UNIVERSITÄT BERN

NeuroTMA

Elise: Efficient Learning of Sequences in Structured Recurrent Networks

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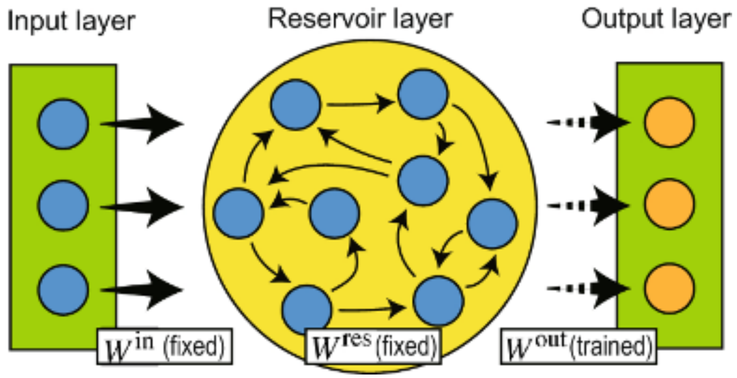
NICE*2025

Learning in recurrent neural networks is challenging

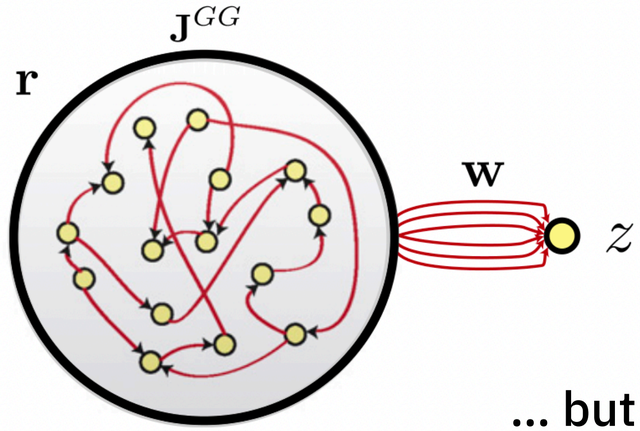
Reservoirs



Lukoševičius et al., 2009

... but does not scale

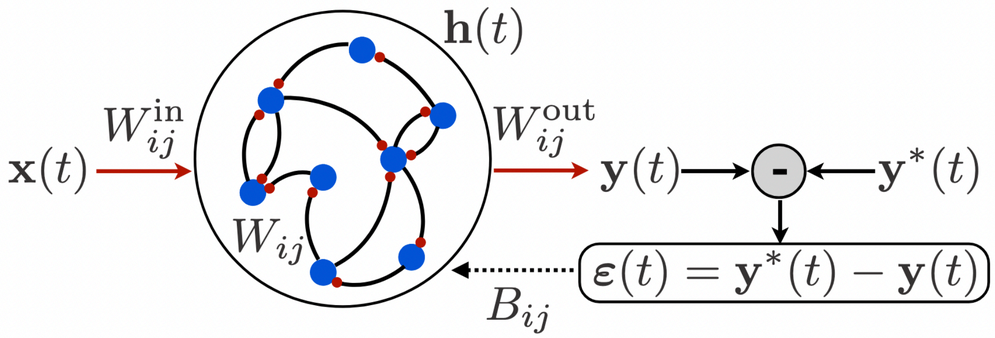
FORCE



Sussillo, Abbot. Neuron (2009)

... but very fast weight dynamics

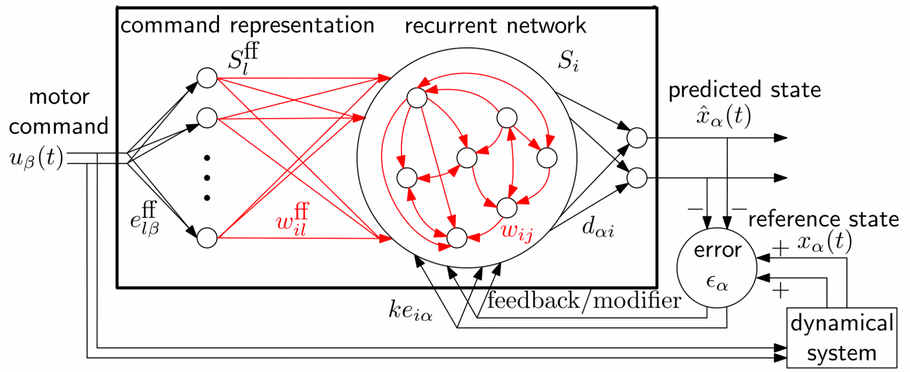
BPTT & approx. (RFLO, RTRL)



Murray. eLife (2018)

... but non-local

FOLLOW

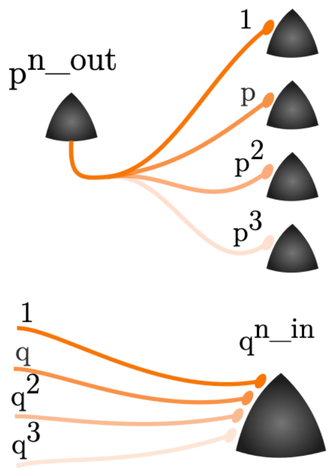


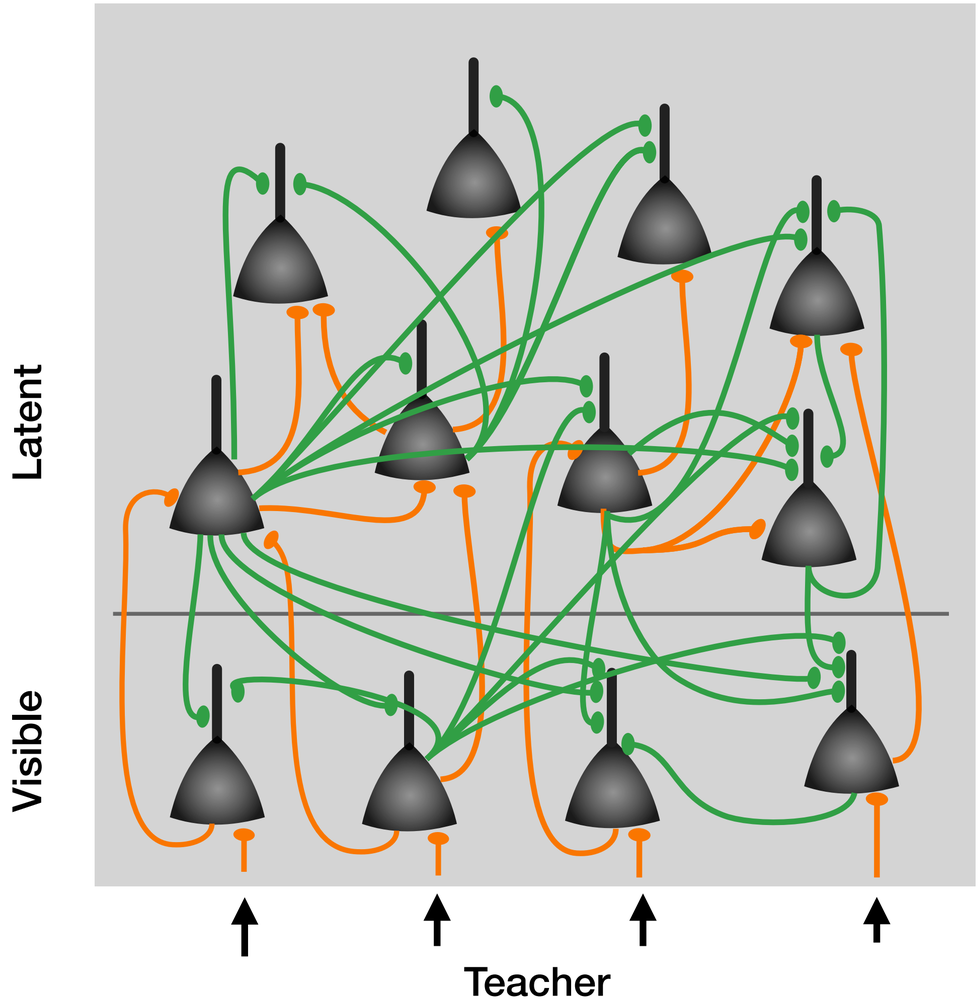
Gilra, Gerstner. eLife (2017)

... but global error signals

Structure in the connectivity

- Somato-somatic connections
  - Sparse & fixed scaffold
- Somato-dendritic connections
  - Dense & learned
- All connections associated with delays





Structure in the neurons

- Dendrite (Current based input)

$$C_{\mathrm{m,v}}\dot{v} = -g_{\mathrm{l}}v + \sum_j w_{ij}^{\mathrm{den}} r_j$$

- Soma (Conductance based input)

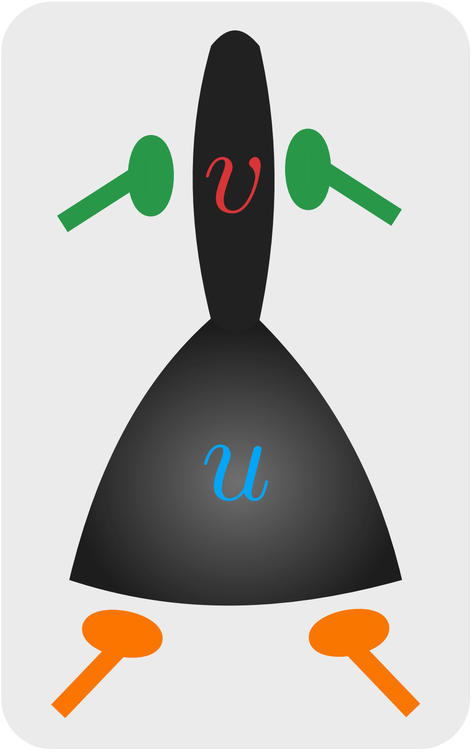
$$C_{\mathrm{m,u}}\dot{u} = -g_{\mathrm{l}}u + g_{\mathrm{den}}\left(v - u\right) + \sum_j w_{ij}^{\mathrm{som}} r_j \left(E^{\mathrm{rev}} - u\right)$$

$$r = \varphi\left(u\right) = \frac{1}{1 + \exp\left(a\left(b - u\right)\right)}$$

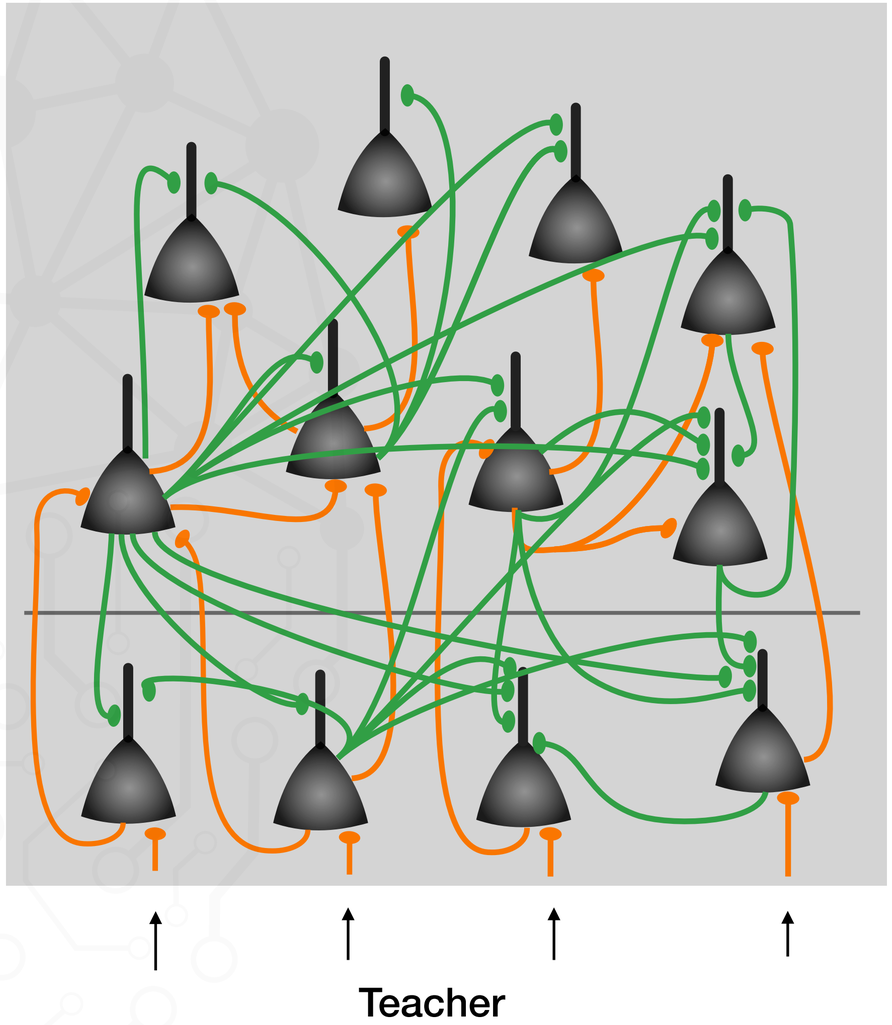
- Local error correcting learning rule

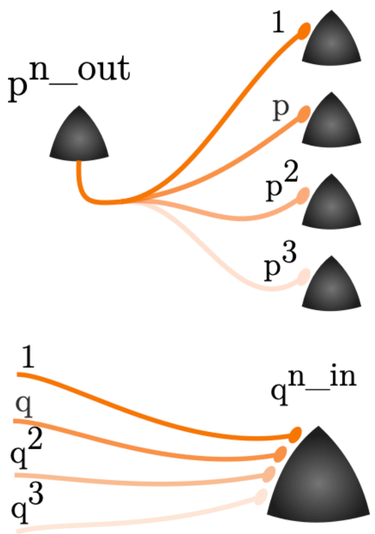
$$\Delta w_{ij}^{\mathrm{den}} = \eta \left[\varphi(u_i) - \varphi\left(\frac{g_{\mathrm{l}}E_{\mathrm{l}} + g_{\mathrm{den}}v_i}{g_{\mathrm{l}} + g_{\mathrm{den}}}\right)\right] \frac{\partial v_i}{\partial w_{ij}}$$

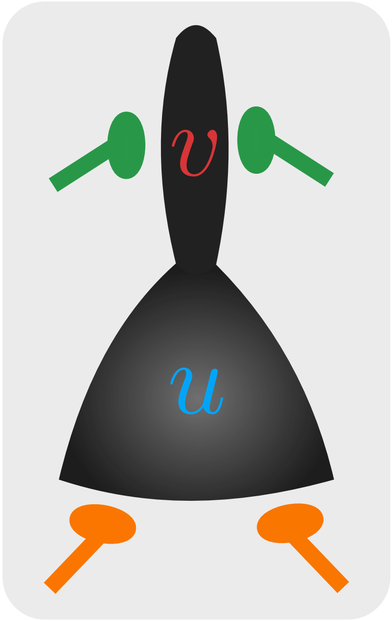
Urbanczik & Senn 2014



The ELiSe model







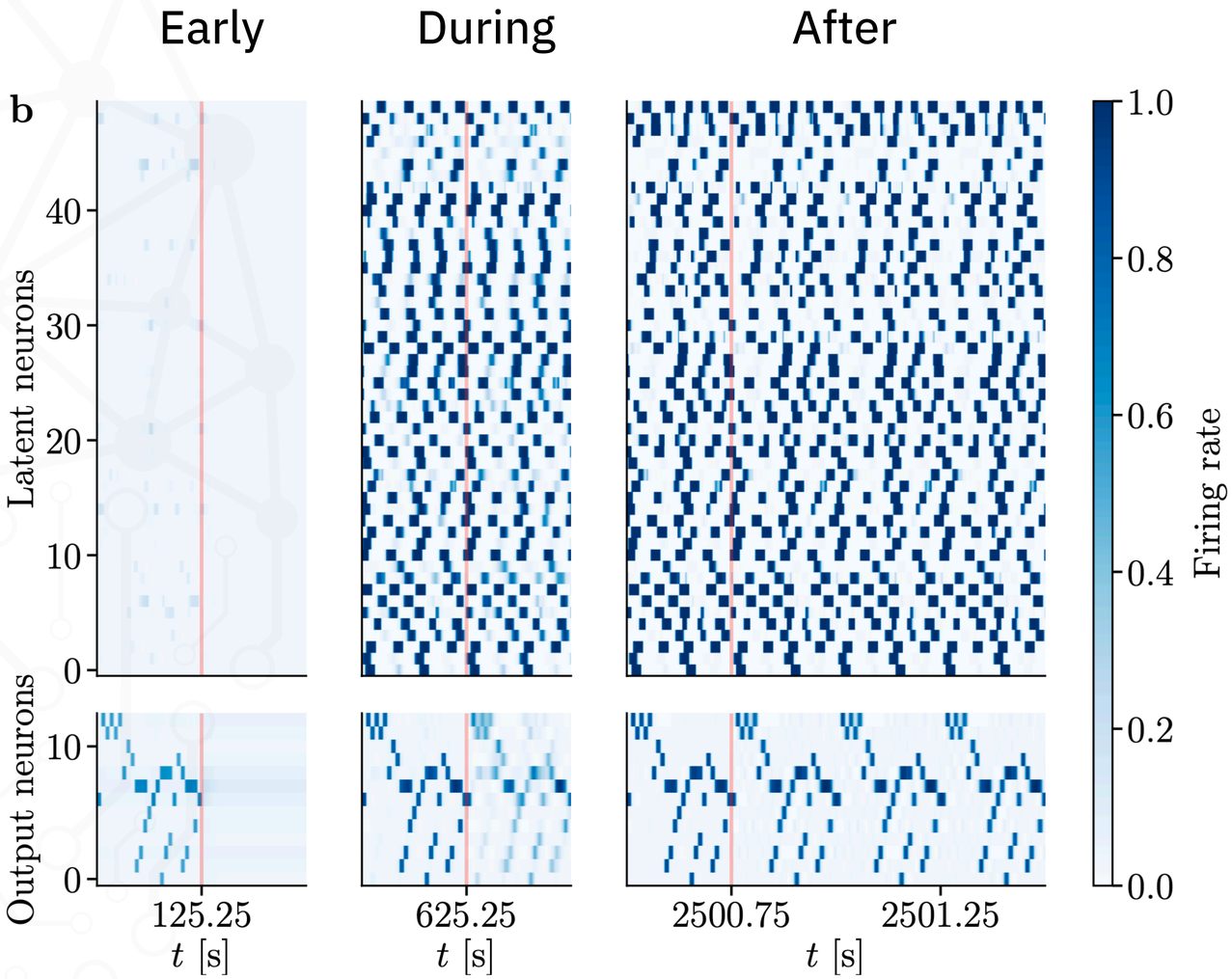
$$C_{\mathrm{m,u}}\dot{u} = -g_{\mathrm{l}}u + g_{\mathrm{den}}\left(v-u\right) + \sum_j w_{ij}^{\mathrm{som}} r_j \left(E^{\mathrm{rev}} - u\right)$$

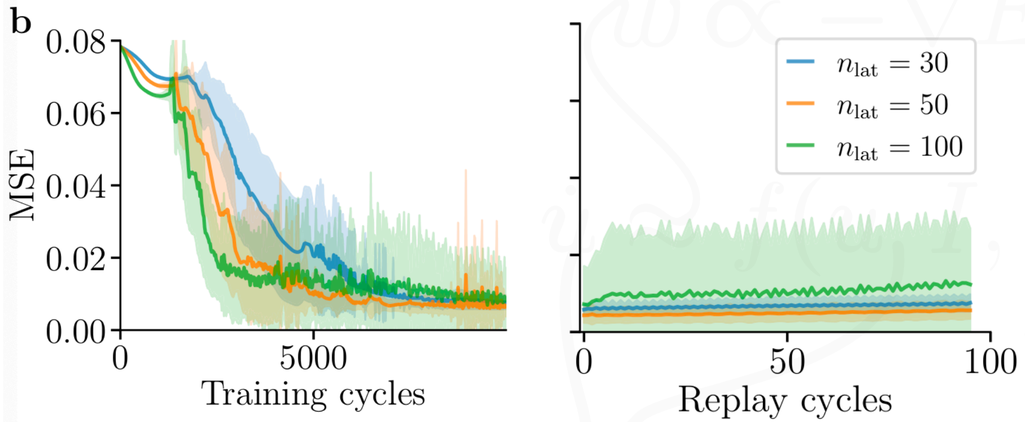
$$C_{\mathrm{m,v}}\dot{v} = -g_{\mathrm{l}}v + \sum_j w_{ij}^{\mathrm{den}} r_j$$

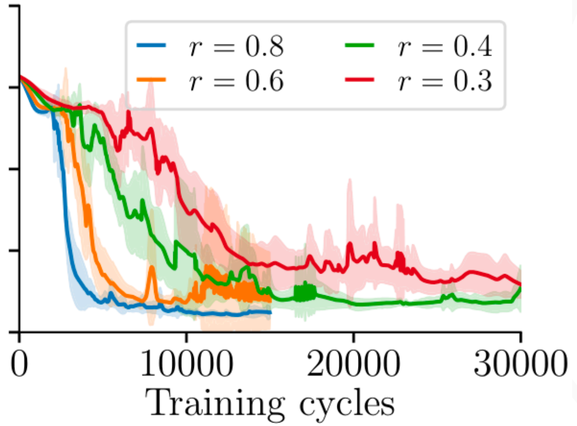
$$\Delta w_{ij}^{\mathrm{den}} = \eta \left[\varphi(u_i) - \varphi\left(\frac{g_{\mathrm{l}}E_{\mathrm{l}} + g_{\mathrm{den}}v_i}{g_{\mathrm{l}}+g_{\mathrm{den}}}\right)\right]\frac{\partial v_i}{\partial w_{ij}}$$

Urbanczik & Senn 2014

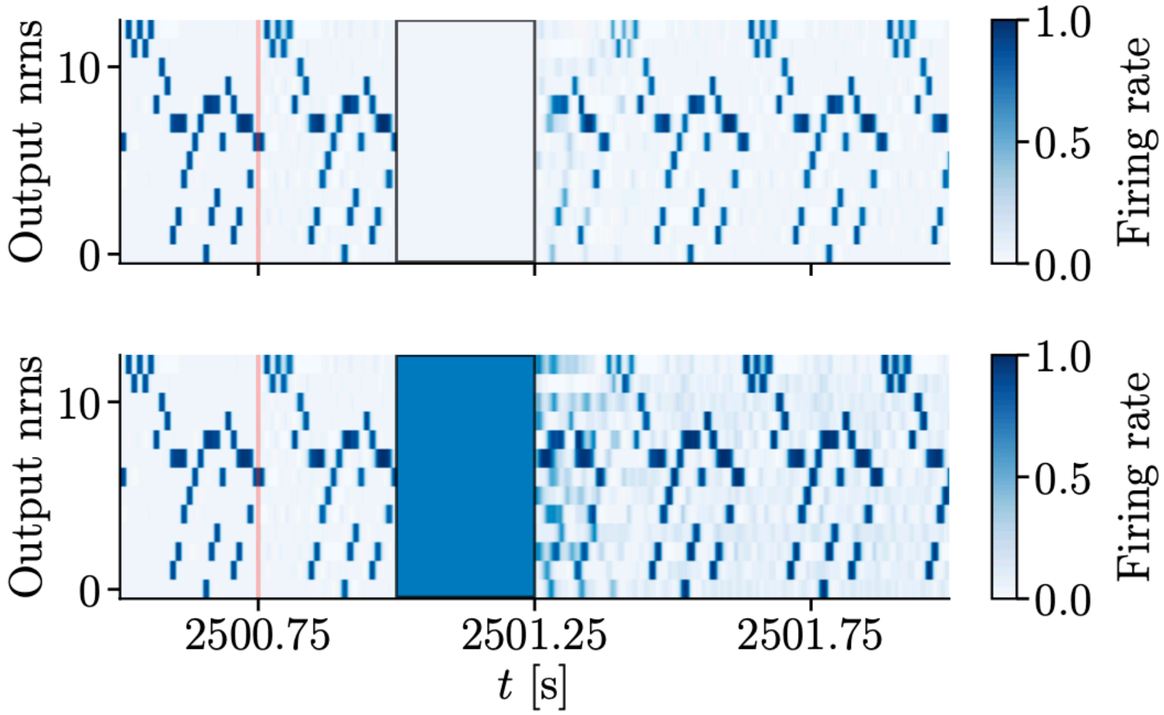
Learning to play Für Elise







Network recovers from disruption



ELiSe

- Pre-print

- Capo-caccia workshop

The team

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Funding

Funded by the European Union

Human Brain Project

Swiss National Science Foundation

Behaviour arises out of complex sequences of neural activity.