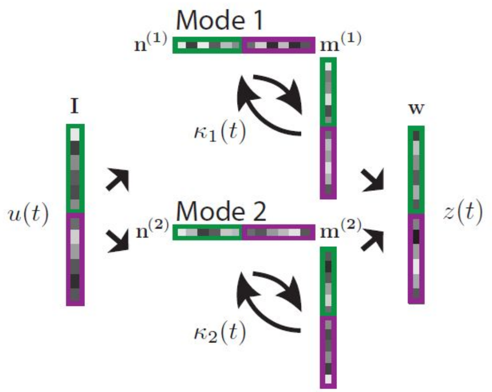
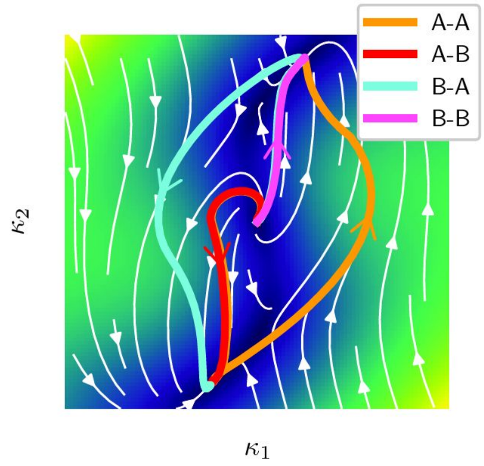
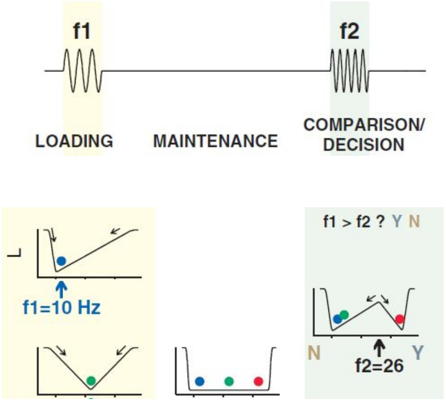
The complementary roles of dimensionality and population structure in neural computations

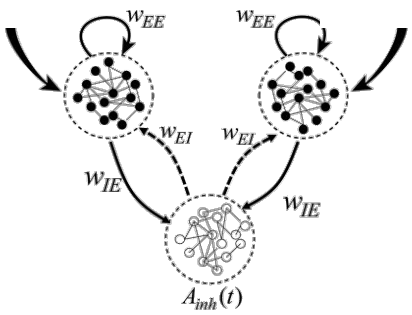
Flexible learning reading group
Dubreuil et al. 2020 *bioRxiv 2020.07.03.185942*





Modeling neural computations: classical vs novel approach





Machens et al. 2005

Computation

Low-d dynamical system

Train

High-d network model

- \+ Any task
- \+ Unbiased
- \+ Exciting
- \- Understanding

Mante&Sussillo et al. 2013; Sussillo et al. 2015; Sohn&Nairan et al. 2019; Yang et al. 2019

Low rank RNNs

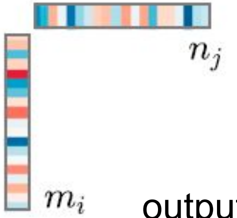
Recurrent   External

$$\tau \dot{x}(t) = -x(t) + \boxed{J\,\phi(x(t))} + \boxed{I^{ff}(t)}$$

$$z(t) = \boxed{w^T}\,\phi(x)$$

Readout

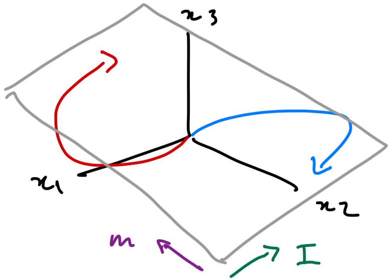
$J_{ij} =$



input pattern

output pattern

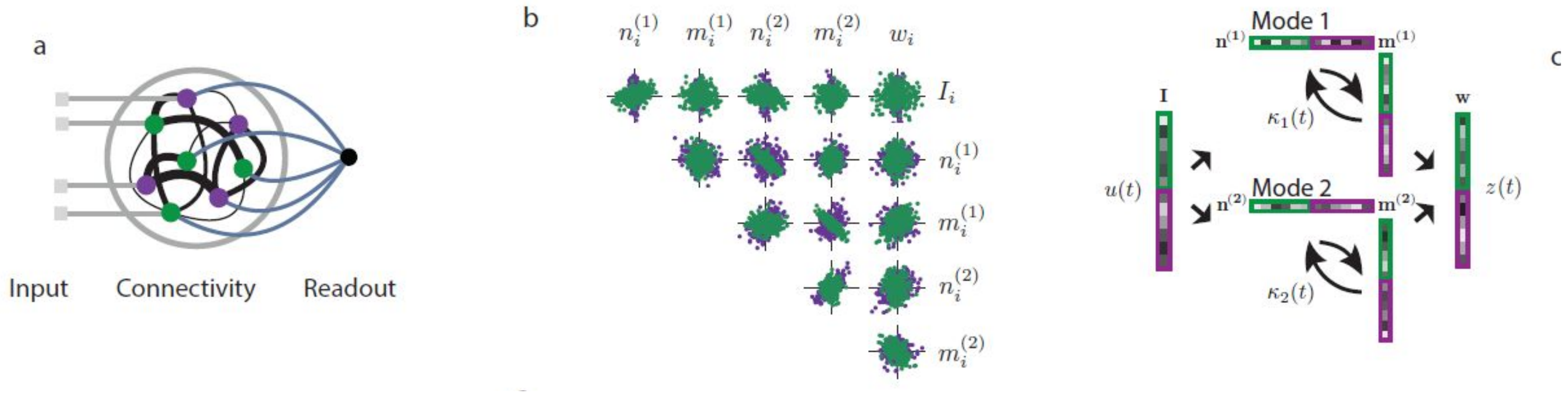
$$I^{ff}(t) = u(t) \cdot I$$



$$x(t) = k(t)\, m + v(t)\, I$$

Mastroguiseppe & Ostojic 2018

This paper (Dubreuil et al. 2020): effect of **“populations”** in connectivity



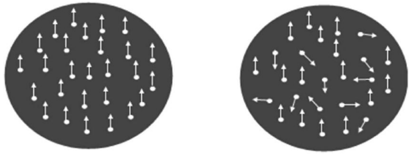
#Populations: flexibility

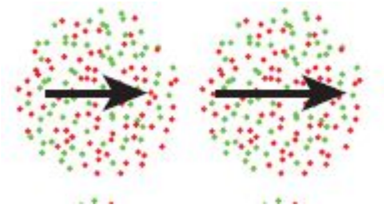
P = 1

P = 2

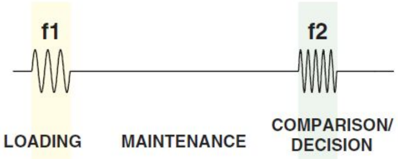
Rank: dimensionality

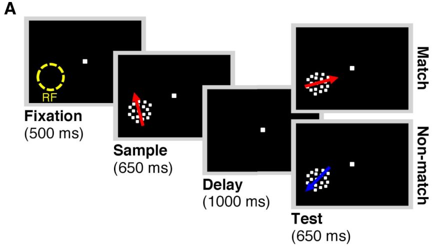
R = 1





R = 2

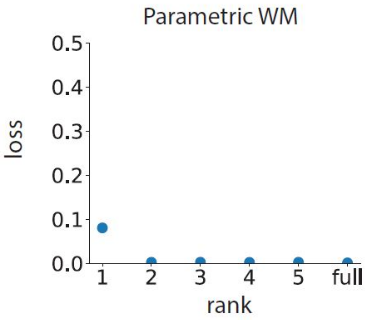


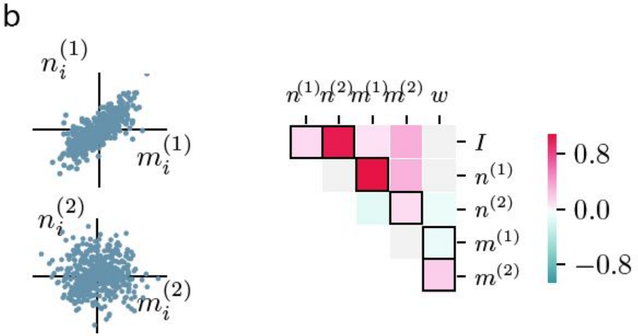


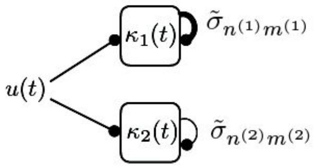
Min. Rank RNN

Covariance & population structure

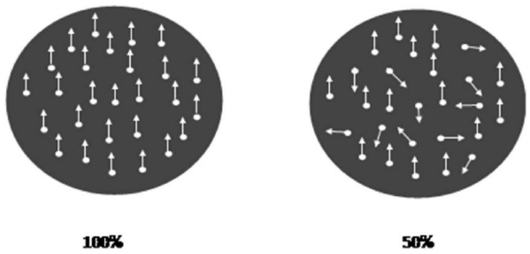
Reduced circuit

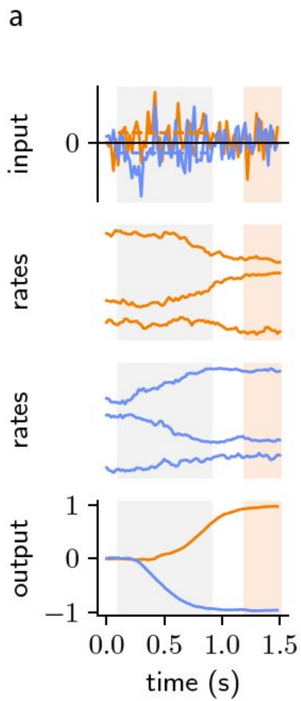


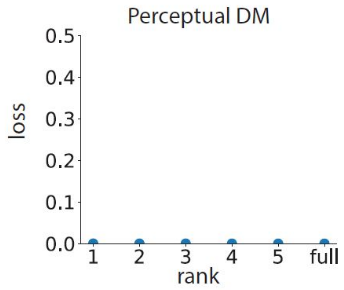


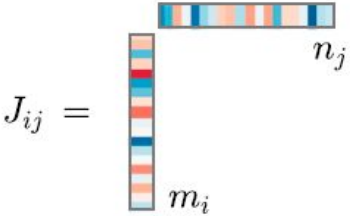


Perceptual decision making with a rank 1 RNN



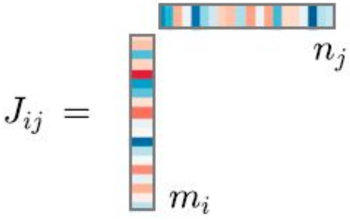


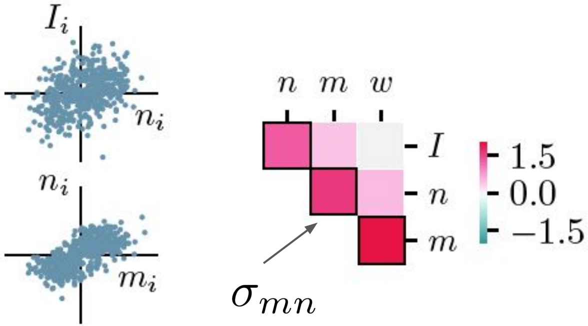




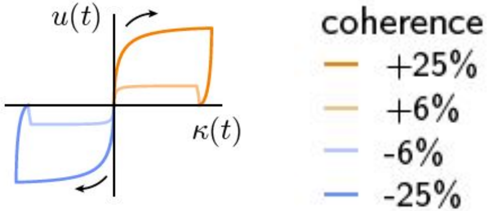
Shadlen & Newsome, 2001

Perceptual decision making: reduced circuit





e

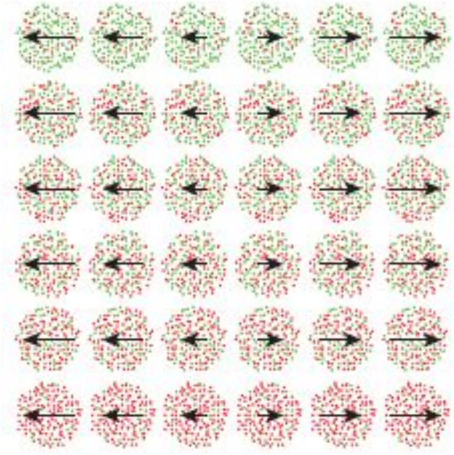


$$\frac{d\kappa}{dt} = -\kappa + \tilde{\sigma}_{mn}\kappa + \tilde{\sigma}_{nI}v(t)$$

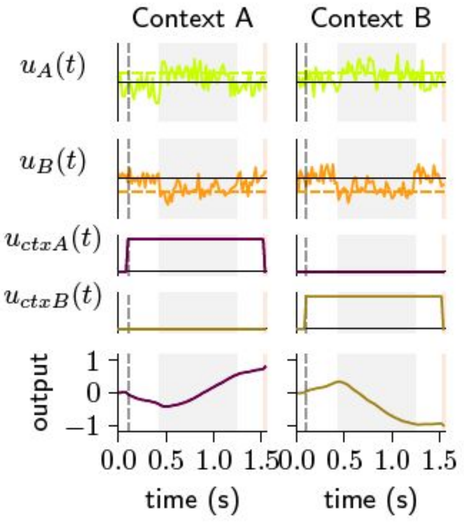
$$\sigma_{nm}\langle\Phi'\rangle(\Delta) \qquad \Delta = \sqrt{\sigma_m^2\kappa^2 + \sigma_I^2 v^2}.$$

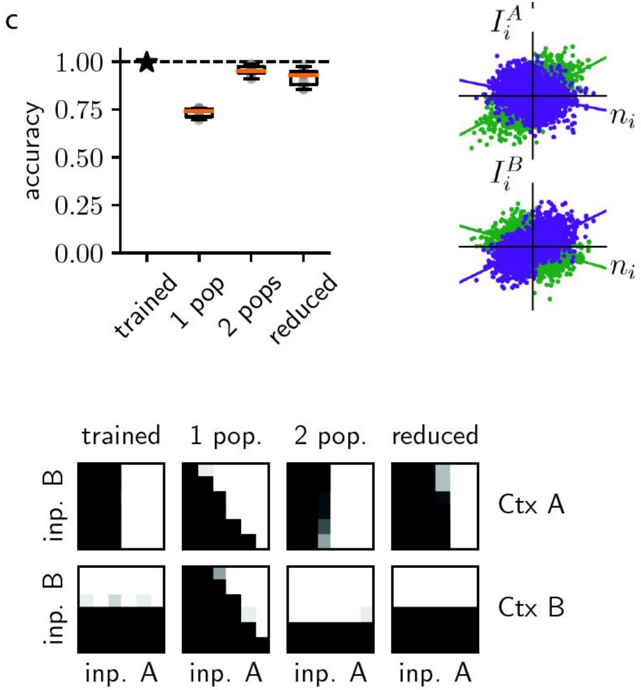
$$\langle\Phi'\rangle(\Delta) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{+\infty} \mathrm{d}z\, e^{-z^2/2}\phi'(\Delta z)$$

Contextual decision making: need 2 populations

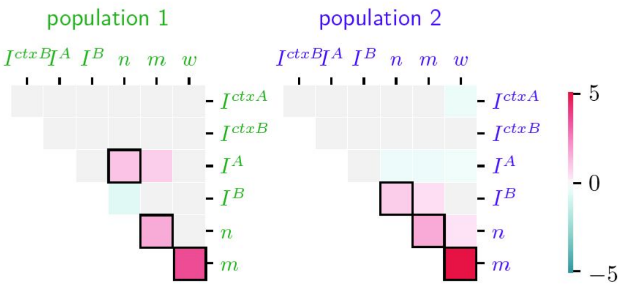


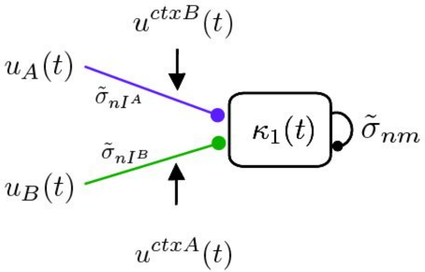
Mante&Sussillo et al. 2013



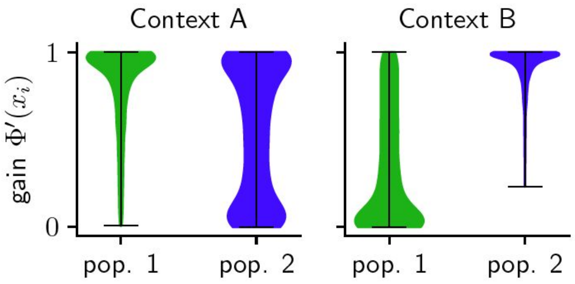


Contextual decision making: reduced circuit





$$\frac{d\kappa}{dt} = -\kappa + \tilde{\sigma}_{mn}\kappa + \sigma^{(1)}_{nI^A}\langle\Phi'\rangle_1 u_A(t) + \sigma^{(2)}_{nI^B}\langle\Phi'\rangle_2 u_B(t)$$



$$\boxed{\frac{d\kappa}{dt} = -\kappa + \tilde{\sigma}_{mn}\kappa + \sigma^{(2)}_{nI^B}\langle\Phi'\rangle_2 u_B(t)}$$

$$\boxed{\frac{d\kappa}{dt} = -\kappa + \tilde{\sigma}_{mn}\kappa + \sigma^{(1)}_{nI^A}\langle\Phi'\rangle_1 u_A(t)}$$

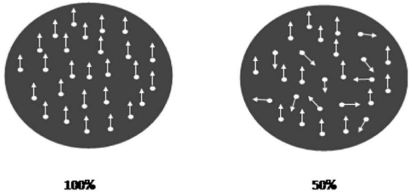
#Populations: flexibility

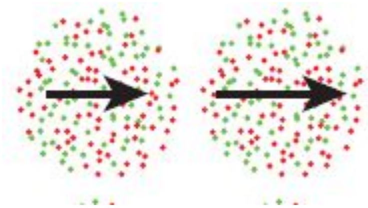
P = 1

P = 2

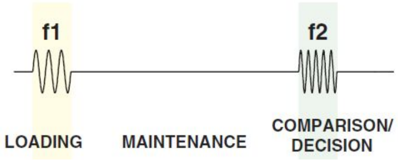
Rank: dimensionality

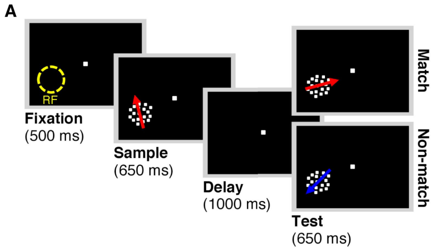
R = 1



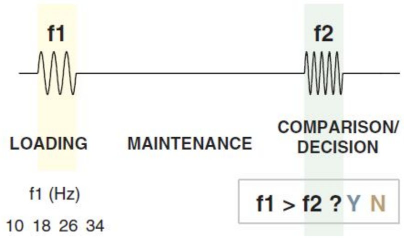


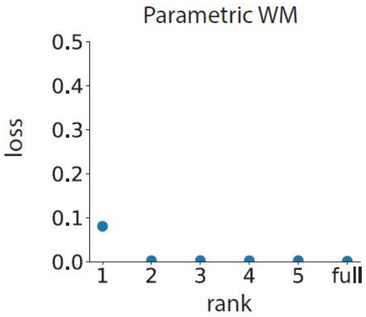
R = 2

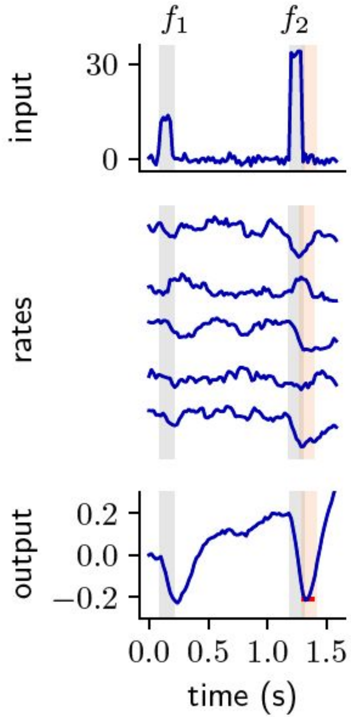




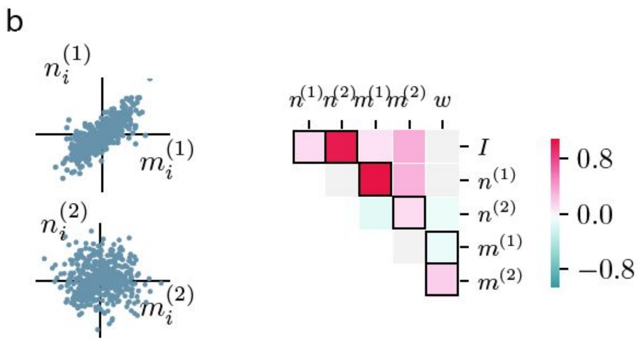
Parametric working memory (Rank = 2, #Populations = 1)

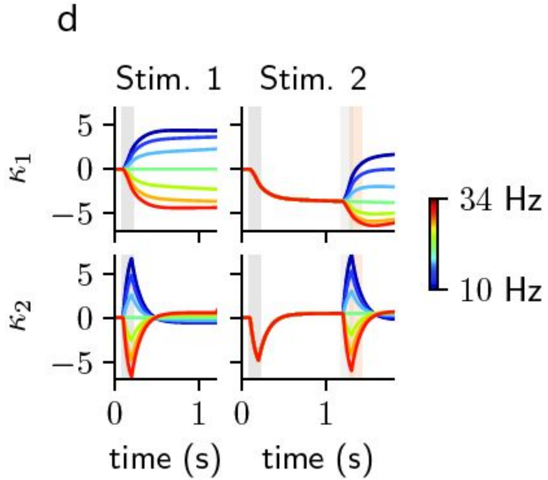


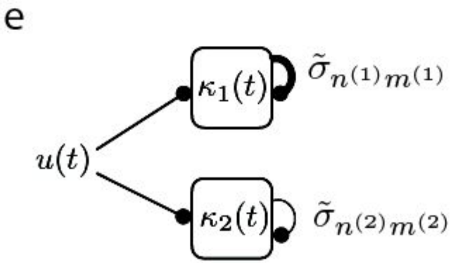




Parametric working memory (Rank = 2, #Populations = 1)



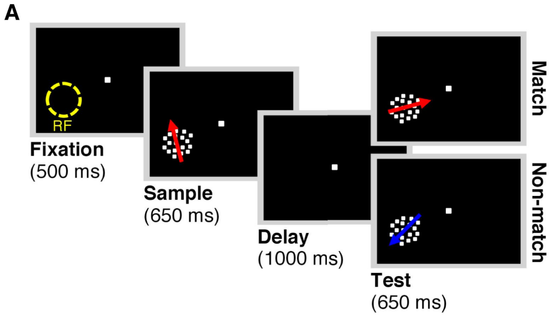


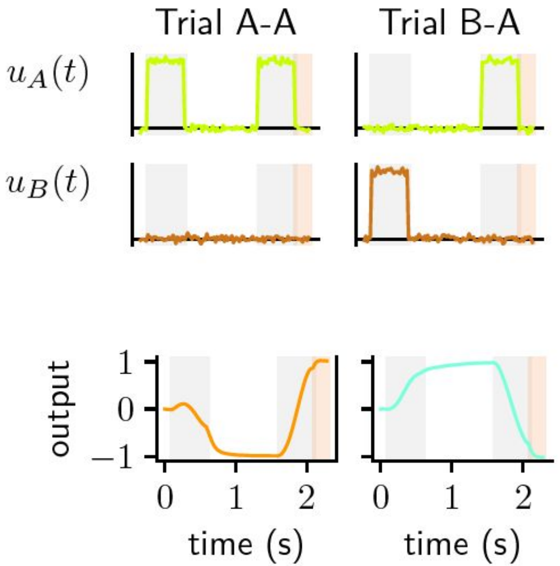


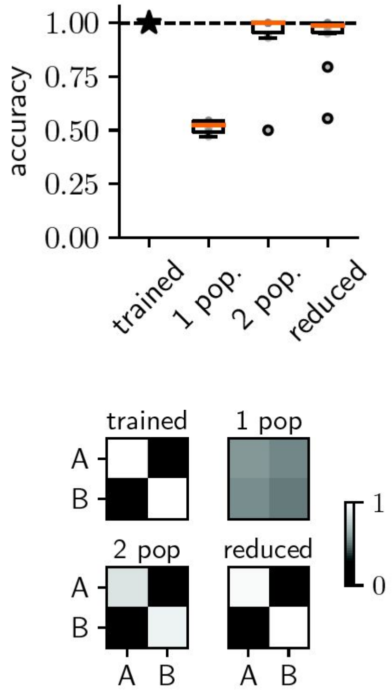
$$\frac{d\kappa_1}{dt} = -\kappa_1 + \tilde{\sigma}_{n^{(1)}m^{(1)}}\kappa_1 + \tilde{\sigma}_{n^{(1)}I}v(t)$$

$$\frac{d\kappa_2}{dt} = -\kappa_2 + \tilde{\sigma}_{n^{(2)}m^{(2)}}\kappa_2 + \tilde{\sigma}_{n^{(2)}I}v(t)$$

Delayed match to sample

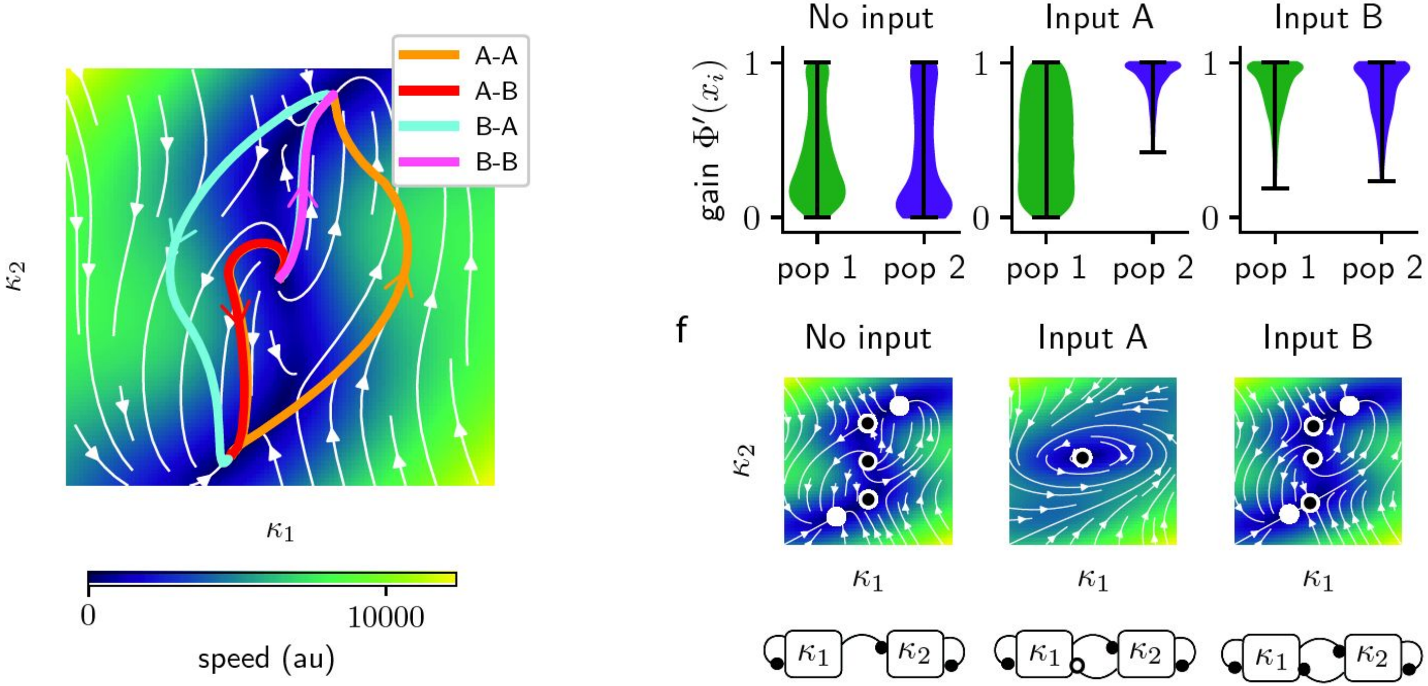






Freeman et al. 2001

Gain modulation flexibly shapes network dynamics



Gain modulation flexibly shapes network dynamics

Effective circuit:

$$\tau \frac{d\kappa_1}{dt} = -\kappa_1 + \tilde{\sigma}_{n^{(1)}m^{(1)}}\kappa_1 + \tilde{\sigma}_{n^{(1)}m^{(2)}}\kappa_2 + \tilde{\sigma}_{n^{(1)}I^A}u_A(t) + \tilde{\sigma}_{n^{(1)}I^B}u_B(t)$$

$$\tau \frac{d\kappa_2}{dt} = -\kappa_2 + \tilde{\sigma}_{n^{(2)}m^{(1)}}\kappa_1 + \tilde{\sigma}_{n^{(2)}m^{(2)}}\kappa_2 + \tilde{\sigma}_{n^{(2)}I^A}u_A(t) + \tilde{\sigma}_{n^{(2)}I^B}u_B(t).$$

Effective couplings:

$$\tilde{\sigma}_{ab} = \sum_{p=1}^{P} \alpha_p \langle \Phi' \rangle_p \sigma_{ab}^{(p)}.$$

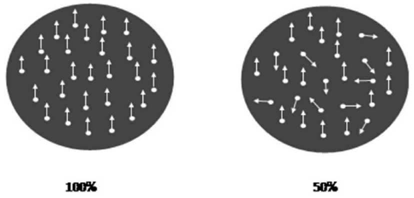
$$\tilde{\sigma}_{n^{(2)}m^{(2)}} \quad = \quad \frac{1}{2}\sigma^{(1)}_{n^{(2)}m^{(2)}}\langle \Phi' \rangle_1 + \frac{1}{2}\sigma^{(2)}_{n^{(2)}m^{(2)}}\langle \Phi' \rangle_2$$

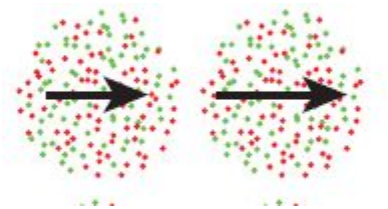
#Populations: flexibility

P = 1 | P = 2

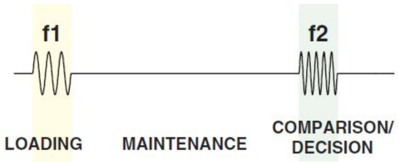
Rank: dimensionality

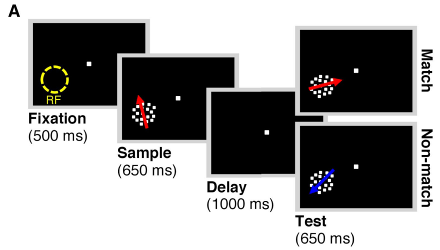
R = 1





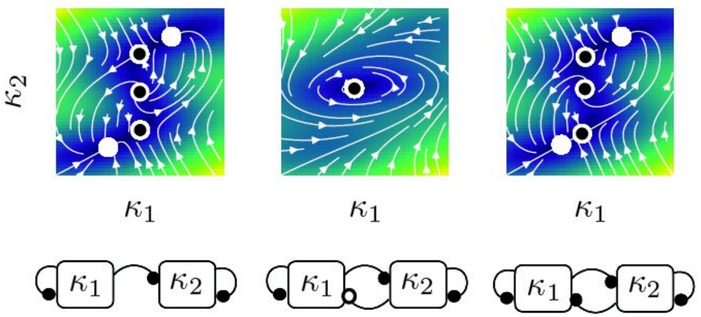
R = 2

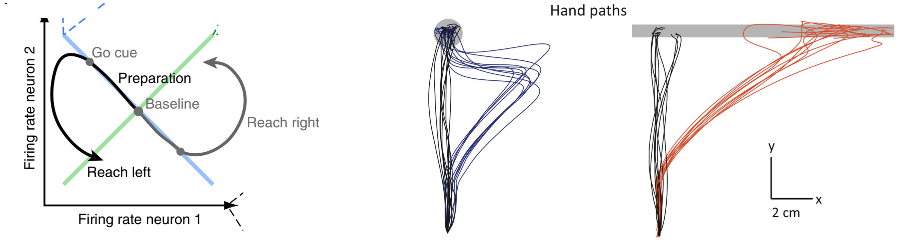




Discussion

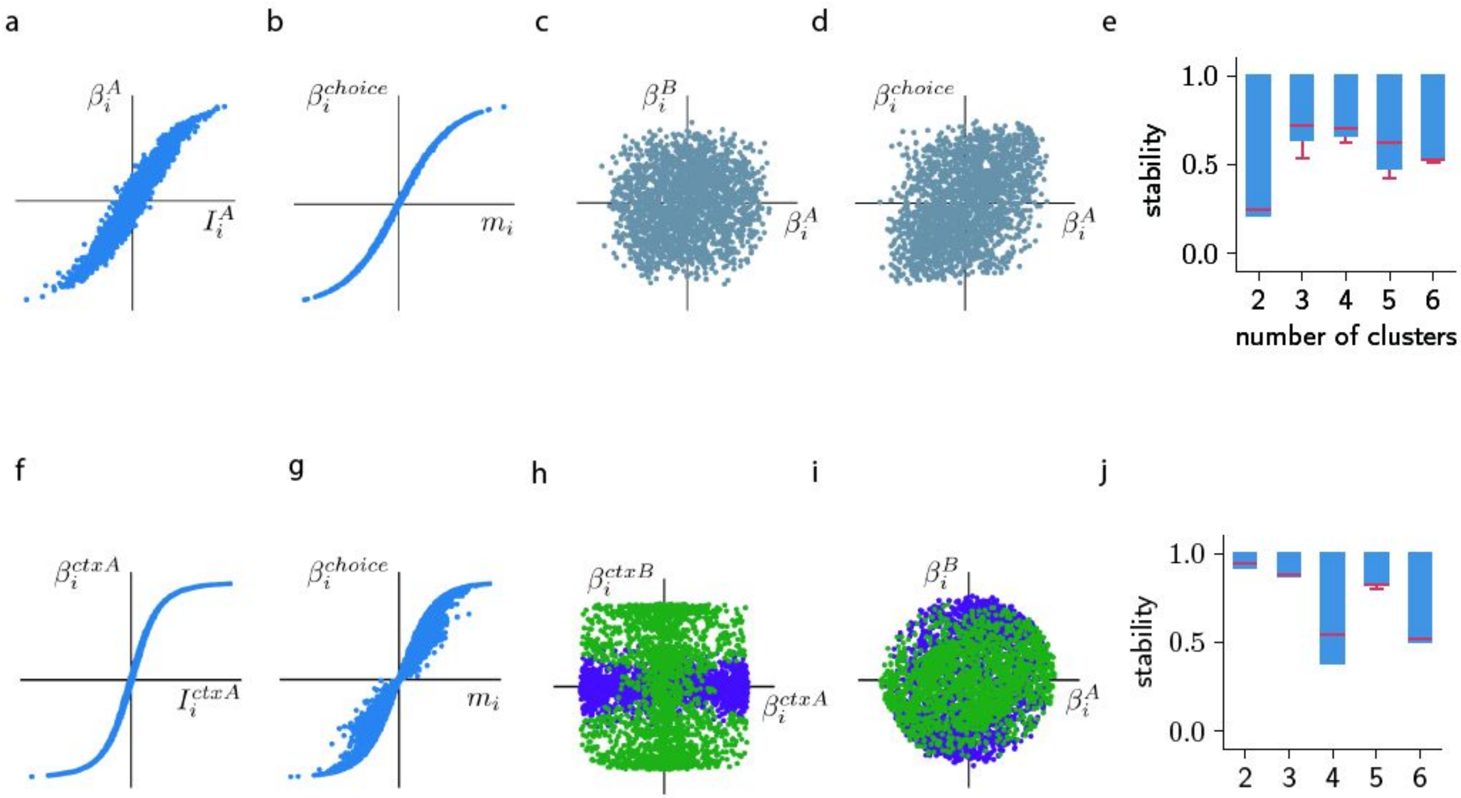
- Awesome: dynamics & circuit





Additional slides

Connectivity determines selectivity



Inactivating specific populations