PANERIS Winter School: Basics of Computational Neuroscience

Neural network simulations of simple cognitive functions

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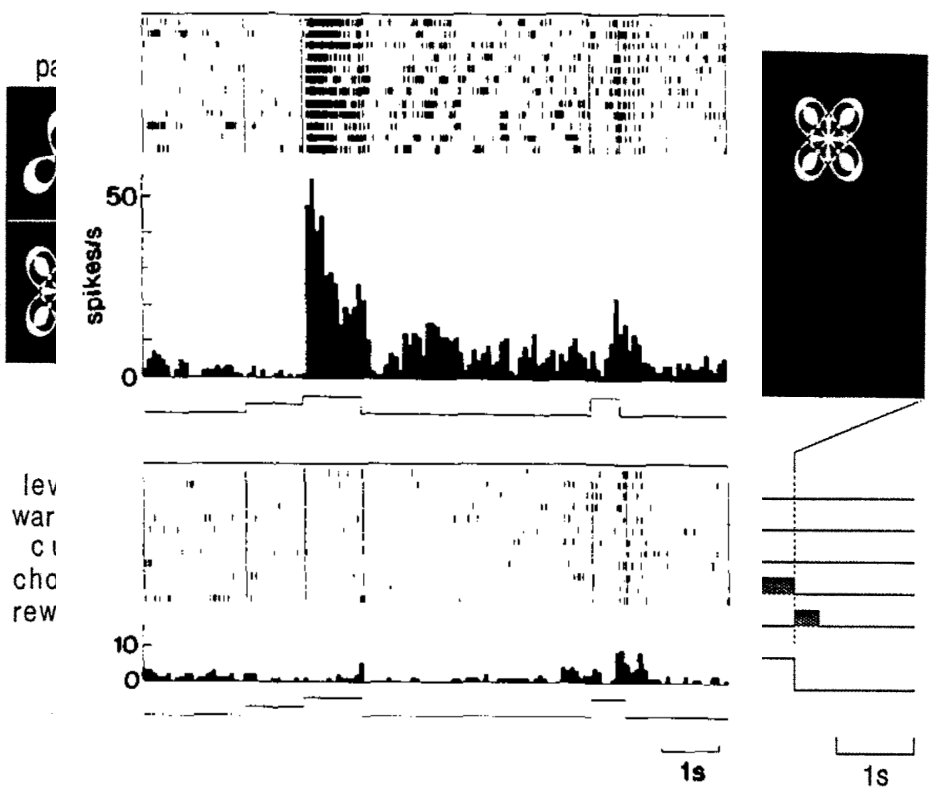
- cortical networks:
  - EI networks: Wilson and Cowan, 1972
  - Inhibition-stabilized networks: Tsodyks et al, 1997; Ozeki et al, 2009
- discrete attractor networks: Amit and Brunel, 1997; Wang, 2002; Wong and Wang, 2006; Roxin and Ledberg, 2008
- ring attractor networks: Wilson and Cowan, 1973; Amari,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

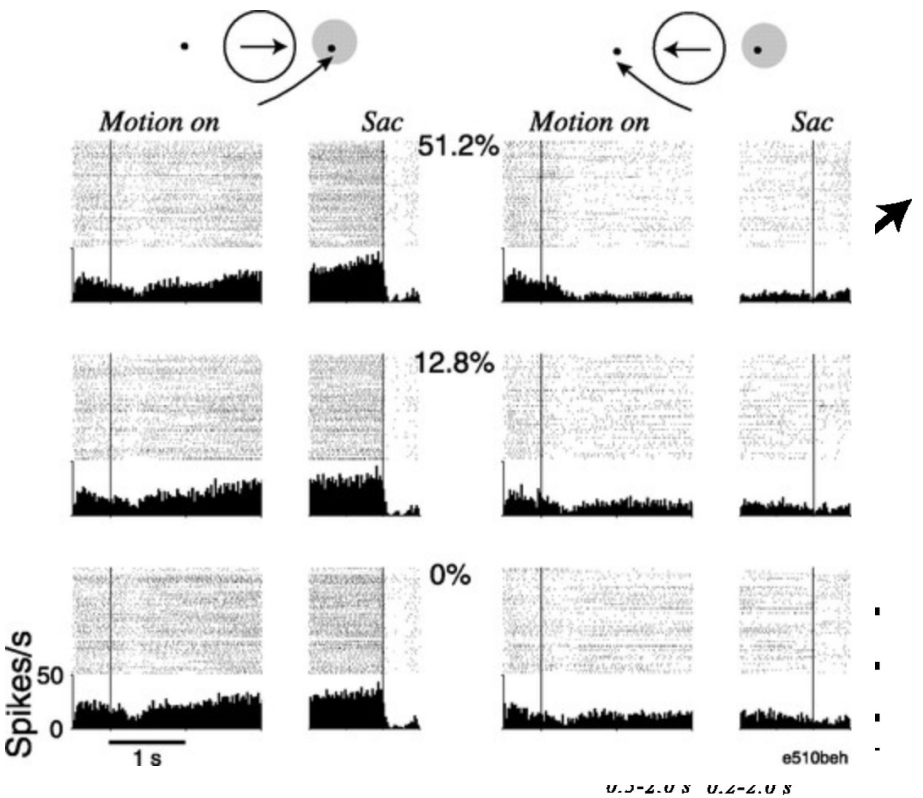
Neural basis of cognition

Working memory



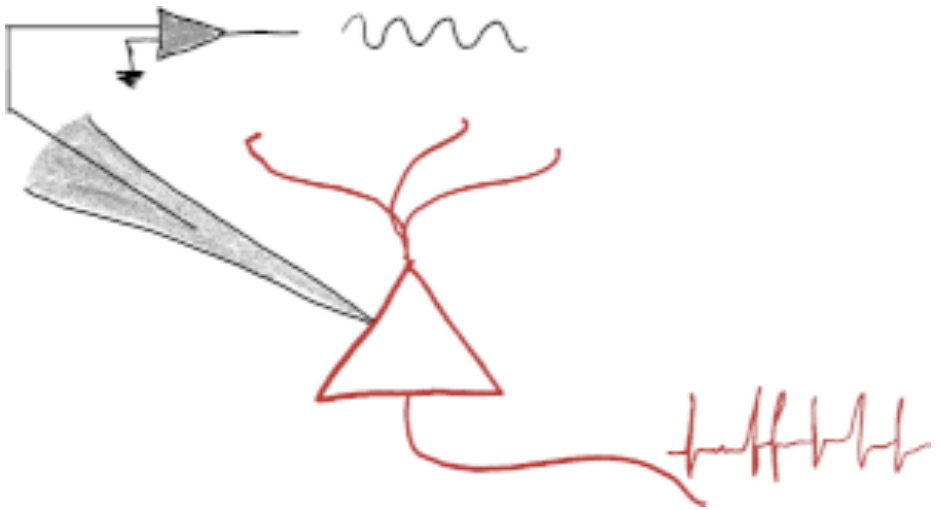
Sakai and Miyashita, 1991

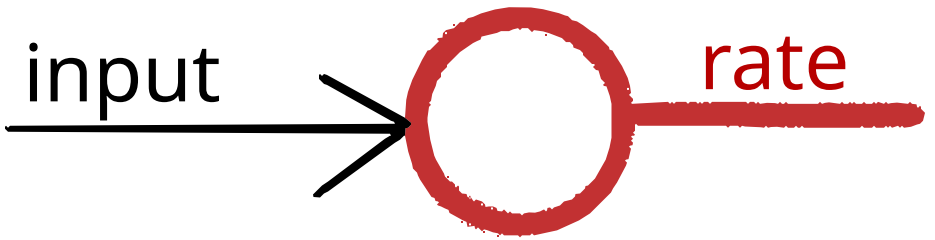
Decision making



Shadlen and Newsome, 2001

The basic unit: the neuron



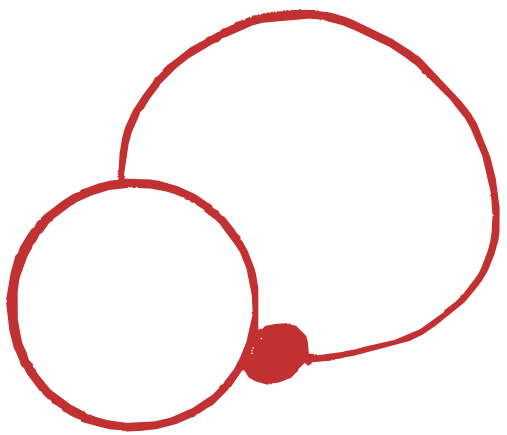


$$\tau \frac{dr(t)}{dt} = -r(t) + I(t)$$

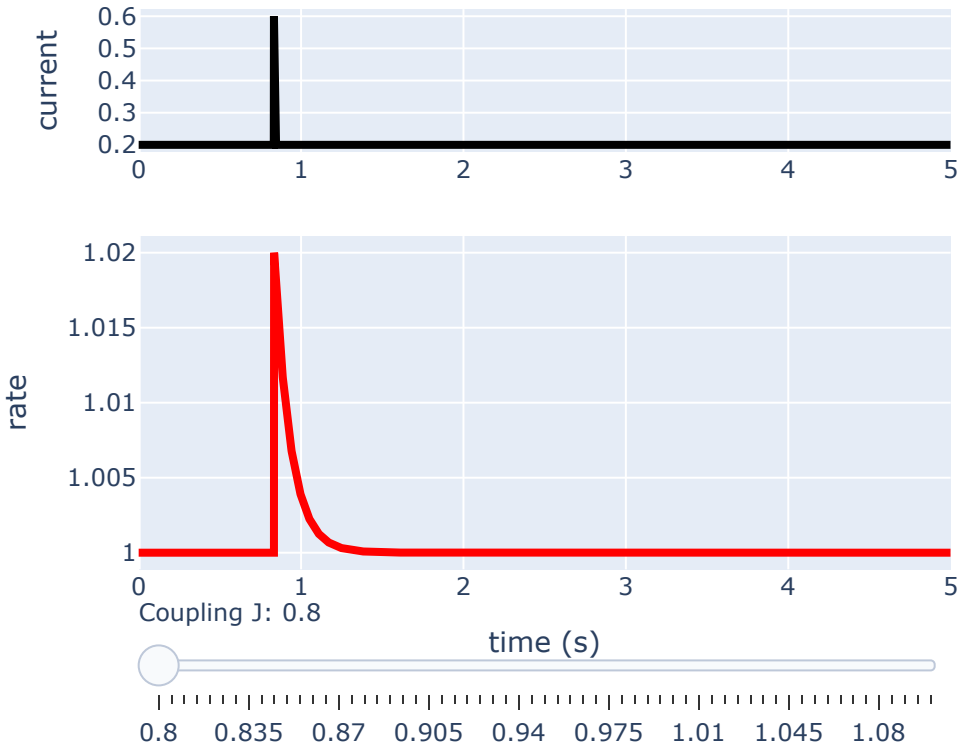
Euler method:

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

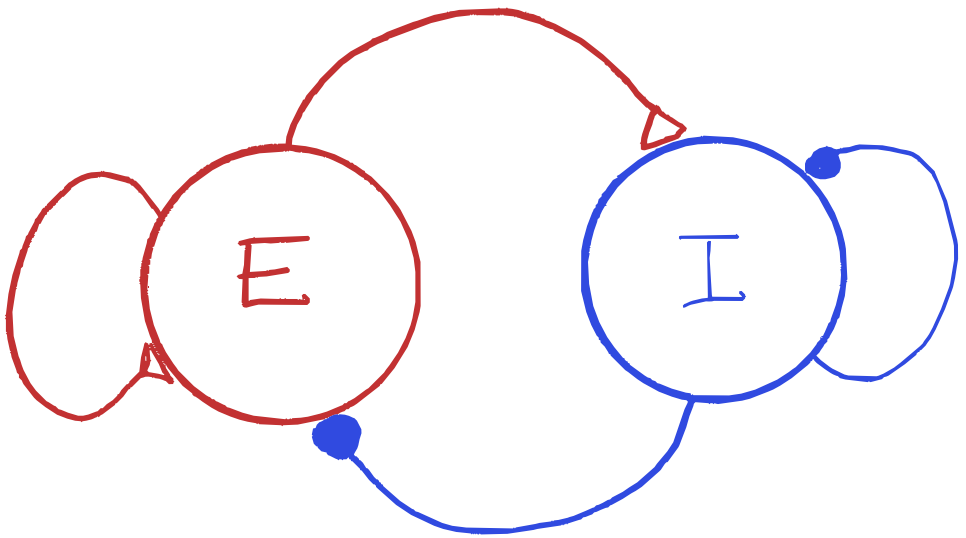
Recurrent excitation in cortex

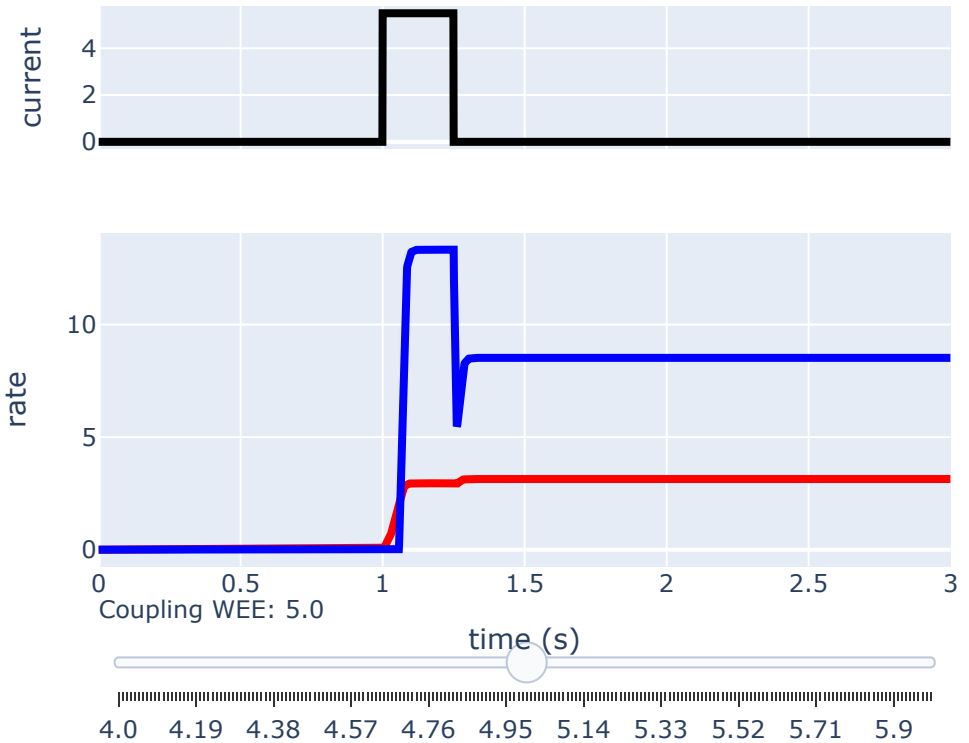


$$\tau \frac{dr}{dt} = -r + Jr$$



E-I network

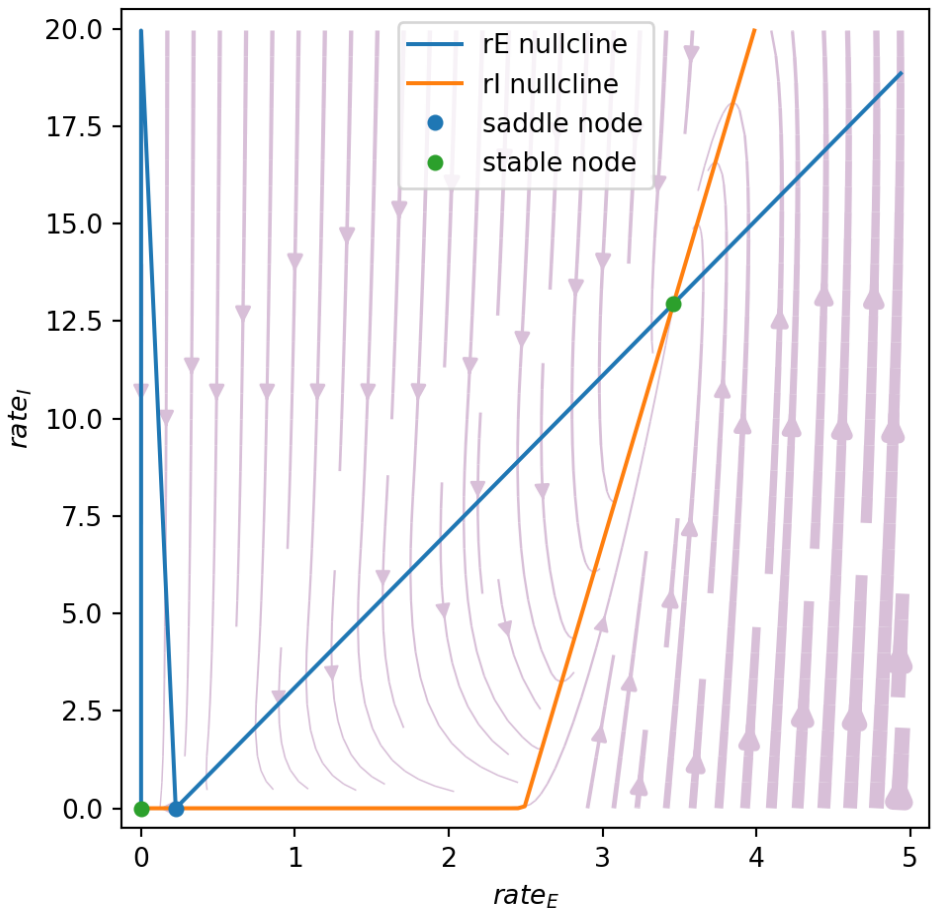


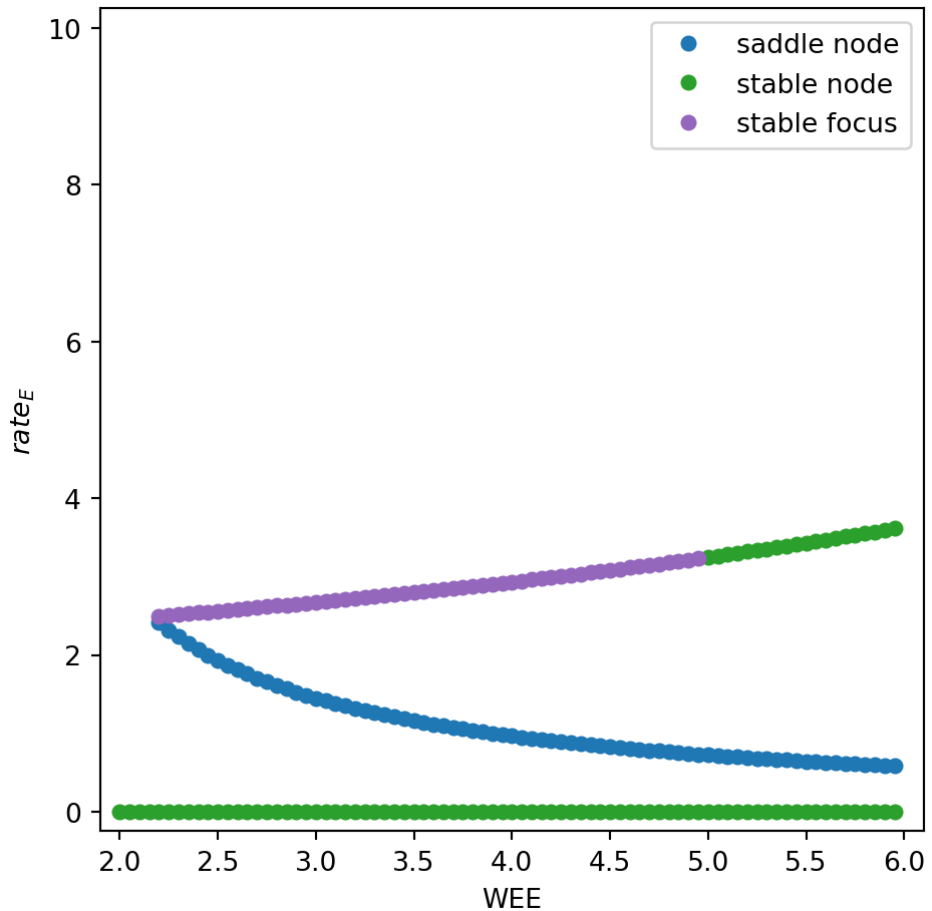


[Math Processing Error]

Wilson and Cowan, 1972

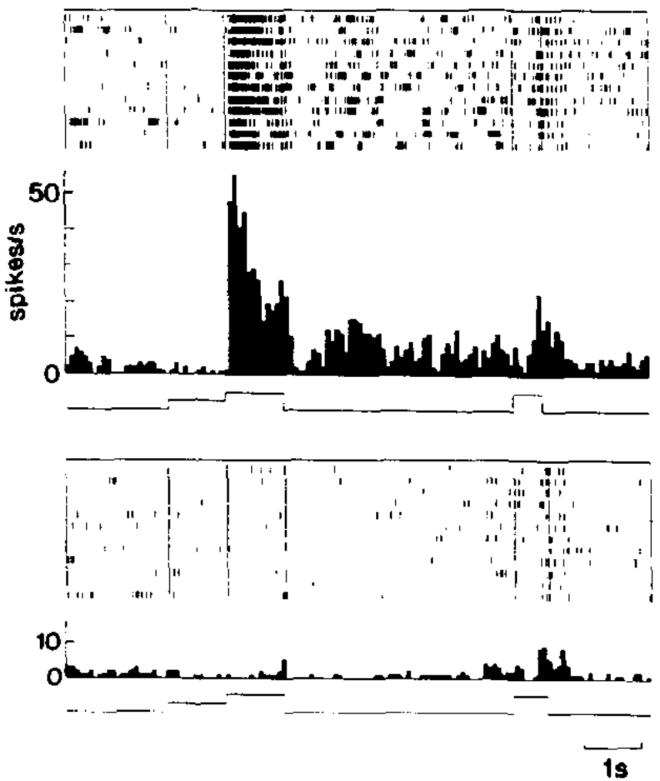
Phase-space analysis



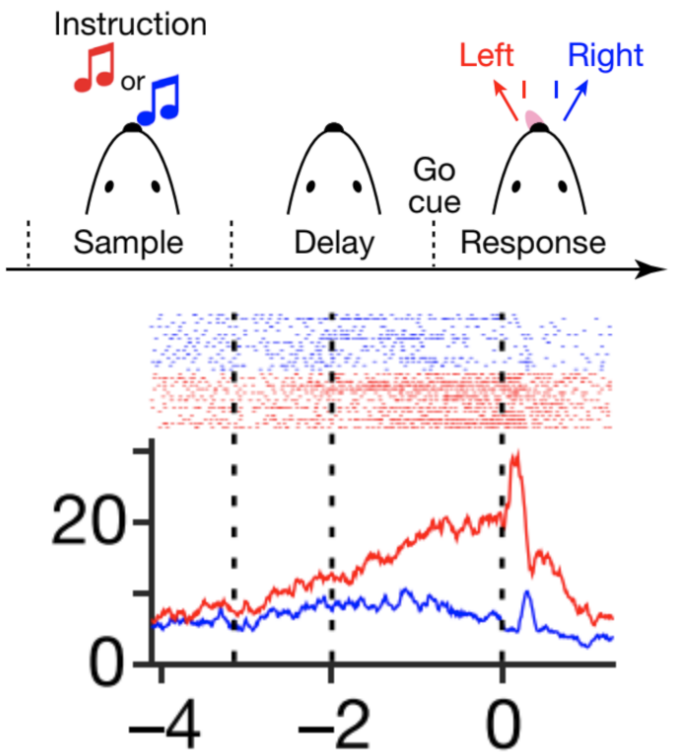


Brainpy: Wang et al 2023

Discrete working memory

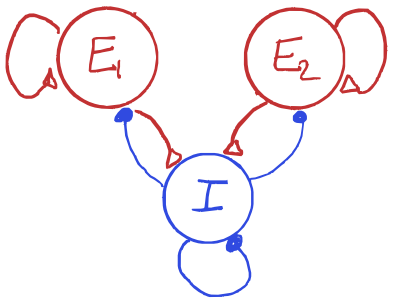


Sakai and Miyashita, 1991



Inagaki et al, 2019

The double-well model



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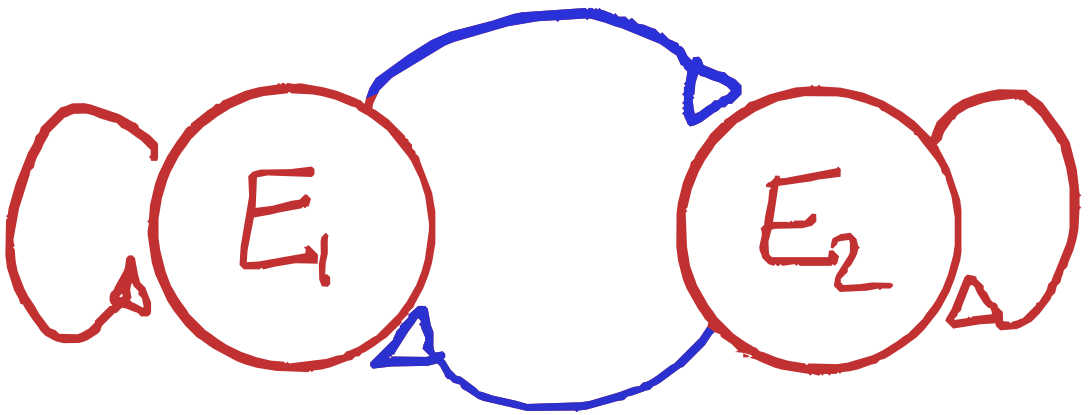

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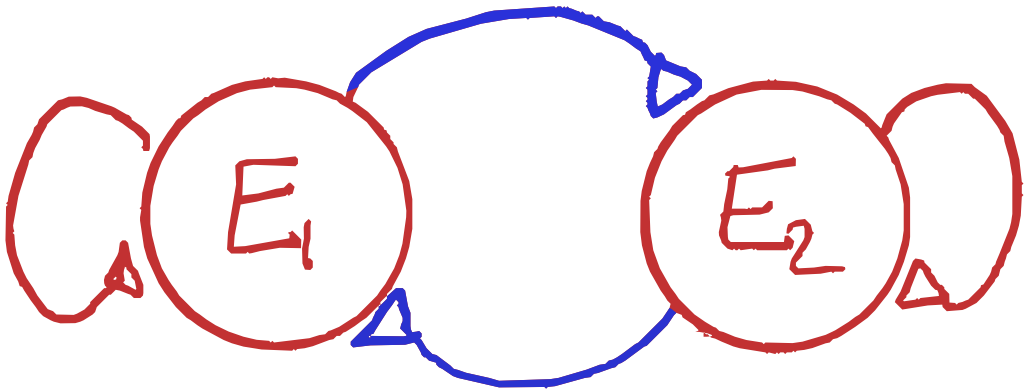

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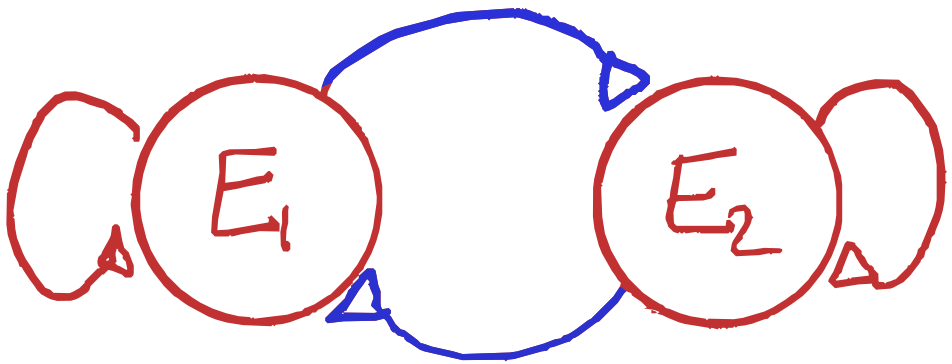
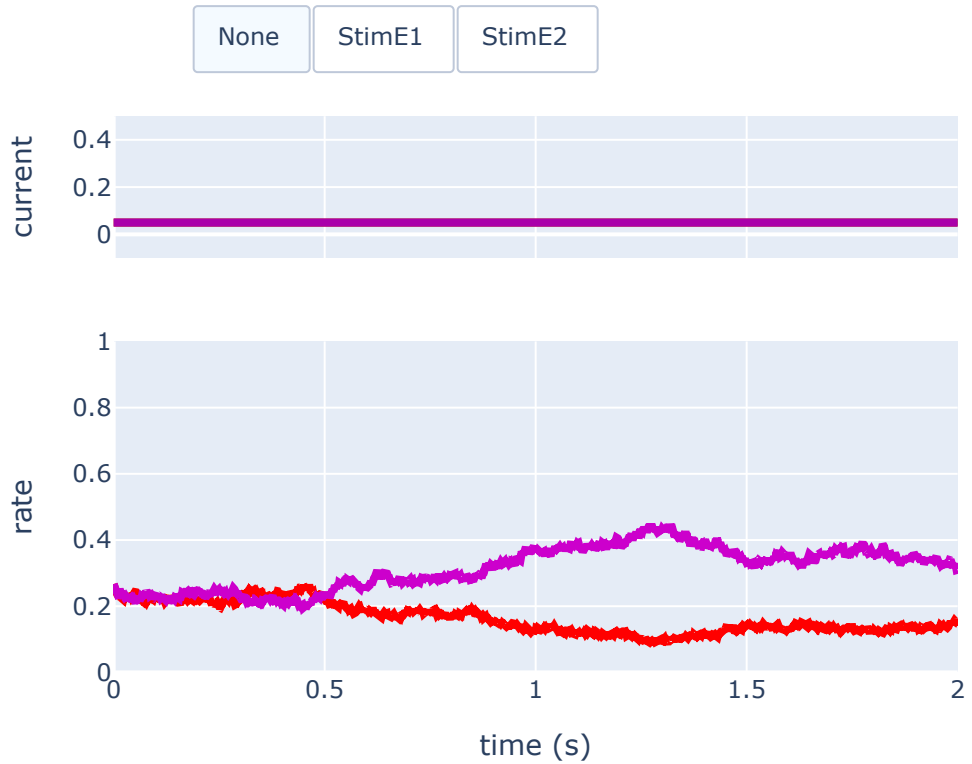
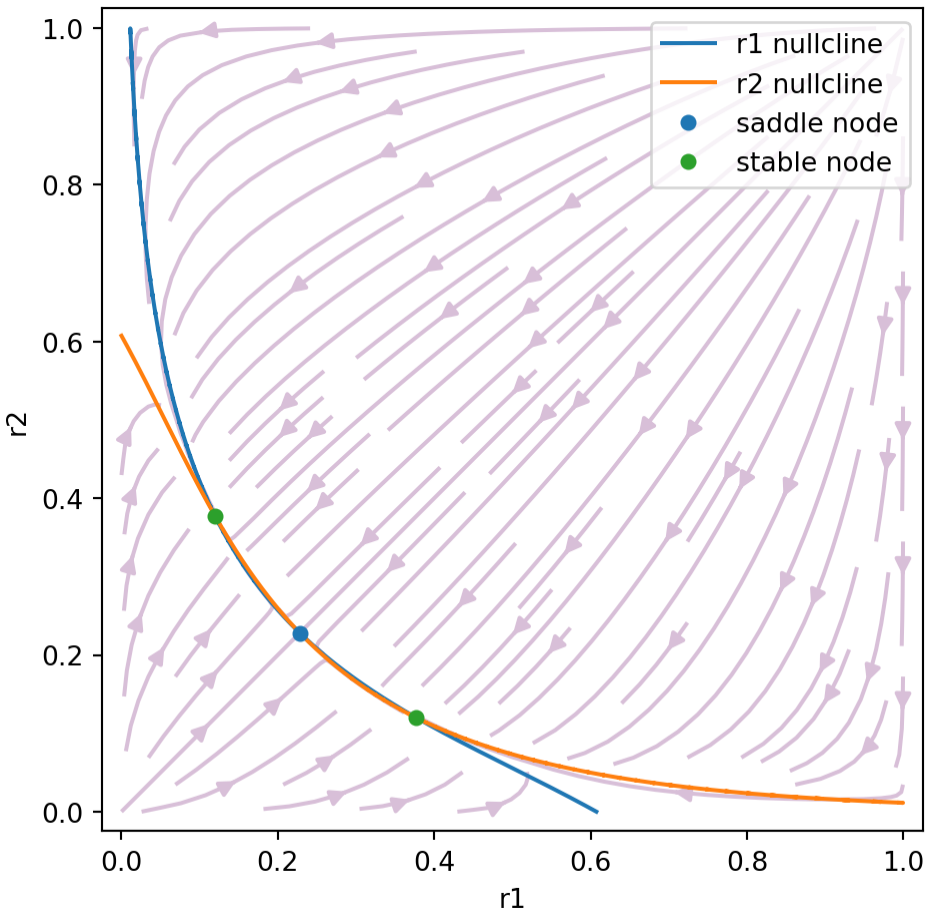
Wong and Wang 2006

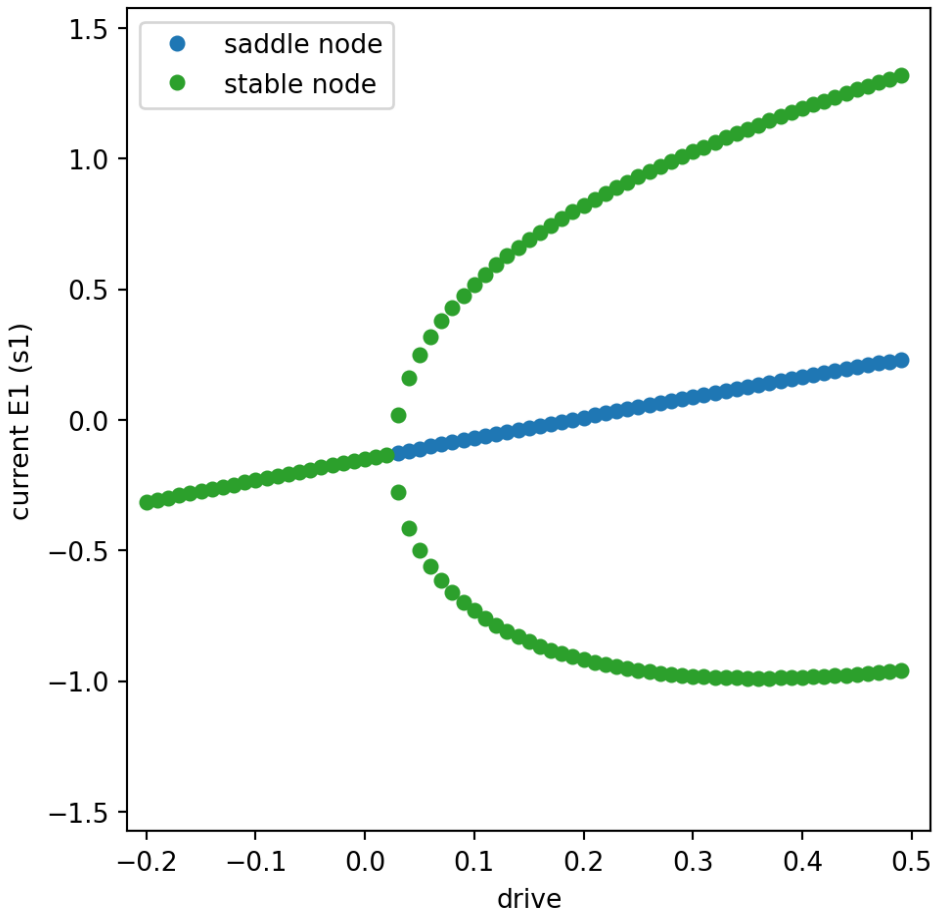
Selective memory



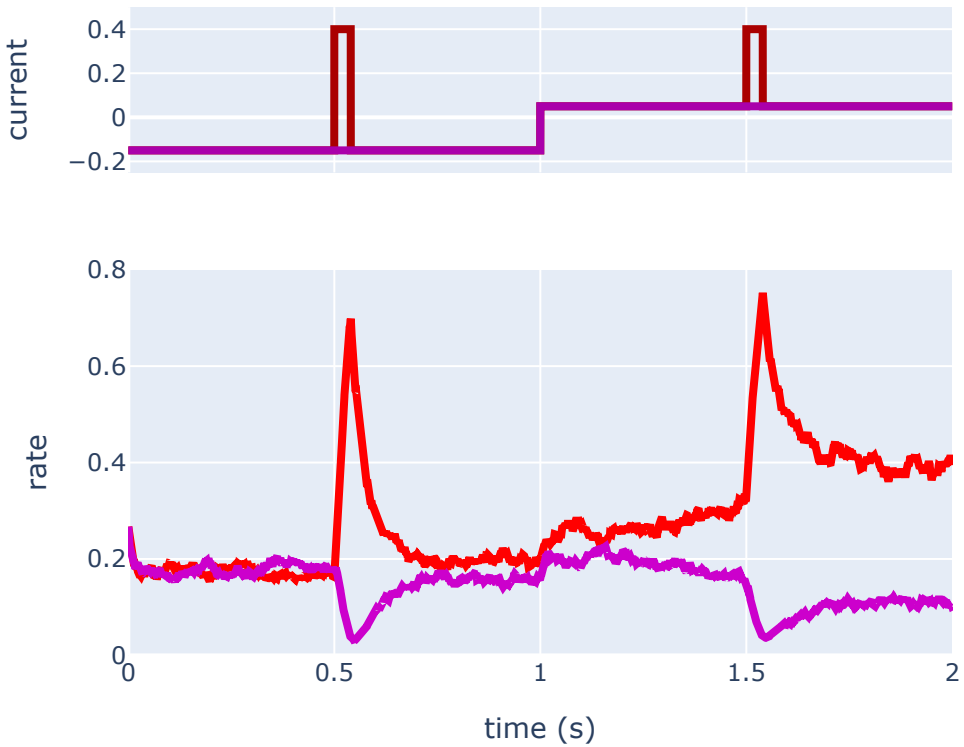


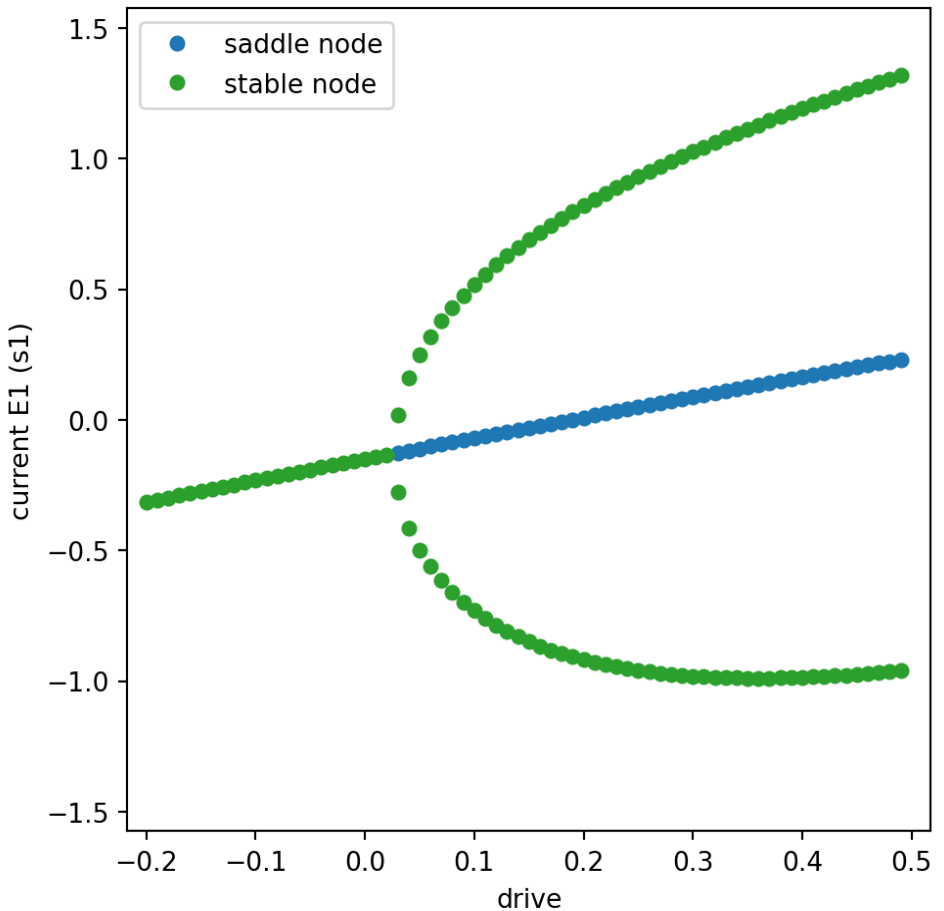
Double-well: Phase-space analysis





Drive modulates network function

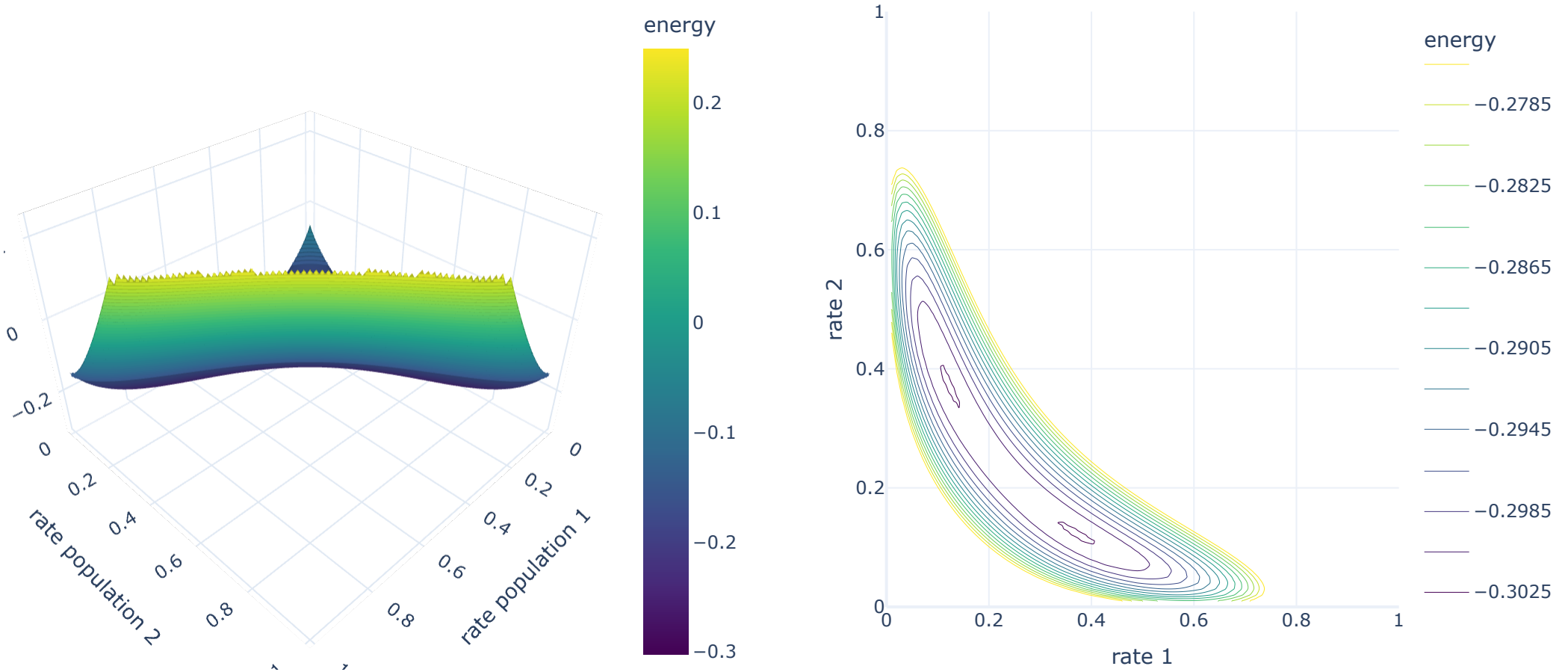




Double-well: Energy landscape

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

Gerstner et al, 2014



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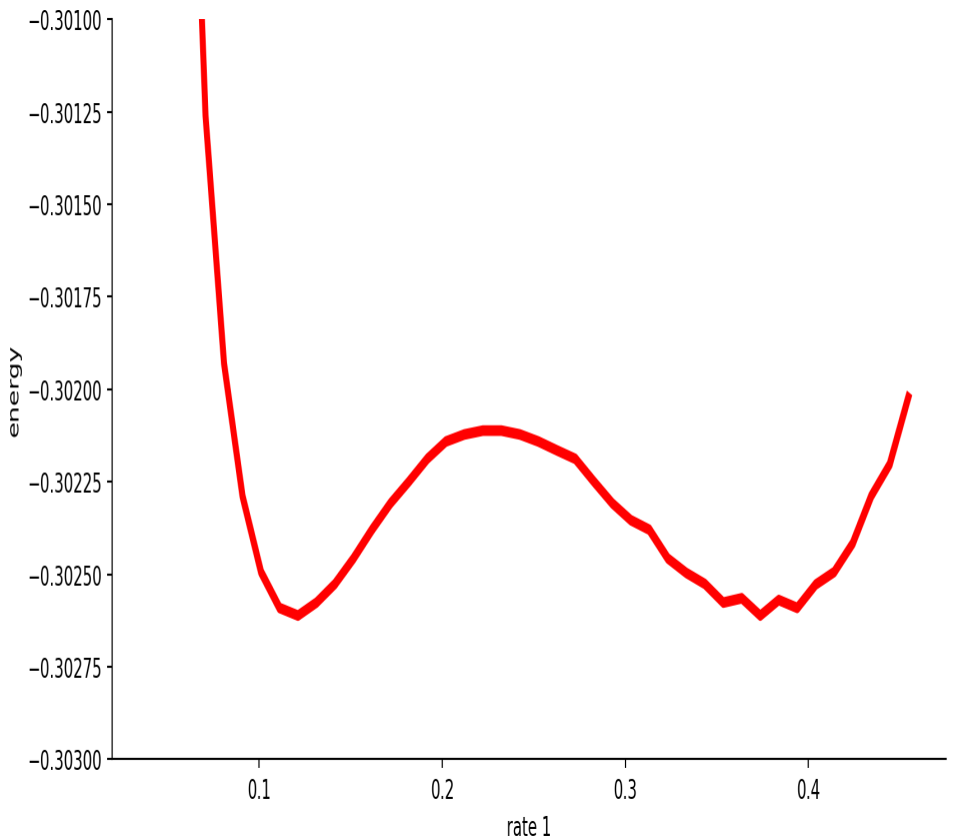
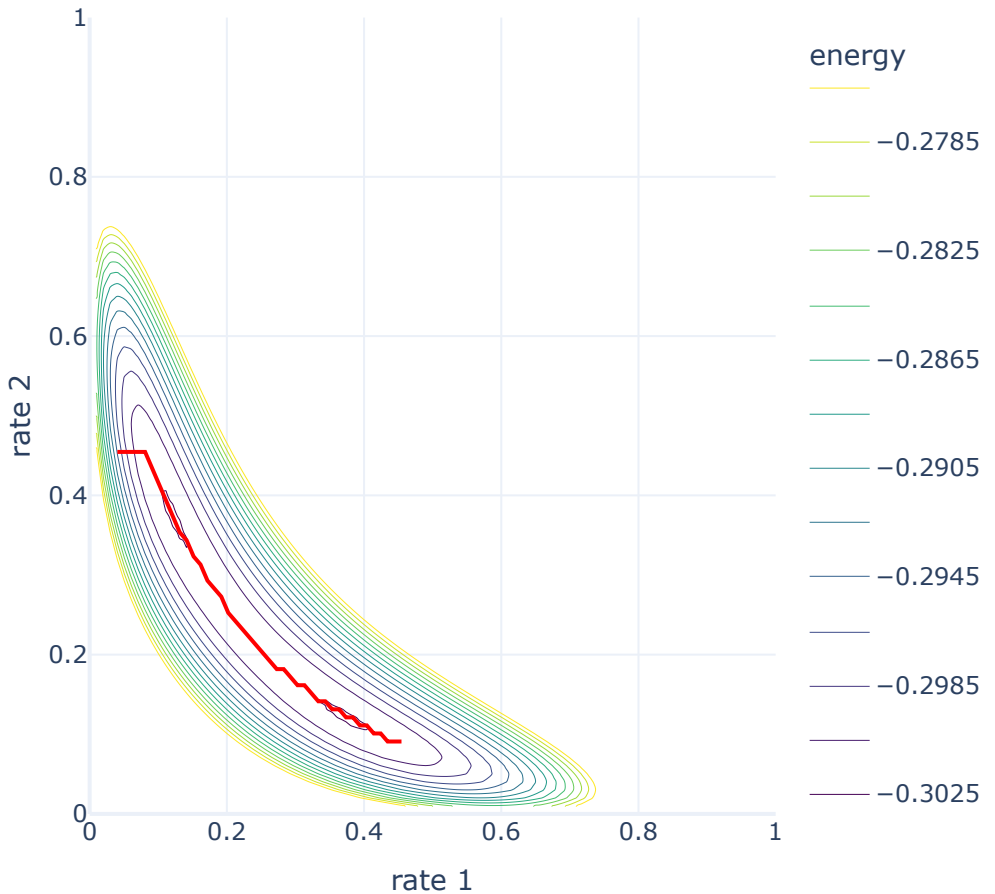
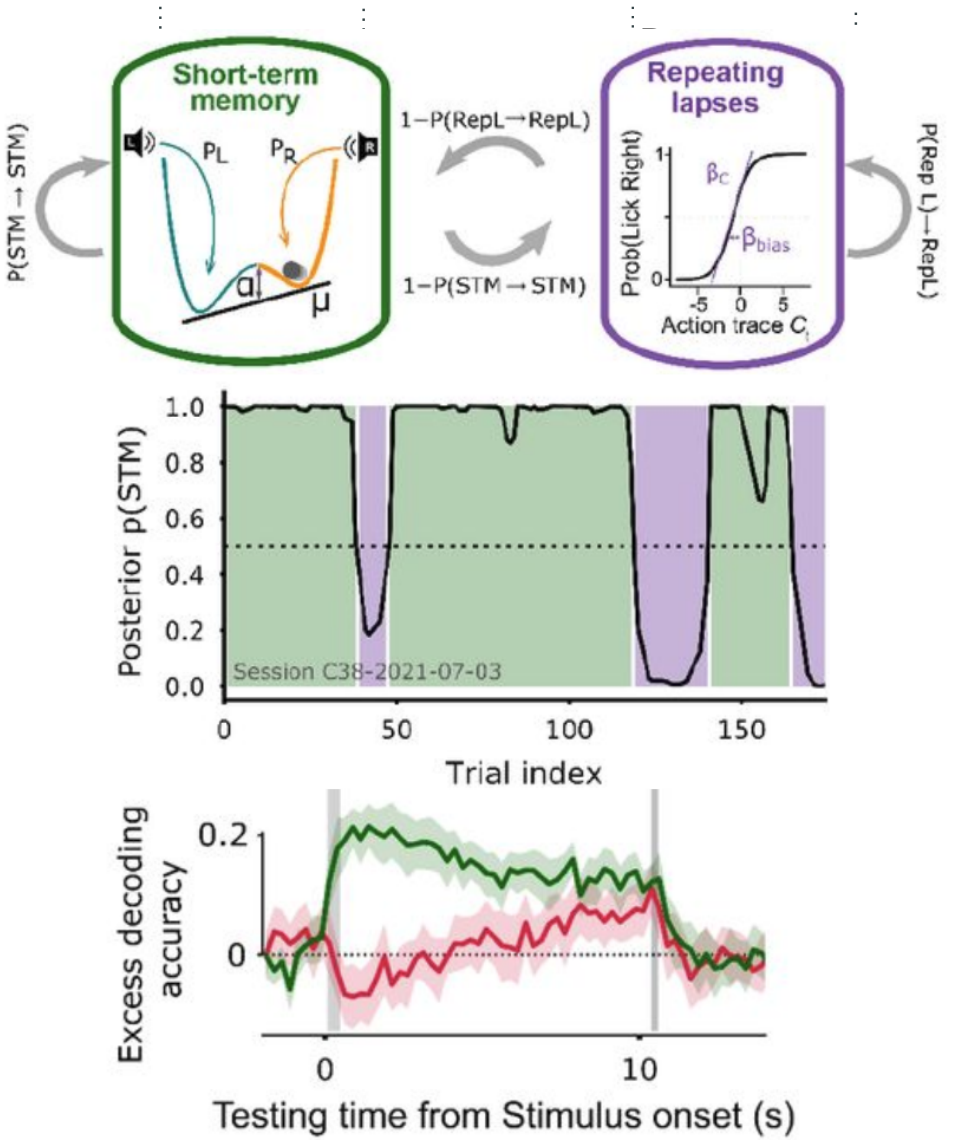
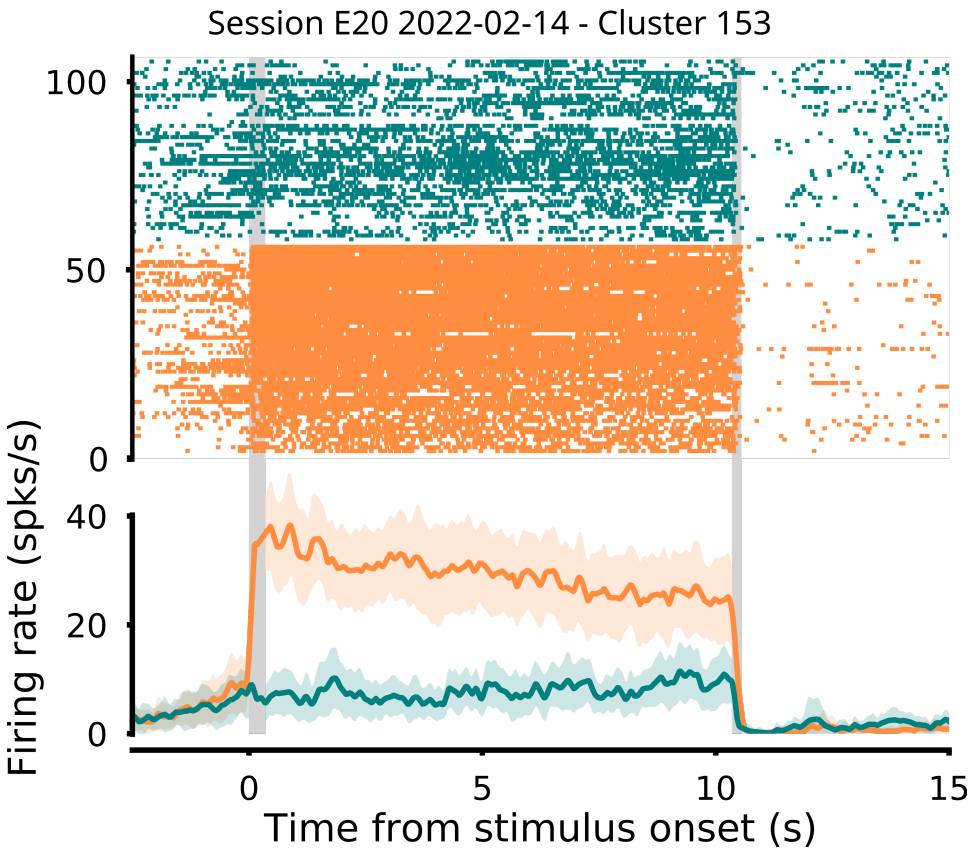
Gerstner et al, 2014





Experimental evidence





(Ona-Jodar et al. bioRxiv 2025)

End of part 1!