



Neural network simulations of simple cognitive functions

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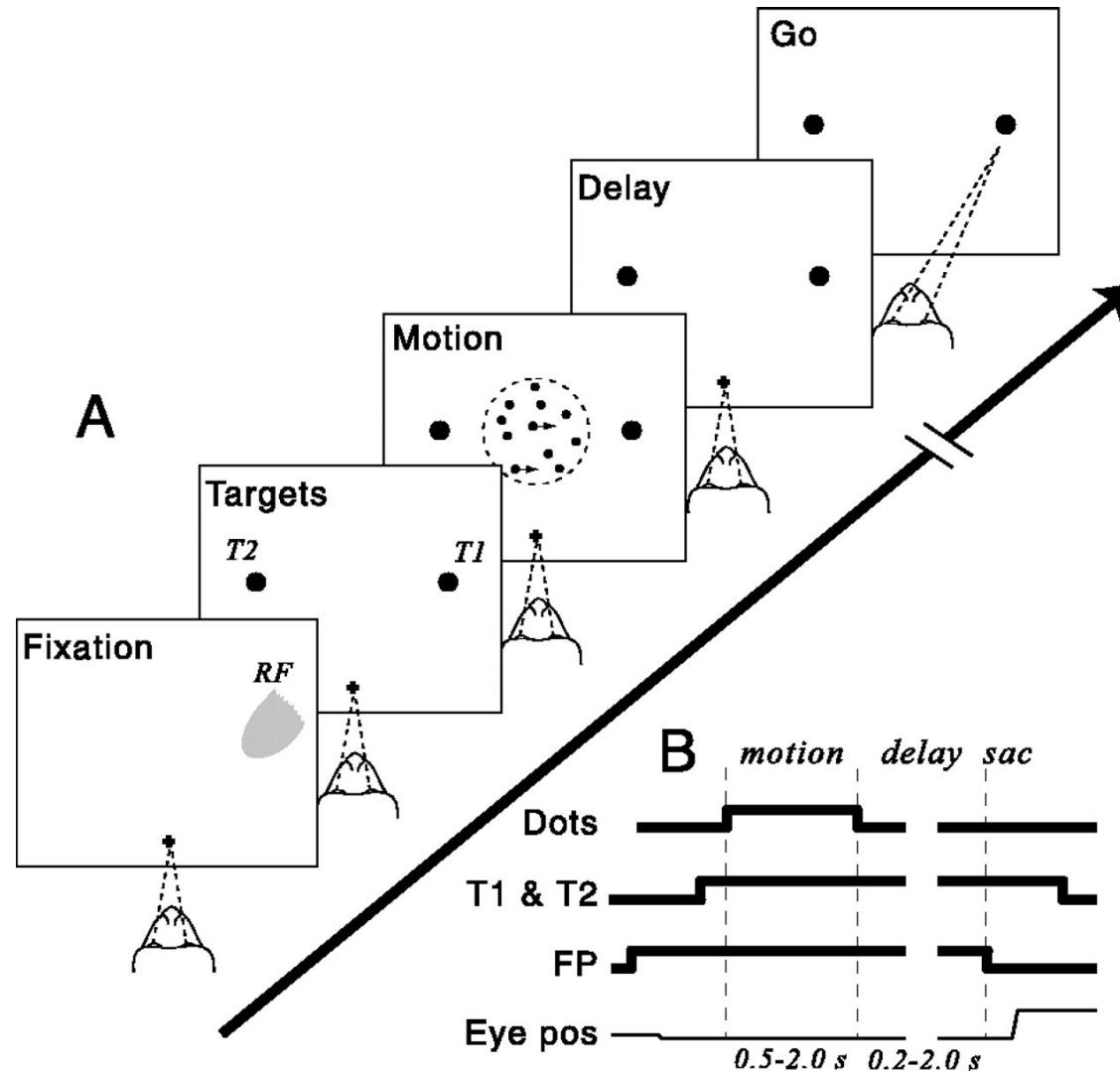
Vilnius
universitetas



Funded by
the European U

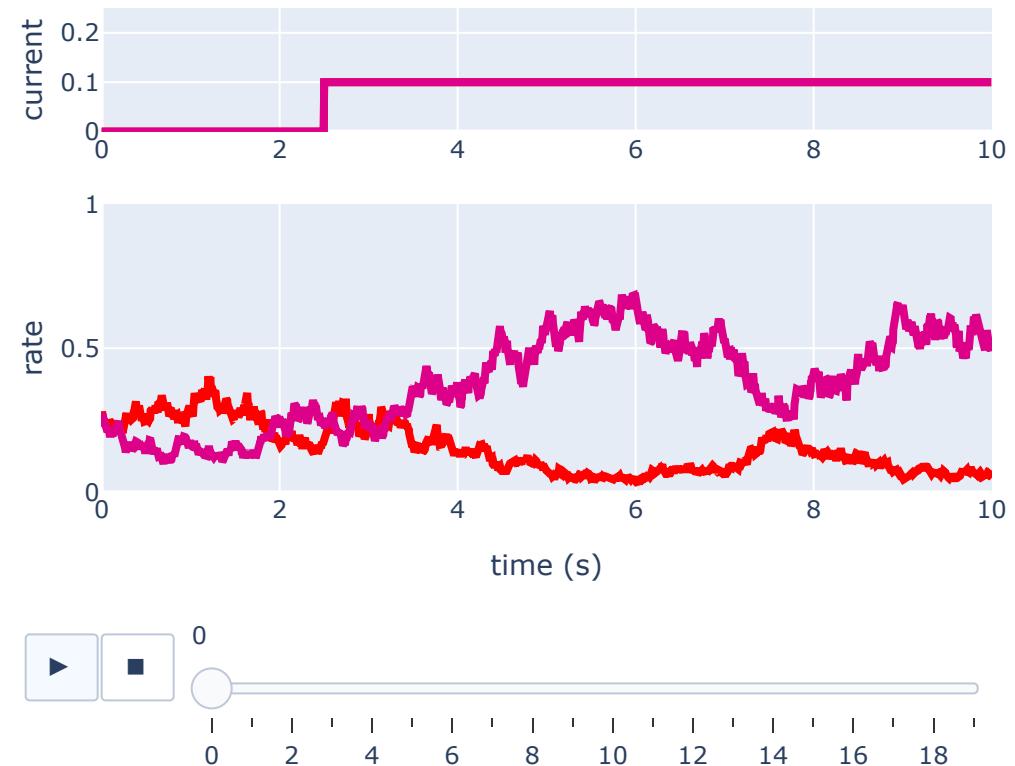
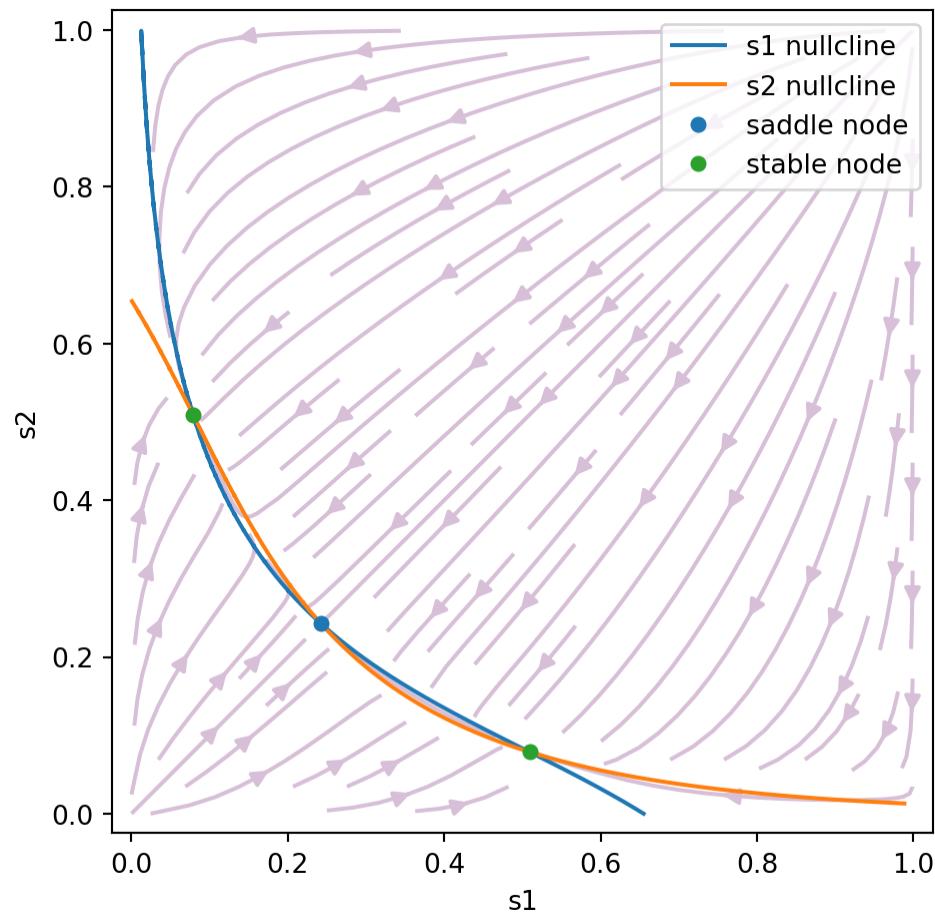
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Decision Making



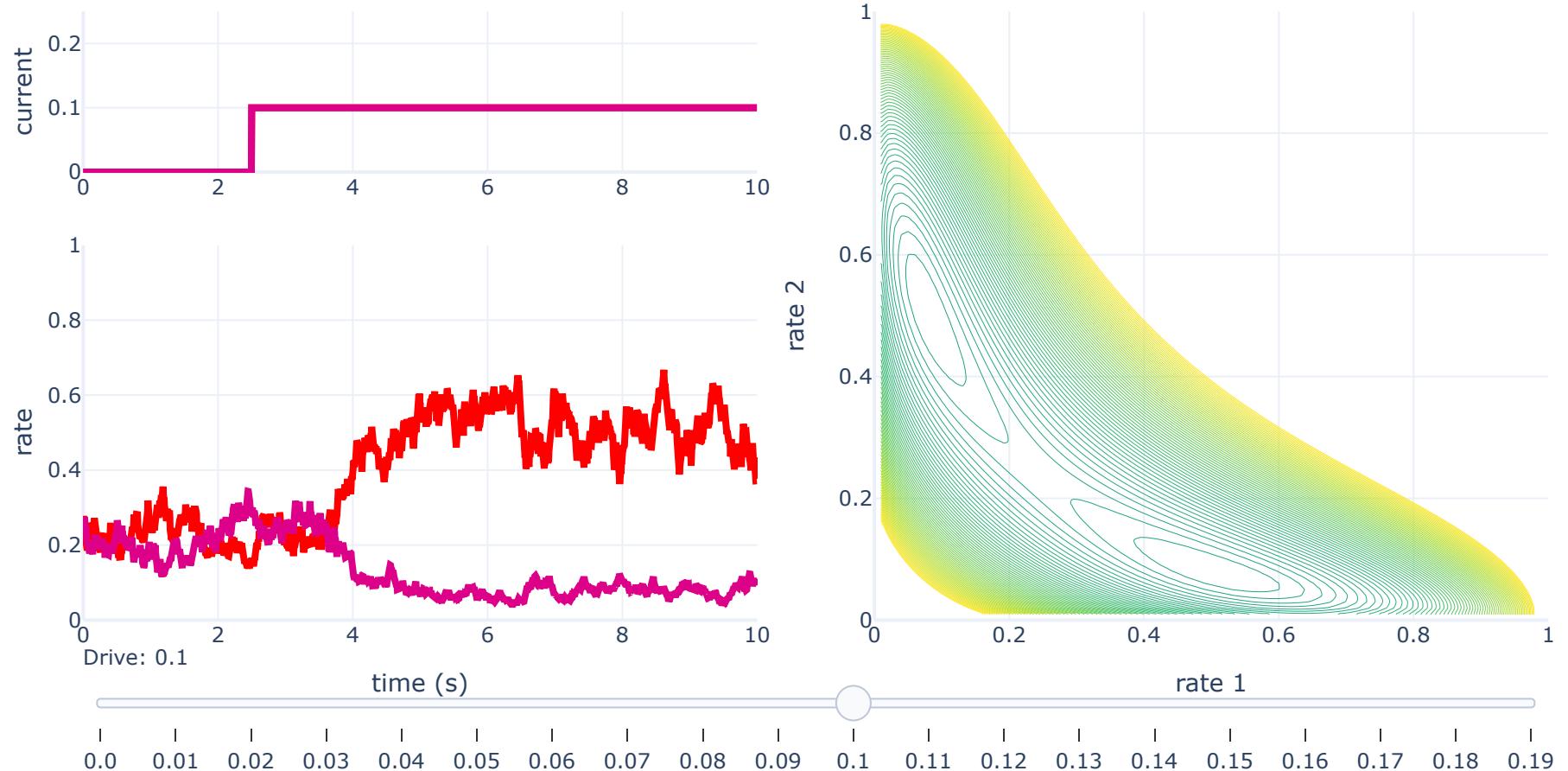
Shadlen and Newsome, 2001

Double-Well: Decision Making

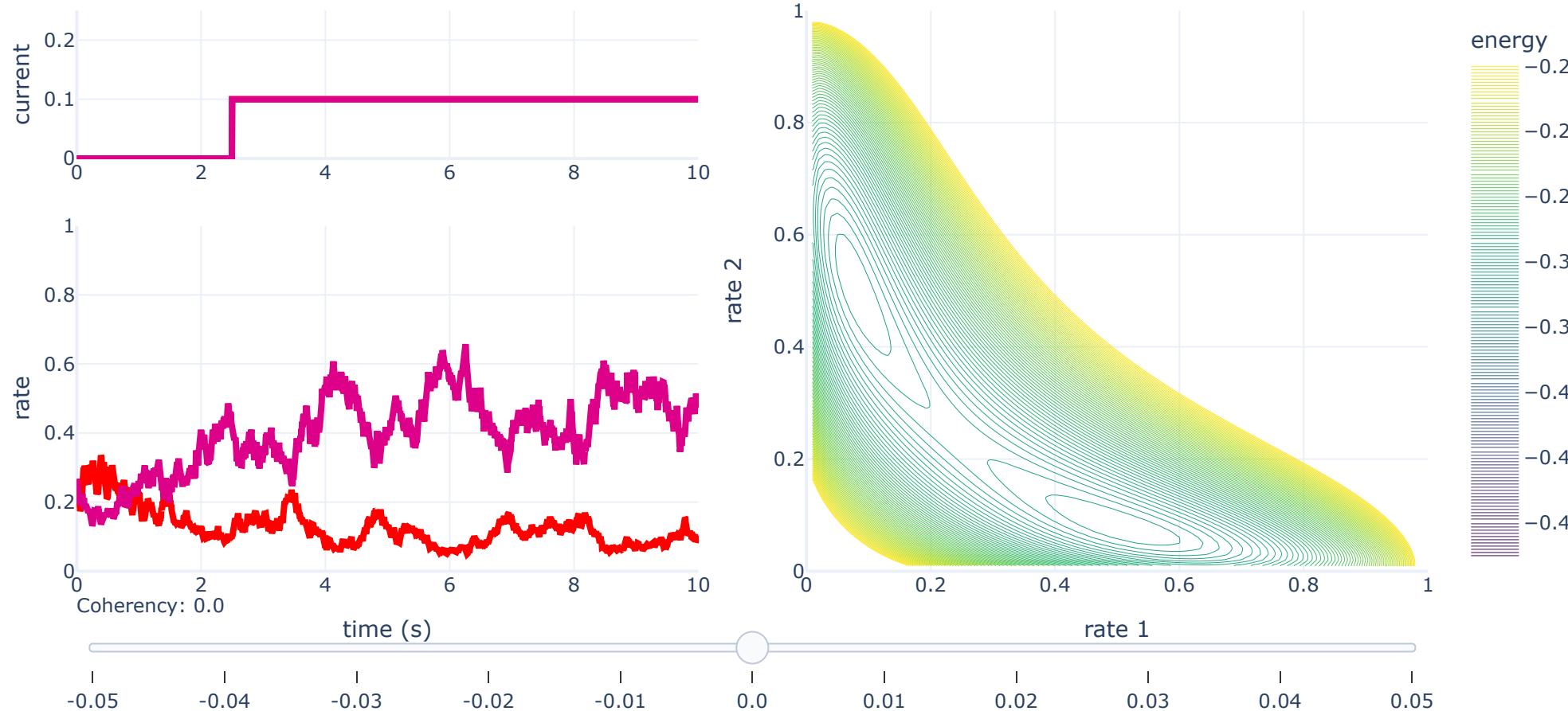


Wang 2002, Wong and Wang 2006

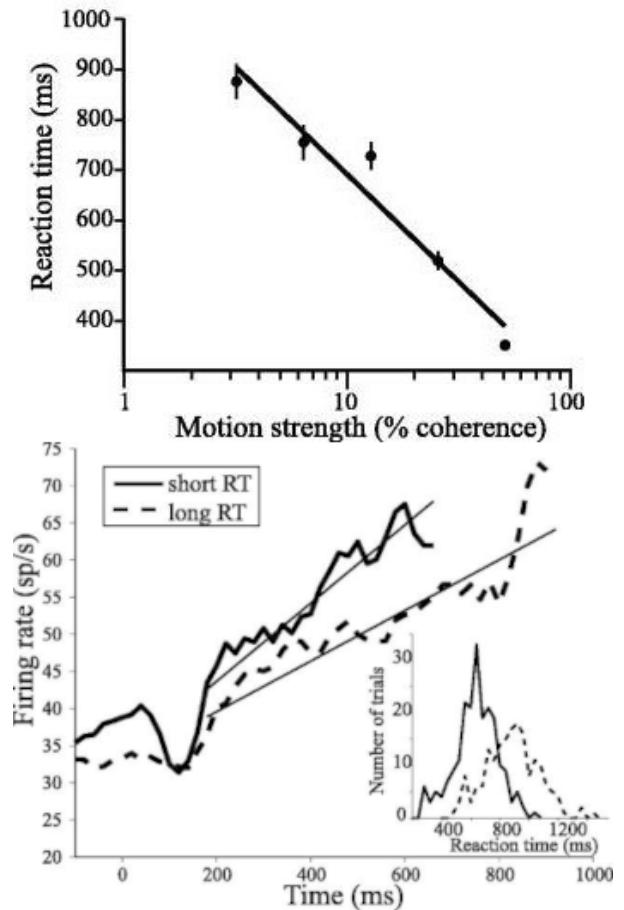
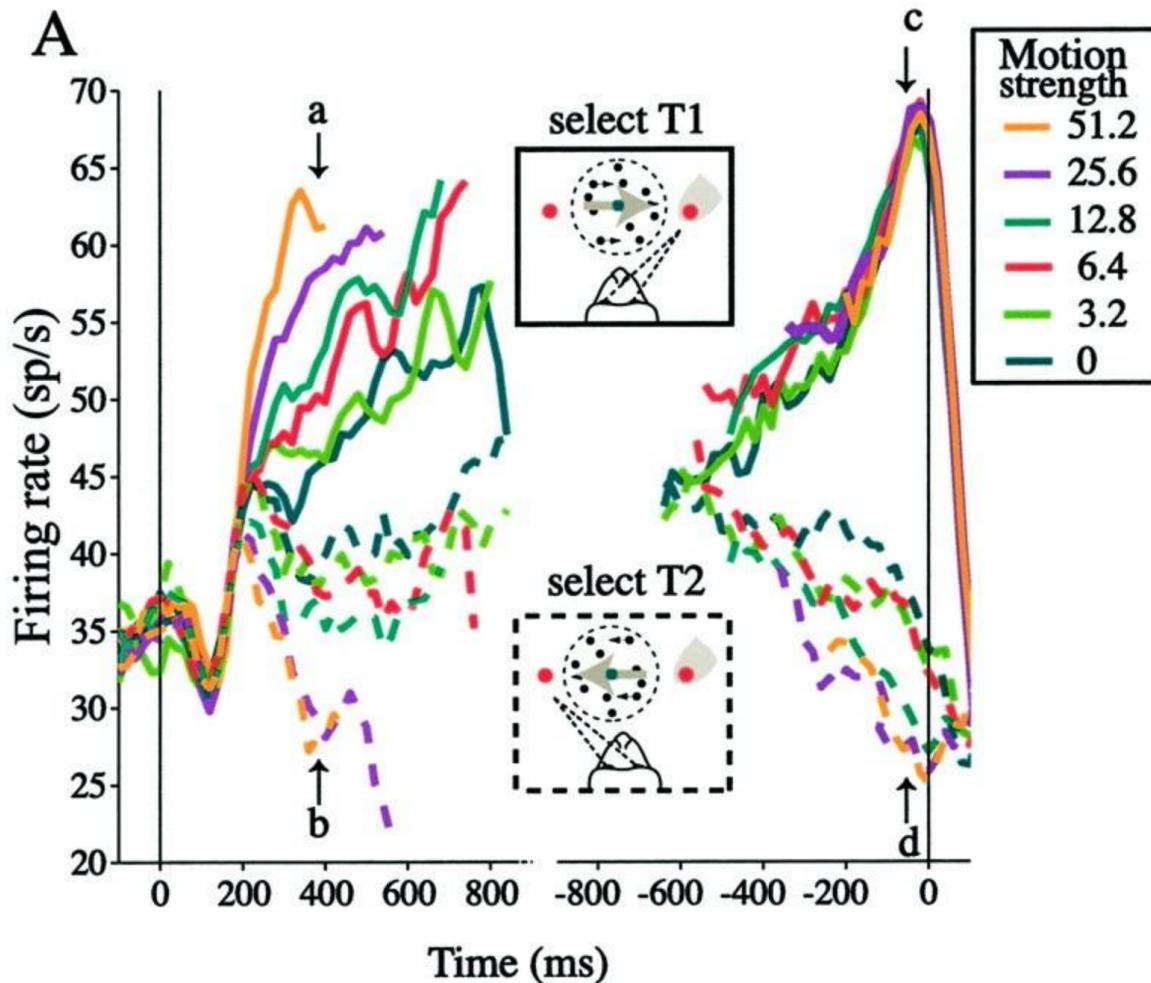
Double well: Decision making



Double well: Decision making

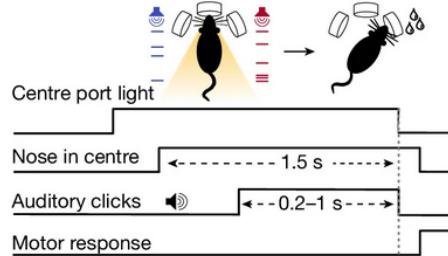


Experimental data

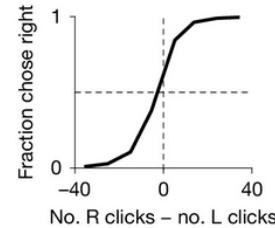


Experimental data

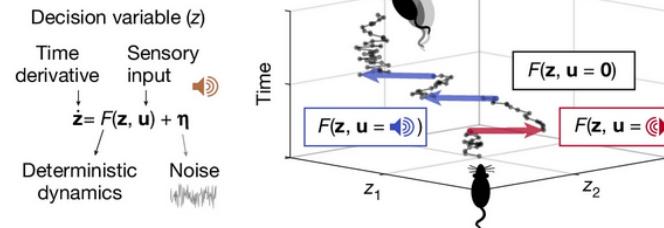
a No. R clicks > no. L clicks?
Yes → go R; no → go L



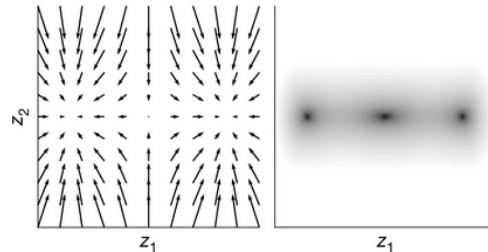
b



c

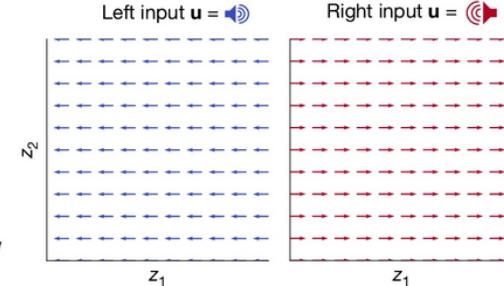


d Autonomous dynamics
 $F(z, 0)$

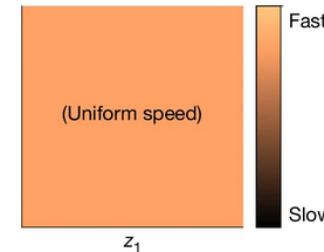


Autonomous speed
 $\|F(z, 0)\|$

e Input dynamics $F(z, u) - F(z, 0)$

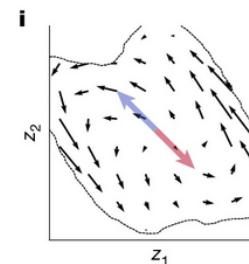
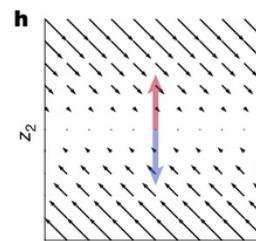
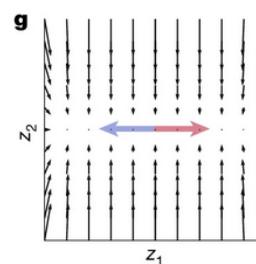
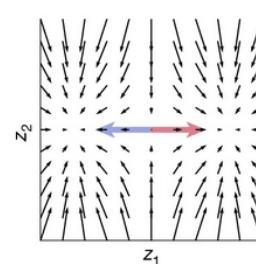


Input speed
 $(\|\text{Left input}\| + \|\text{Right input}\|)/2$



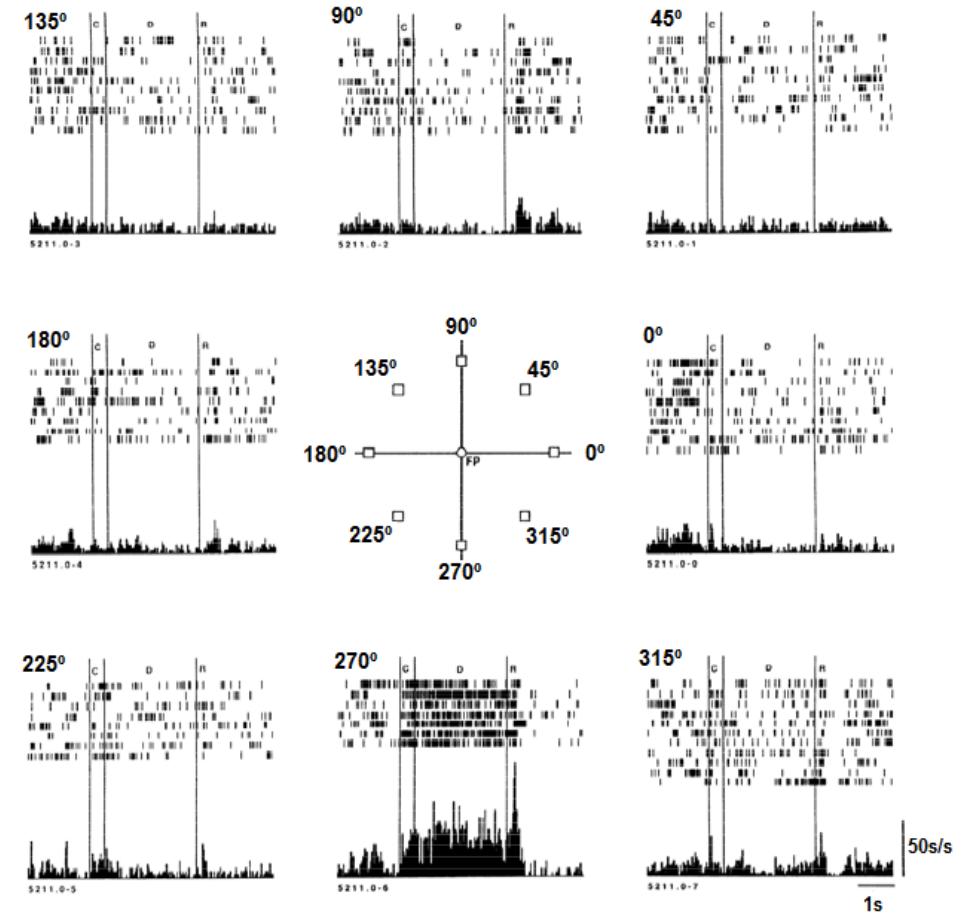
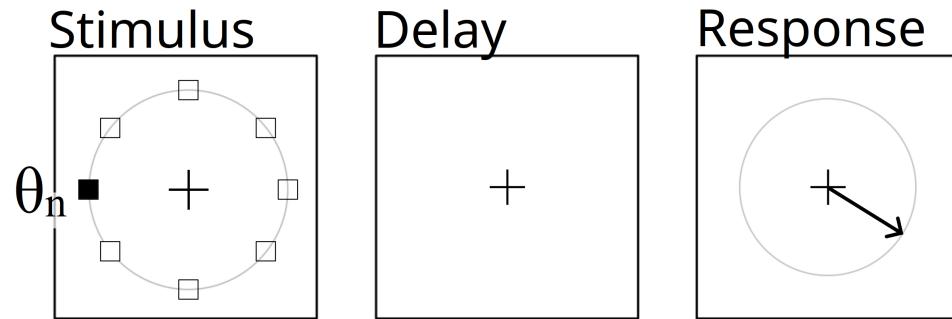
f

Autonomous dynamics
Input from left click
Input from right click



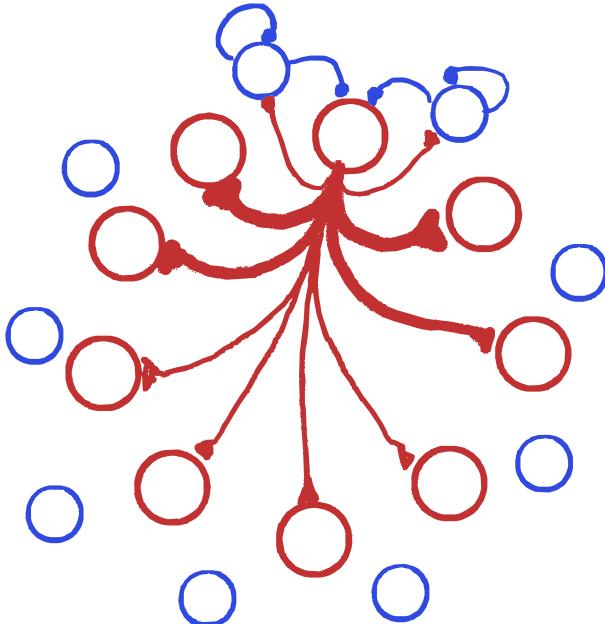
Luo et al. 2025

Continuous spatial memory



Funahashi et al 1989

Ring attractor model



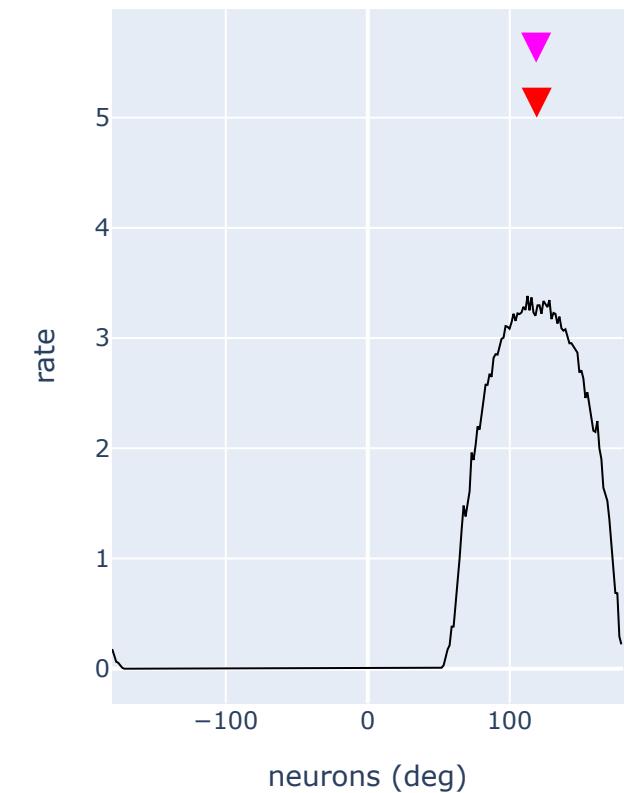
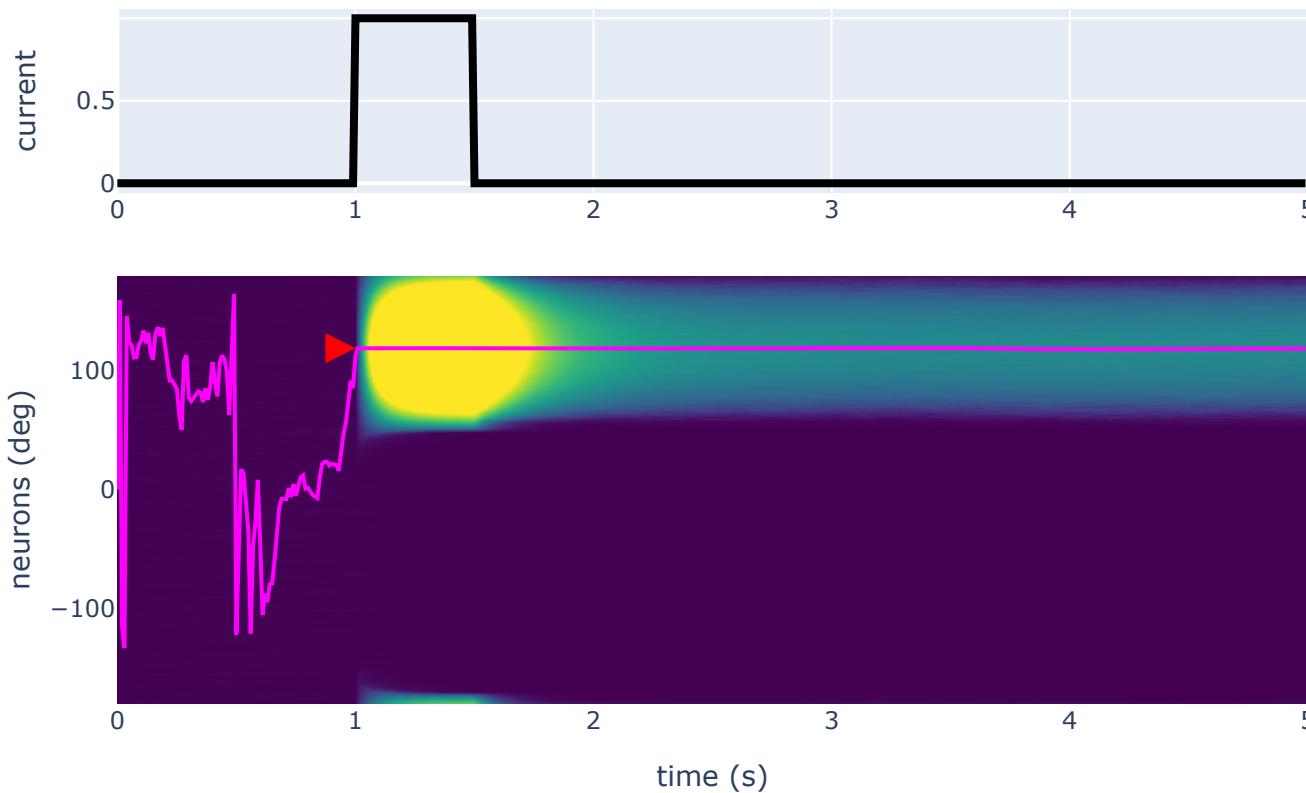
$$\tau_E \frac{dr_i^E(t)}{dt} = -r_i^E(t) + F_E \left[\sum_j W^{EE}_{ij} r_j^E(t) - W^{EI} r^I(t) \right]$$
$$\tau_I \frac{dr^I(t)}{dt} = -r^I(t) + F_I \left[W^{IE} \sum_j r_j^E(t) - W^{II} r^I(t) \right]$$
$$W_{ij}^{EE} = J_E \cos(\theta_i - \theta_j)$$



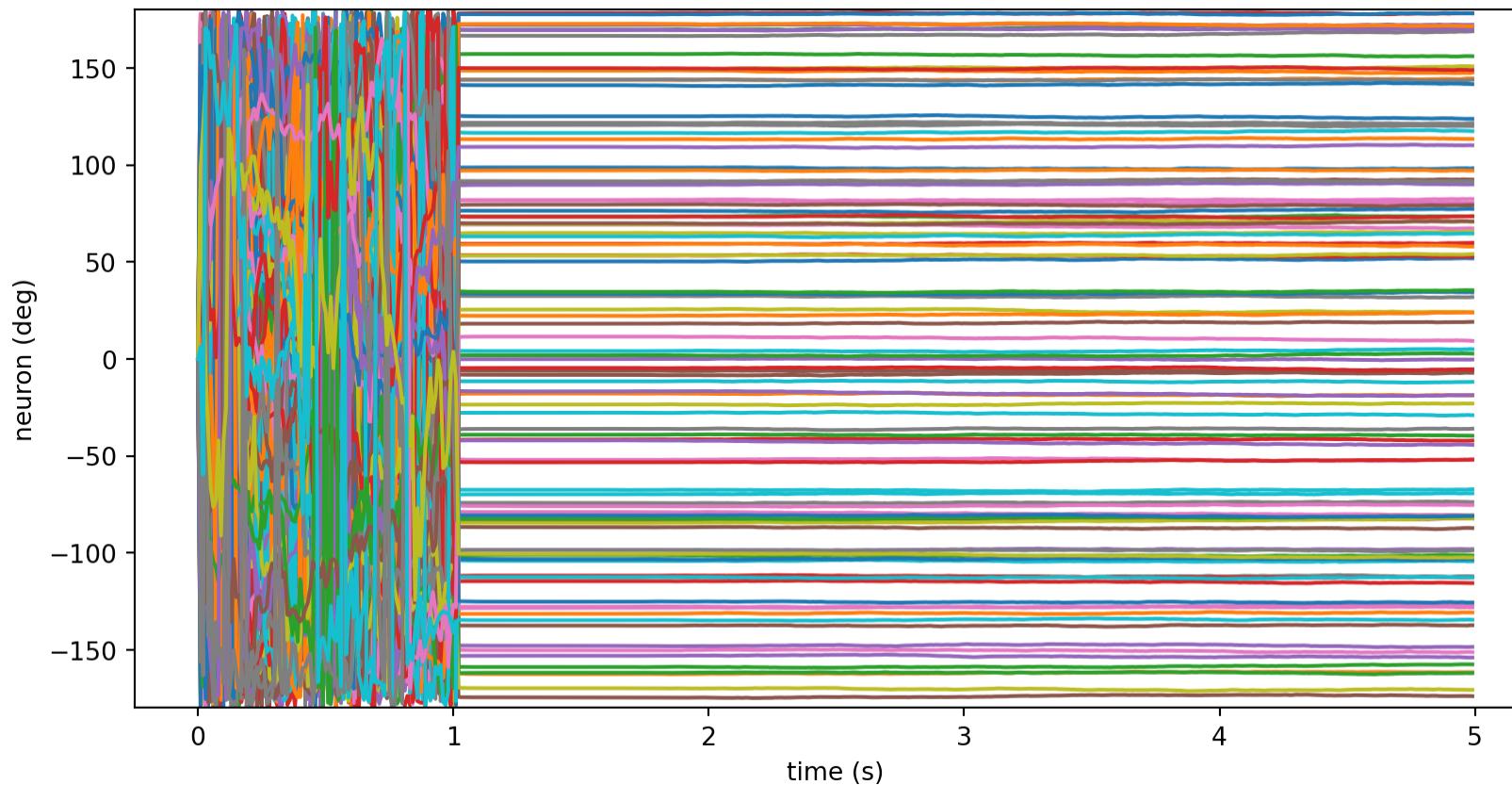
$$\tau \frac{dr_i(t)}{dt} = -r_i(t) + F \left[\sum_j J_{ij} r_j(t) \right]$$

$$J_{ij} = J_E \cos(\theta_i - \theta_j) - \frac{\gamma W^{EI} W^{IE}}{1 + \gamma W^{II}}$$

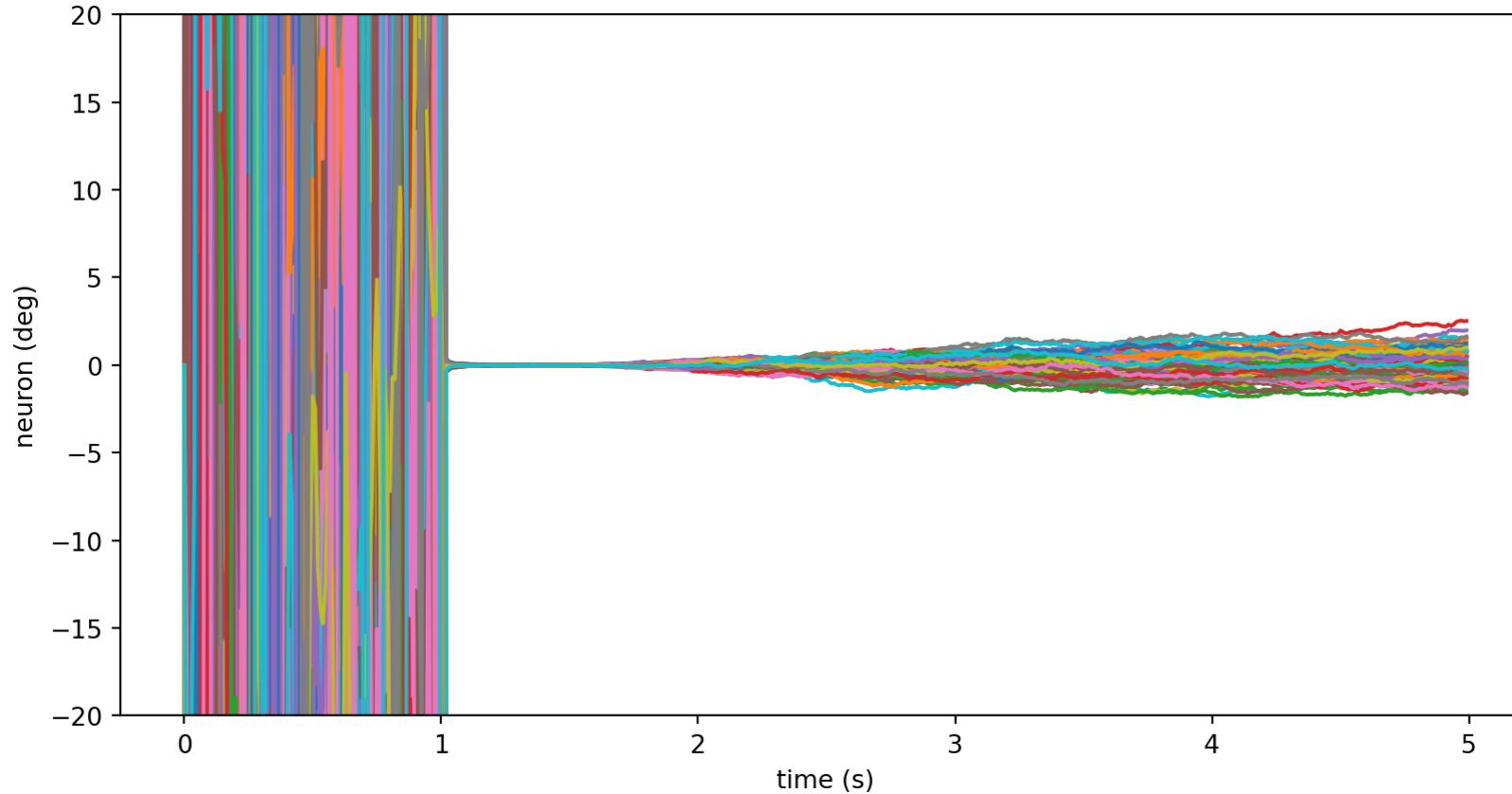
Ring attractor network



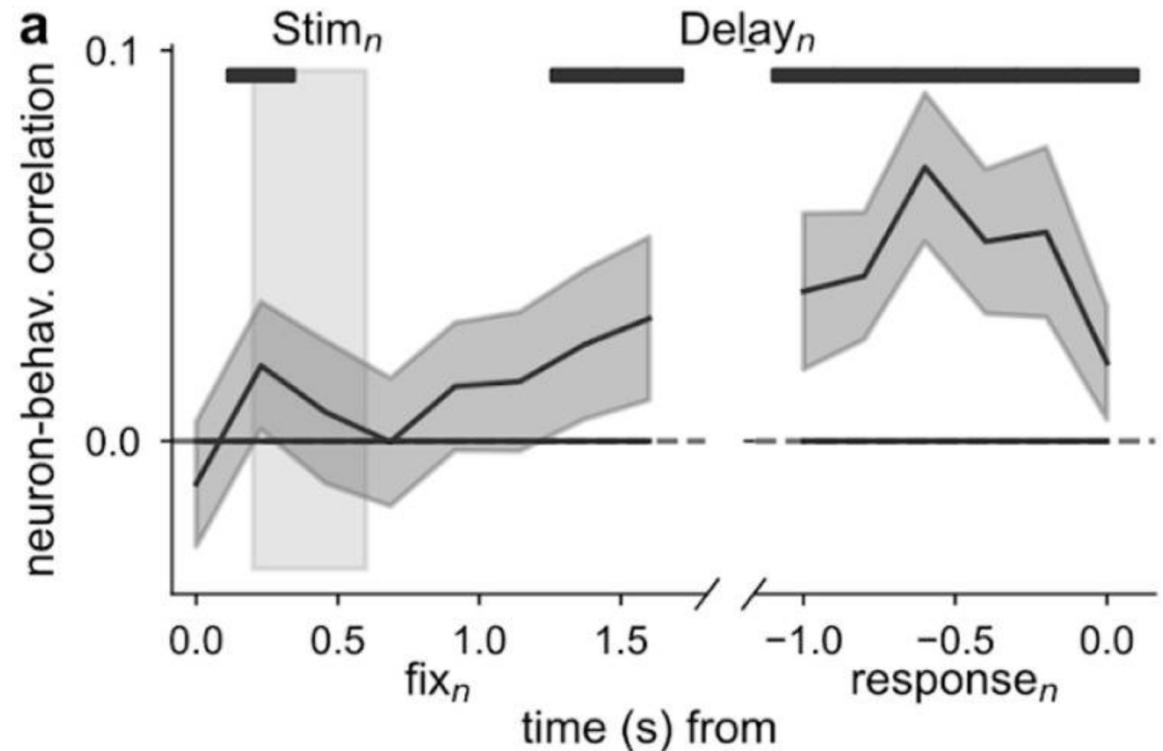
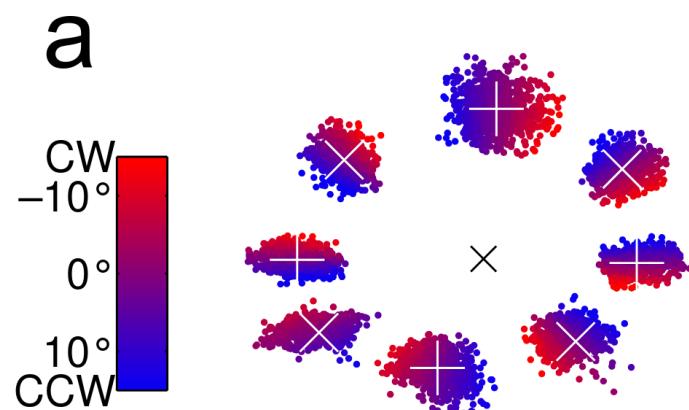
Ring attractor model



Ring attractor model



Experimental evidence



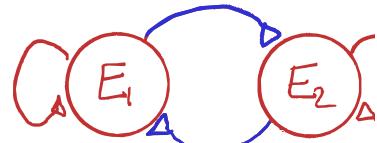
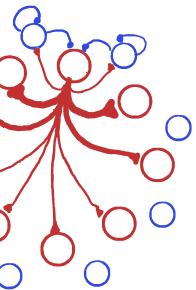
Wimmer et al 2014

Tschiersch et al 2025

Network models reviewed

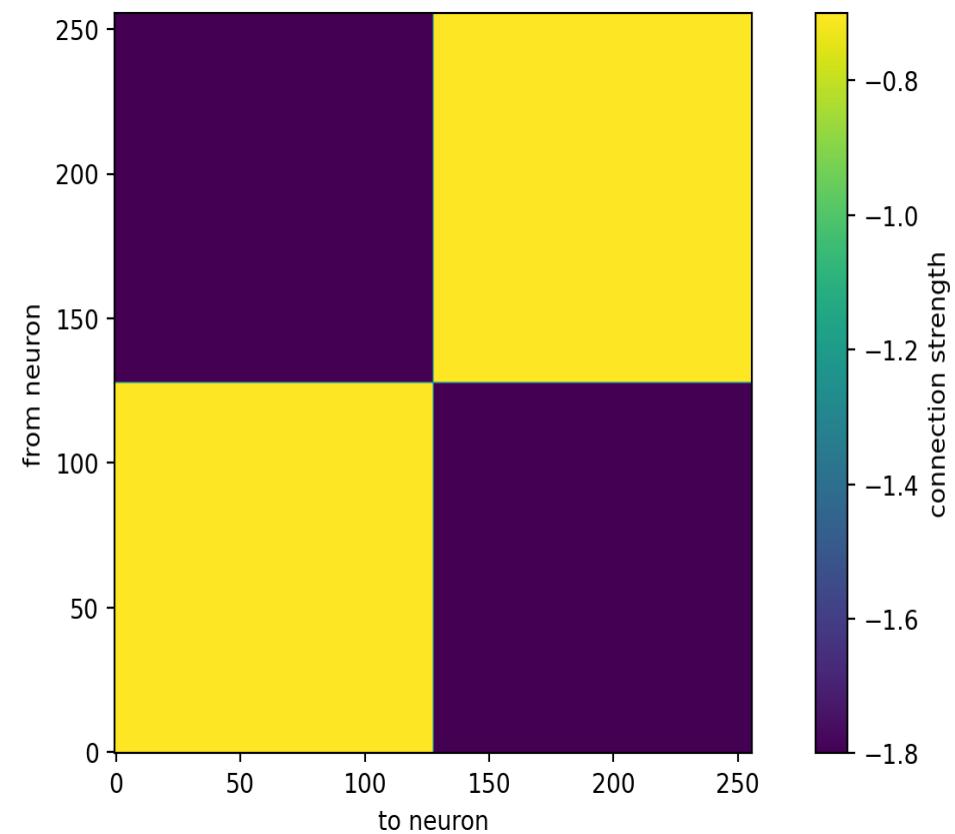
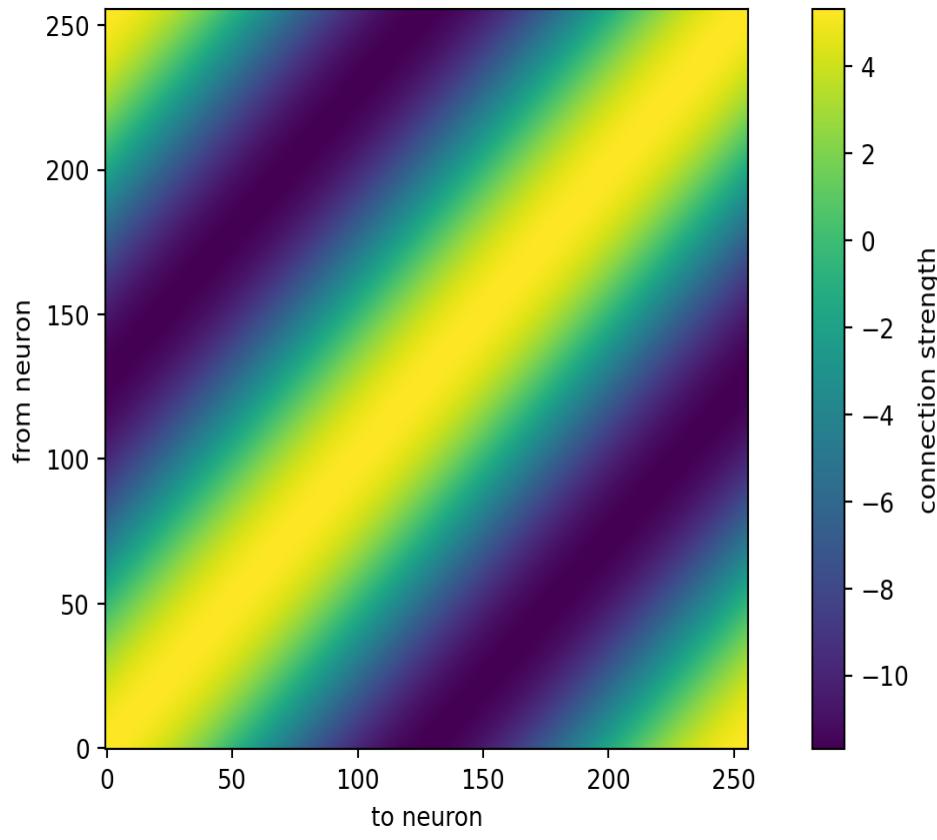
- E-I networks:
 - Wilson-Cowan network
 - Inhibition-stabilized network
- Double well networks:
 - selective working memory
 - decision making
- Ring attractor network

As an RNN: $\tau \frac{dI_i(t)}{dt} = -I_i(t) + \sum_j J_{ij} F[I_j(t)]$



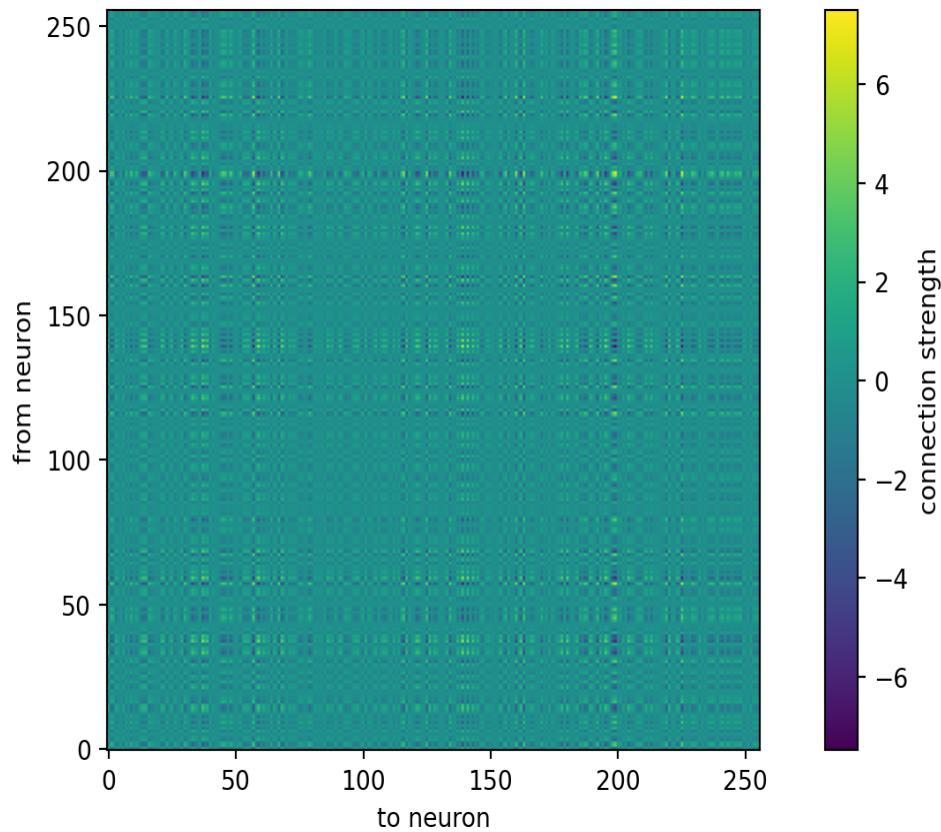
$$J_{ij} = \mathbf{J}_E \cos(\theta_i - \theta_j) - \frac{\gamma W^{EI} W^{IE}}{1 + \gamma W^{II}}$$

$$J_{ij} = \begin{cases} \mathbf{J}_E, & C(i)=C(j) \\ \mathbf{J}_I, & C(i)\neq C(j) \end{cases}$$

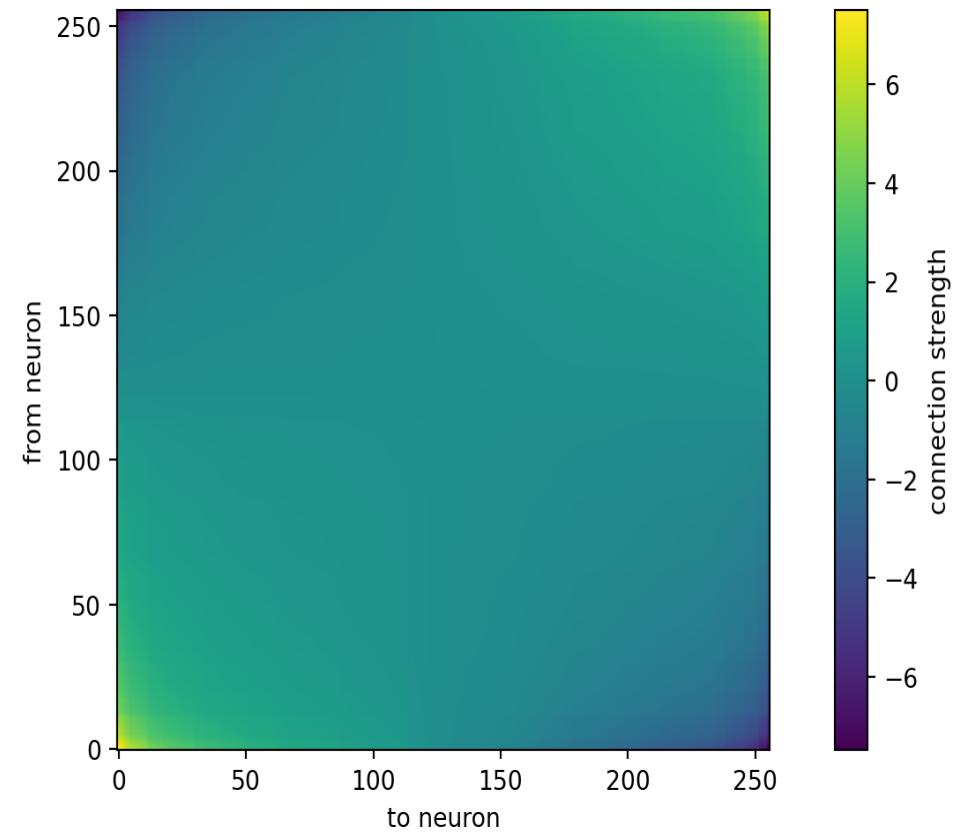


Rank-1 RNN

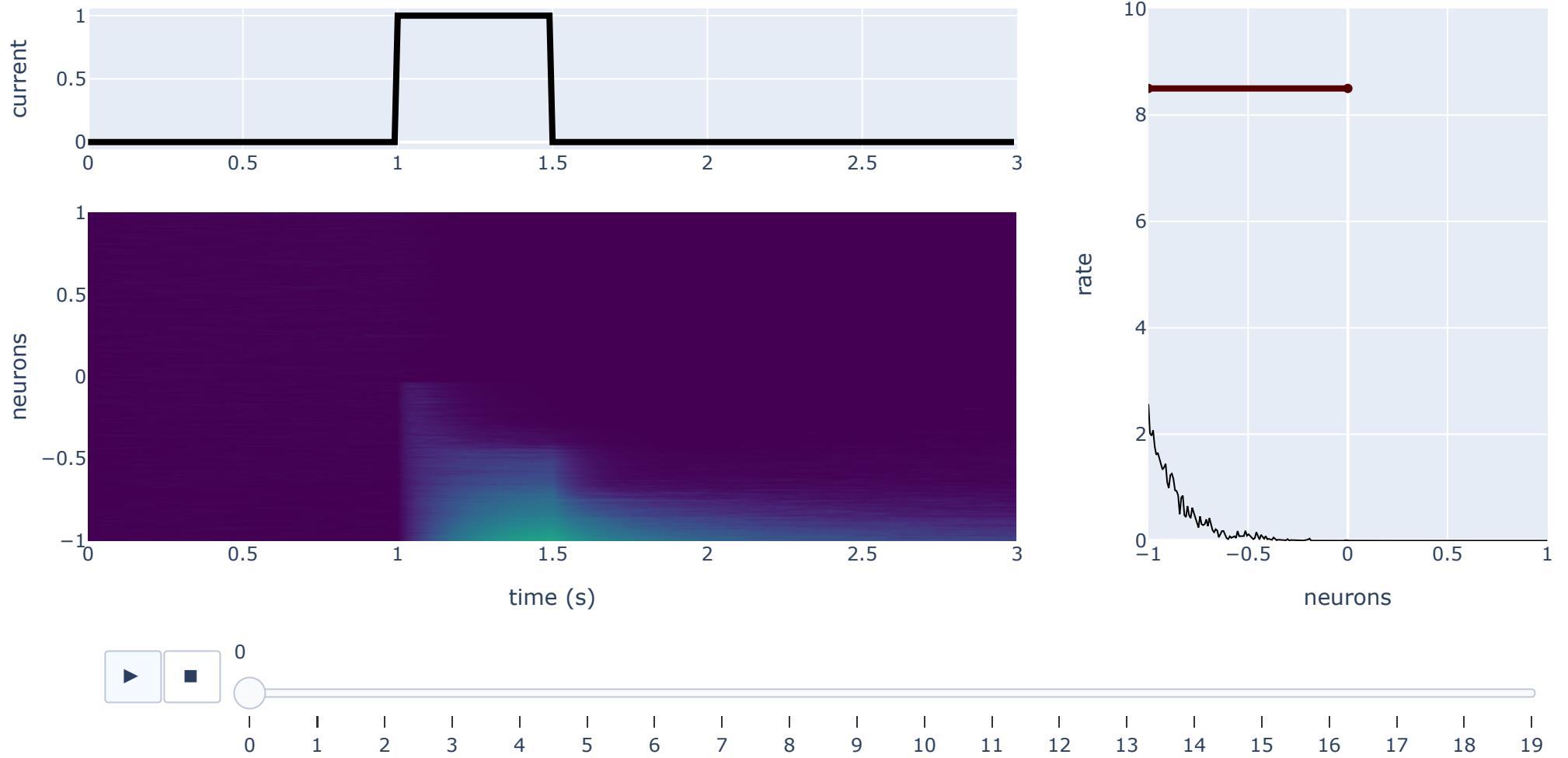
$$J_{ij} = \xi_i \xi_j$$



Now reorder ξ :

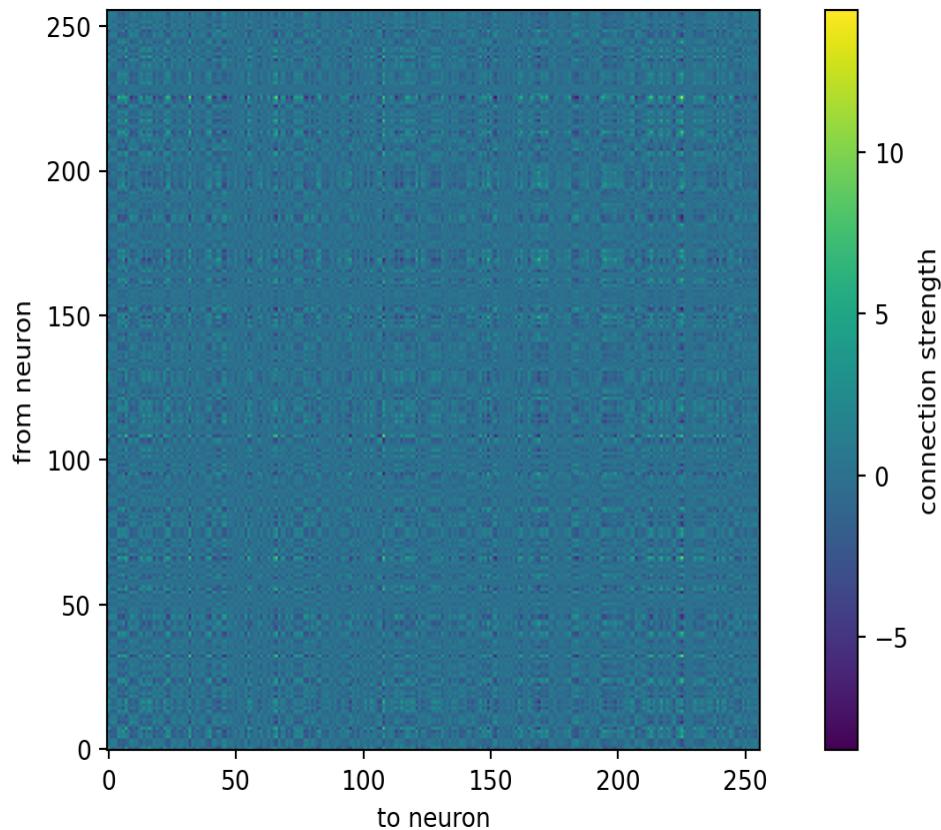


Dynamics in rank-1 RNN

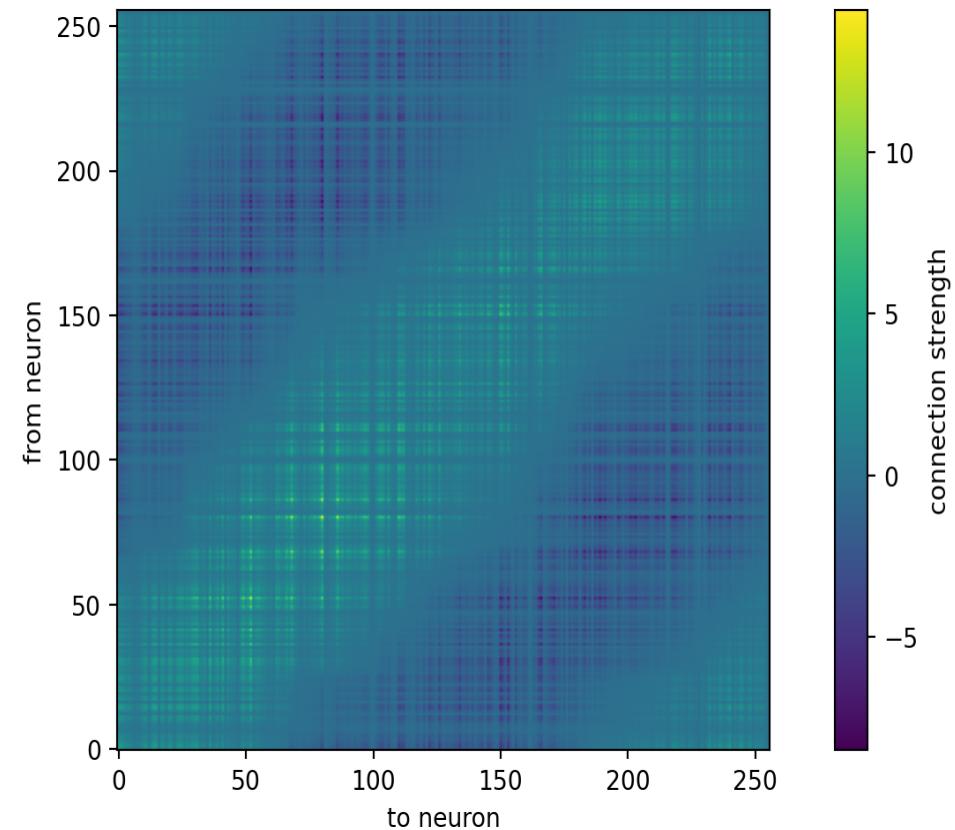


Rank-2 RNN

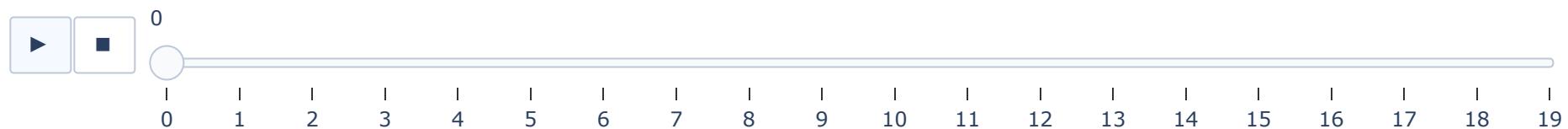
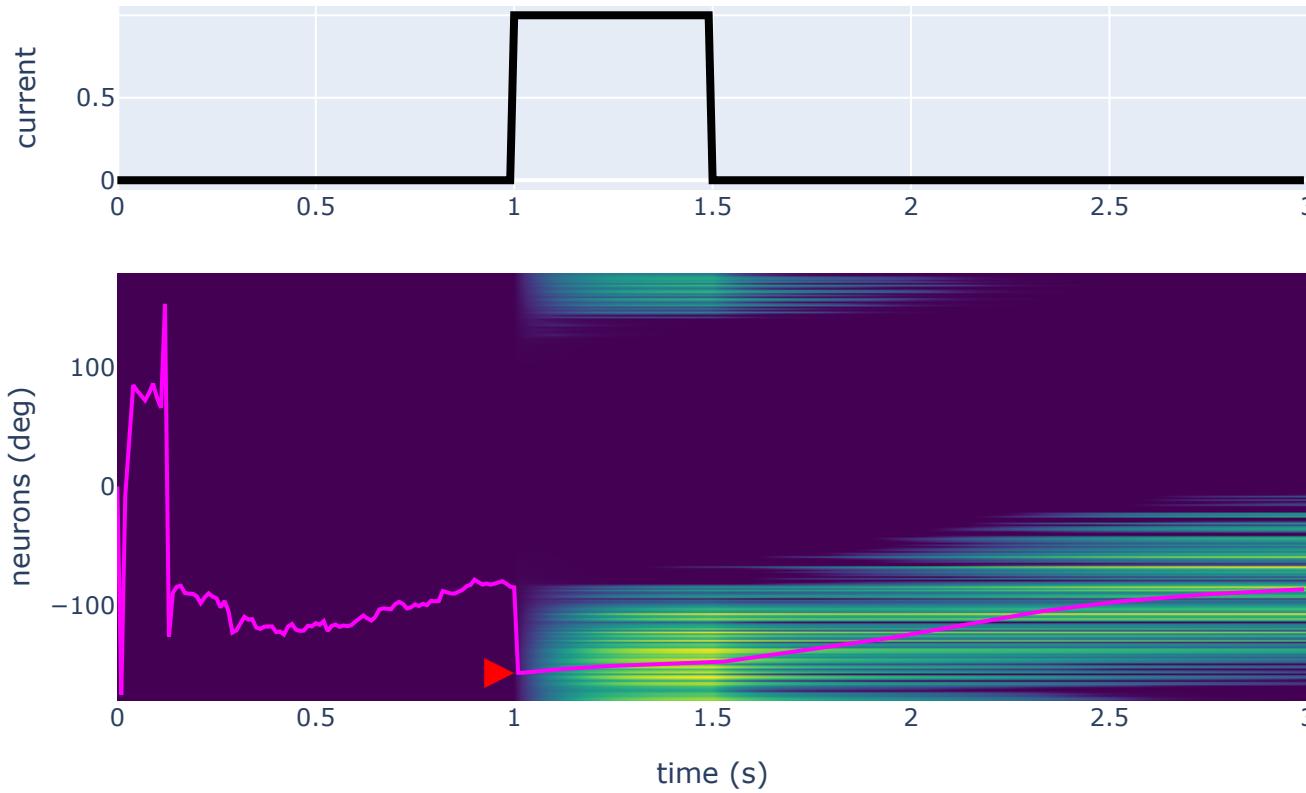
$$J_{ij} = \xi_i \xi_j + \psi_i \psi_j$$



Now reorder $\xi + i\psi$:

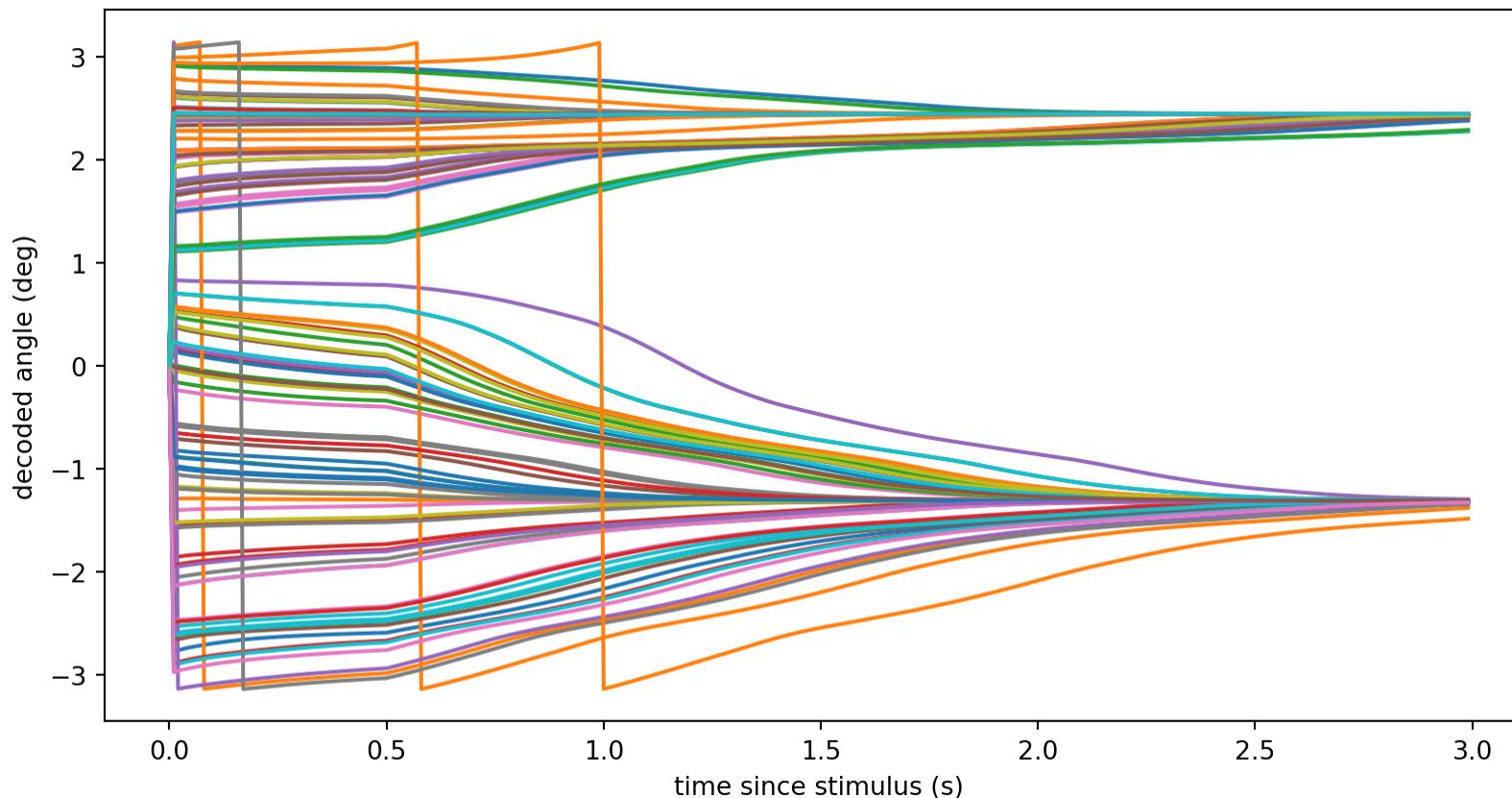


Dynamics in rank-2 RNN



Dynamics in rank-2 RNN

Stable bumps converge on a few fixed points: not truly ring attractor dynamics



Are ring attractors biologically plausible?

- cellular homeostatic mechanisms: Renart et al 2003
- slow synapses: Istkov et al 2011; Hansel and Mato 2013
- connectivity training: Darshan and Rivkind 2022; Clark et al 2025
- efficient coding? Ganguli Simoncelli 2014; Yang et al 2024

End of part 2