Robust representations for olfactory-spatial association learning

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August 04, 2025

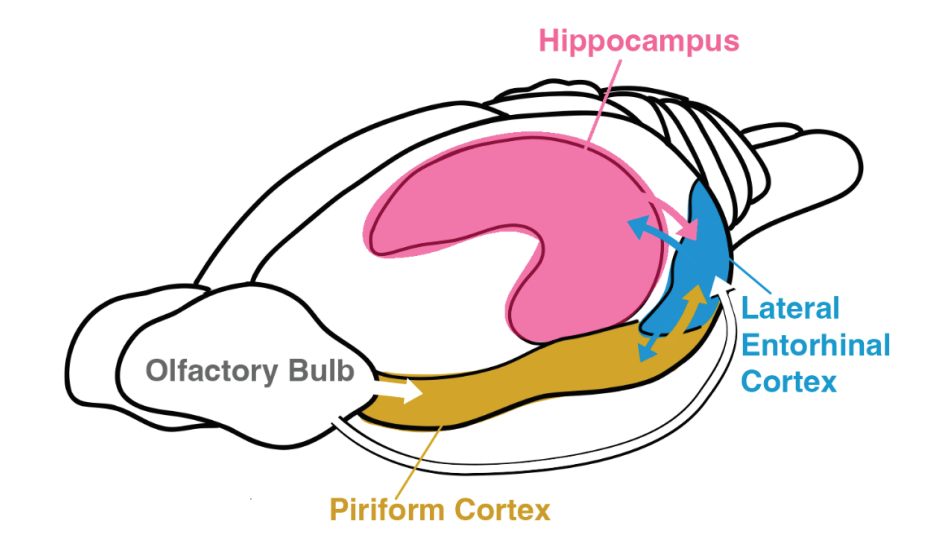
Outline

1. Project recap
2. Modeling & Simulation
3. Results
4. Conclusion

Outline

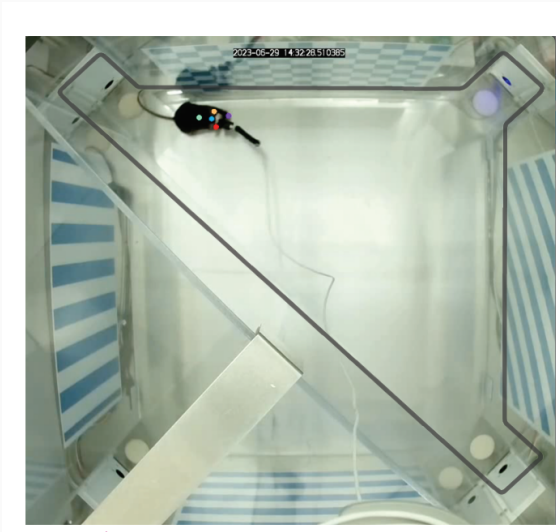
The LEC is key to sensory associations and spatial memory

- Piriform Cortex encodes olfactory information
- Hippocampus encodes spatial information
- Lateral Entorhinal Cortex (LEC) encodes both olfactory & spatial information

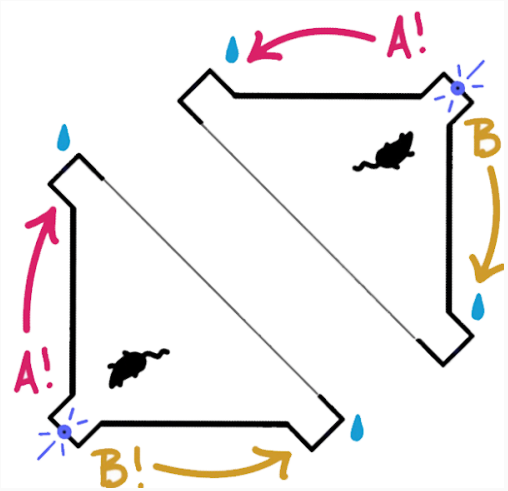


Poo et al., 2022
Bitzenhofer et al., 2022
Lee et al., 2021

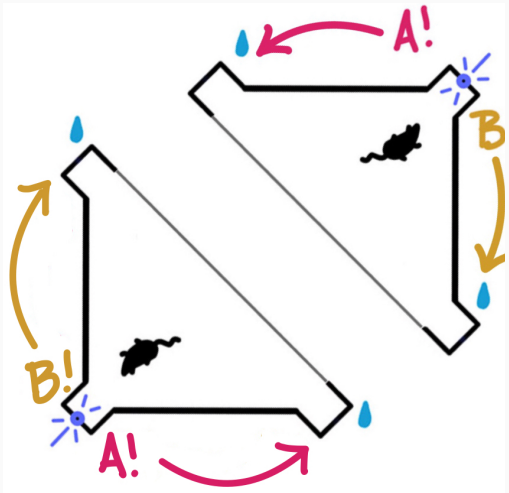
Half triangle task for olfactory-spatial association learning



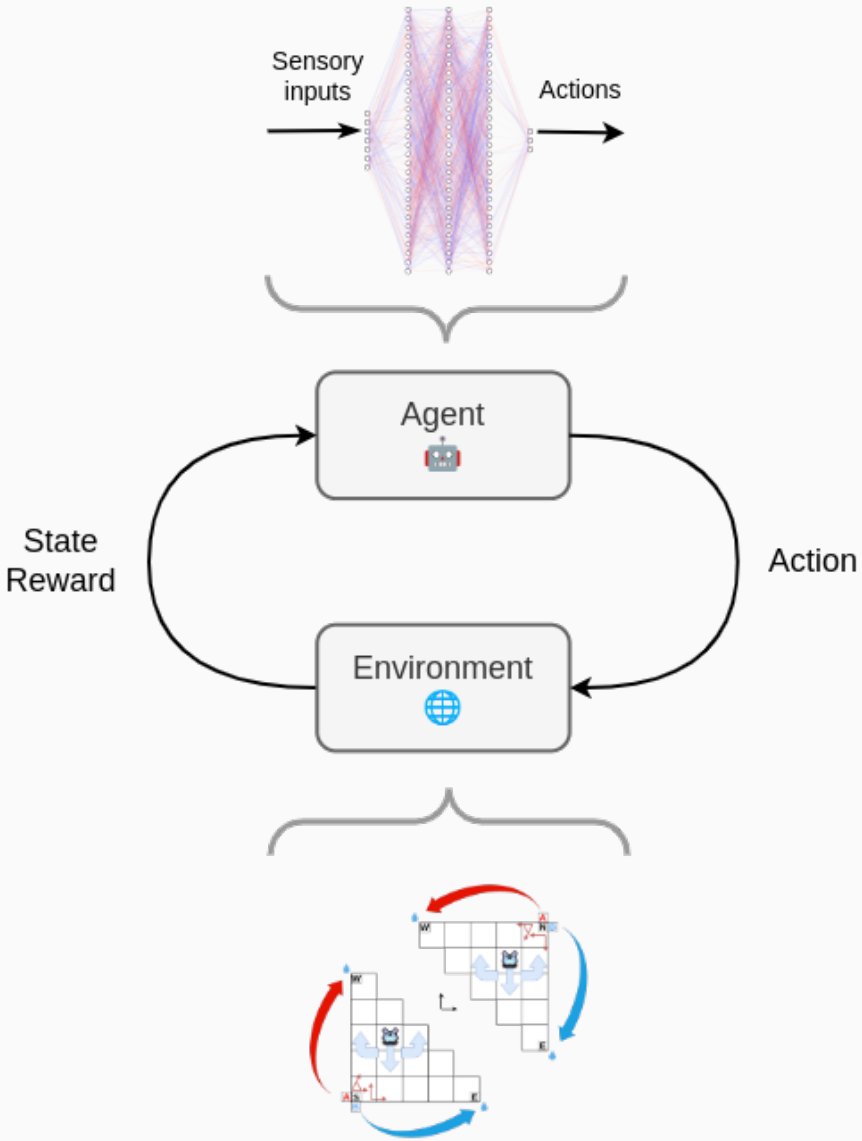
East/West task



Left/Right task



Deep Reinforcement Learning model



- Agent learns a policy (sequences of actions) that maximize rewards
- RL $\rightarrow$ no need to have ground truth data (as in supervised learning)

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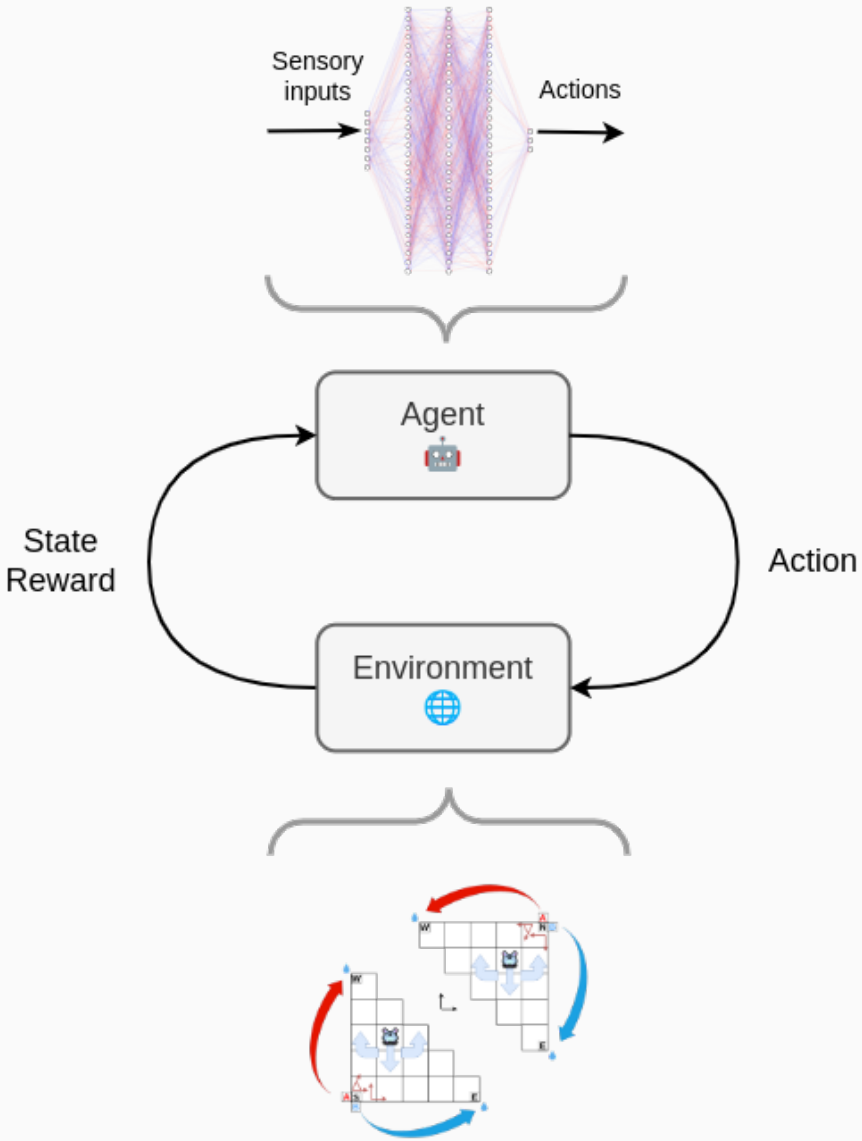

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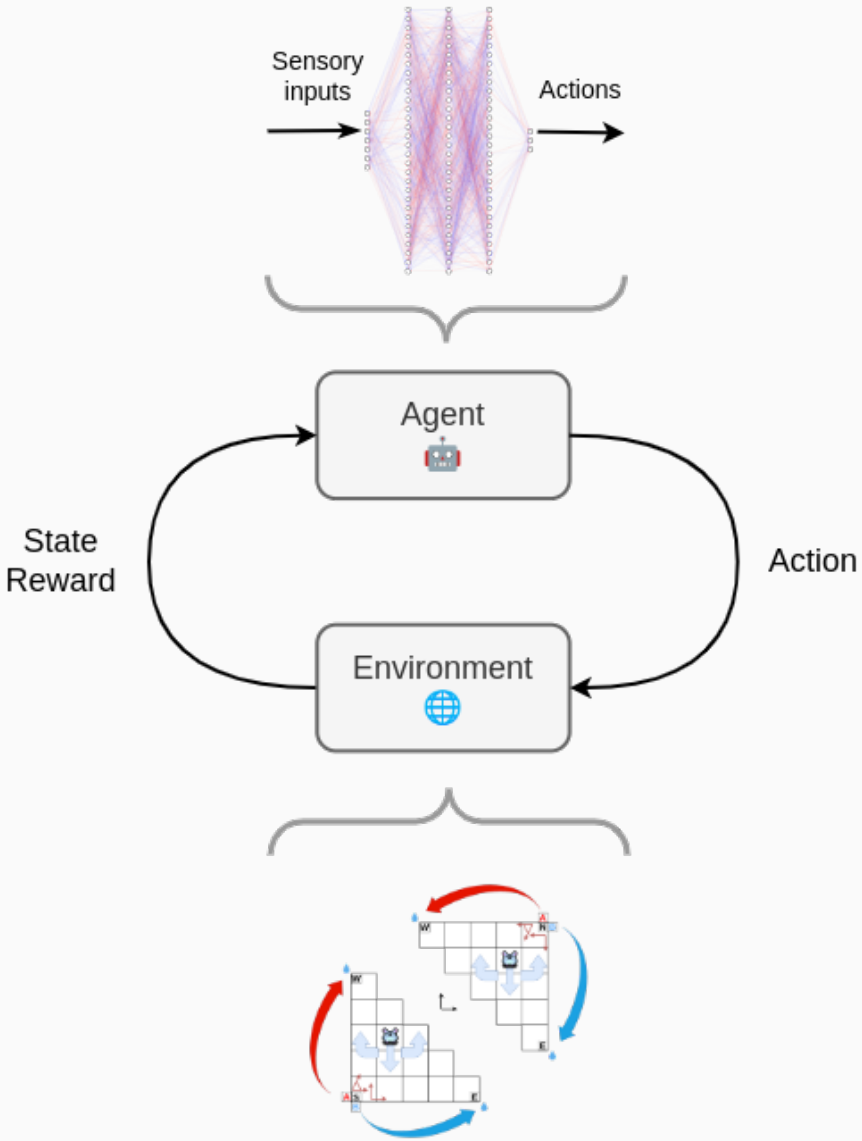

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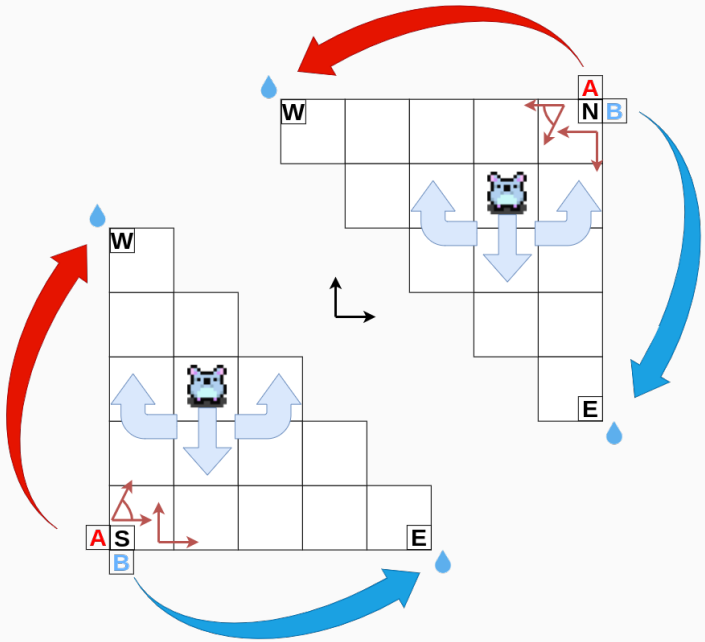
The environment



- 3 actions: $\Leftarrow$ $\Uparrow$ $\Rightarrow$
- Duplicated coordinates inputs:
  - Cartesian coordinates from north & south port
  - Polar coordinates from north & south port

Questions & Hypothesis

Questions

- What function does the network learn?
- How the constrains of the task affect learning & the representations learned?
- How do the representations learned compare between the *in vivo* and the *in silico* neurons?

Hypothesis

- The network will use the most efficient coordinate information (Cartesian vs. polar) based on the task (left/right vs. east/west)
- The structure of the network's weights will reflect this prioritization of information
- Some neurons will encode a joint representation of {odor & space} (*i.e.*, conjunctive cells)

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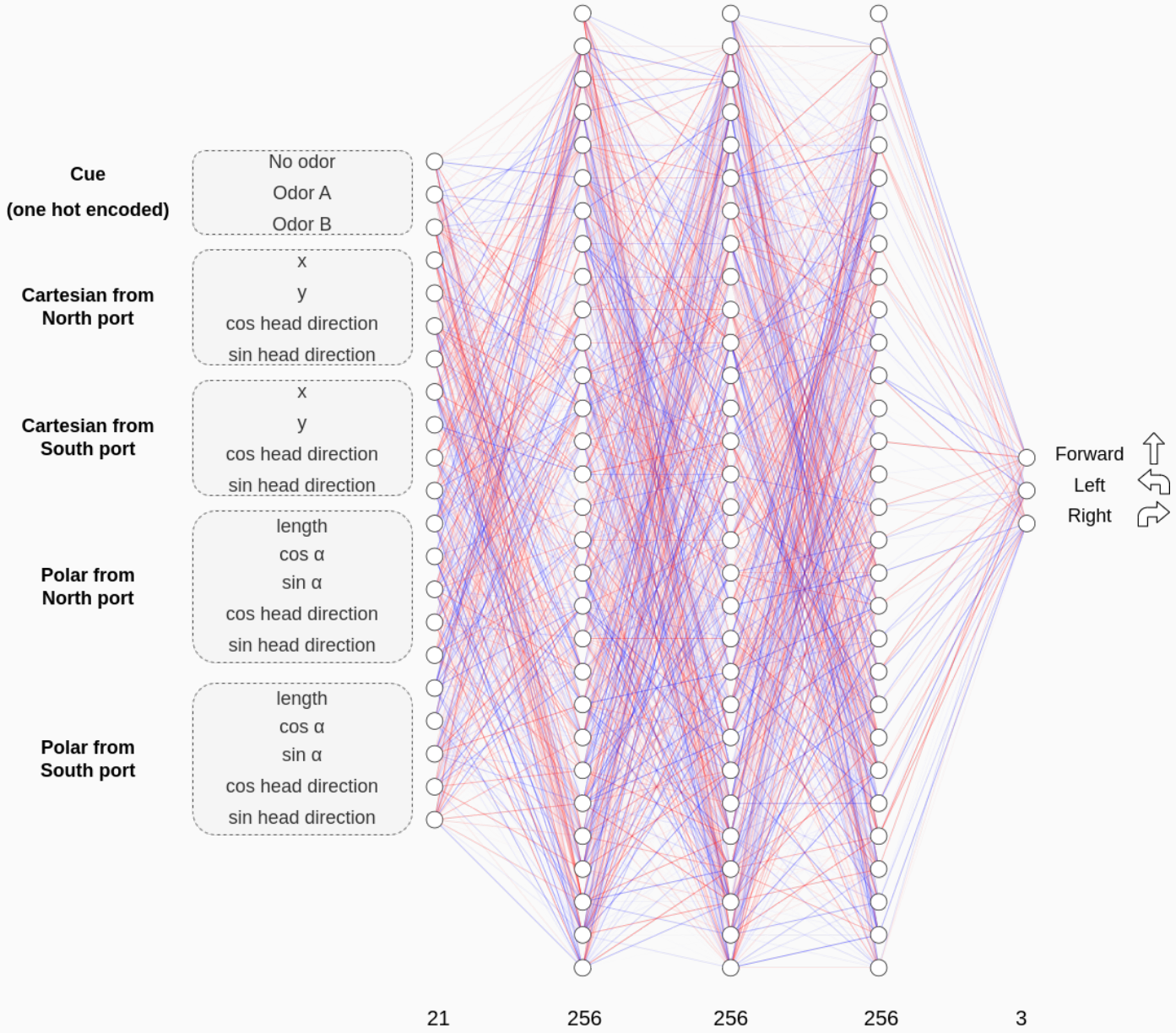
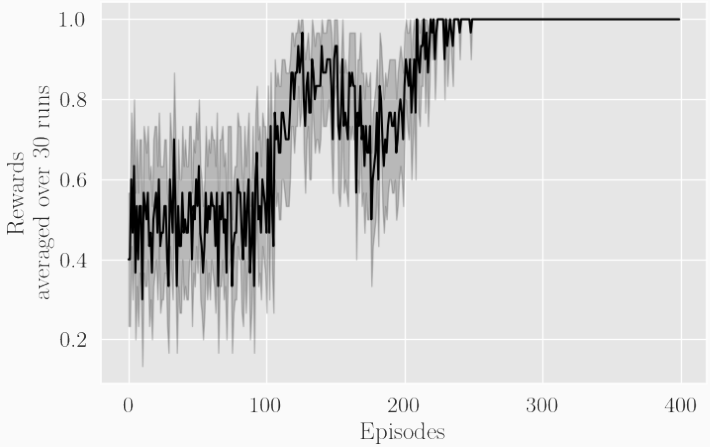
Outline

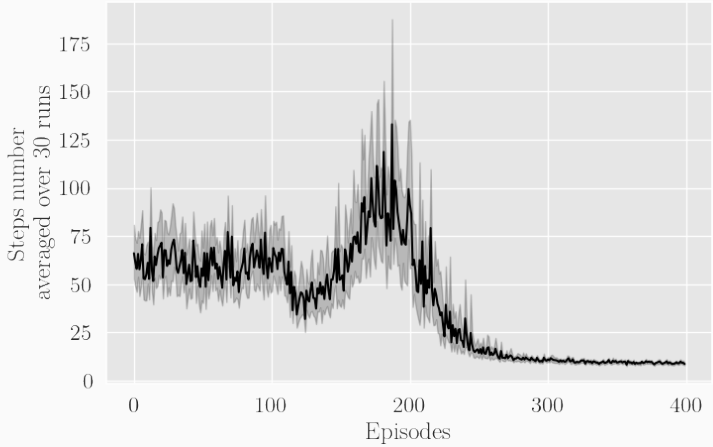
State space & network architecture



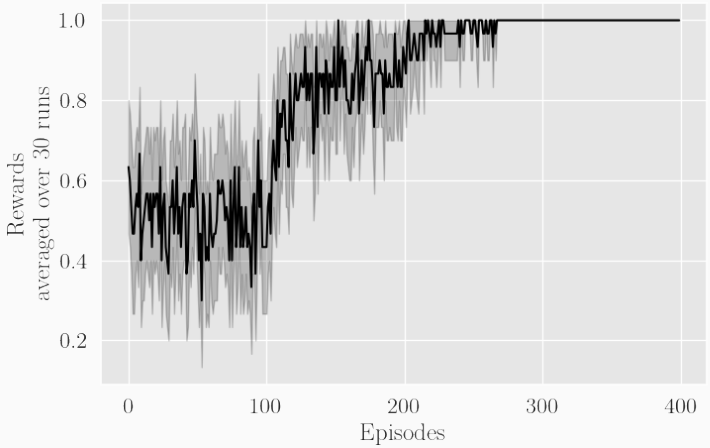
Training

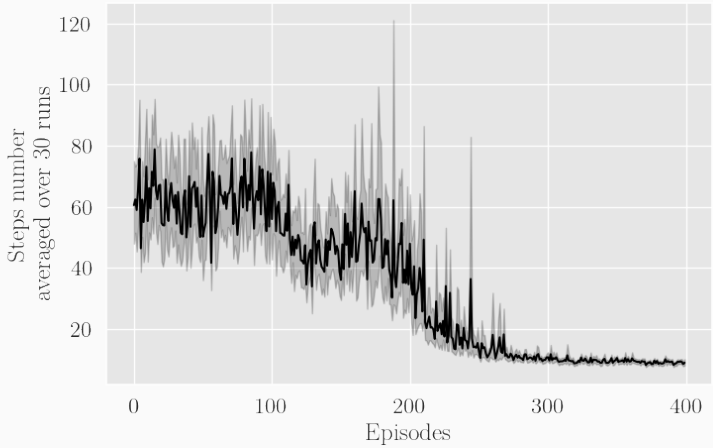
East/West





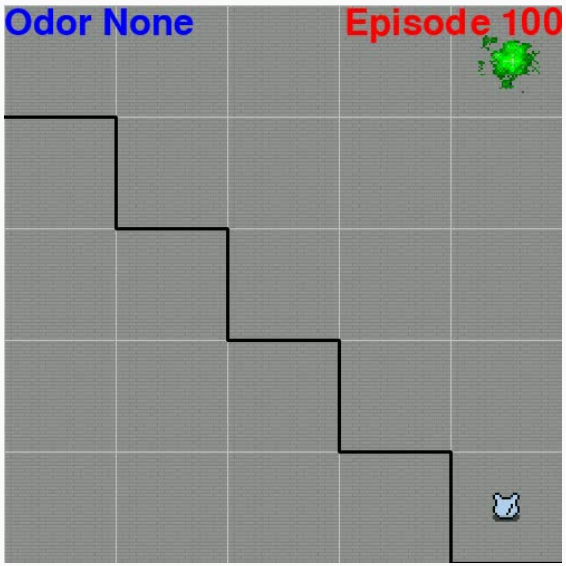
Left/Right



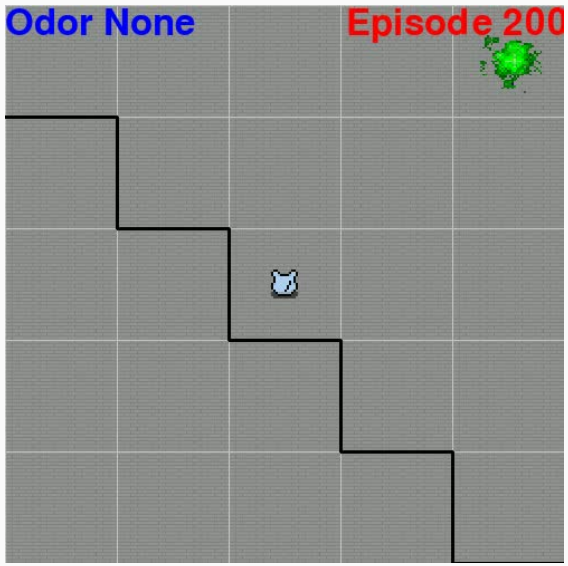


Agent behavior

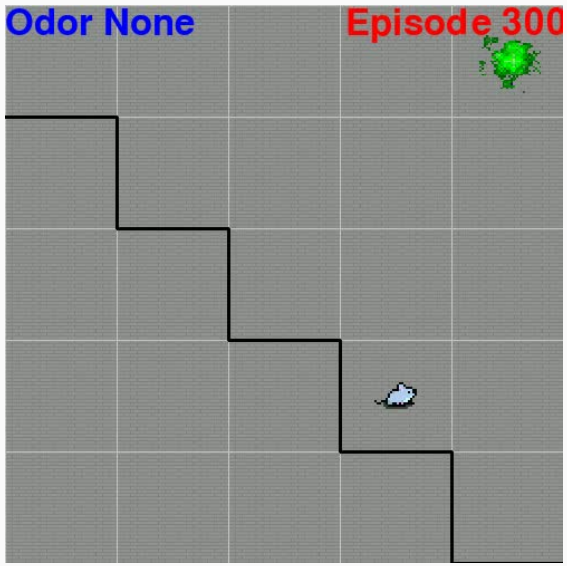
Naive agent



Intermediate agent

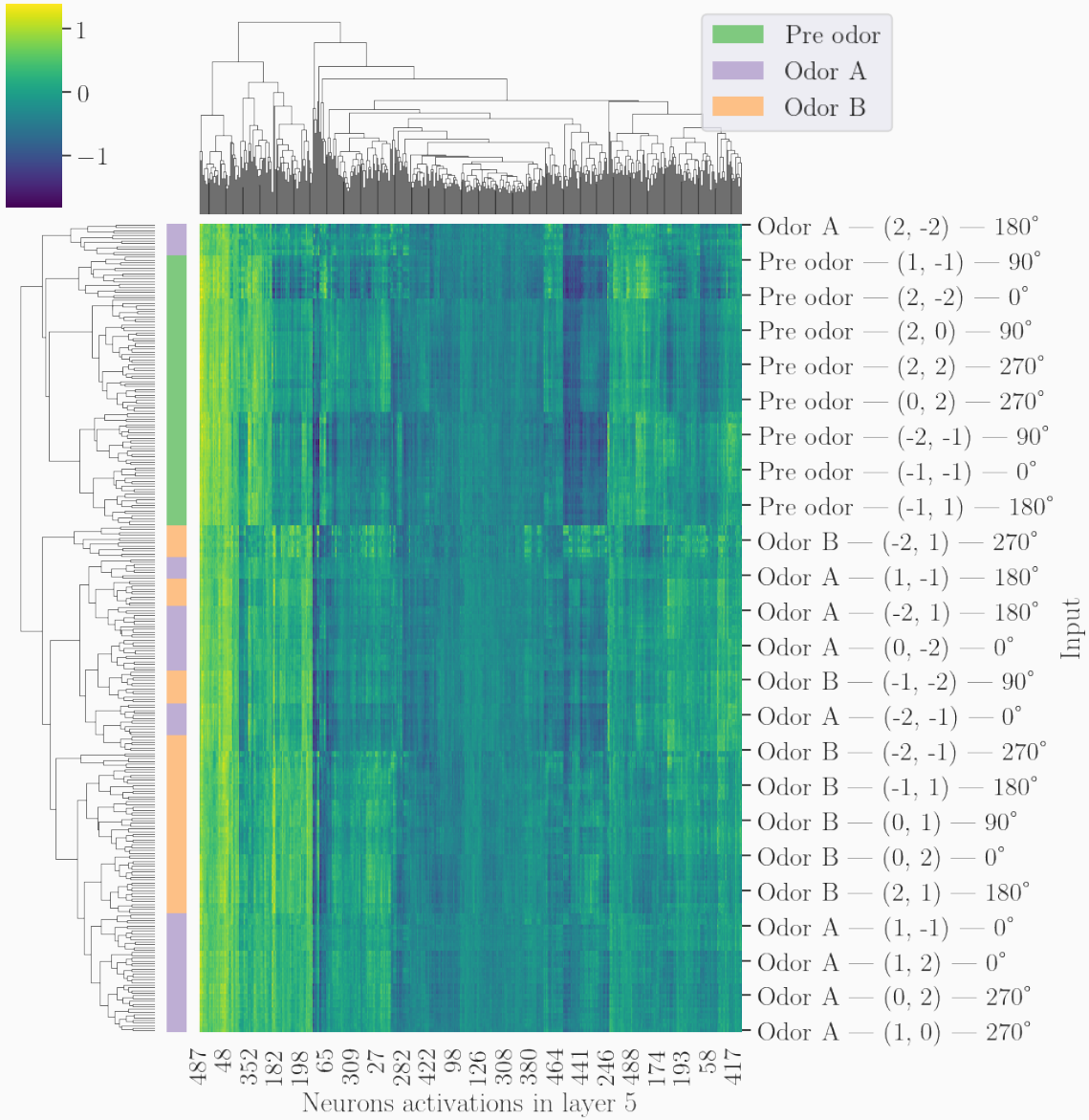


Trained agent

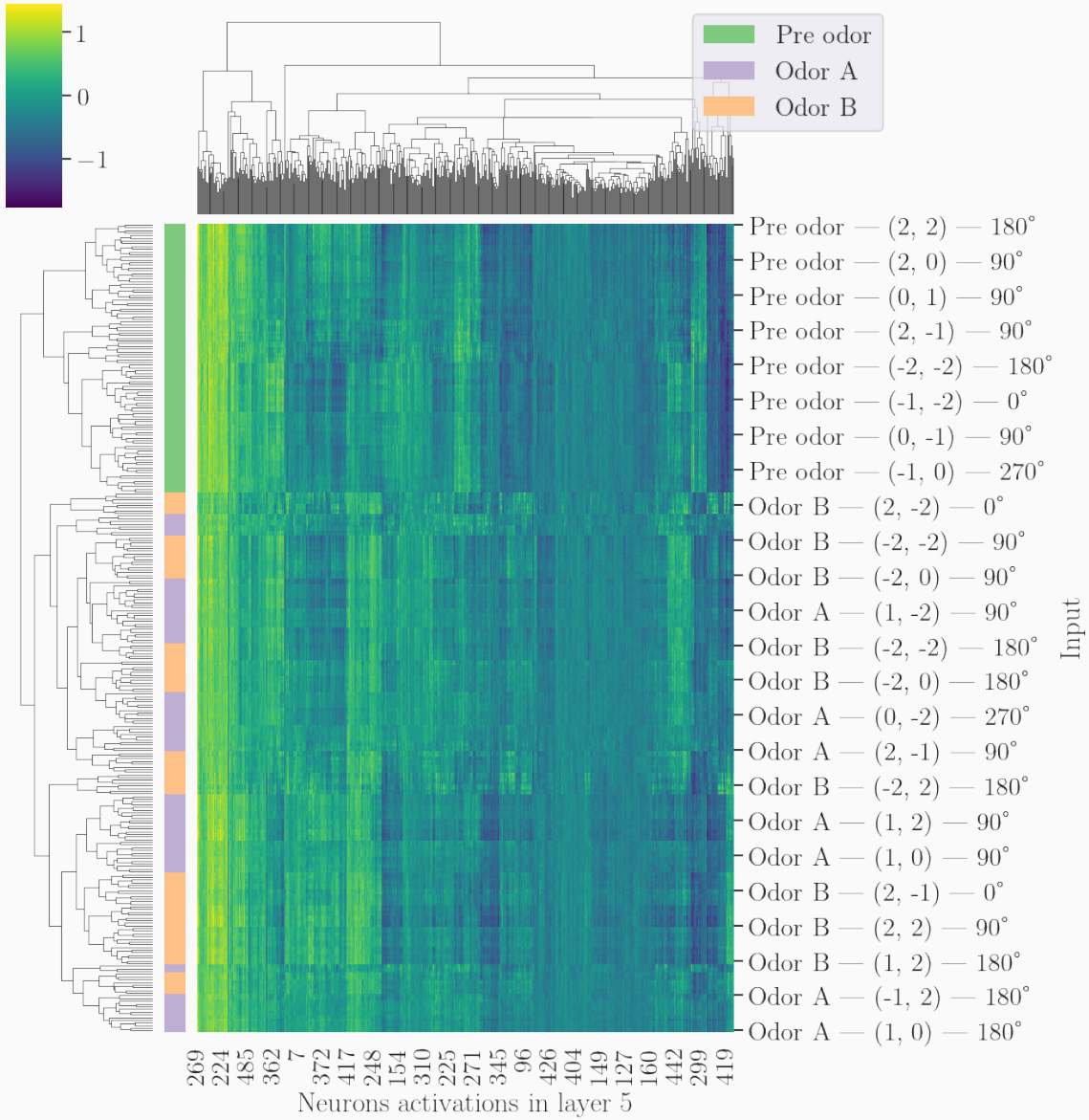


Outline

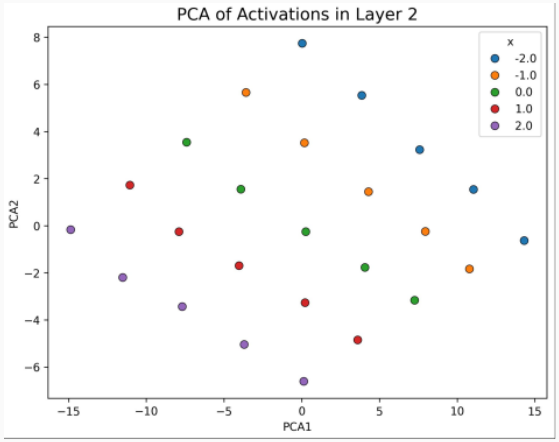
Pre-odor activations cluster together – East/West

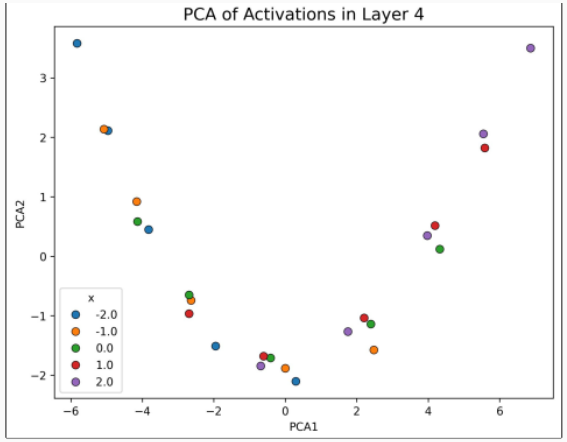


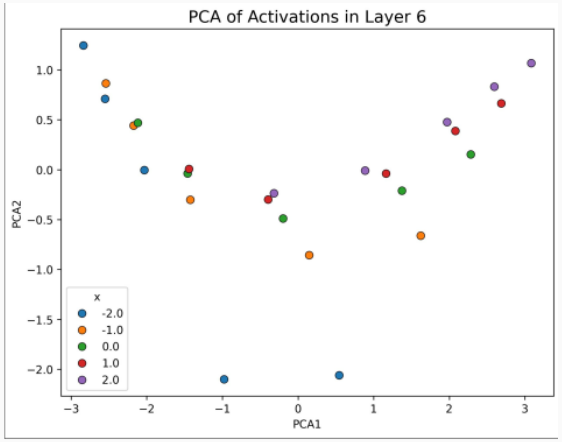
Pre-odor activations cluster together – Left/Right

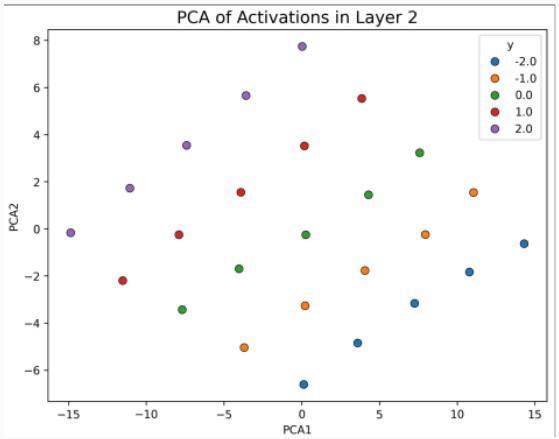


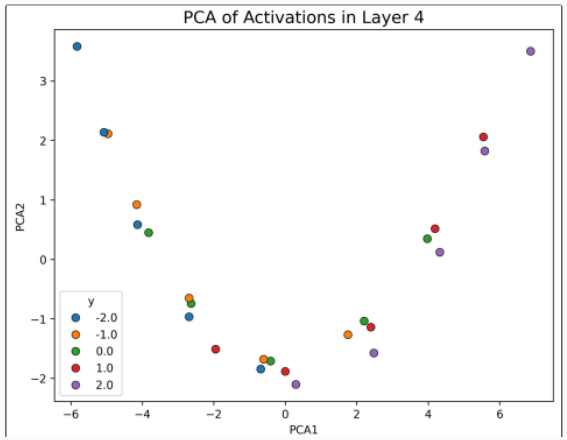
PCA on activations by layer on $\{x, y\}$ coordinates – Left/Right

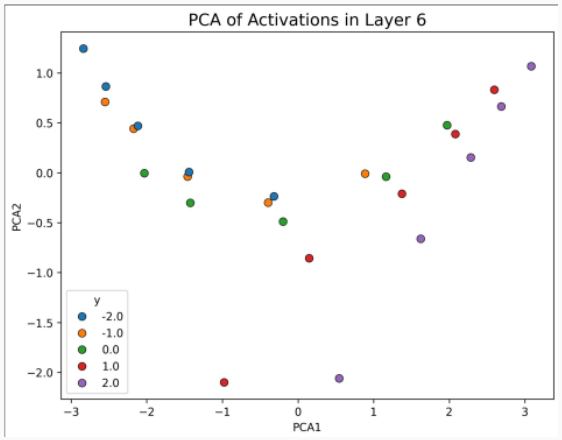






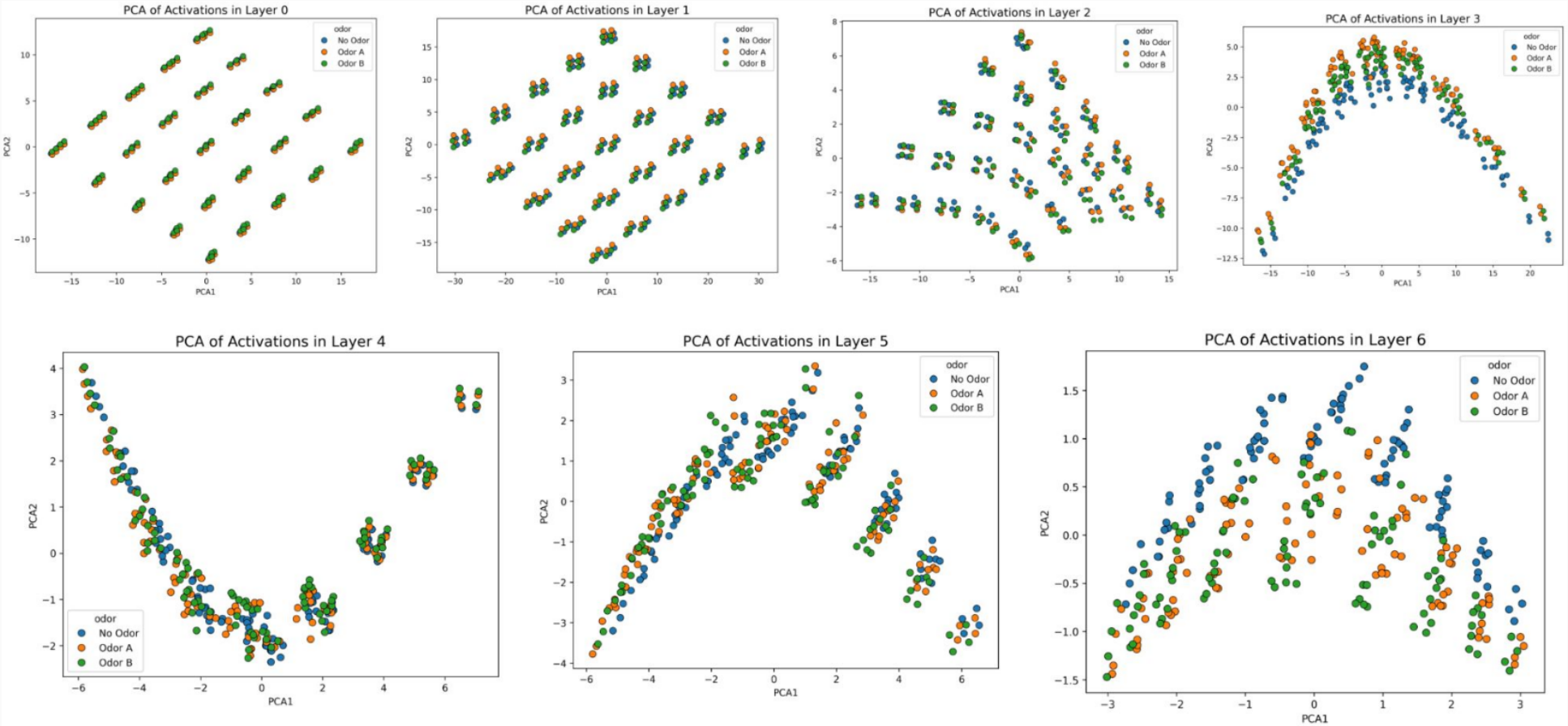






- From grid shape in early layer to half moon cluster in late layers
- Seems to encode the lower/upper triangle

PCA on activations by layer on odor cue – Left/Right

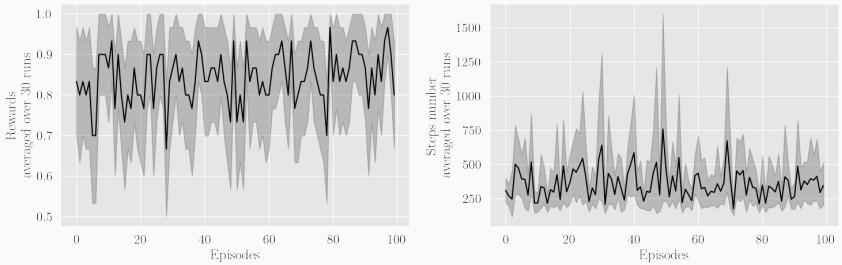


- From grid shape in early layer to half moon cluster in late layers
- Seems that odor cues cluster by tile/grid

Cartesian inputs unchanged – polar inputs perturbed

East/West

Silencing inputs



Left/Right

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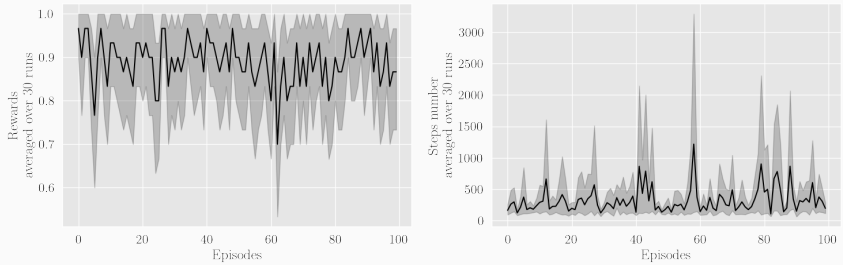
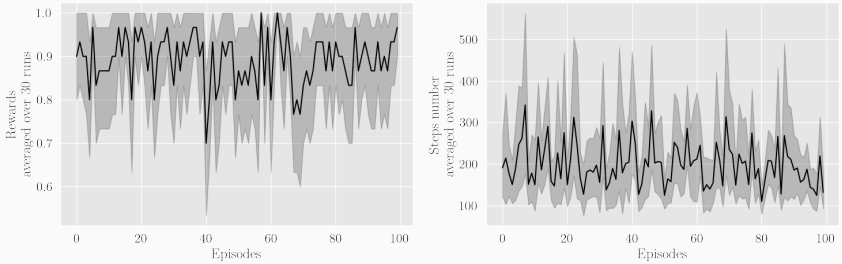


Randomizing inputs



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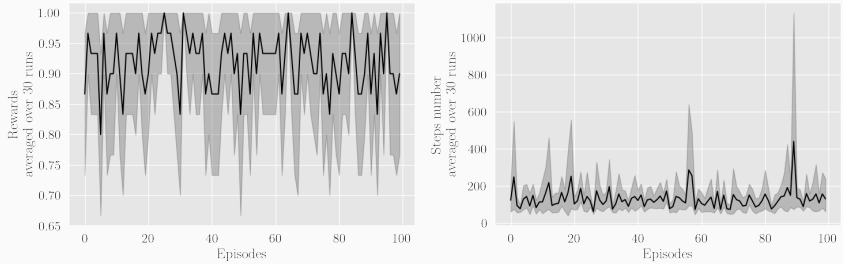

Polar inputs unchanged – Cartesian inputs perturbed

East/West

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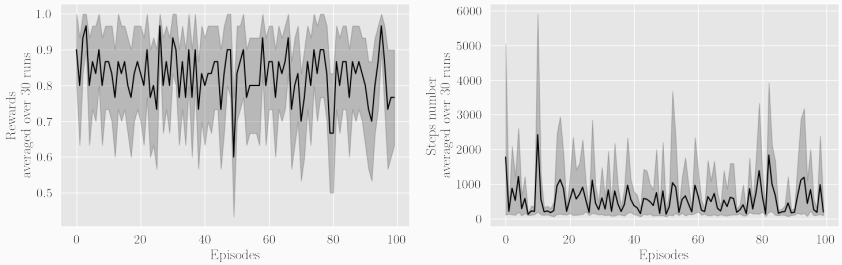

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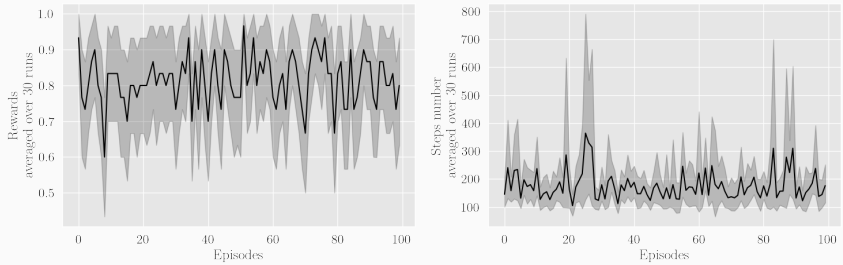

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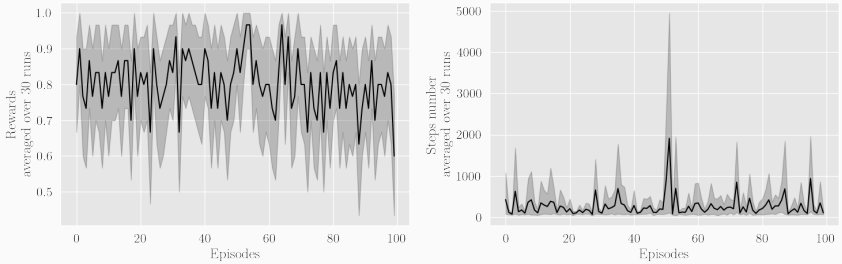

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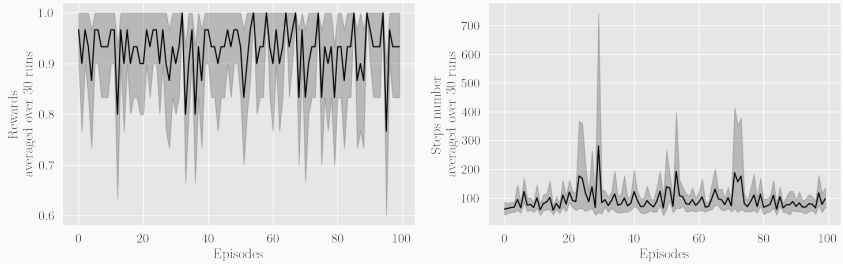
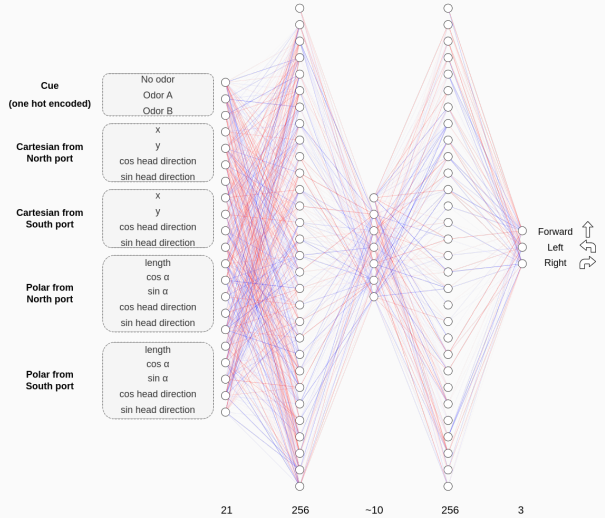


Bottleneck network $\rightarrow$ performance degrades below ~ 10 neurons



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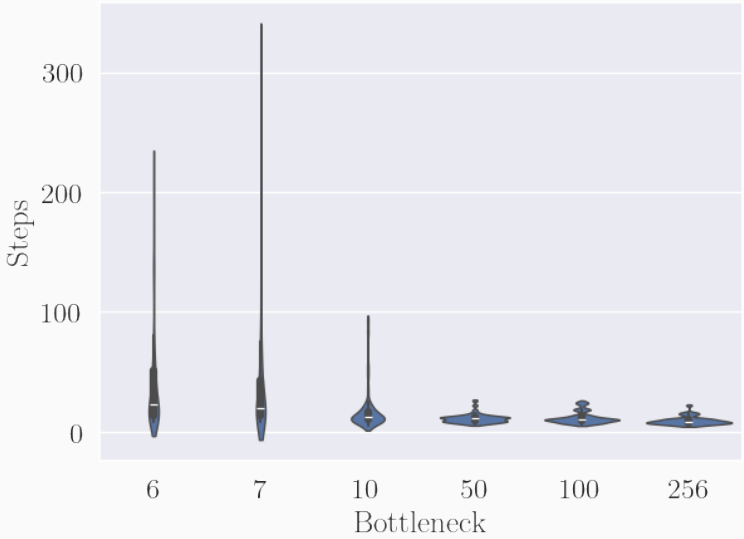

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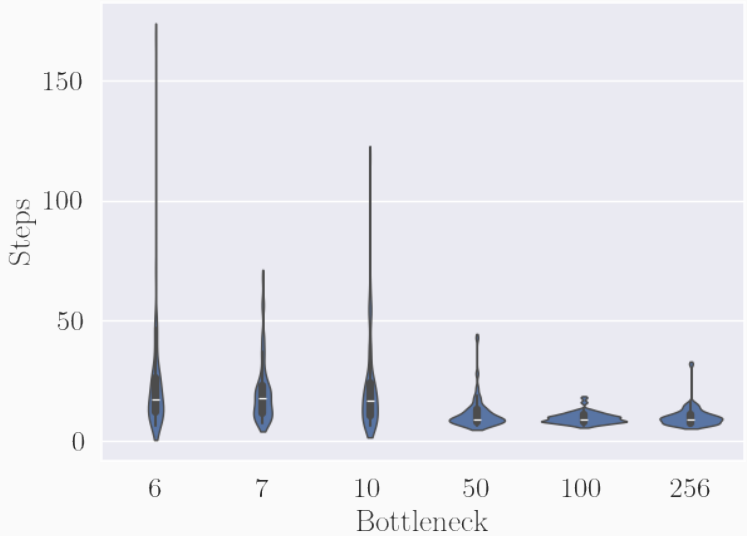

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Partial conclusions so far

- Hierarchical clustering → the pre-odor activations cluster together, but no other clear pattern seems to emerge
- Dimensionality reduction analysis → the network seems to mainly encode the position of the agent on the grid
- With this task setup, it seems both types of coordinates information are required to solve the task → is this a negative result that invalidates our original hypothesis or is this due to overfitting?
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Next steps

- What happens in between tiles? Did the network learn to interpolate?
- Add dropout during training to make the network more robust to perturbations and avoid overfitting?
- Identify the potential functions of the neurons in the bottleneck layer? What type of information do they encode? Any sign of potential conjunctive cells?
- End of this project → still looking for well defined results/principles/rules for a potential MVP (Minimum Viable Publication)

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Questions ?

Pytorch network

```
DQN(
  (mlp): Sequential(
    (0): Linear(in_features=21, out_features=512, bias=True)
    (1): Linear(in_features=512, out_features=512, bias=True)
    (2): ReLU()
    (3): Linear(in_features=512, out_features=512, bias=True)
    (4): ReLU()
    (5): Linear(in_features=512, out_features=512, bias=True)
    (6): ReLU()
    (7): Linear(in_features=512, out_features=3, bias=True)
  )
)
```