Population Vector Navigation

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Summary:

We train a feedforward network to minimize the similarity between population vectors at different simulated locations and contexts. We also train a recurrent neural network to distinguish locations while path integrating along simulated trajectories. The feedforward network learns spatial representations similar to biological place cells, and remaps between contexts. The recurrent neural network learns to path integrate, and its spatial representations are similar to biological place and band cells.

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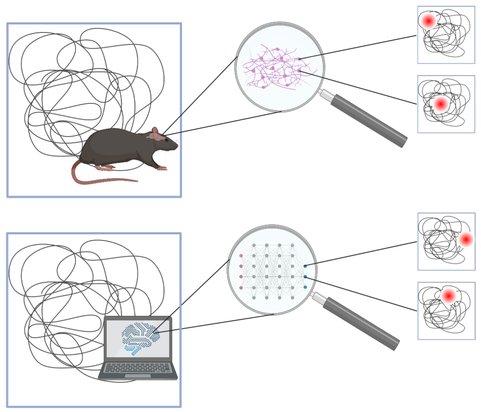
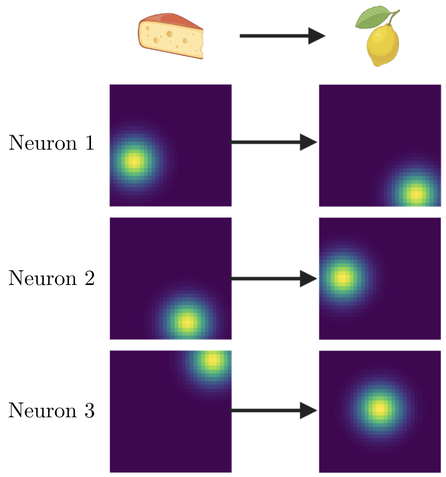
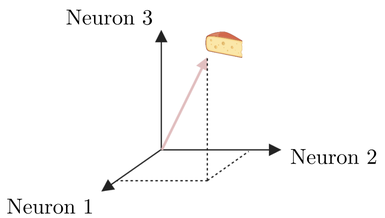
Navigating neural networks learn biologically plausible representations

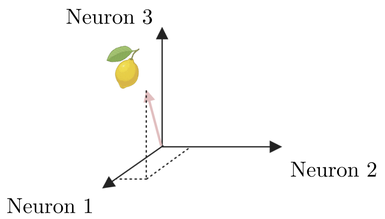


Biological neurons change their spatial responses when contextual cues change



Information is encoded in population vectors





How *should* population vectors encode position and context?

- All positions are uniquely encoded
- Close locations are similar in representation
- Distant locations are dissimilar in representation
- There are no privileged locations in space
- Non-negativity

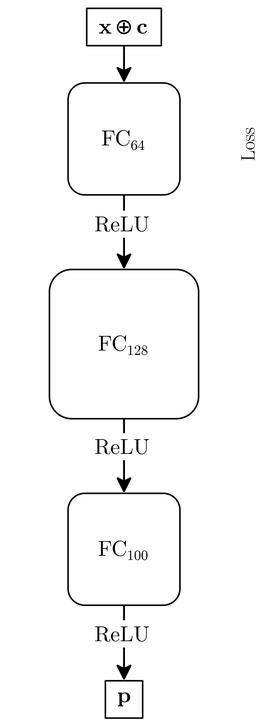
↓ Find $\mathbf{p}$ that minimizes

$$\text{(I)} \quad \mathcal{L} = \mathbb{E}\left[\left(e^{-\frac{0.5}{\sigma^2}|\mathbf{x}-\mathbf{x}'|^2} - \mathbf{p}(\mathbf{x})\cdot\mathbf{p}(\mathbf{x}')\right)^2\right]$$

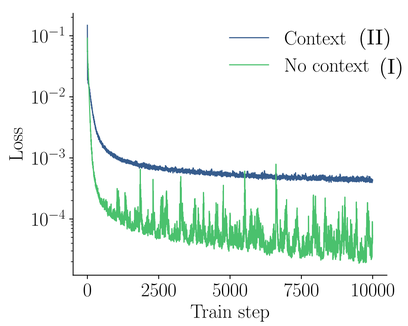
$$\text{(II)} \quad \mathcal{L} = \mathbb{E}\left[\left(e^{-\frac{0.5}{\sigma^2}|\mathbf{x}-\mathbf{x}'|^2} e^{-\frac{0.5}{\sigma^2}|c-c'|^2} - \mathbf{p}(\mathbf{x},c)\cdot\mathbf{p}(\mathbf{x}',c')\right)^2\right]$$

(I): Spatial objective
(II): Conjunctive spatial and context objective

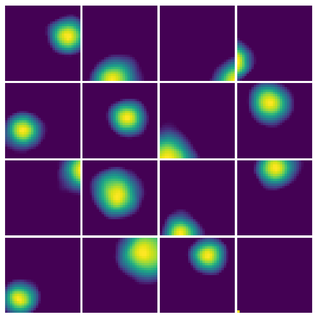
Feedforward networks learn biologically plausible place cell-like spatial representations and remapping across contexts



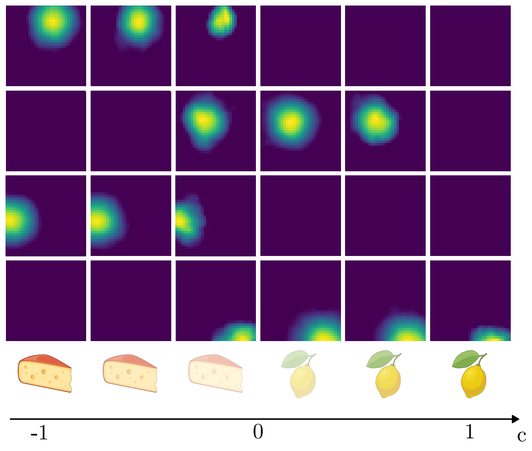
Feedforward architecture



Loss histories for feedforward models

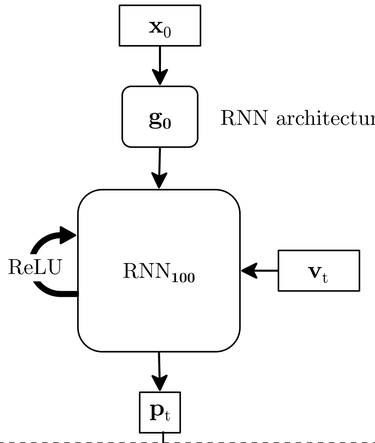


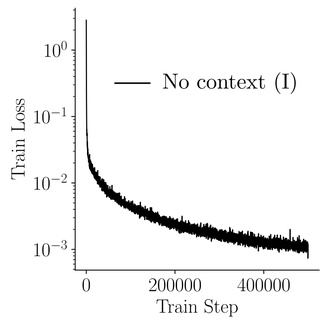
Learned spatial representations, $\mathbf{p}$ with no context signal



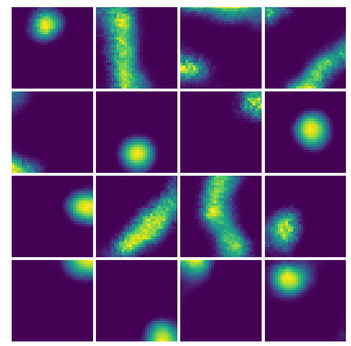
Remapping of learned spatial representations $\mathbf{p}$ for different context signal strengths

A recurrent neural network learns biologically plausible band and place cell-like spatial representations and path integration





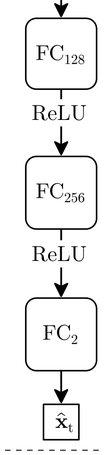
RNN loss history

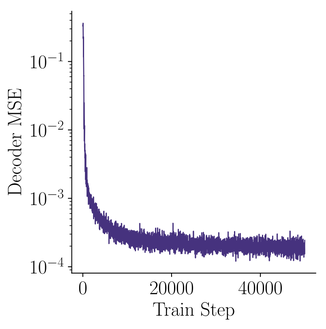


Spatial representations $\mathbf{p}$, of a trained RNN

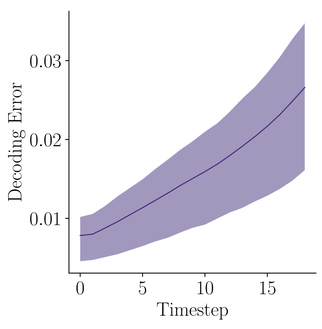
Decoder

Trained separately to decode RNN output into true position using MSE loss.

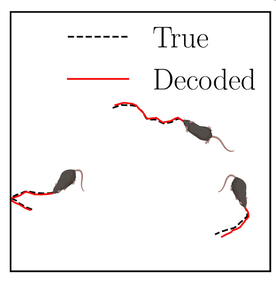




Decoder loss history



Decoding error (Euclidean); mean and quartiles for every trajectory step



Example true and decoded trajectories

Illustrations were created using BioRender.com