Effect Of Homeostatic Regulation On Dynamics Of Recurrent Neuronal Networks

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Networks misbehaving

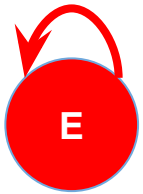
Neuronal network dynamics (simulated, in nature) can become unstable

This can lead to:

- an explosion of network activity or other pathological states, or
- dying out of network activity

Typical causes:

- strong excitatory feedback
  - loop of increased FR and synaptic input
- correlation-based plasticity dynamics
  - loop of increased correlations and synaptic coupling



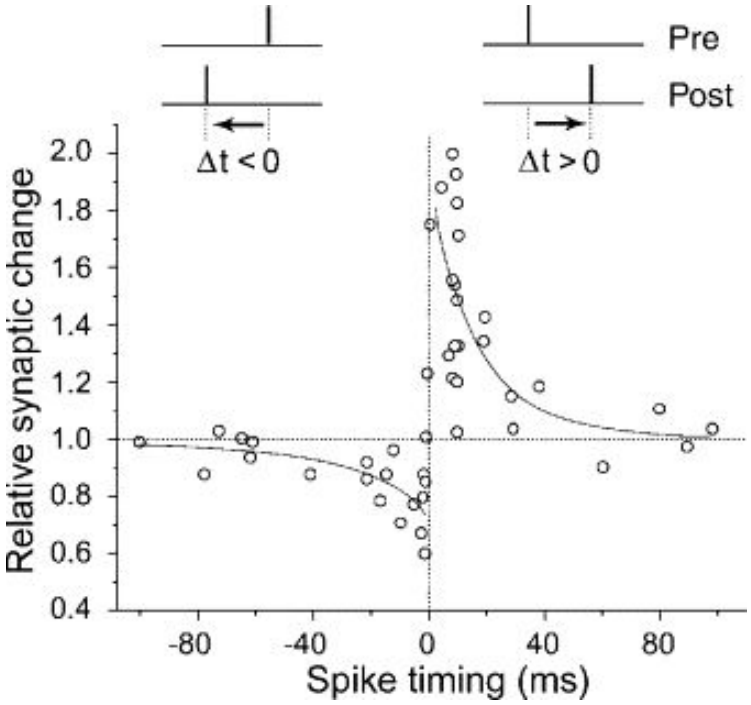
Spike-time dependent synaptic plasticity (STDP)

- Update rule for facilitation:

$$\Delta^{+}w = \lambda \cdot (1 - w)^{\mu+} \cdot \text{pre\_trace}$$

- Update rule for depression:

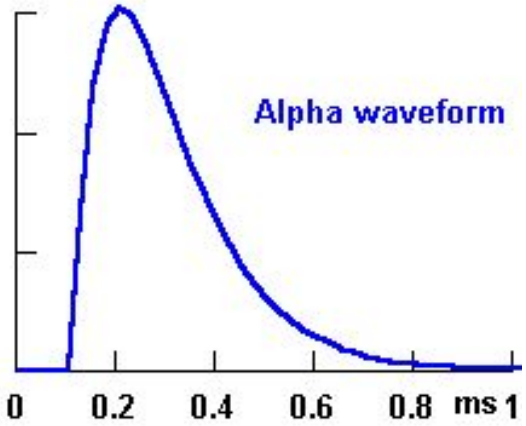
$$\Delta^{-}w = -\alpha \cdot \lambda \cdot w^{\mu-} \cdot \text{post\_trace}$$



Bi & Wang (2002)

Current-based integrate-and-fire model

- α- function shaped synaptic currents



AlphaSyn

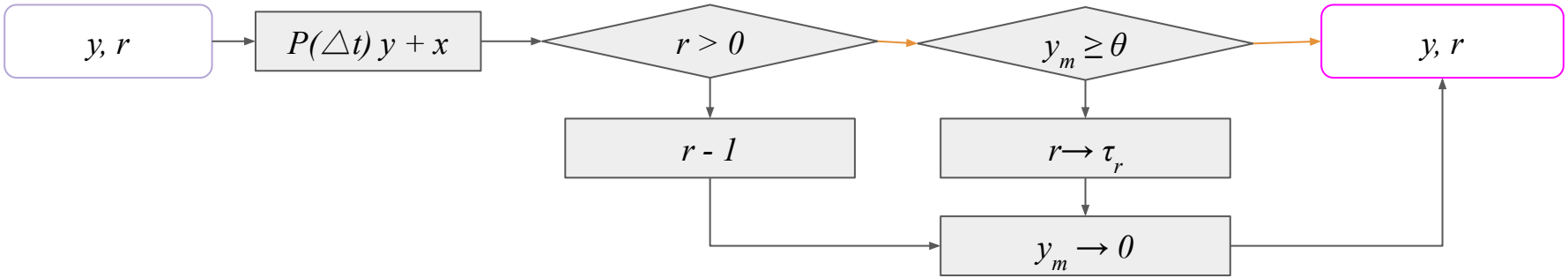
Current-based integrate-and-fire model

- α- function shaped synaptic currents
- Sub-threshold dynamics
  - Exact integration scheme*
- External current
  - state variable and DE

- Rotter S, Diesmann M (1999). Exact simulation of time-invariant linear systems with applications to neuronal modeling. Biologial Cybernetics 81:381-402.

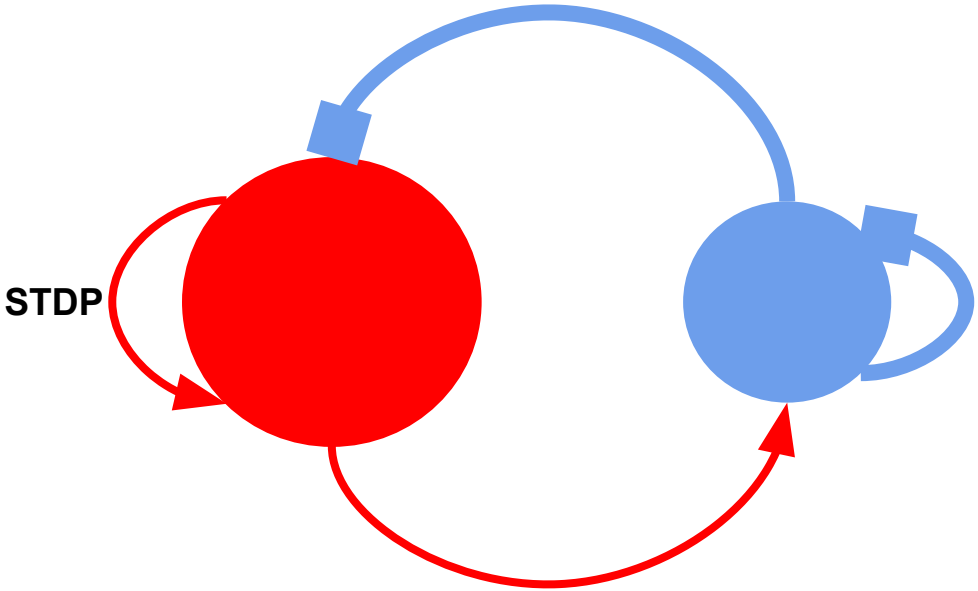
Current-based integrate-and-fire model

- α- function shaped synaptic currents
- Sub-threshold dynamics
  - Exact integration scheme
- External current
  - state variable and DE
- Operation scheme



M. Diesmann et al. / Neurocomputing (2001)

Recurrent neuronal network



$N_{Neurons} = 12500$

- 80% excitatory
- 20% inhibitory

$N_{Connections} = 1250$

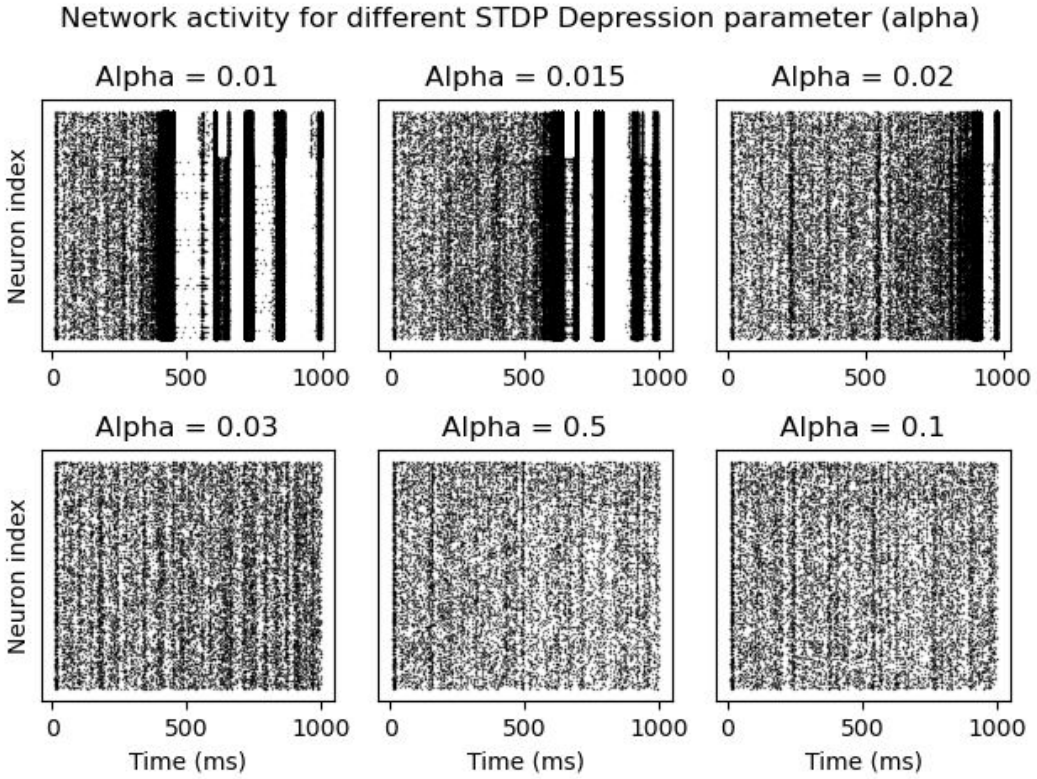
Results

Unstable dynamics in our RNN

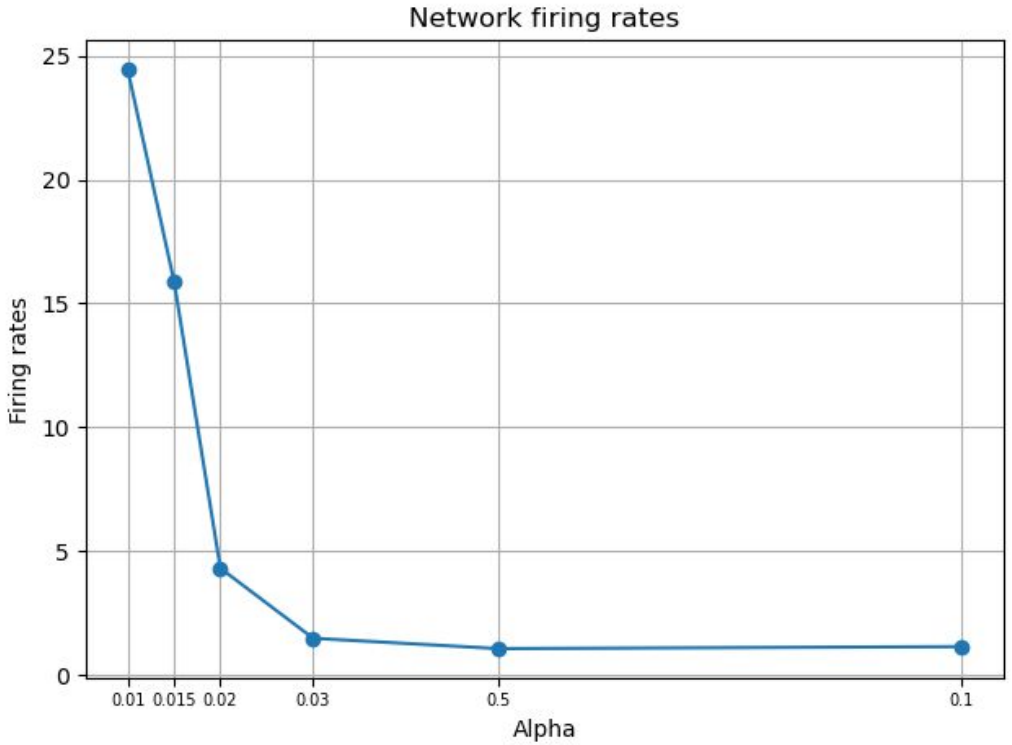
Making the network stable-unstable → changing depression in excitatory weights

$$\Delta^{-} w = -\alpha \cdot \lambda \cdot w^{\mu_-} \cdot \text{post\_trace}$$

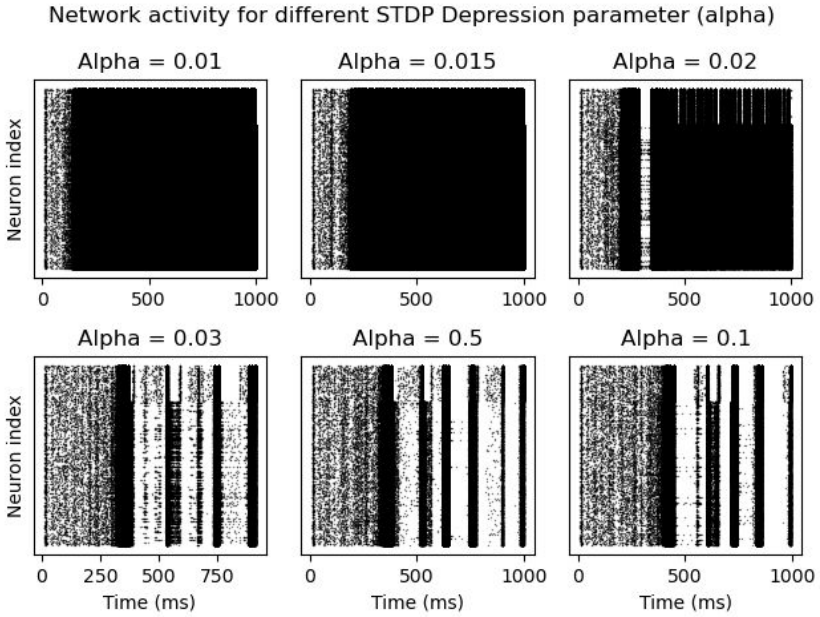
Unstable dynamics in our RNN

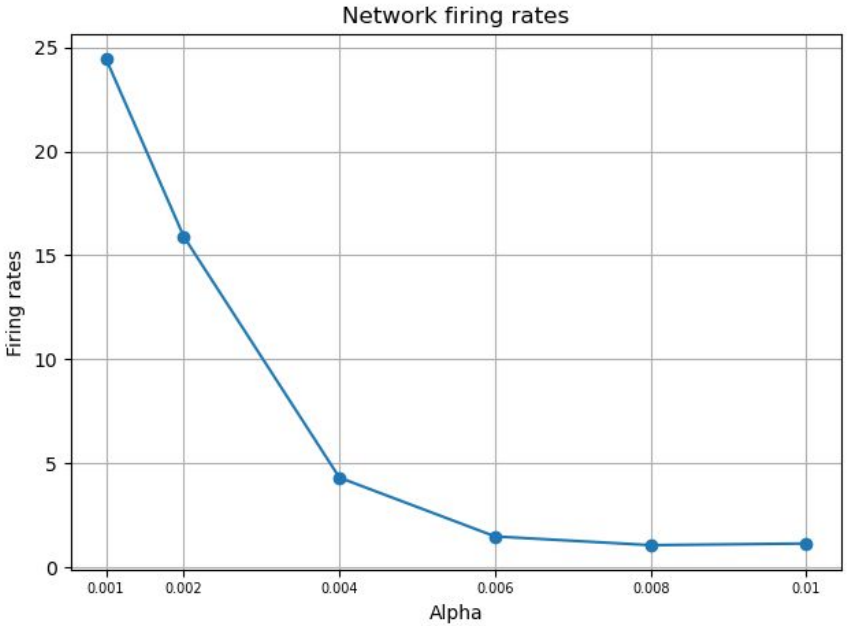


Unstable dynamics in our RNN

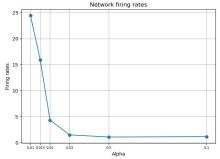


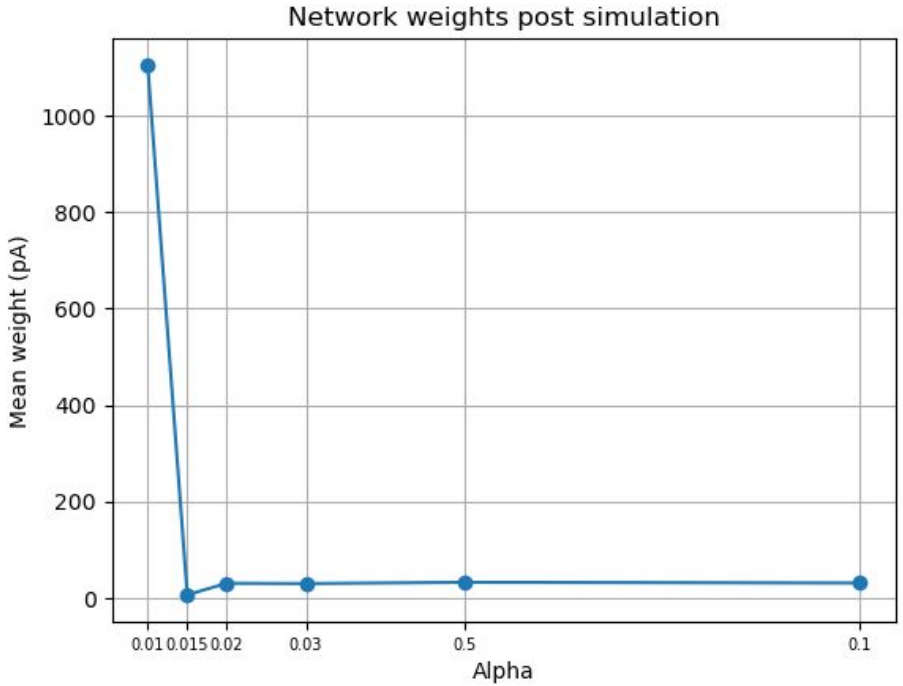
Unstable dynamics in our RNN



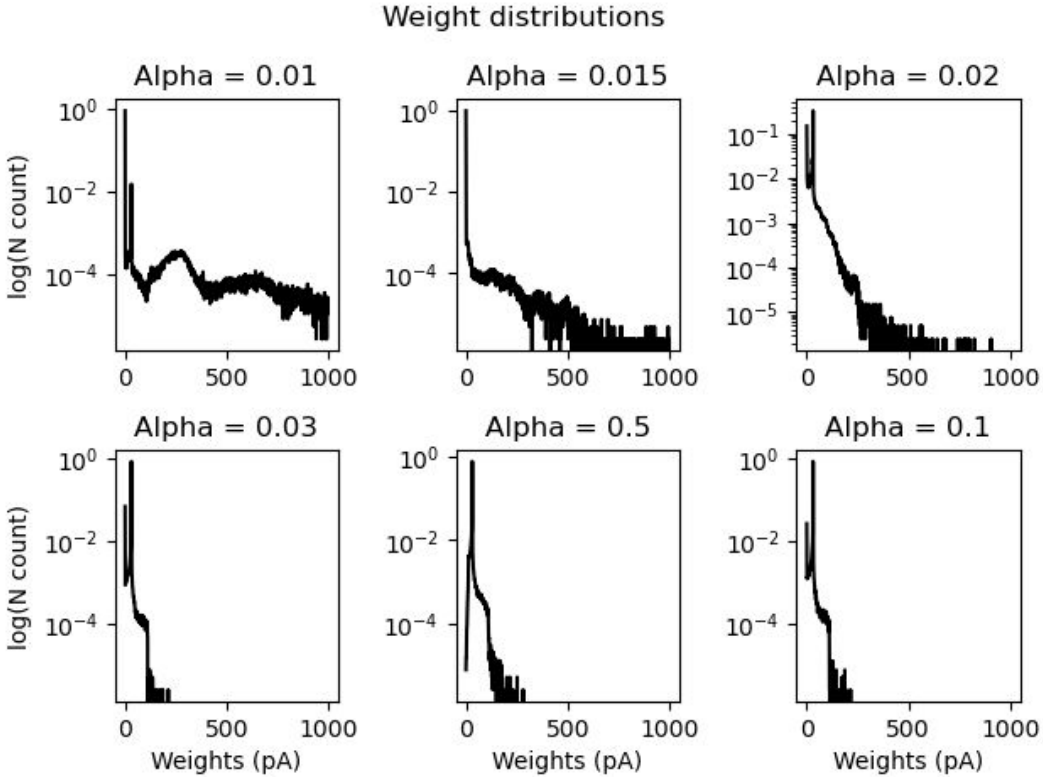


Unstable dynamics in our RNN

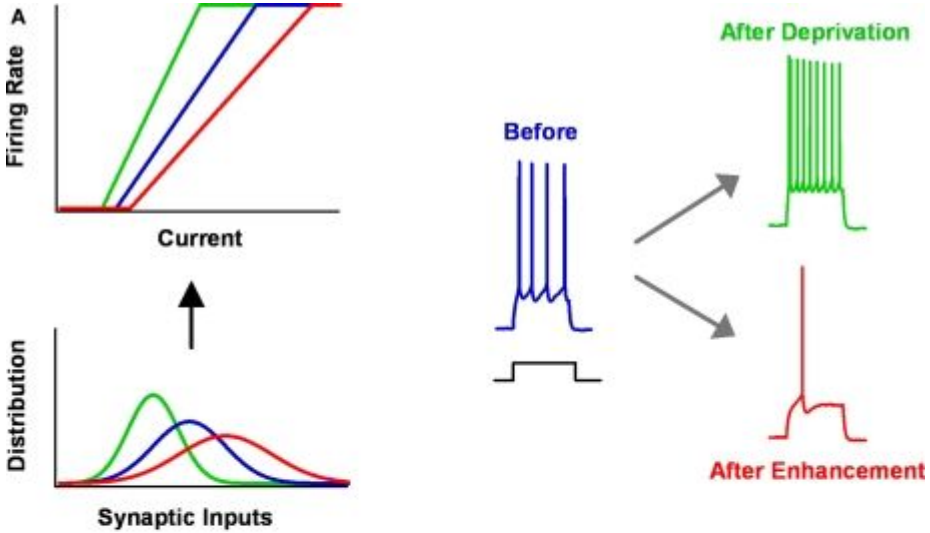




Unstable dynamics in our RNN



Intrinsic plasticity as a homeostatic mechanism



Watt and Desai (2010)

Implementing slow adaptation

Adaptive, current-based exponential integrate and fire neuron (Brette & Gerstner, 2005)

Membrane potential:

$$C\frac{dV}{dt} = -g_L(V - E_L) + g_L\Delta_T \cdot \exp\left(\frac{V - V_T}{\Delta_T} - w(t) + I_{syn}(t) + I_e\right)$$

and

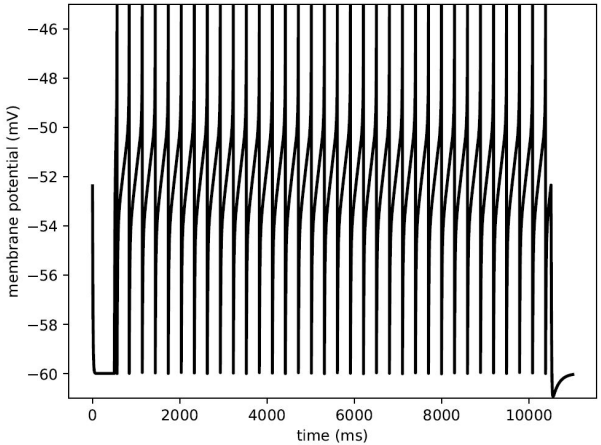
$$\tau_w \frac{dw}{dt} = a(V - E_L) - w$$

parameter a: subthreshold adaptation (=0)

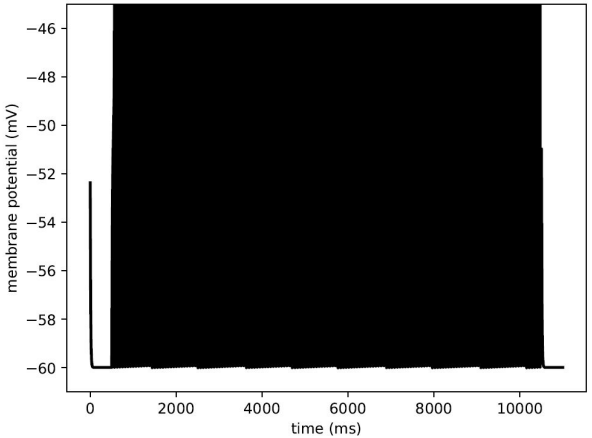
parameter b: spike-triggered adaptation

parameter tau_w: adaptation time constant

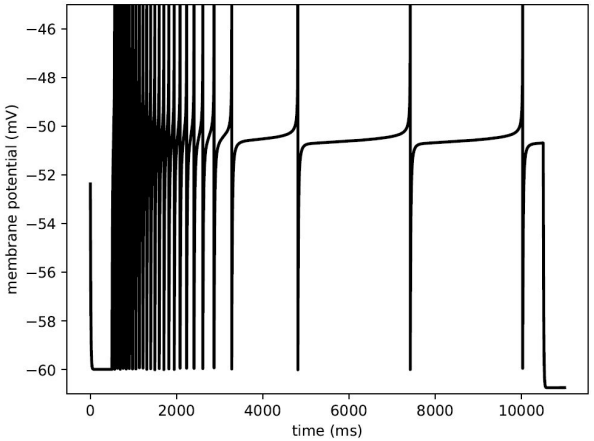
Setting parameters for the adaptive neuron model



Default adaptation parameters
a = 0, b = 80.4, tau_w = 144

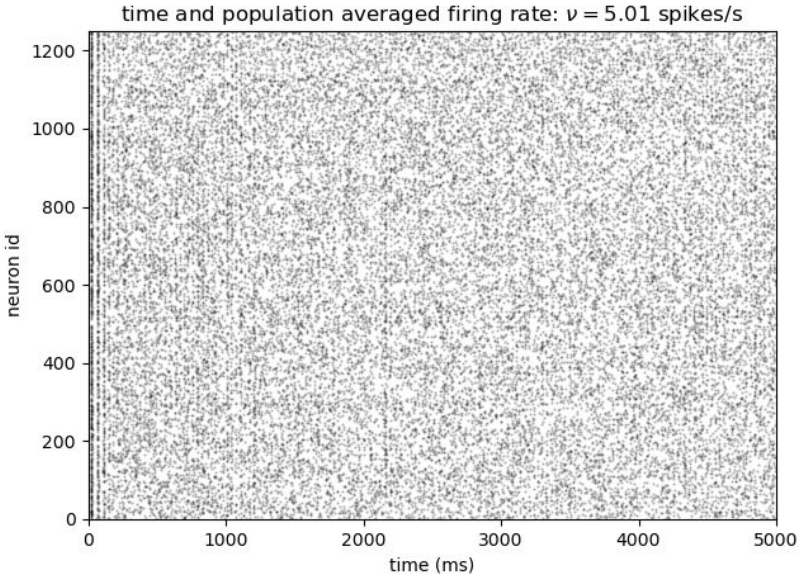


No adaptation parameters
a = 0, b = 0, tau_w = 144

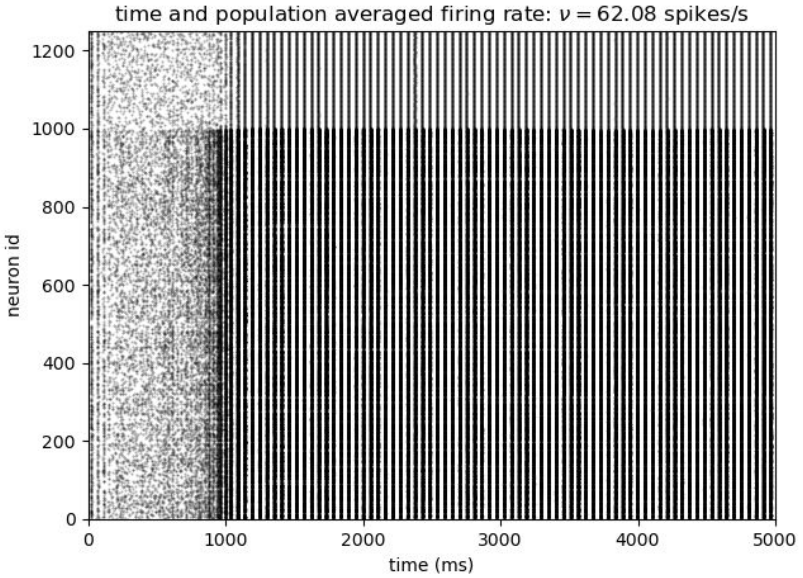


Slow adaptation parameters
a = 0, b = 1, tau_w =57960

STDP induces synchronous firings

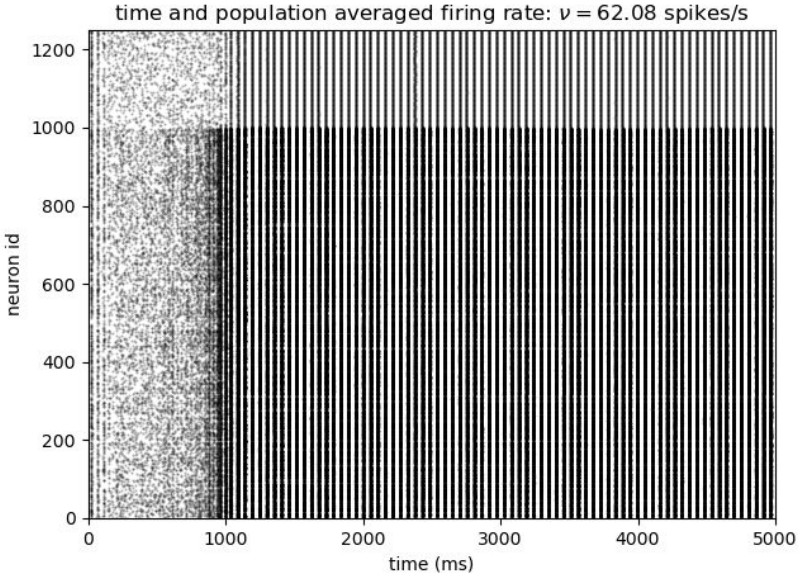


adaptation OFF (b=0)
alpha = 0.1

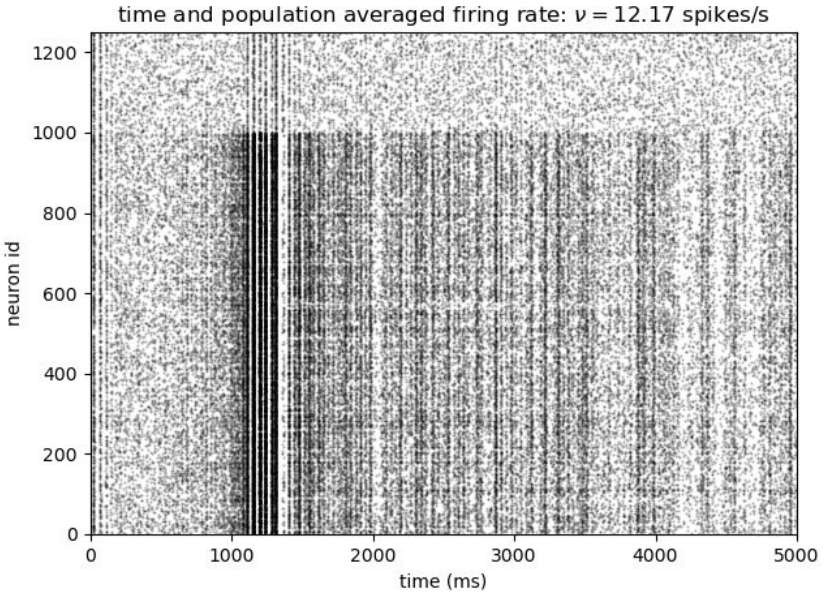


adaptation OFF (b=0)
alpha = 0.02

Slow adaptation as a homeostatic mechanism

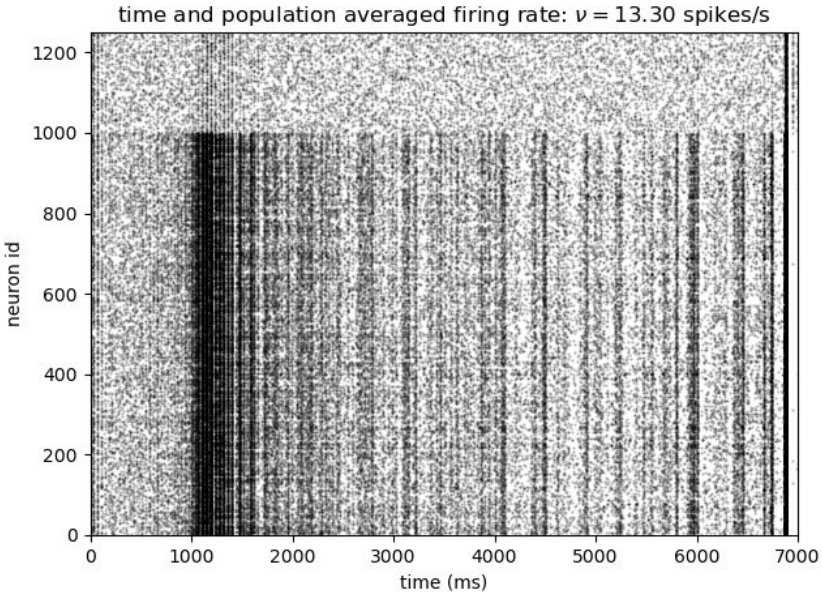


adaptation OFF (b=0)
alpha = 0.02

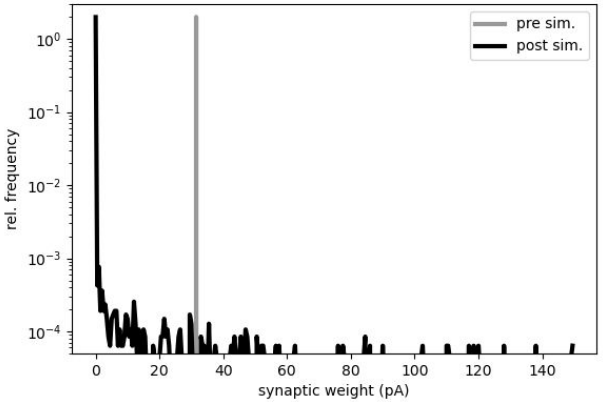


slow adaptation ON (b=1)
tau_w = 11592 ms

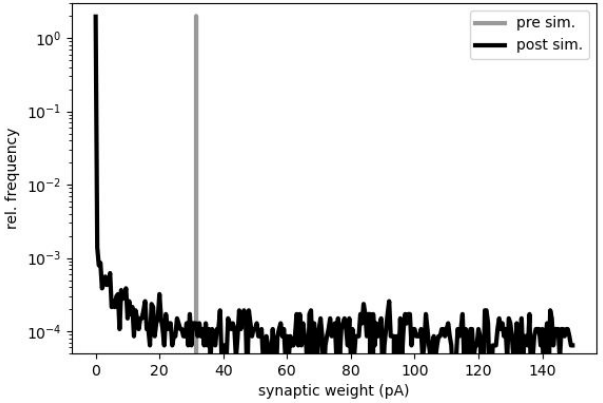
Unstable dynamics?



slow adaptation ON (b=1)
tau_w = 11592 ms



adaptation OFF



adaptation ON

Thank you for your attention!!

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All of you
Funding