The navigation map inside you - Place and grid cells

A simple model to understand place cell mapping

Brains, Dynamics and Computation 2025
Group 9
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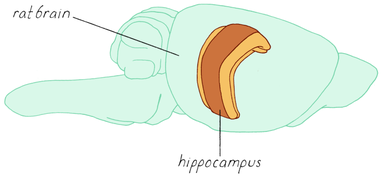
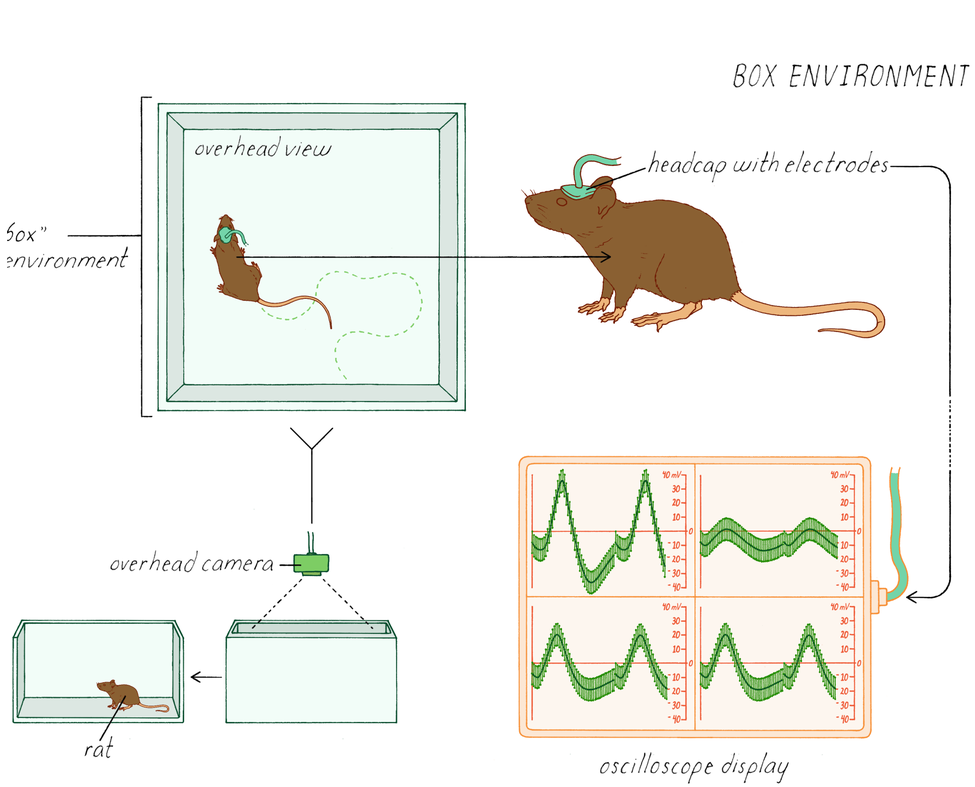
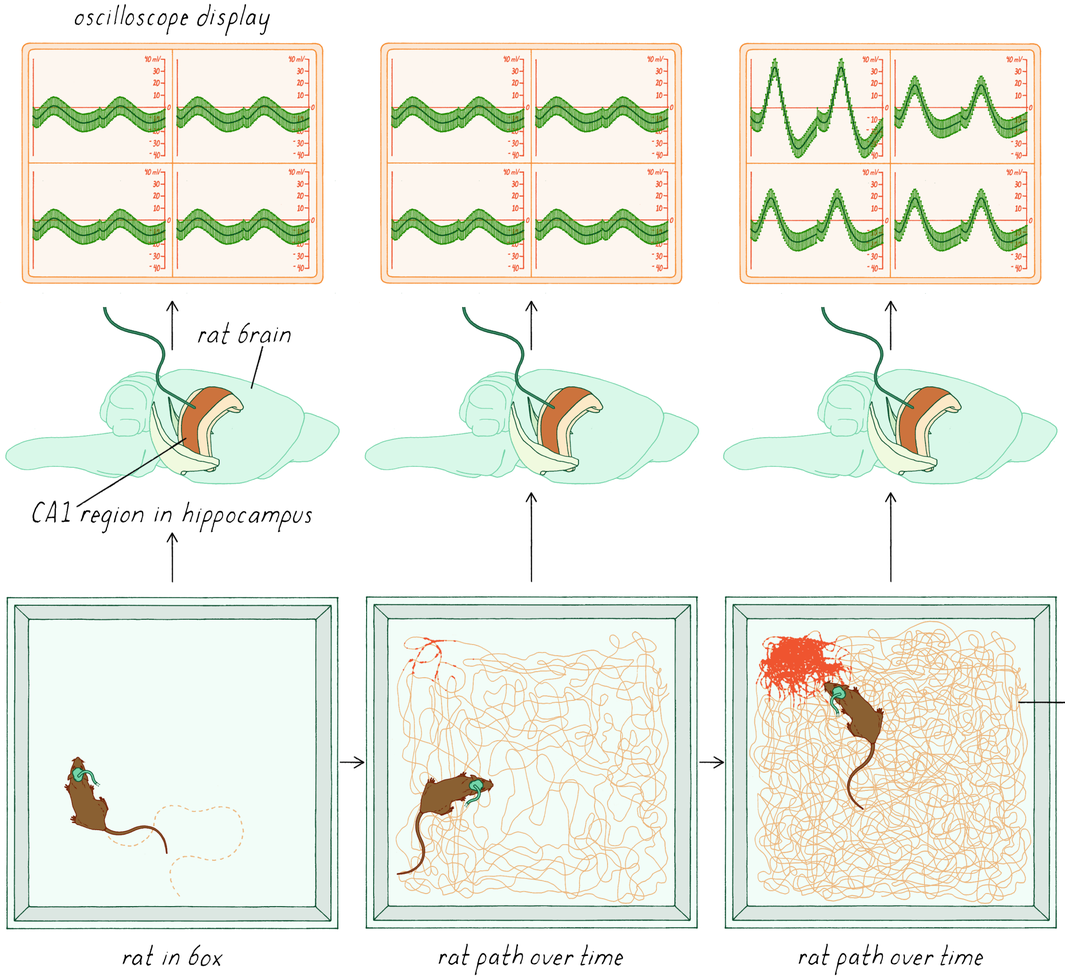
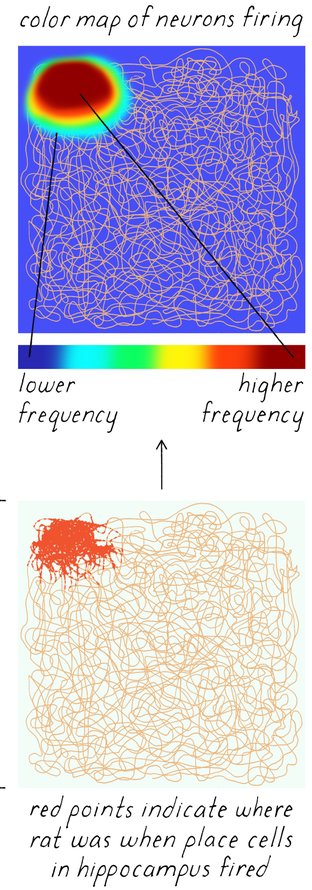
Navigating your way - Place cells



RECORDING FROM PLACE CELLS



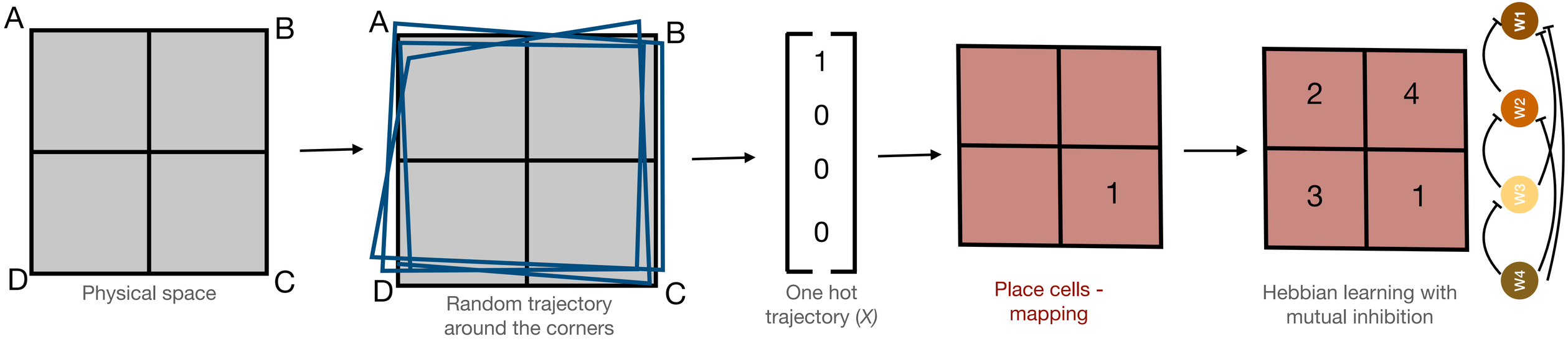




*"it dawned on me that **these (place) cells** weren't particularly interested in what the animal was doing or why it was doing it but rather they were interested in where it was in the **environment** at the time"* - John O Keefe

https://explorebiology.org/collections/neuroscience/grid-and-place-cells-keys-to-the-spatial-map-in-your-brain

Navigating your way - How did we go about it?



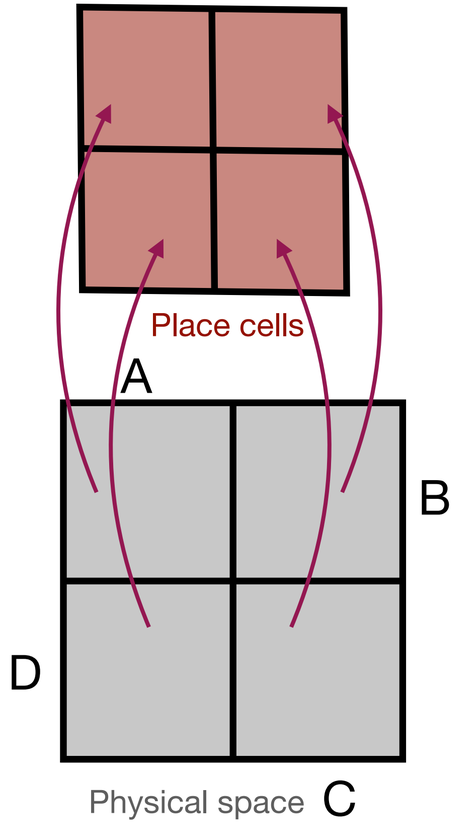
$$W^{t+1} = W^t + \eta P(X - \gamma)^T$$

Weight update rule

Learning rate

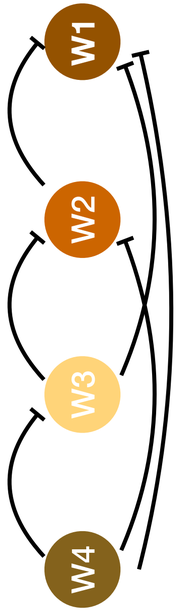
Decay term

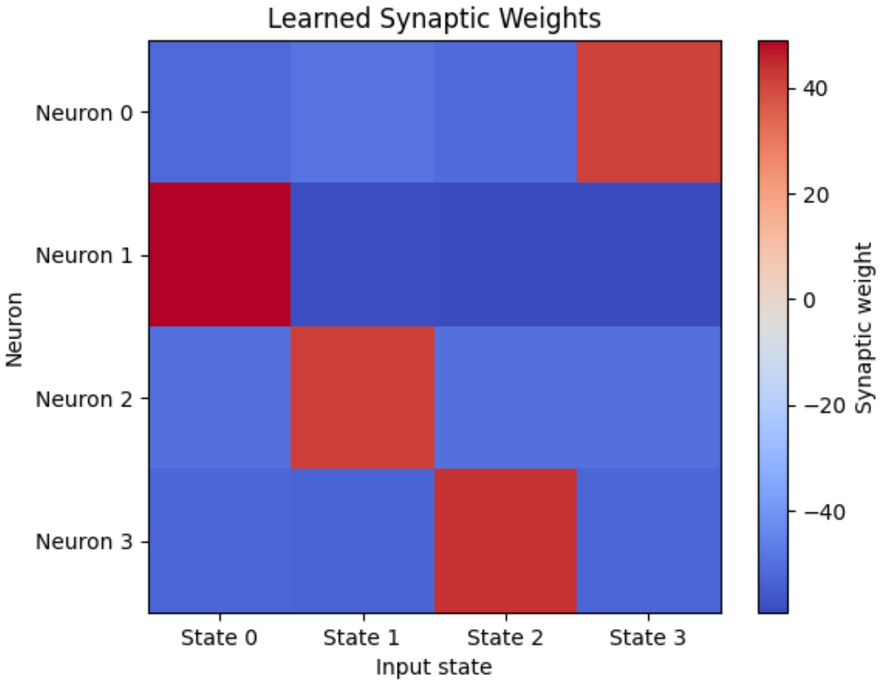
Simulating place cells encoding

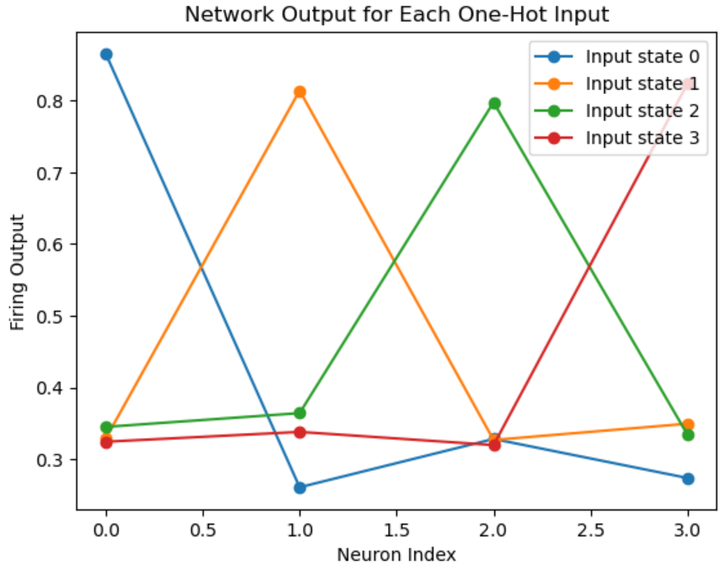


Mapping place to 4 corners of the square matrix

4 perceptrons with lateral inhibition







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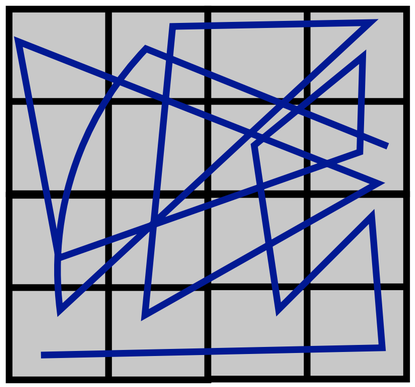
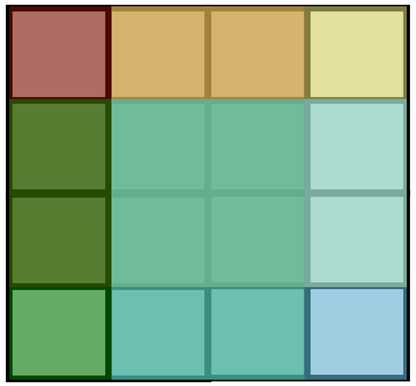
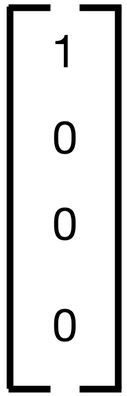
Navigating your way - How did we go about it?



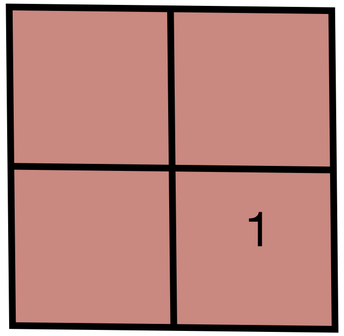
Continuous physical space



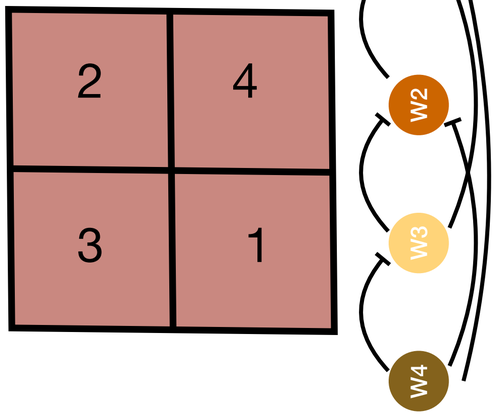
Splitting the grid to 3*3 kernels



One hot trajectory (*X*)



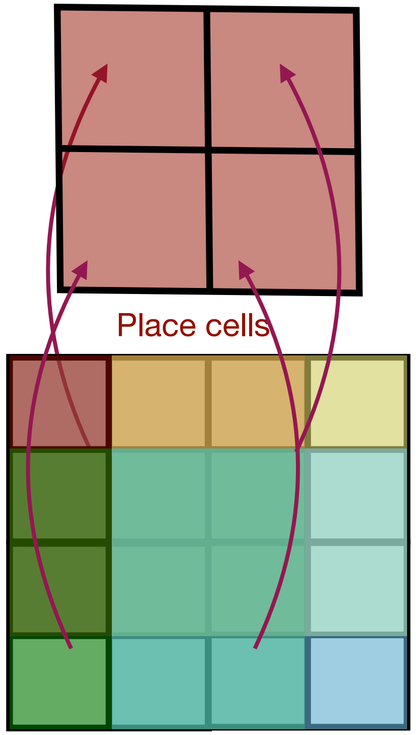
Place cells - mapping



Hebbian learning with mutual inhibition

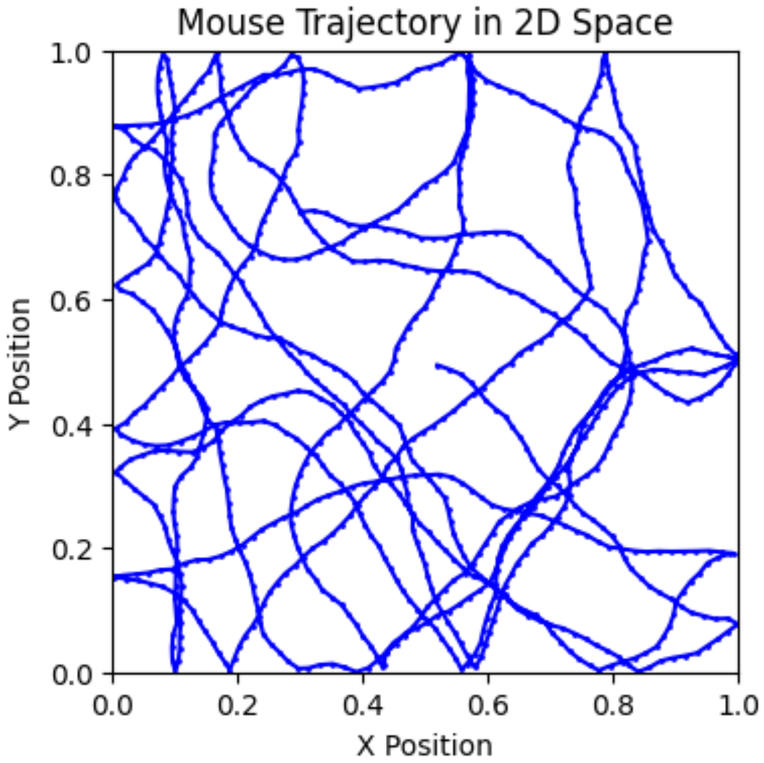
$$W^{t+1} = W^t + \eta P(X - \gamma)^T$$

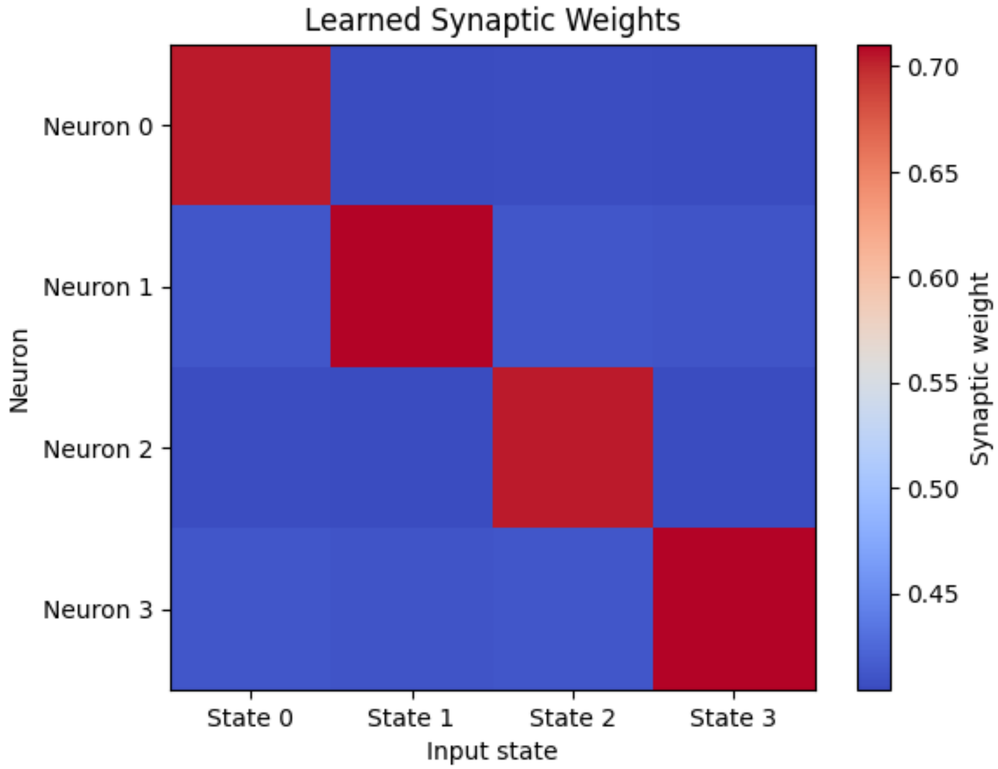
Simulating continuous trajectory onto 4 place cells



Physical space with kernels

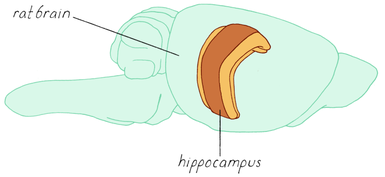
Mapping place cells in a continuous matrix

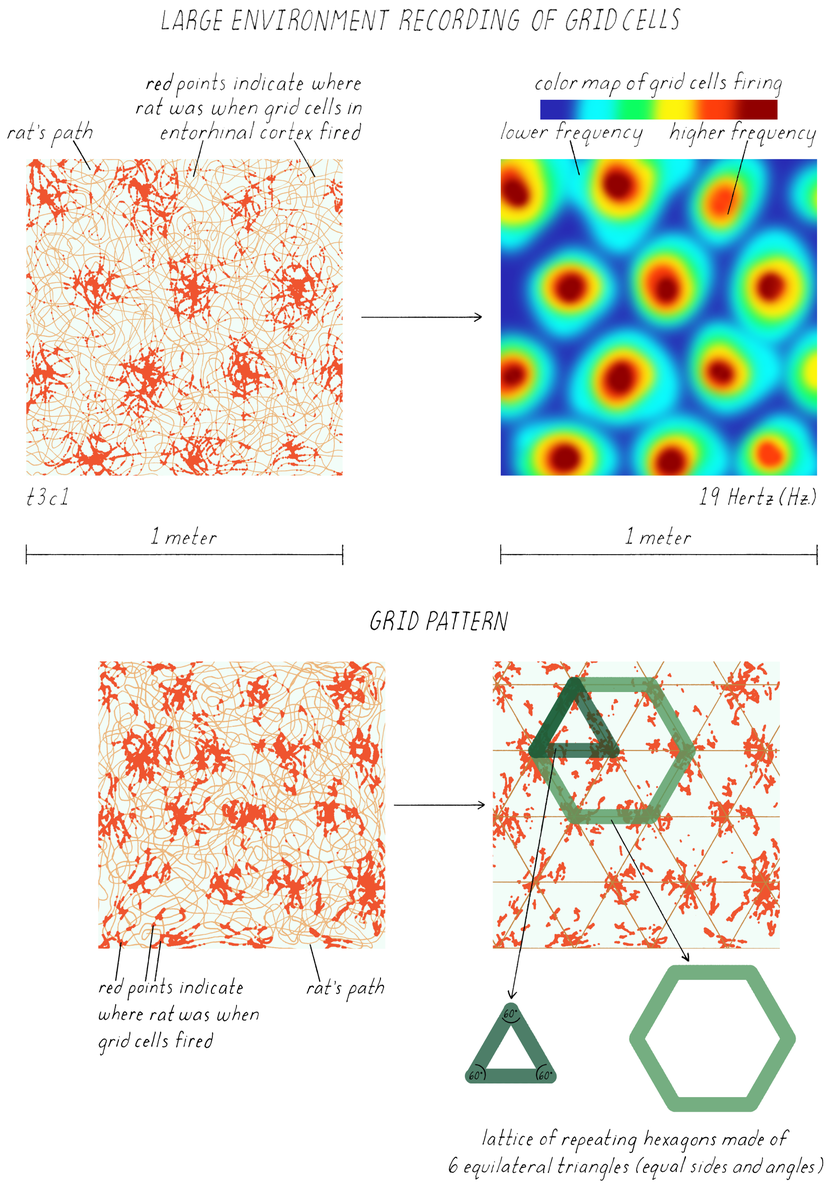


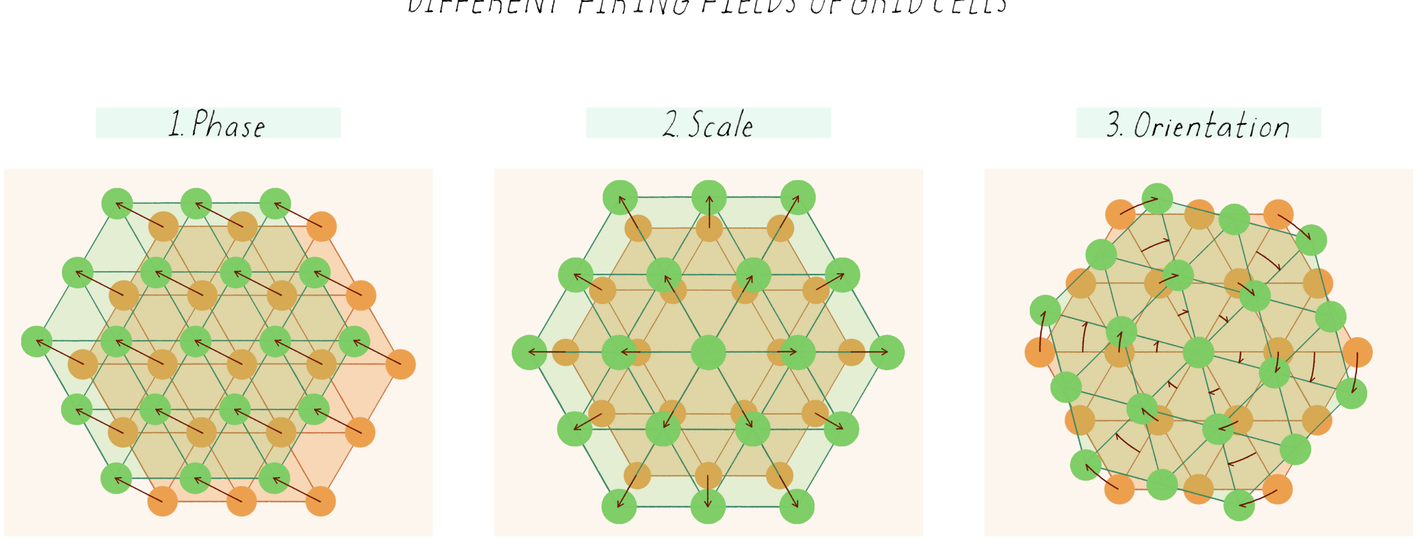


$$W^{t+1} = W^t + \eta P(X - \gamma)^T$$

How do grid cells map the physical space







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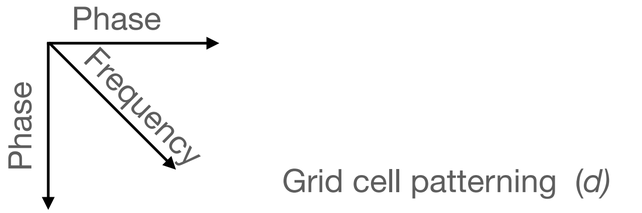
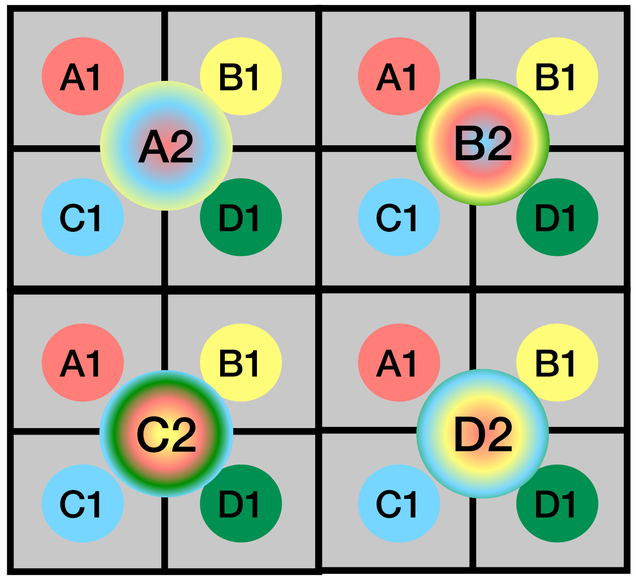
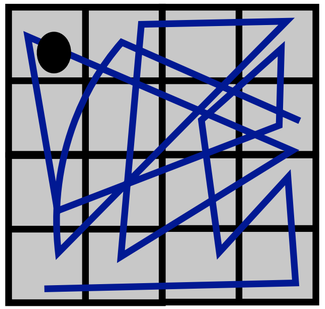


Grid cell patterning (*d*)





Matrix generation (*m*)

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$g^t = (d \,.\, m)$$

$$g \in \{0,1\}$$

Grid cell activation

$$P_p^t = \sigma(W_p^t \,.\, G^t + M_p \,.\, P^{t-1})$$

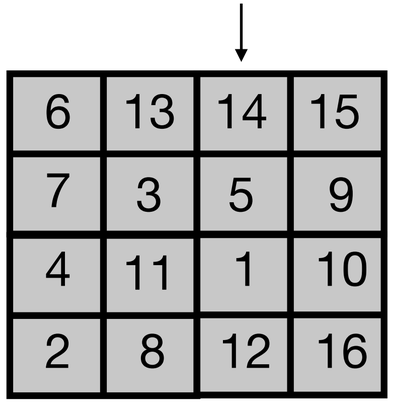
Grid cell activation

Lateral inhibition

$$\sigma(x) = 1/(1 + e^{-x/T})$$

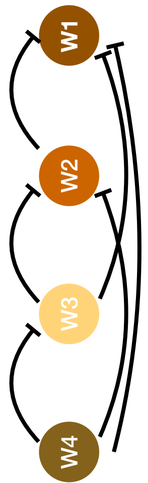
T = temperature

Asynchronous state update for place cell activation



6	13	14	15
7	3	5	9
4	11	1	10
2	8	12	16

Unique place cell mapping



$$W^{t+1} = W^t + \eta P_p (G_g - \gamma)^T$$

Weight update rule

How do grid cells map the physical space

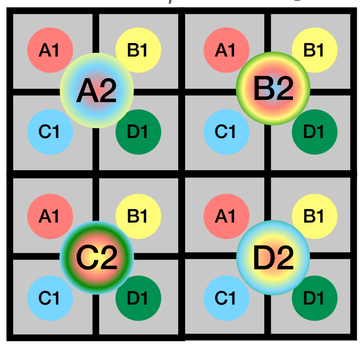
Weight update rule

$$W^{t+1} = W^t + \eta P_p (G_g - \gamma)^T$$

Learning rate

Decay term

Grid cell patterning



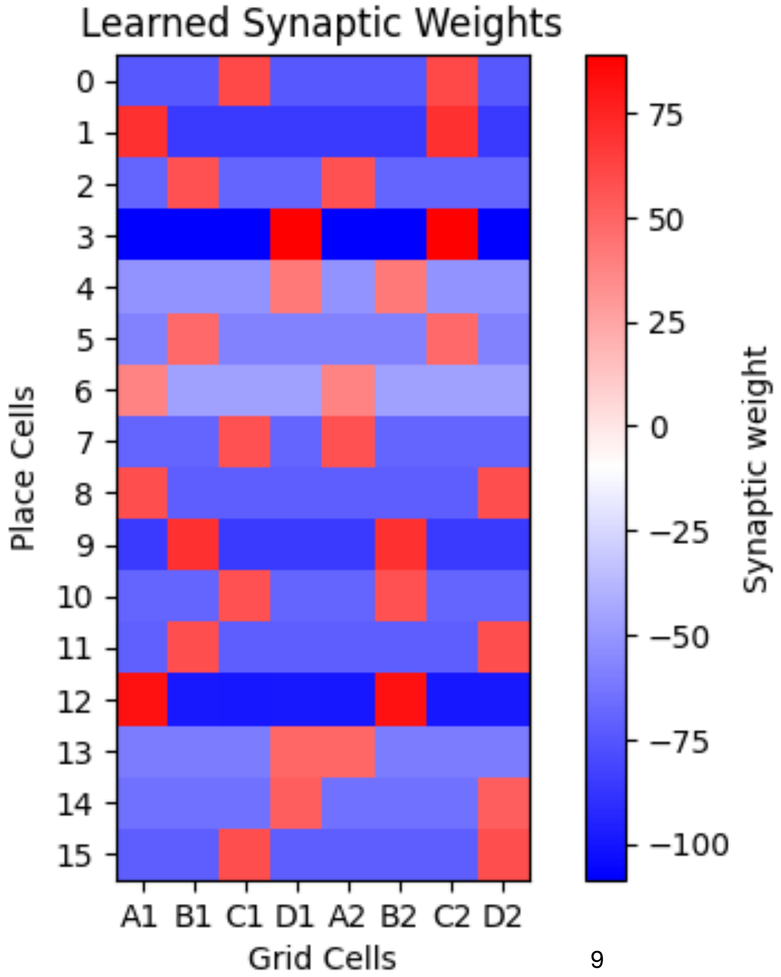
Hyperparameters

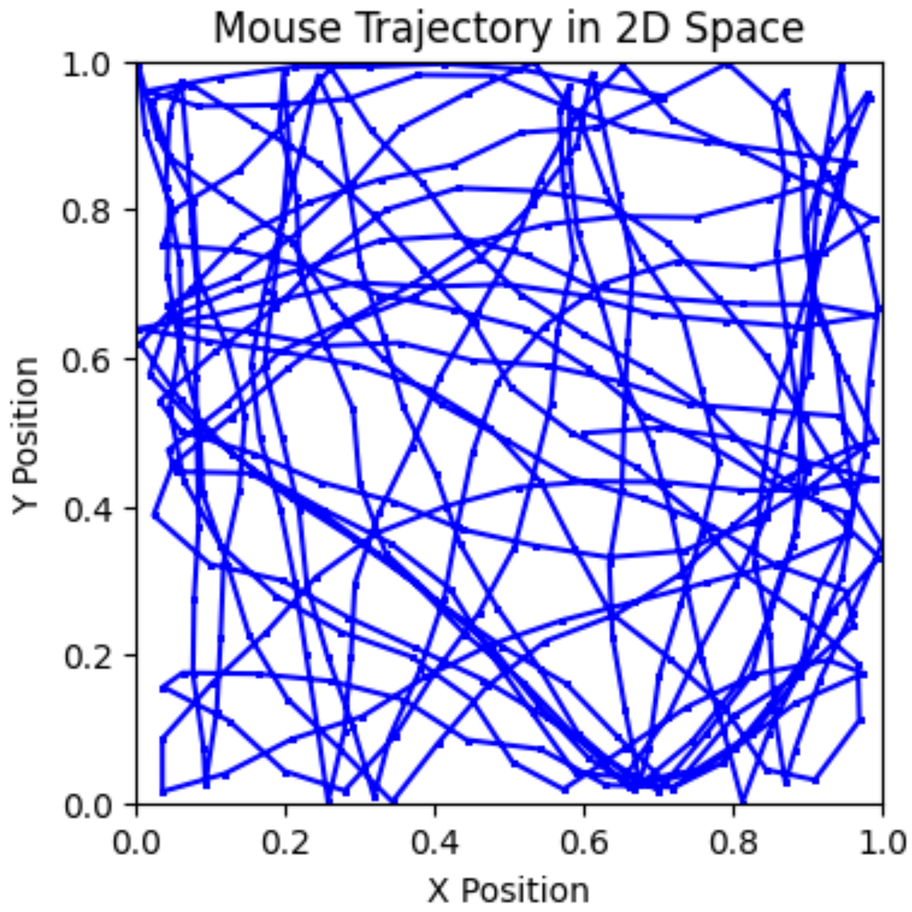
$\eta = 0.5$

$\gamma = 0.55$

$\mu = 2$

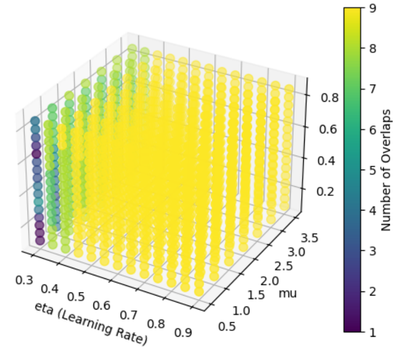
$T = 0.01$

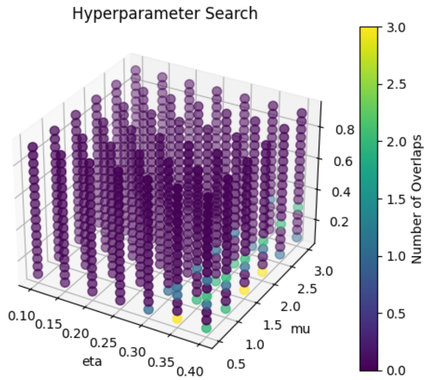


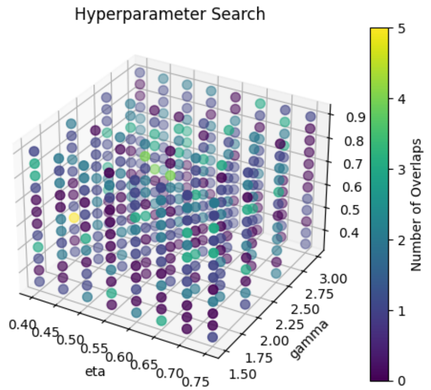


Future directions/Limitations

- Achieving unique mapping for a true random network
- Introduce biologically inspired neurons - LIF neurons (E-I populations
- Not hard-encoding grid cell activation patterns
- Output is dependent on the initial randomisation (of weights)
- Encoding path direction and location
- Understanding memory and replay functions
- Remapping of place cells to a new navigational source
- Tuning in the hyperparameters







Acknowledgements

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Organisers of the BDC 2025 workshop