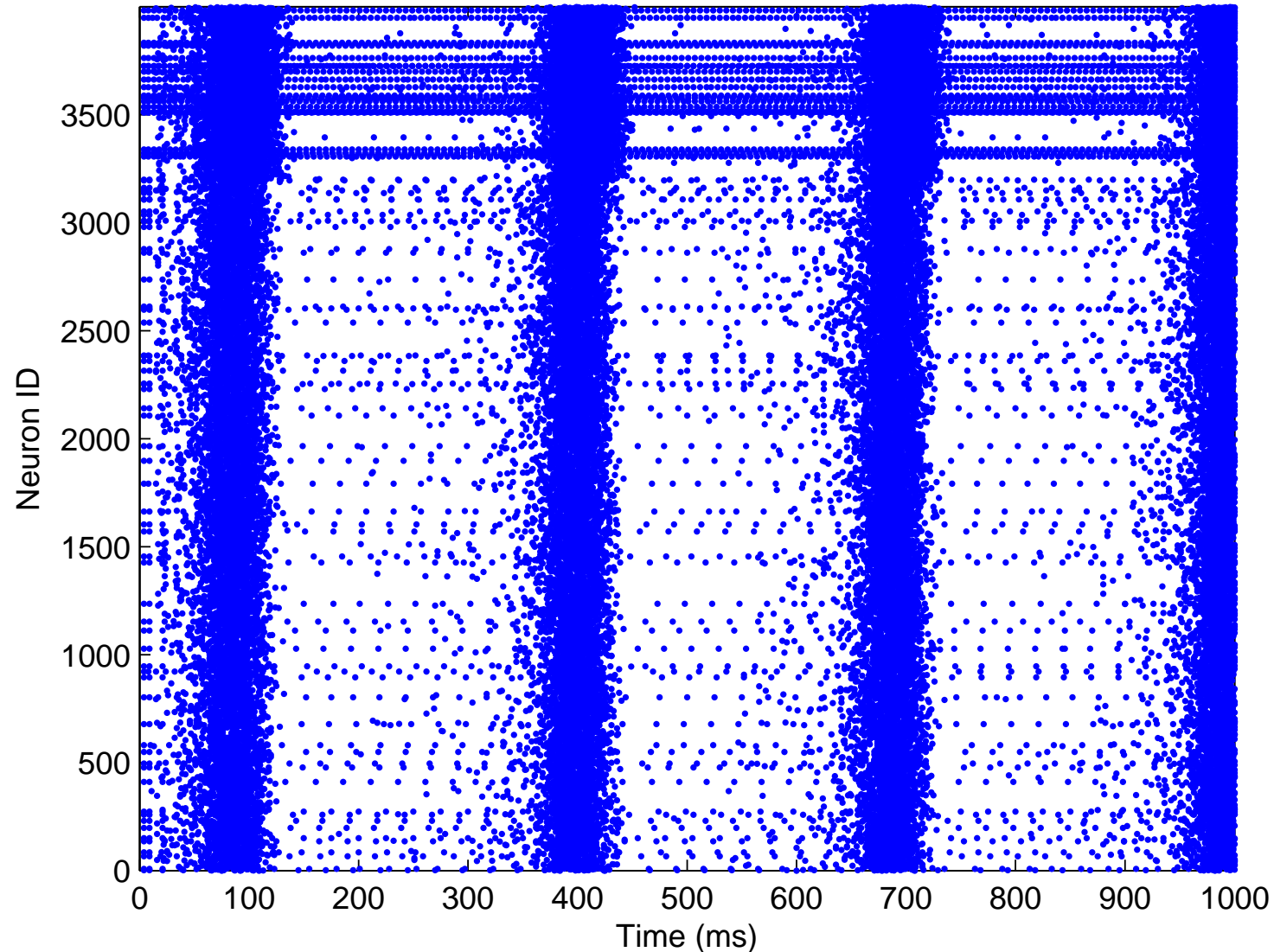
Statistical approach - 1

- The idea is: the higher the membrane potential of a neuron (that receives a spike), the sooner it is likely to emit an action potential.
- Starting with a random network of Izhikevich neurons, fed with input to random neurons with random delays;
- We store all the activity in the network (especially membrane potential evolution).



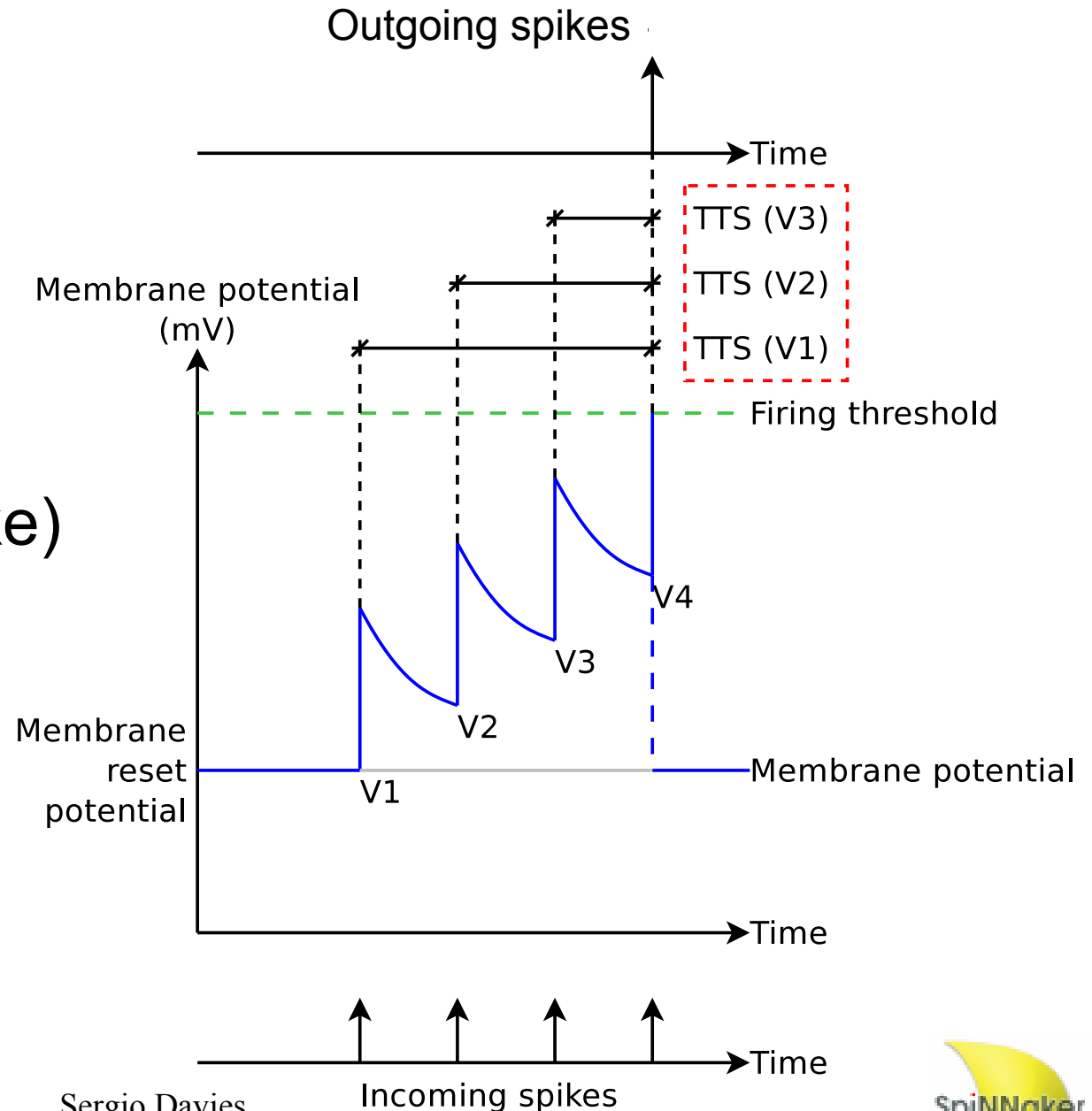
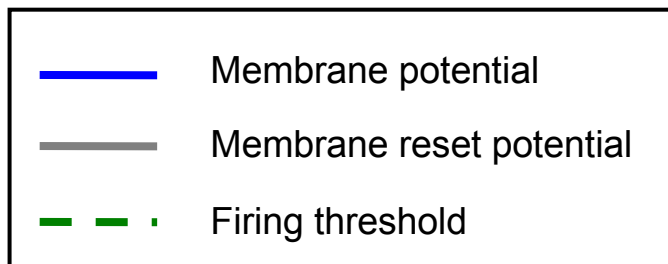
Statistical approach - 2

Raster plot in Matlab (fixed-point)



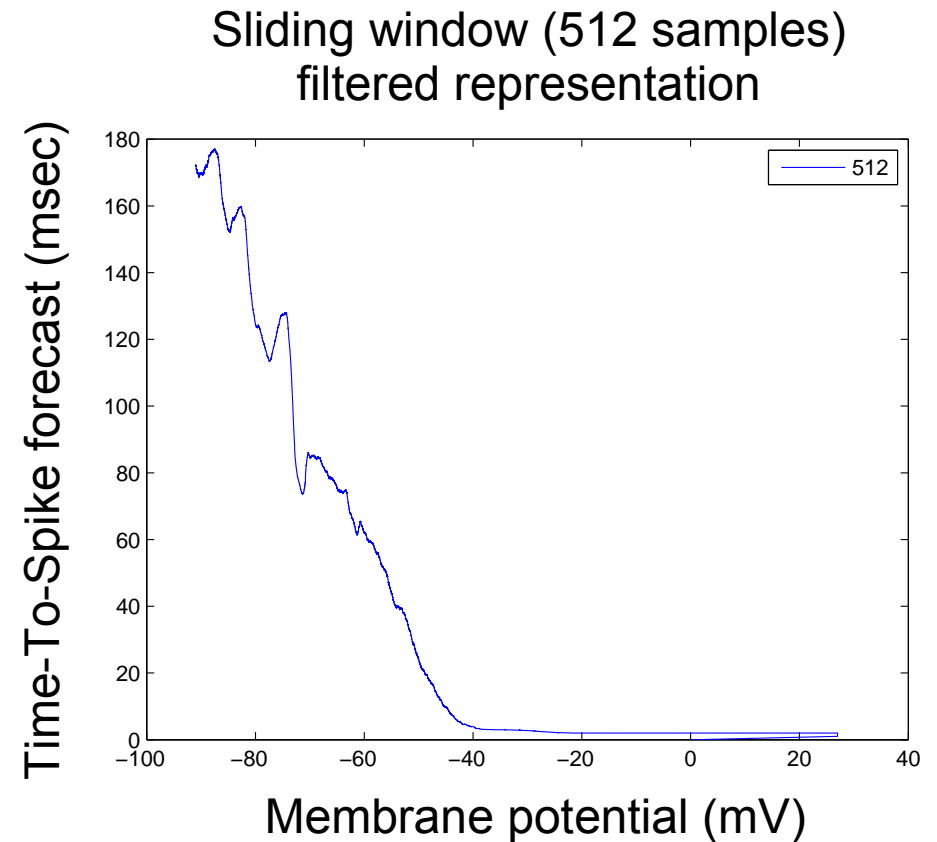
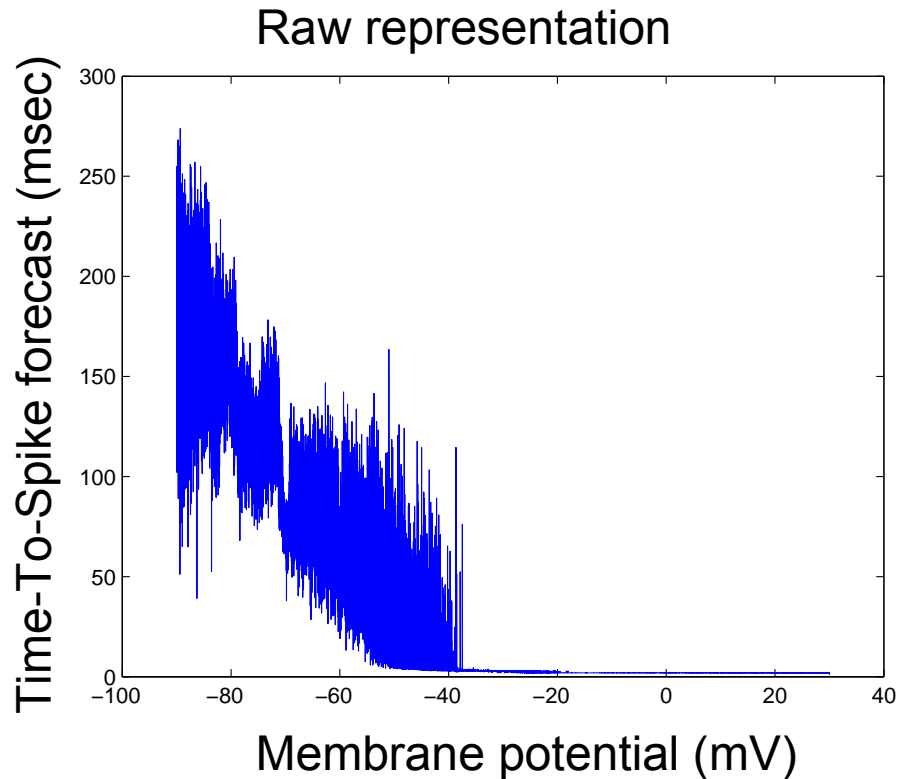
Statistical approach - 3

- We evaluate all the couples (membrane potential; time-to-spike)



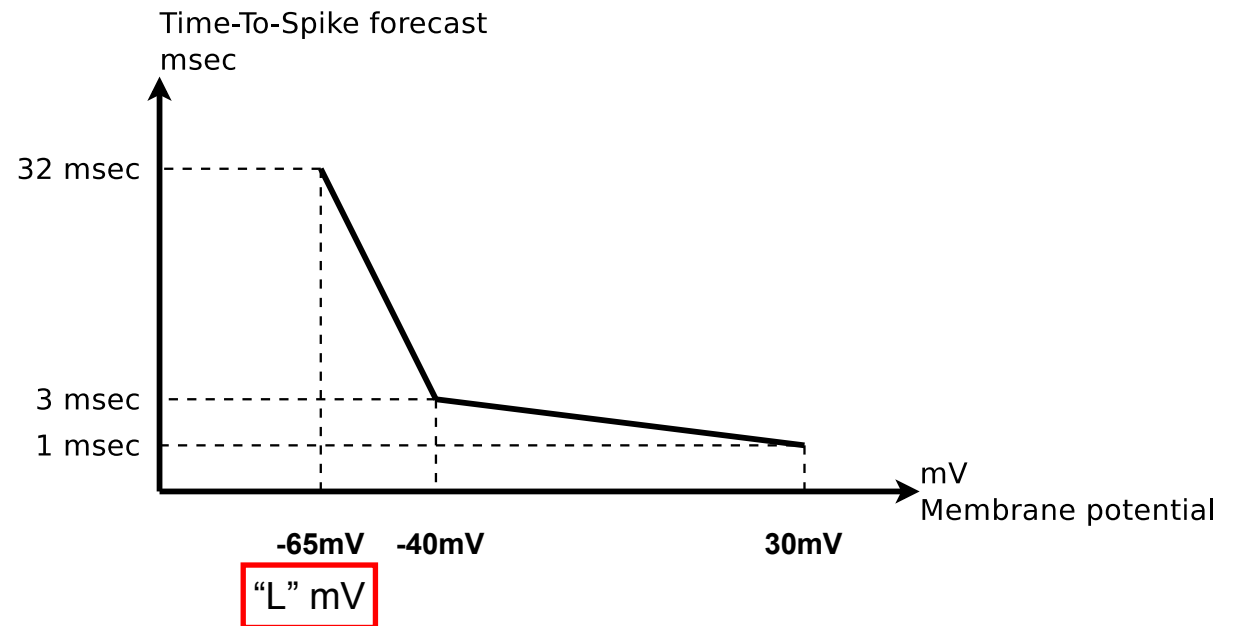
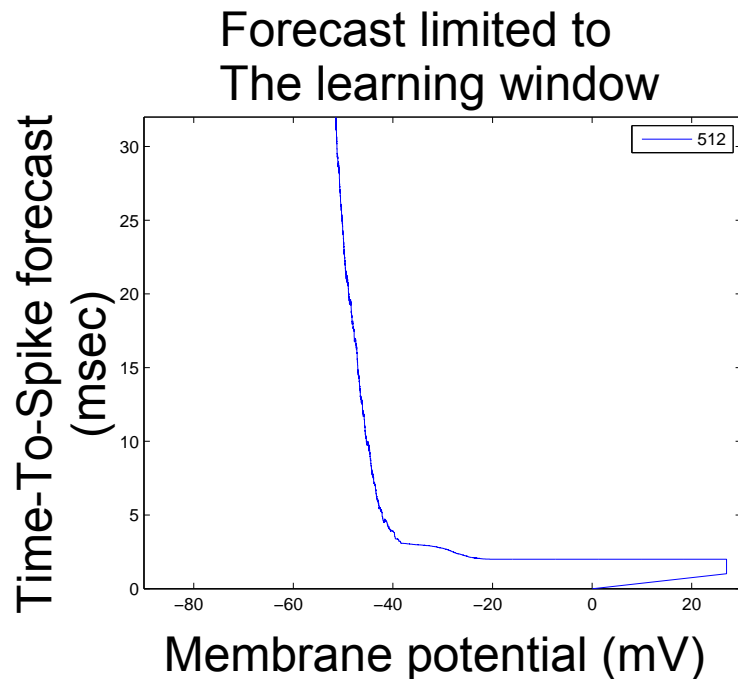
Results of the statistical approach

- Representation of all the couples computed before



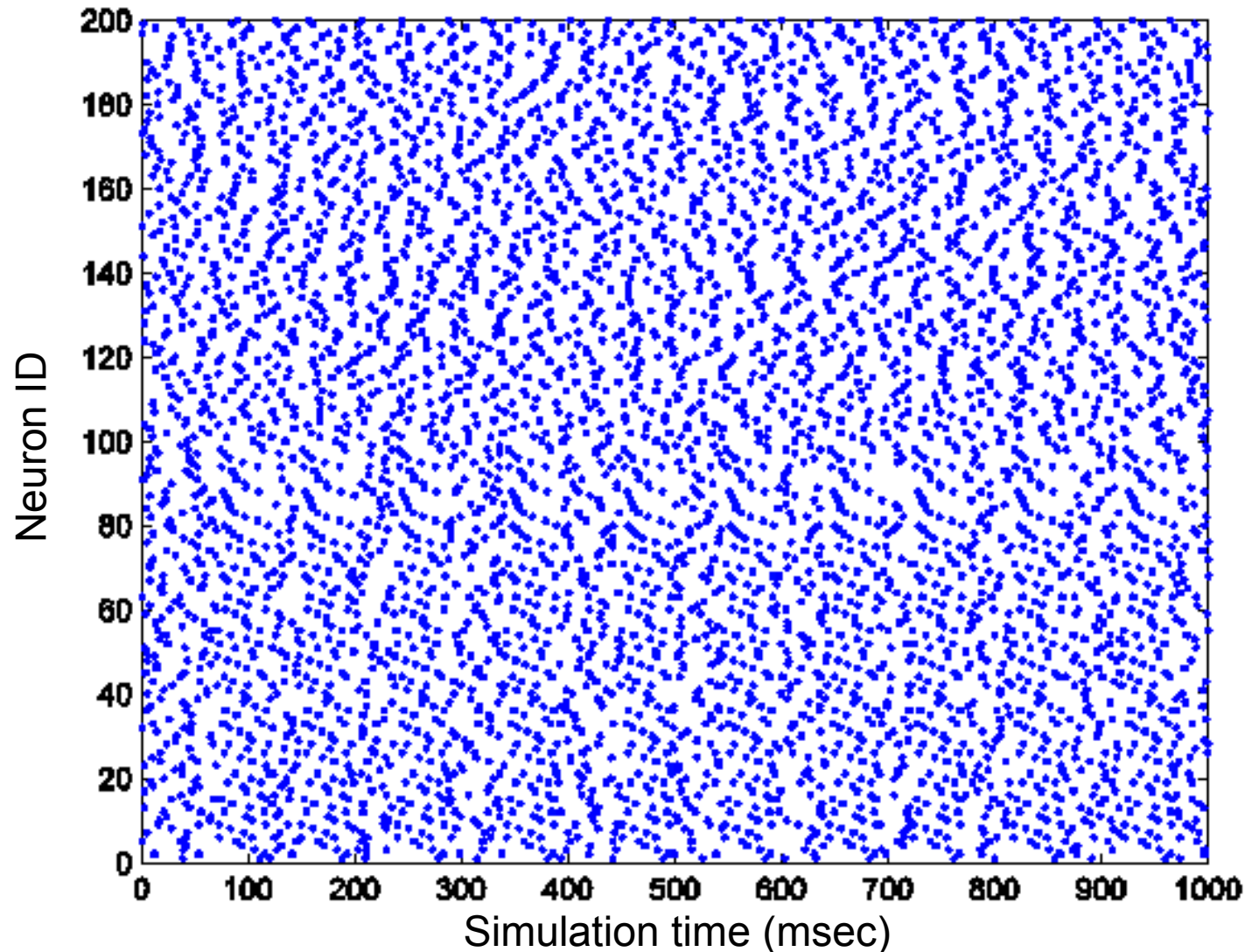
The STDP-TTS

- The wider the STDP time window, the greater the uncertainty of the forecast of the time-to-spike. We limit the STDP time window to 32 msec.



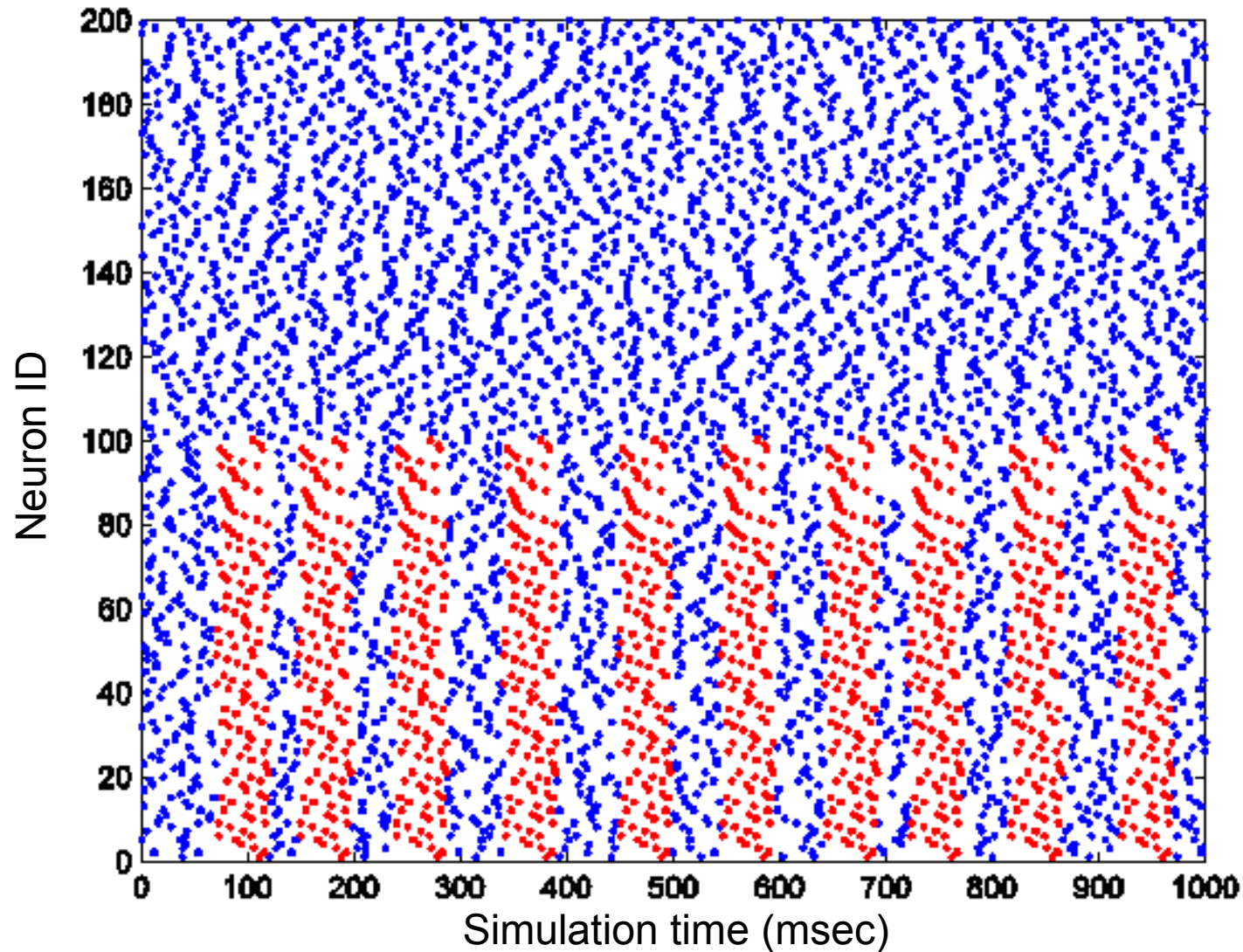
Input provided

Can you identify any pattern in this raster plot?



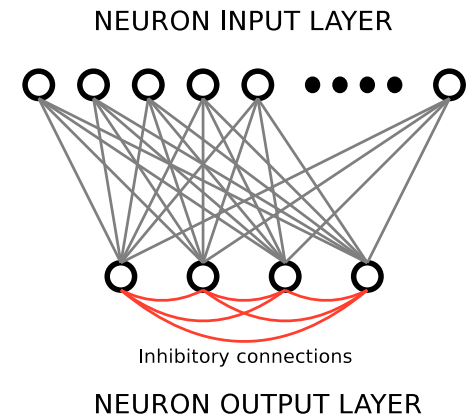
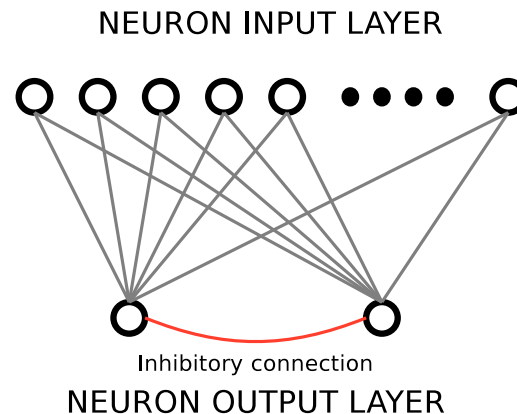
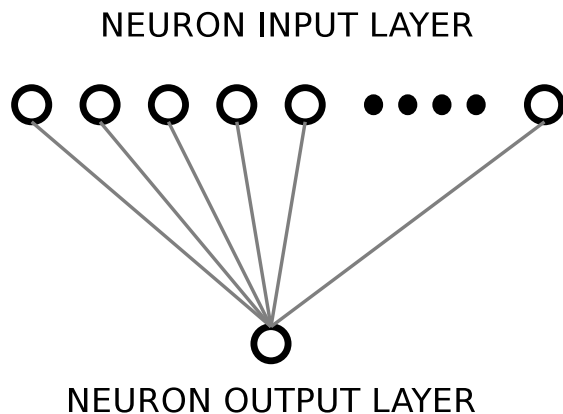
Input provided

Solution: in red the pattern



Testing the features

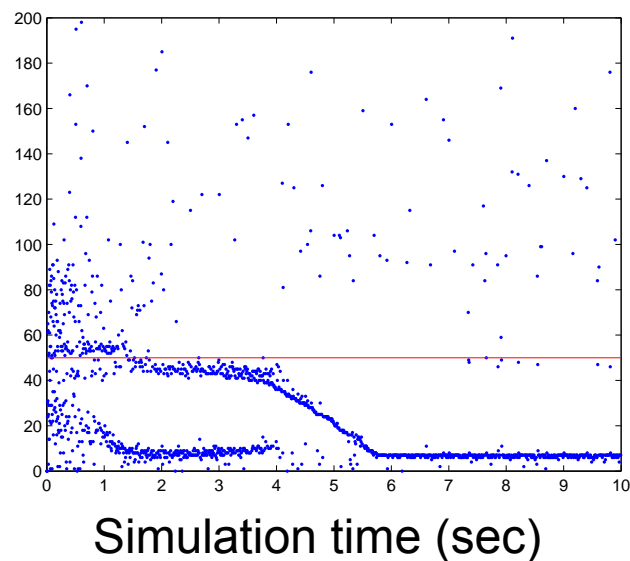
- To test this forecast learning rule we use as a benchmark the tests ran by Masquelier et al. in 2008 and 2009.



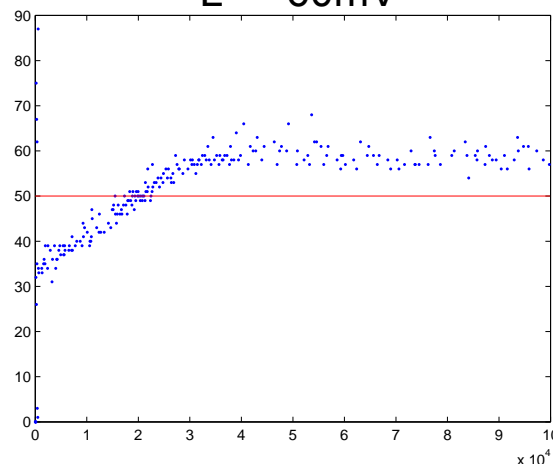
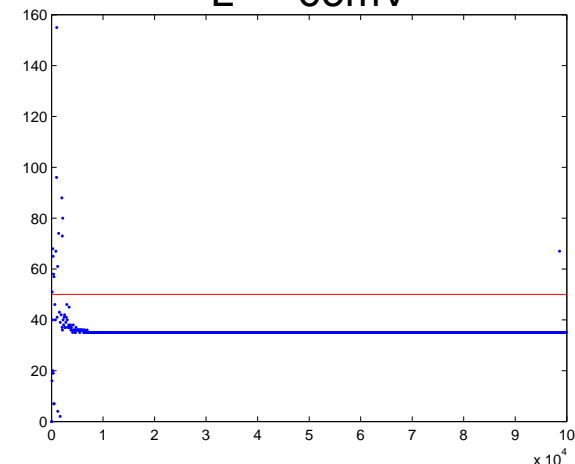
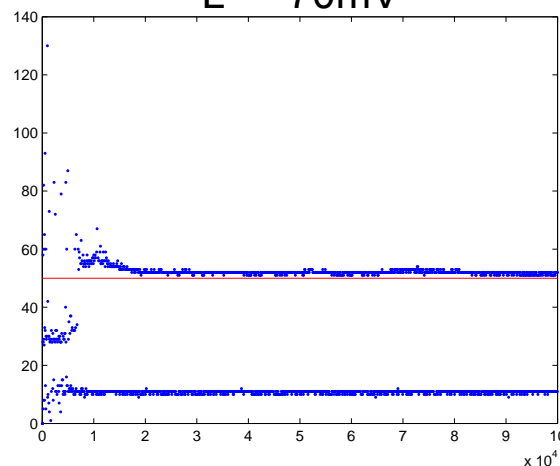
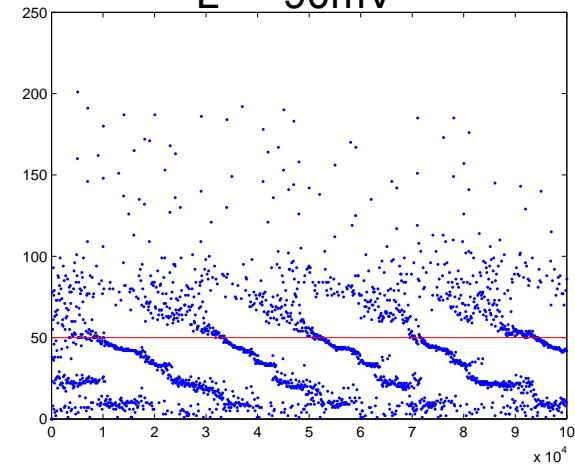
Results of the tests - 1

Standard STDP

Delay after pattern input (msec)



STDP-TTS (with forecast)

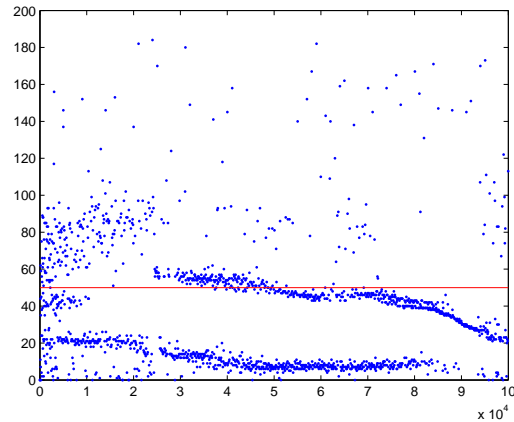
 $L = -60\text{mV}$  $L = -65\text{mV}$  $L = -70\text{mV}$  $L = -90\text{mV}$ 

Results of the tests - 2

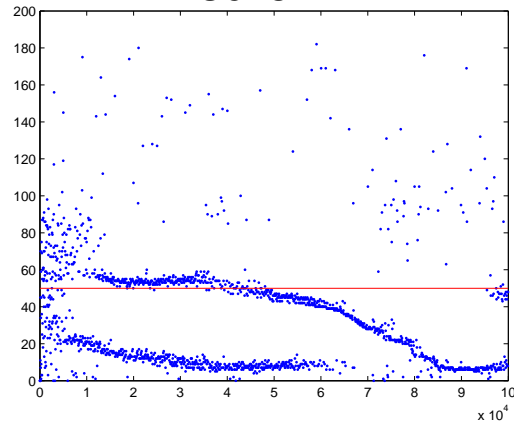
Two output neurons – one input pattern

Standard STDP

Neuron 1

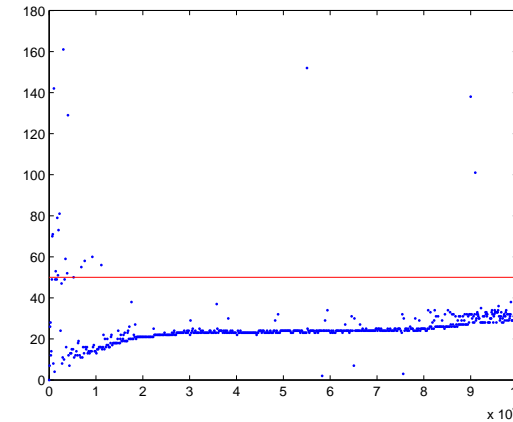


Neuron 2

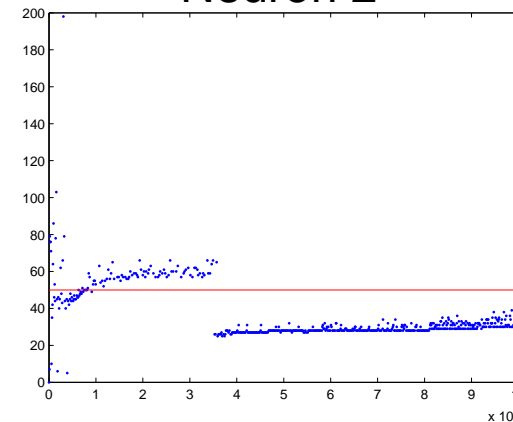


STDP with forecast

Neuron 1



Neuron 2



Results of the tests - 3

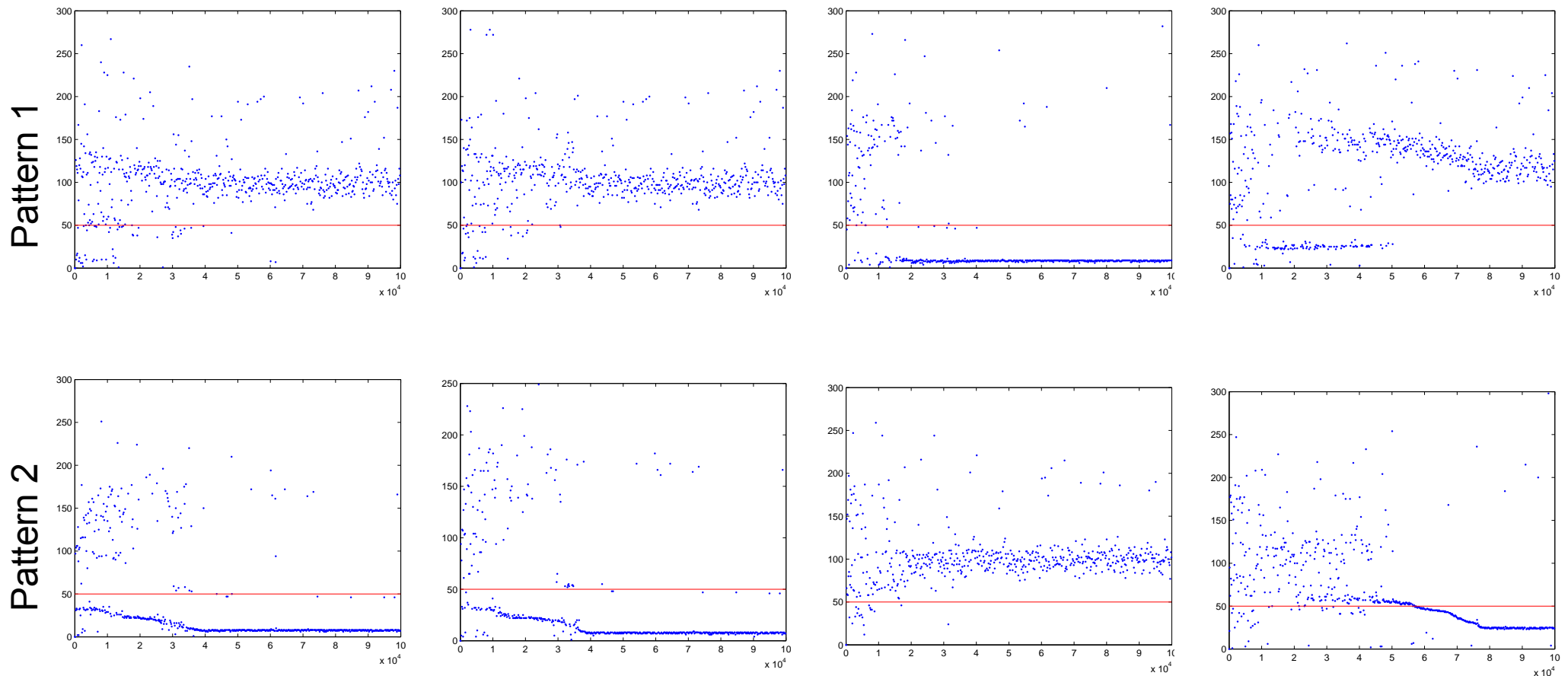
Four output neurons – two input patterns
standard STDP

Neuron 1

Neuron 2

Neuron 3

Neuron 4



Results of the tests - 4

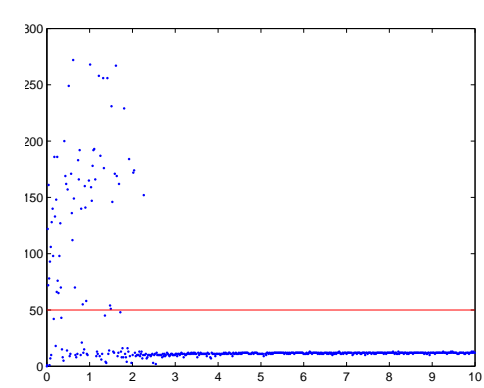
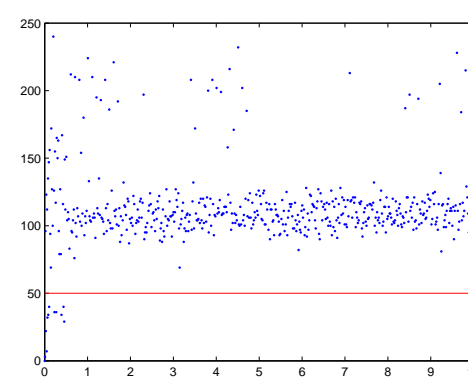
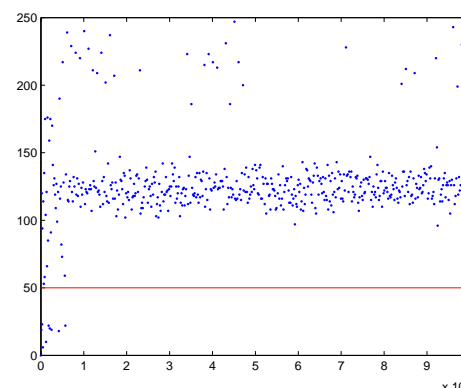
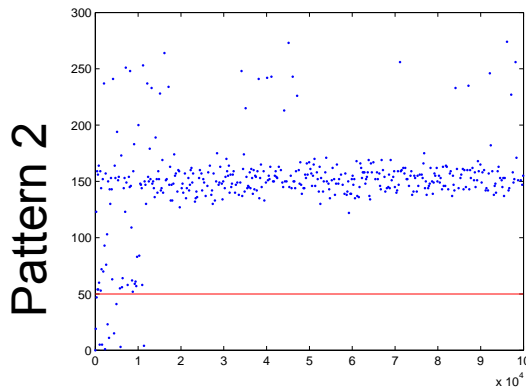
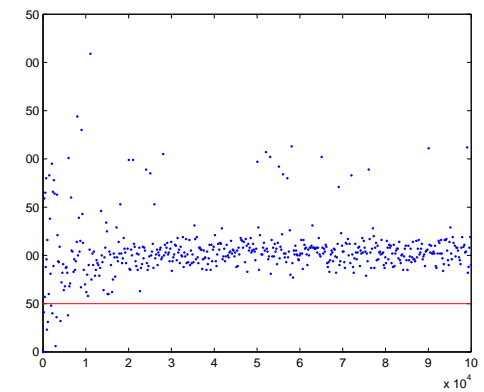
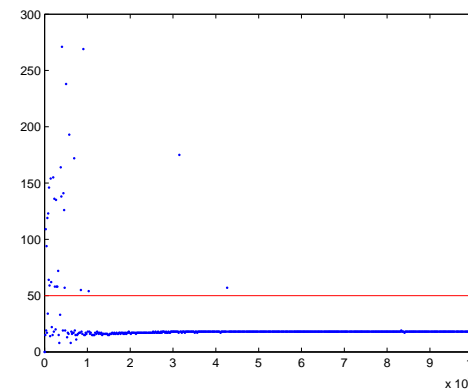
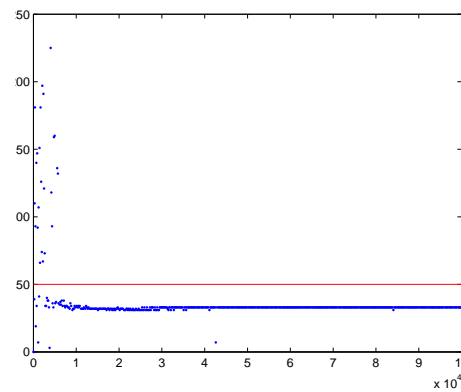
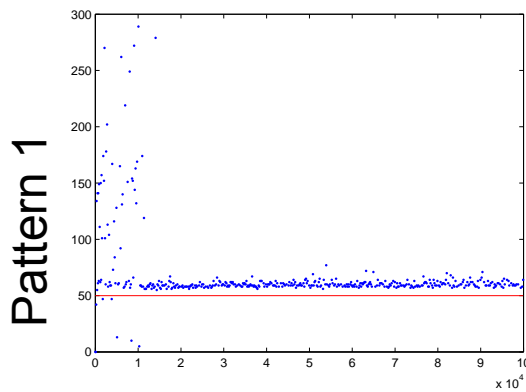
Four output neurons – two input patterns
STDP with forecast

Neuron 1

Neuron 2

Neuron 3

Neuron 4



Thank you!!!

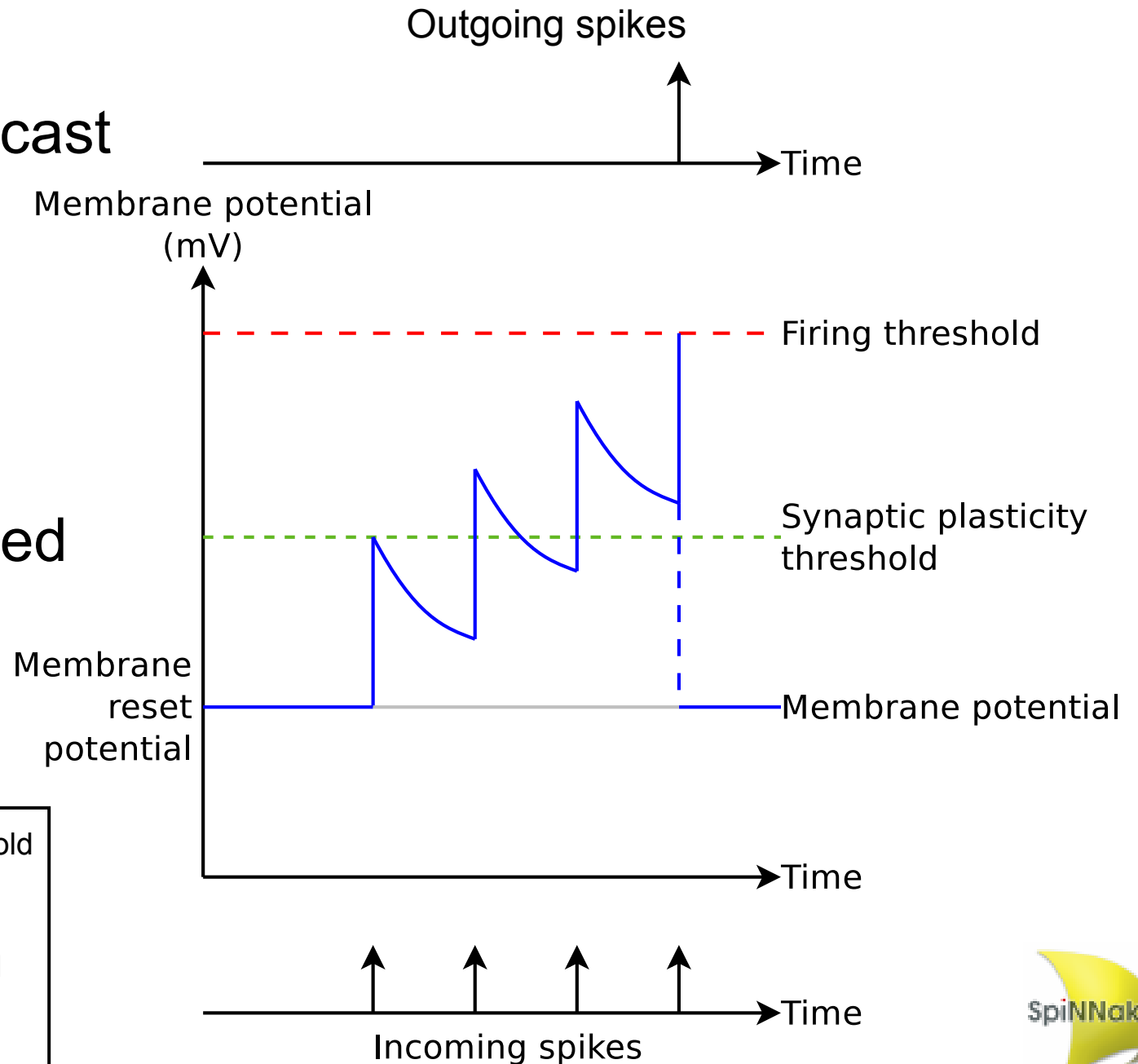


Questions???

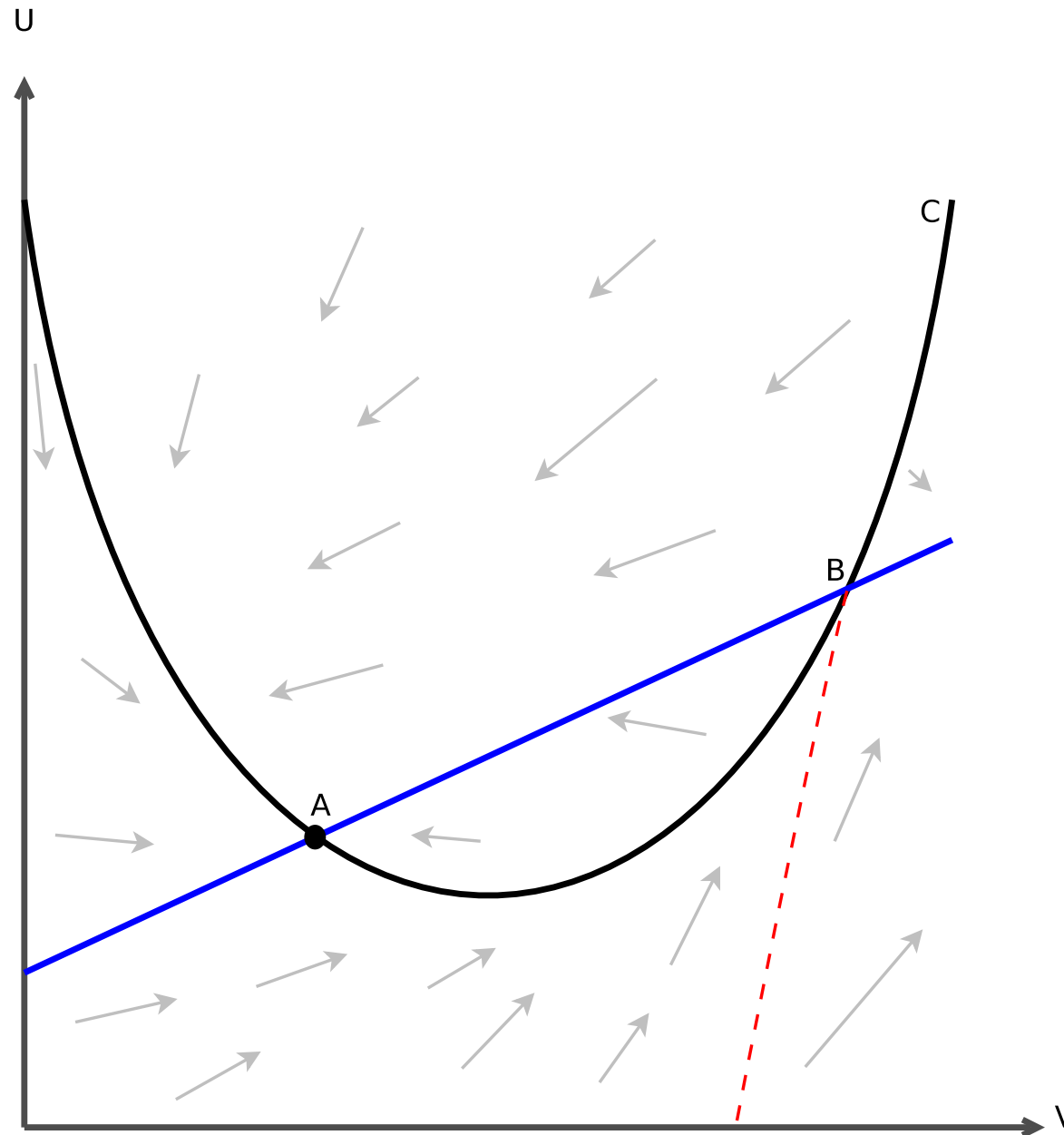
Backup slides

Limitations of the new rule

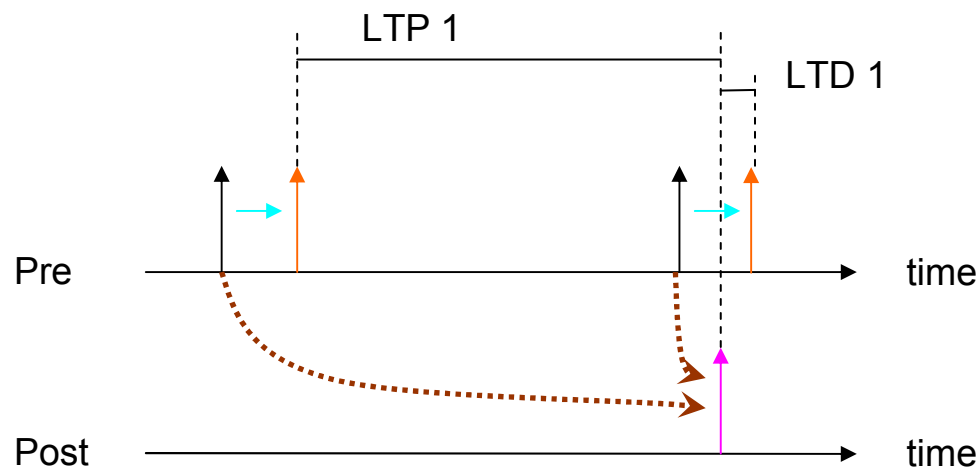
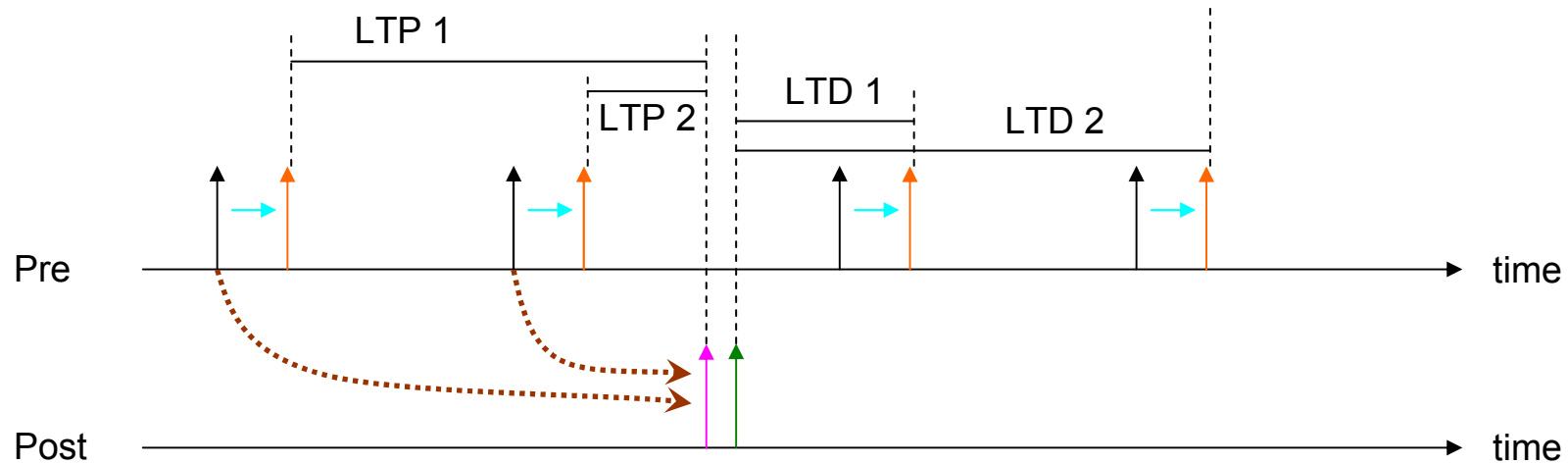
- STDP with forecast cannot tune to the earliest spikes
- The forecast function is related to the type of Izhikevich neuron



The Izhikevich phase space



Implementation on SpiNNaker



- Incoming spike
- Incoming spike delayed by synapse
- Synaptic delay
- Forecast based on the current neuron membrane potential
- Forecasted spike
- Real outgoing spike