PANERIS Winter School: Basics of Computational Neuroscience

Neural network simulations of simple cognitive functions

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Vilniaus universitetas

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Coordination and Support Action u
"Pan-European Network for Neuros
Research Infrastructure and Streng
Support capacities" (project no 101

Materials

Materials for the class: github.com/acompte/attractors.

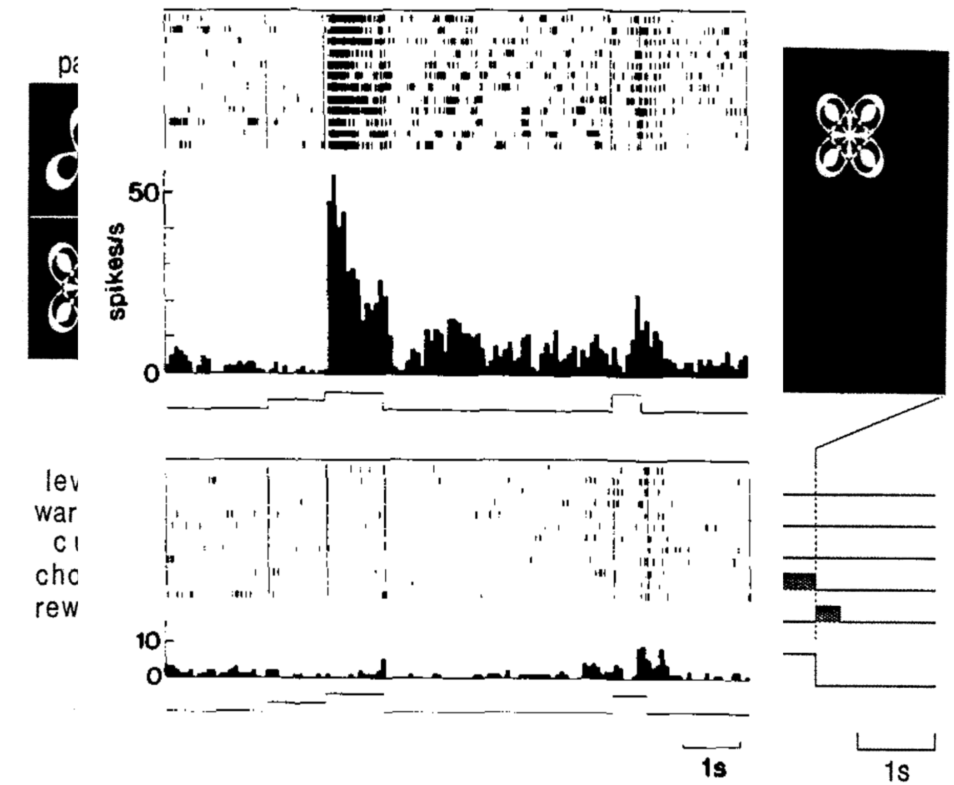
Ctrl-click launch | binder to open exercises

Contents

- cortical networks:
  - EI networks: Wilson and Cowan, 1972
  - Inhibition-stabilized networks: Tsodyks et al, 1997; Ozeki et al, 2009
- discrete attractor networks: Amit and Brunel, 1997; Wang, 2002; Wong and Wang, 2006; Roxin and Ledberg, 2008
- ring attractor networks: Wilson and Cowan, 1973; Amari, 1977; Hansel and Sompolinsky, 1998
- low-rank RNNs: Mastrogiuseppe and Ostojic, 2018

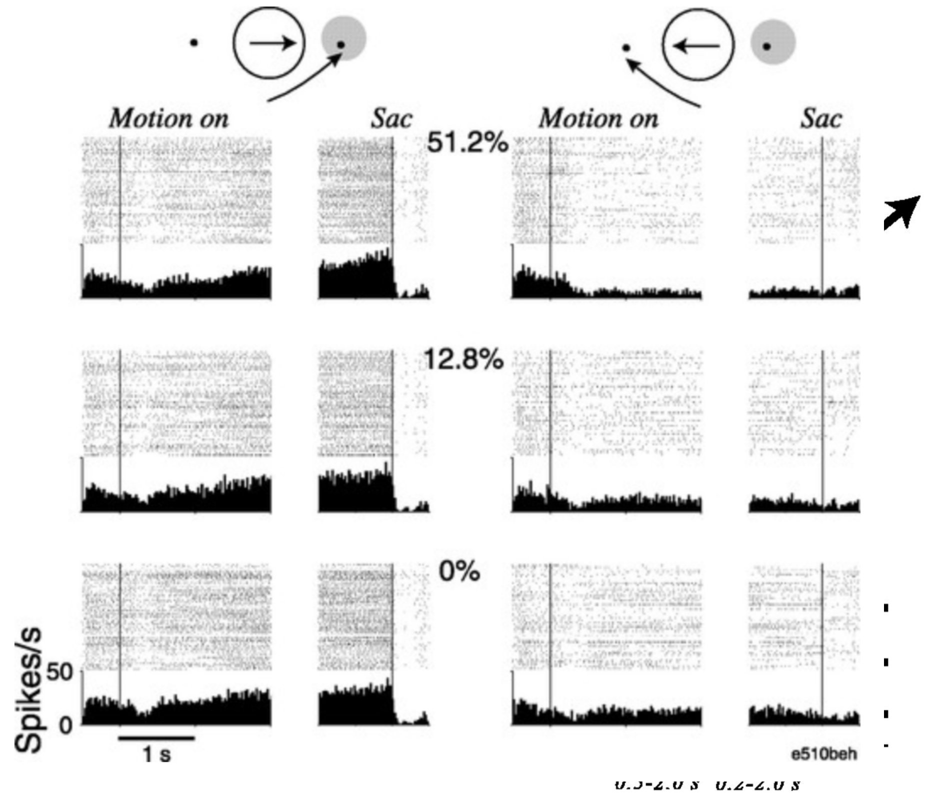
Neural basis of cognition

Working memory



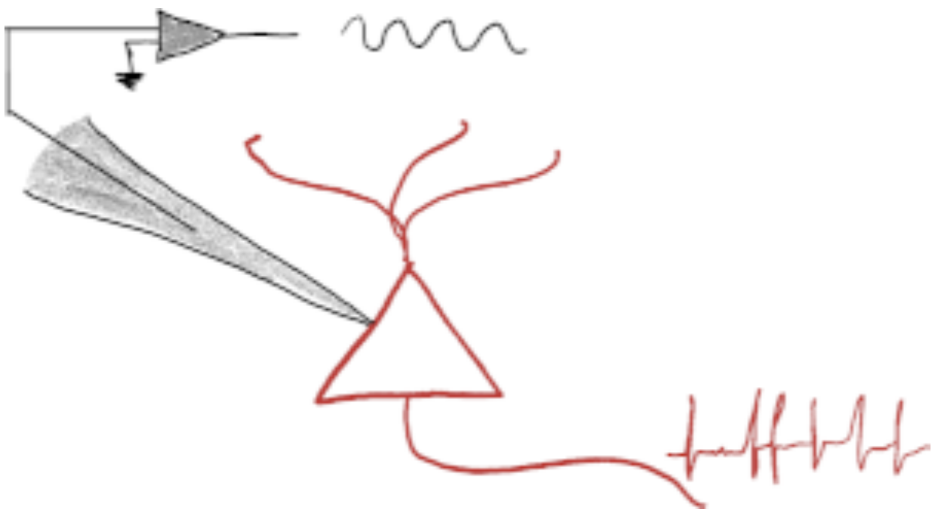
Sakai and Miyashita, 1991

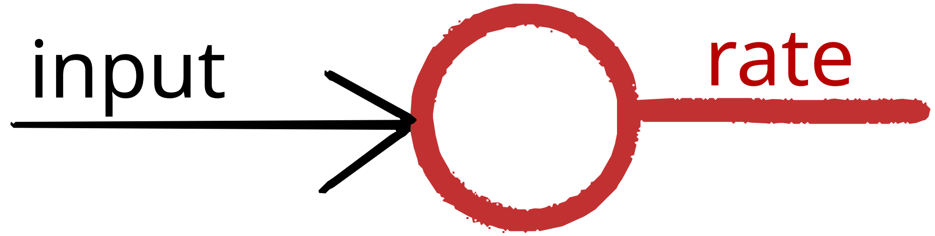
Decision making



Shadlen and Newsome, 2001

The basic unit: the neuron



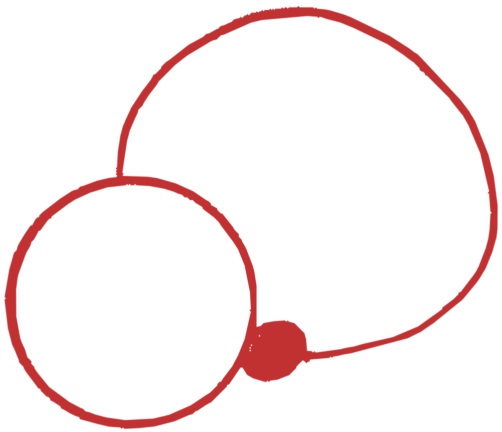


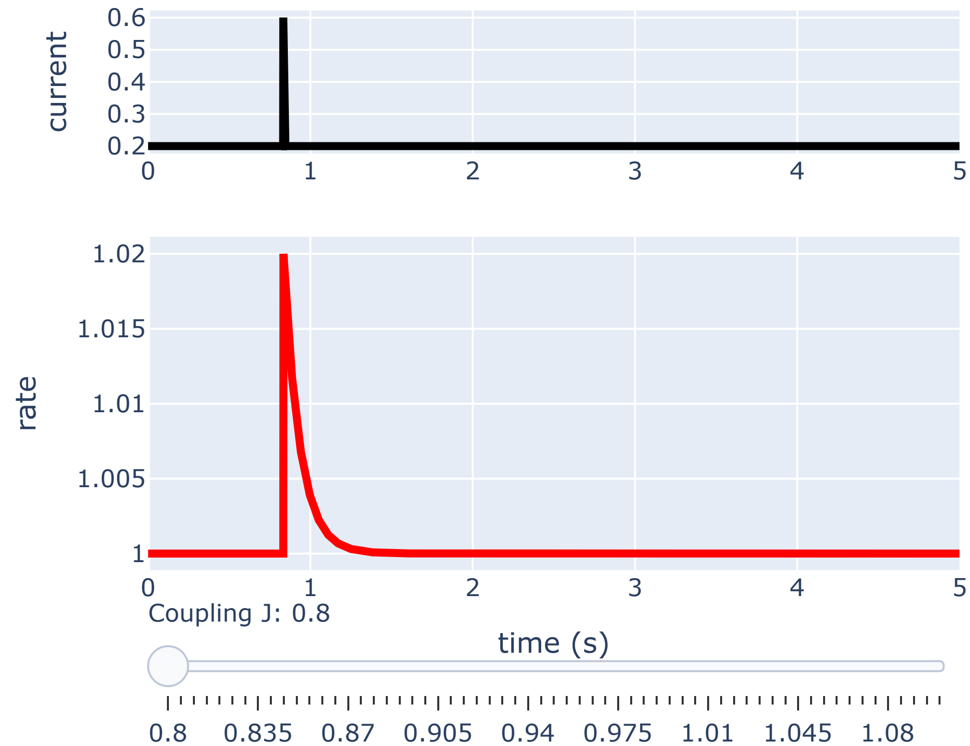
$$\tau \frac{dr(t)}{dt} = -r(t) + I(t)$$

Euler method:

$$\tau \frac{r(t+dt) - r(t)}{dt} = -r(t) + I(t) \quad \Rightarrow \quad r(t+dt) = r(t) + \frac{dt}{\tau}[-r(t) + I($$

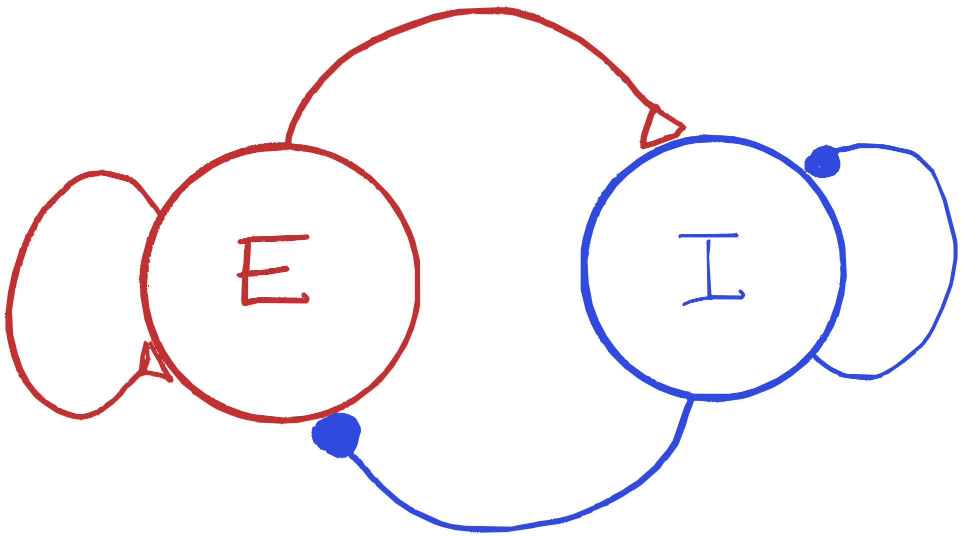
Recurrent excitation in cortex

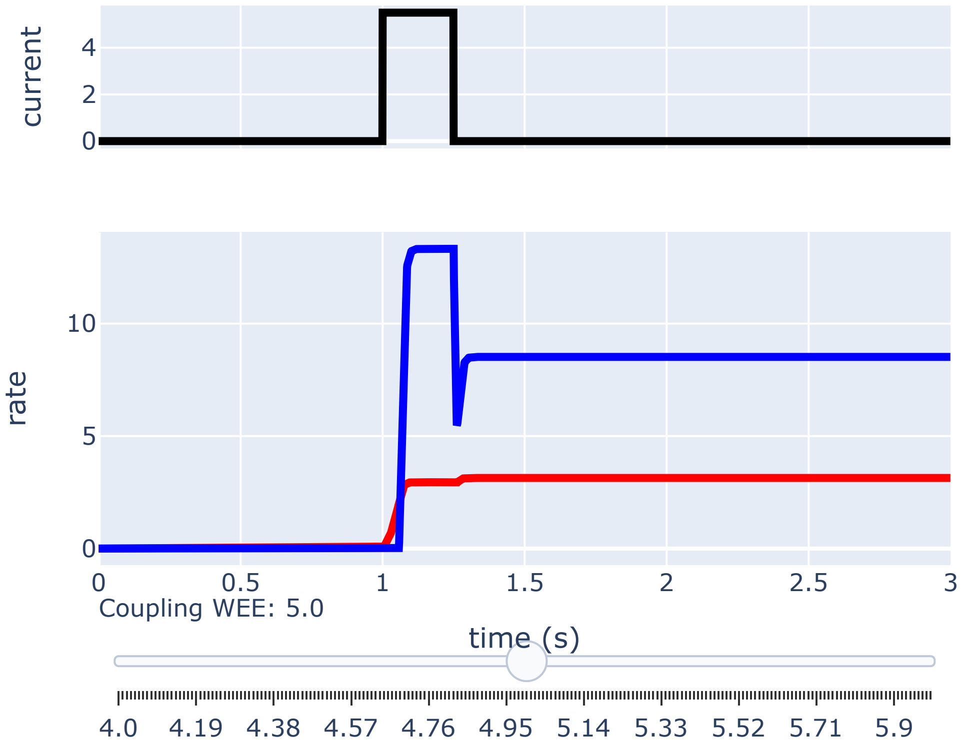




$$\tau \frac{dr}{dt} = -r + Jr$$

E-I network



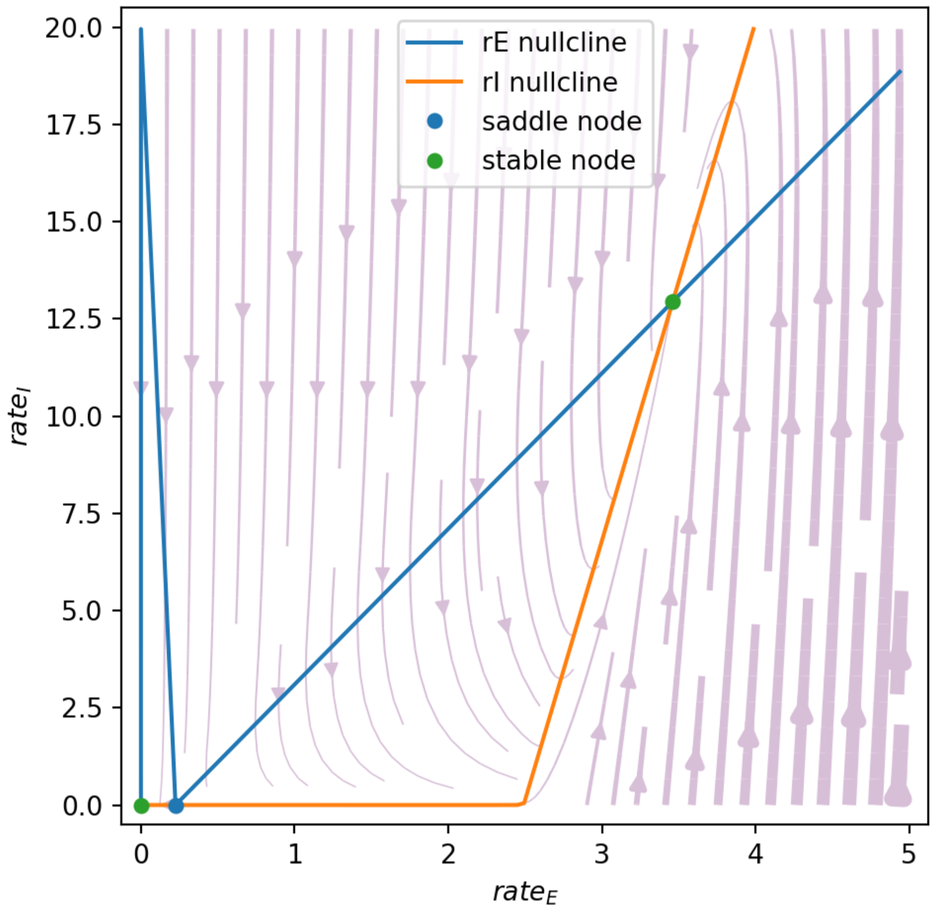


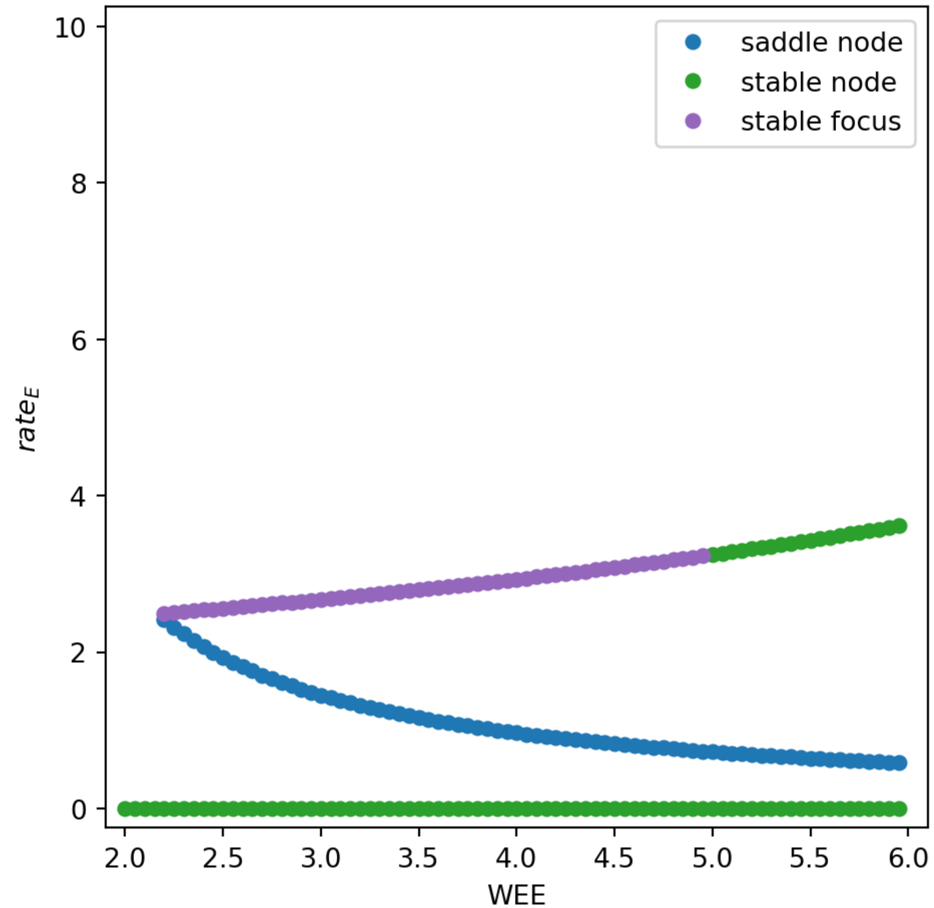
$$\tau_E \frac{dr_E(t)}{dt} = -r_E(t) + G_E[W_{EE} r_E(t) - W_{EI} r_I(t) + I_E(t) - \theta_E]_+$$

$$\tau_I \frac{dr_I(t)}{dt} = -r_I(t) + G_I[W_{IE} r_E(t) - W_{II} r_I(t) + I_I(t) - \theta_I]_+$$

Wilson and Cowan, 1972

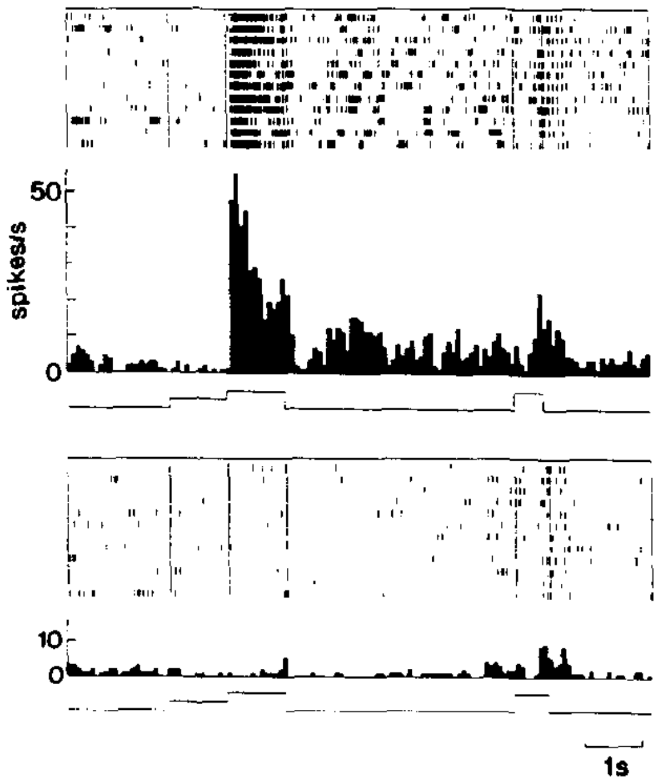
Phase-space analysis

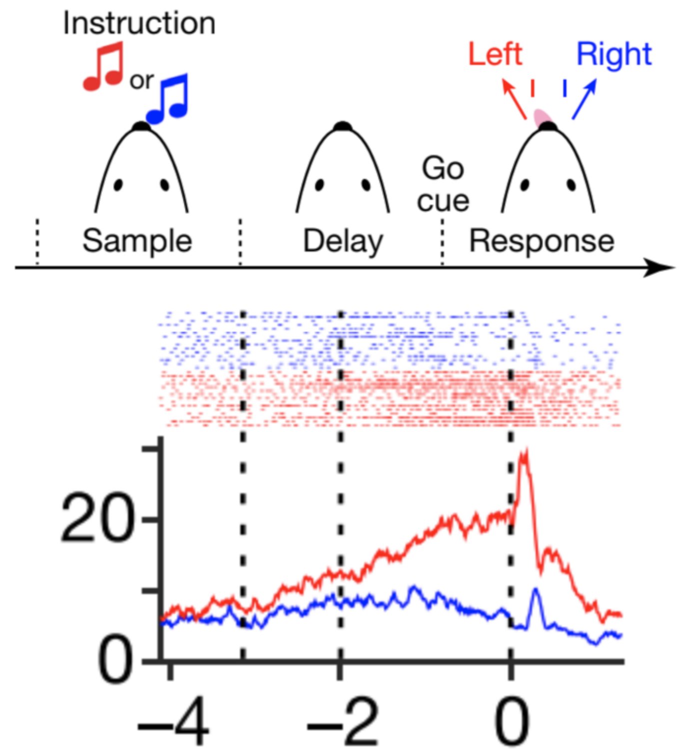




Brainpy: Wang et al 2023

Discrete working memory

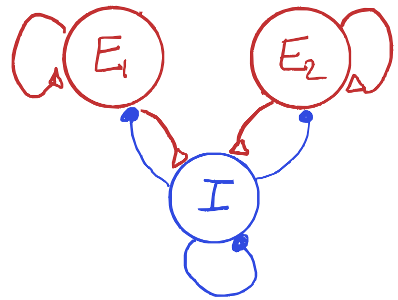




Sakai and Miyashita, 1991

Inagaki et al, 2019

The double-well model

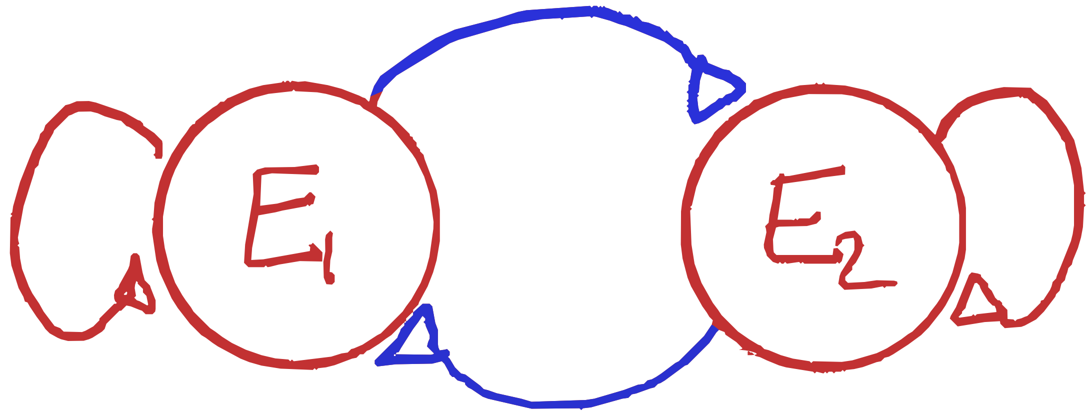


$$\tau_E \frac{dI_{E1}(t)}{dt} = -I_{E1}(t) + W_{EE}\, g_E(I_{E1}(t)) - W_{EI}\, g_I(I_I(t)) + S_1(t)$$

$$\tau_E \frac{dI_{E2}(t)}{dt} = -I_{E2}(t) + W_{EE}\, g_E(I_{E2}(t)) - W_{EI}\, g_I(I_I(t)) + S_2(t)$$

$$\tau_I \frac{dI_I(t)}{dt} = -I_I(t) + W_{IE}\, g_E(I_{E1}(t)) + W_{IE}\, g_E(I_{E2}(t)) - W_{II}\, I_I(t)$$

The double-well model

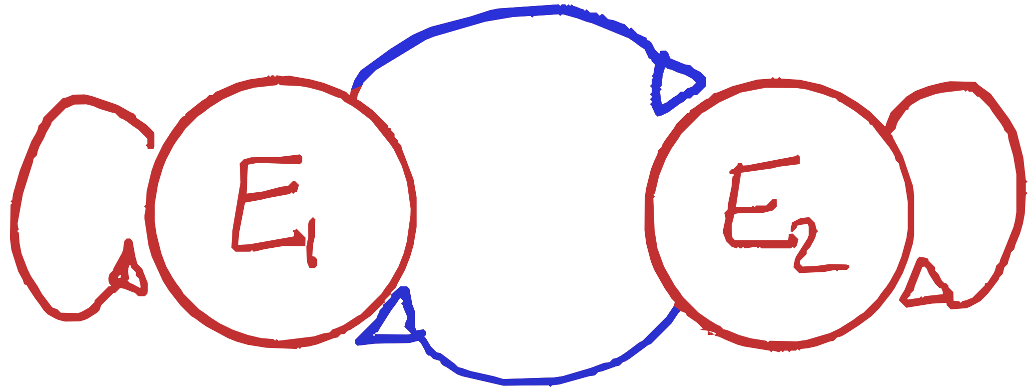


$$\tau_E \frac{dI_{E1}}{dt} = -I_{E1} + (W_{EE} - \alpha) g_E(I_{E1}) - \alpha g_E(I_{E2}) + S_1$$

$$\tau_E \frac{dI_{E2}}{dt} = -I_{E2} + (W_{EE} - \alpha) g_E(I_{E2}) - \alpha g_E(I_{E1}) + S_2$$

$$\alpha = -\gamma W_{EI} W_{IE}$$

The double-well model

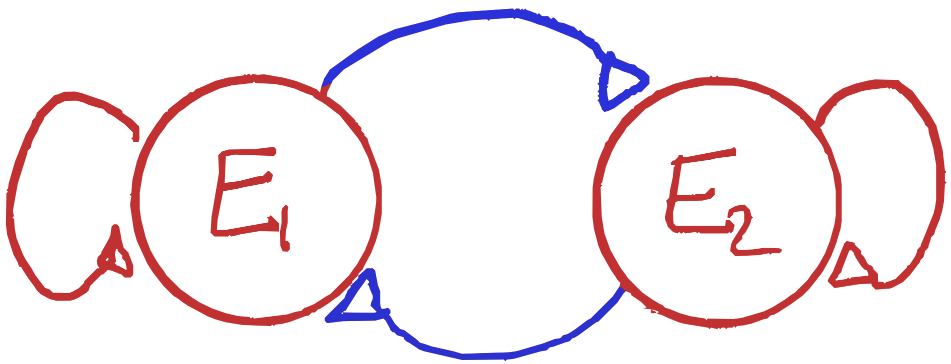


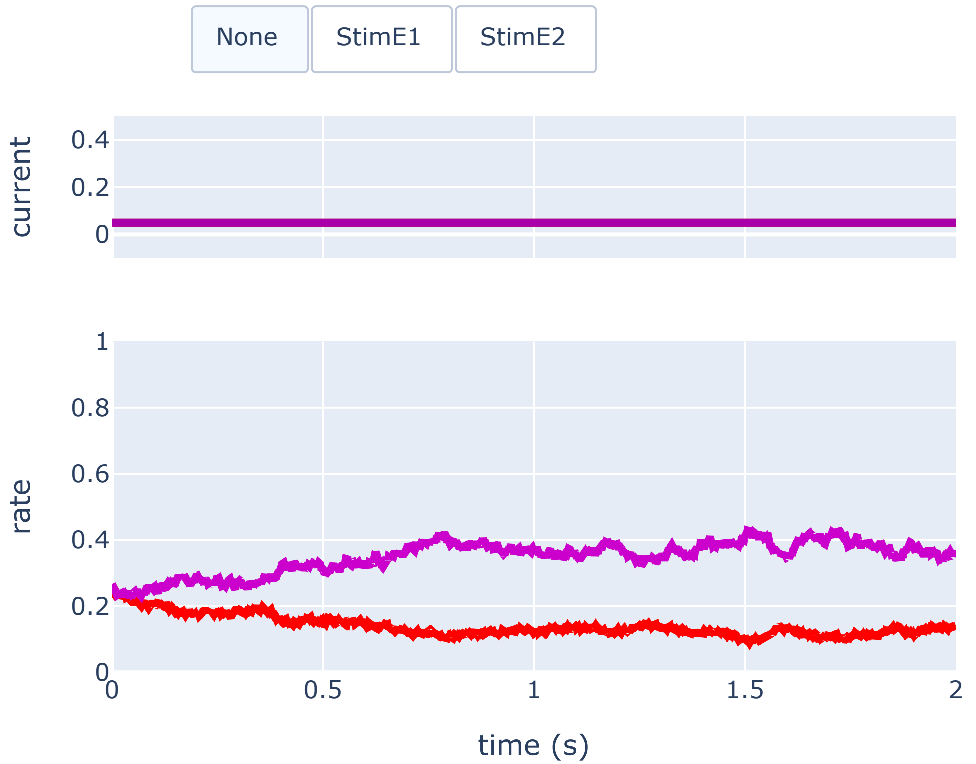
$$\tau_E \frac{dI_{E1}}{dt} = -I_{E1} + J_E g_E(I_{E1}) - J_I g_E(I_{E2}) + S_1$$

$$\tau_E \frac{dI_{E2}}{dt} = -I_{E2} + J_E g_E(I_{E2}) - J_I g_E(I_{E1}) + S_2$$

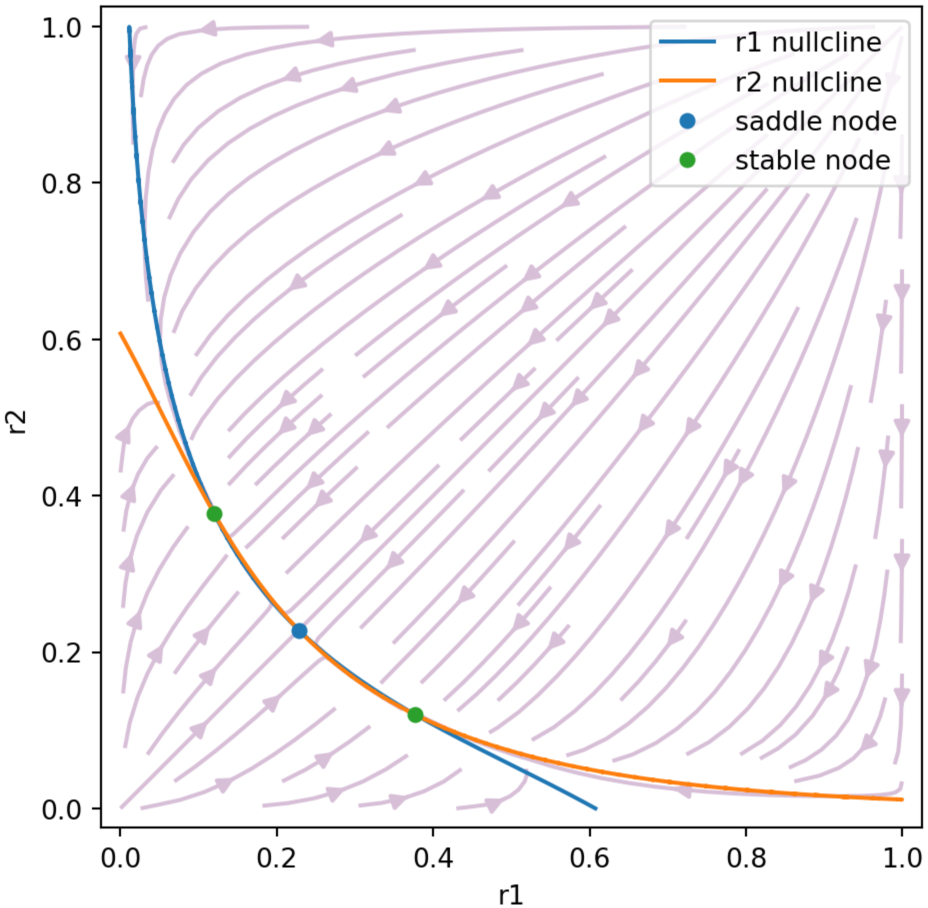
Wong and Wang 2006

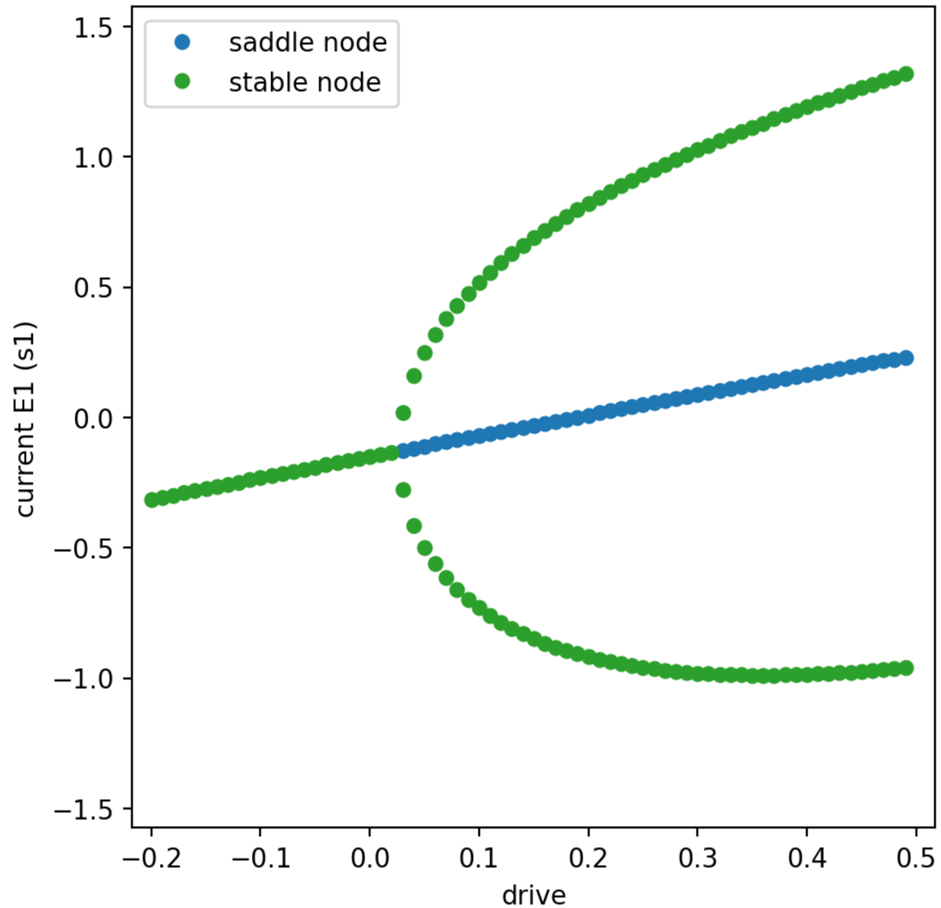
Selective memory



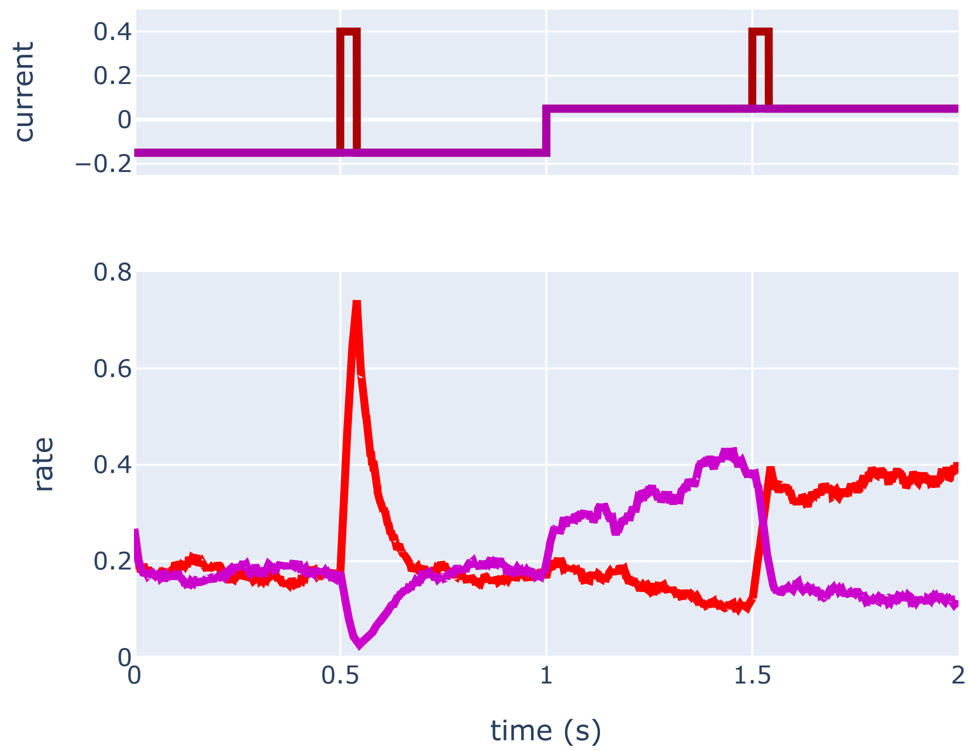


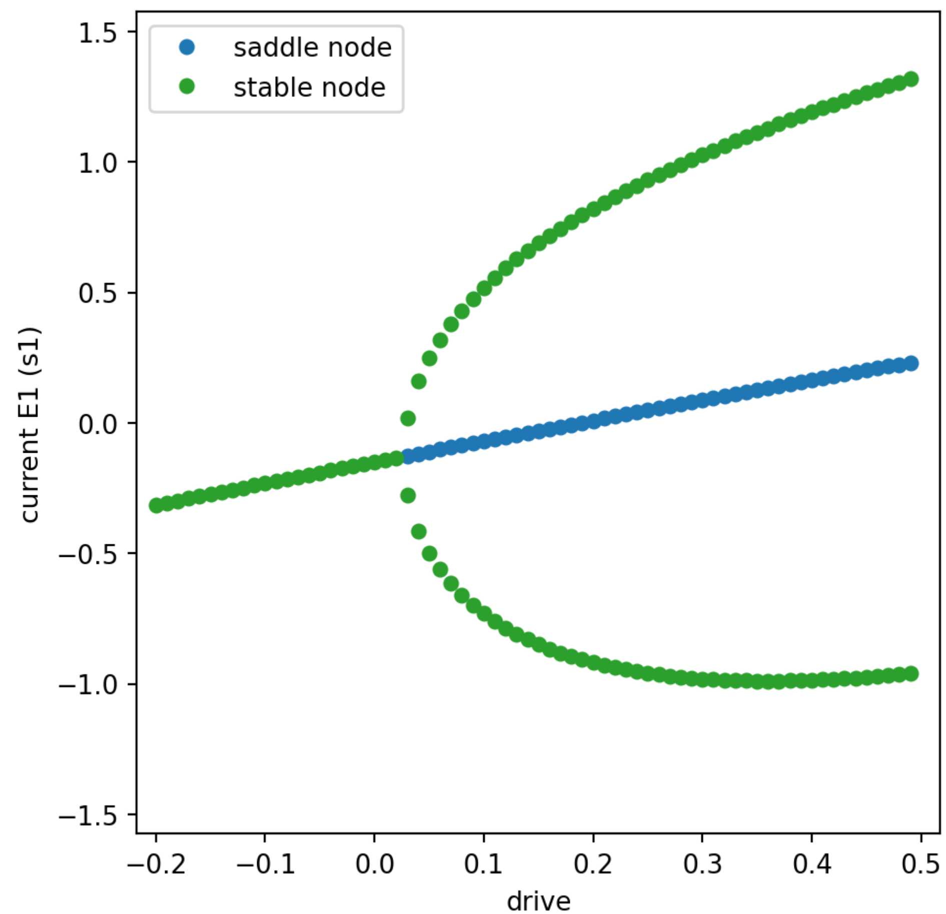
Double-well: Phase-space analysis





Drive modulates network function

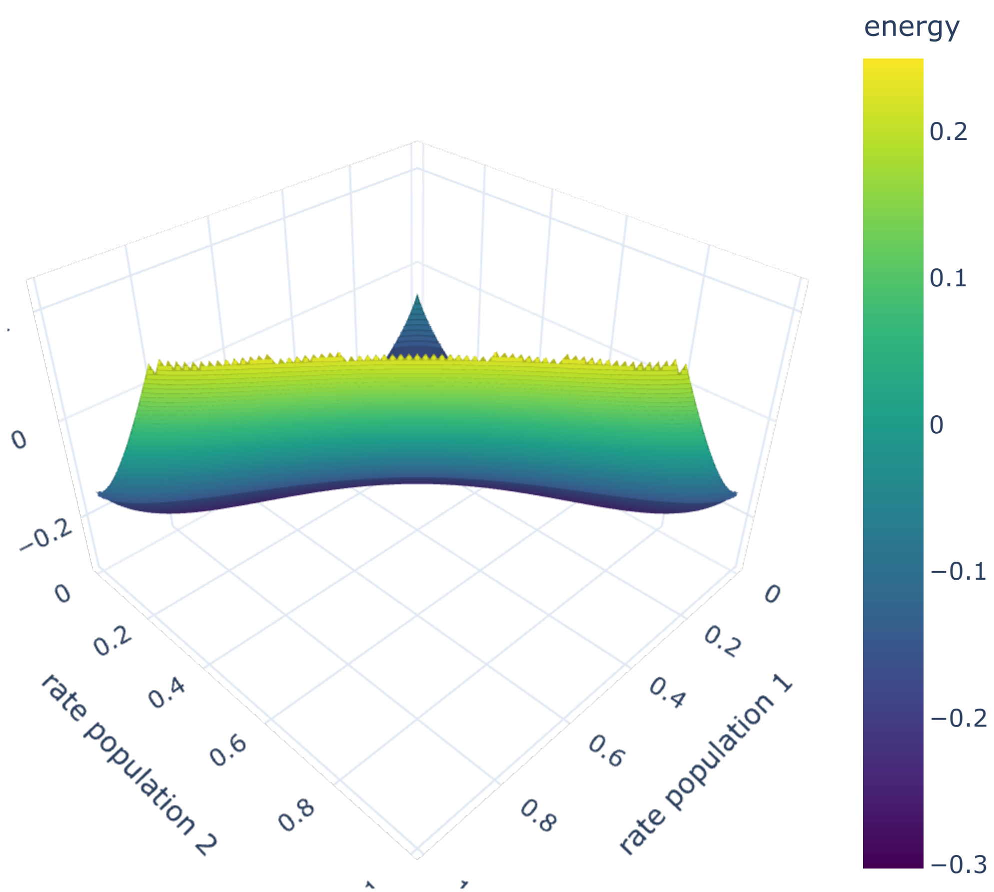


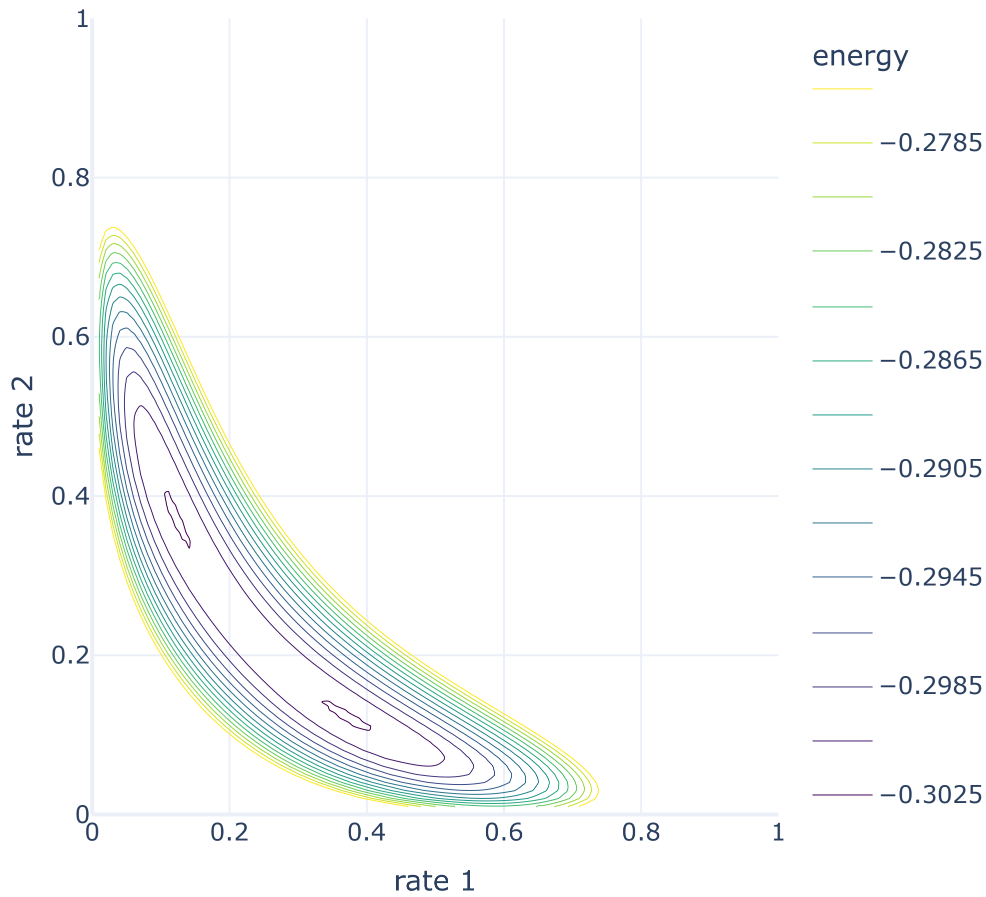


Double-well: Energy landscape

$$E(r_1,r_2) = -\frac{J_E}{2}(r_1^2 + r_2^2) + J_I r_1 r_2 - S(r_1 + r_2) + \int_0^{r_1} g_E^{-1}(x)dx + \int_0^{r_2} g_E^{-1}(x)dx$$

Gerstner et al, 2014

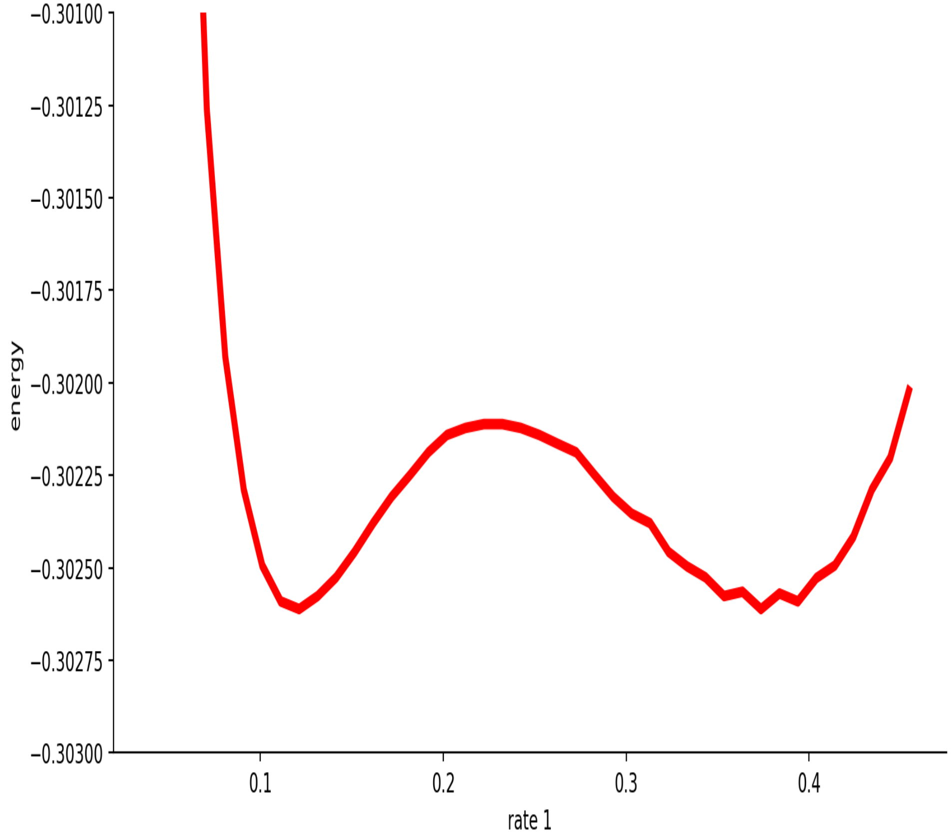


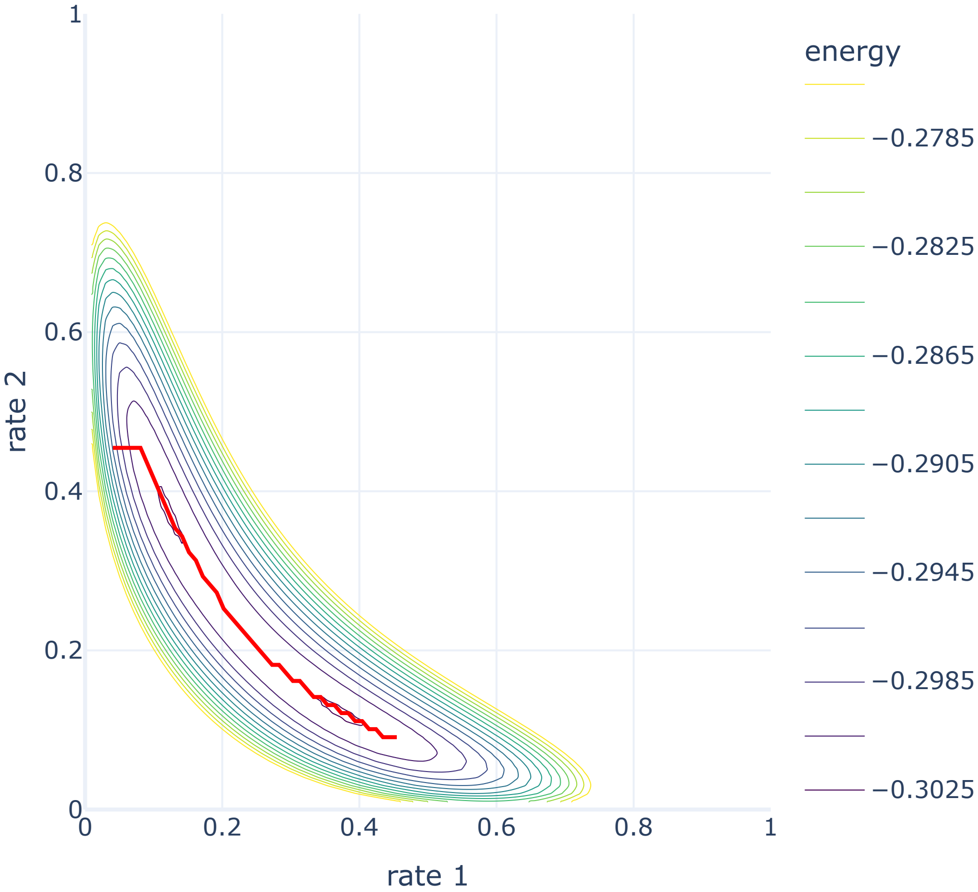


Double-well: Energy landscape

$$E(r_1,r_2)=-\frac{J_E}{2}(r_1^2+r_2^2)+J_I r_1 r_2-S(r_1+r_2)+\int_0^{r_1} g_E^{-1}(x)dx+\int_0^{r_2} g_E^{-1}(x)dx$$

Gerstner et al, 2014





Experimental evidence

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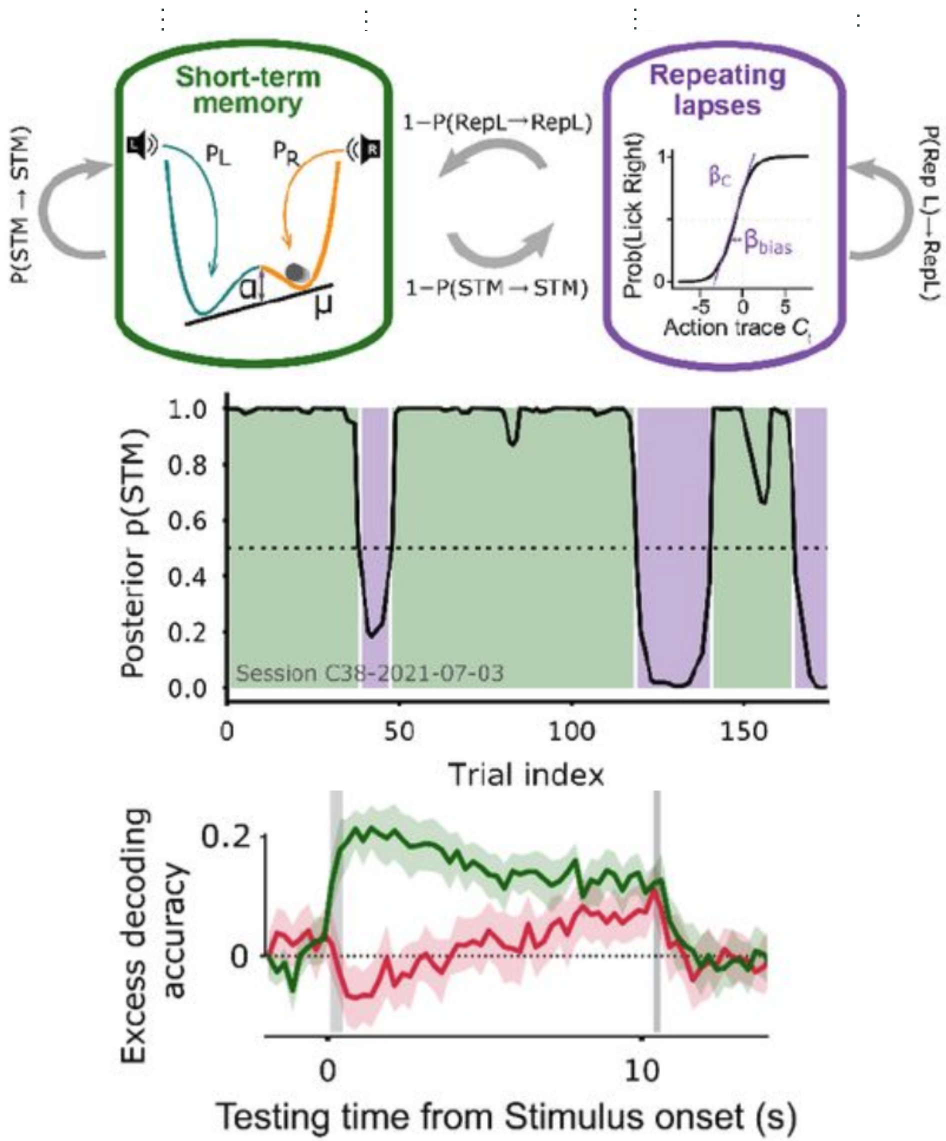

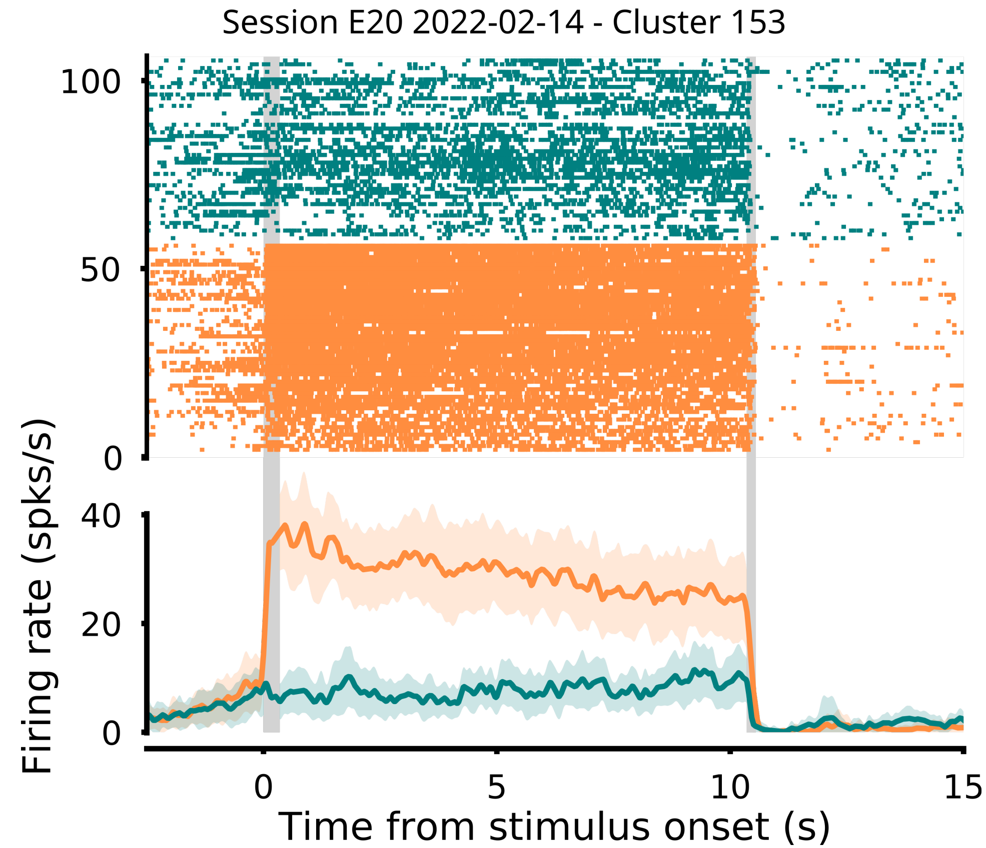

(Ona-Jodar et al. bioRxiv 2025)

End of part 1!