# Modelling spatial navigation and decision making

**Jesse Geerts**

**HBP hippocampal modelling meeting**

**9th March 2018**

# Outline

- Striatal and hippocampal contributions to spatial learning in the water maze
- Successor features in the hippocampus: model-based / model-free?
- Future plans

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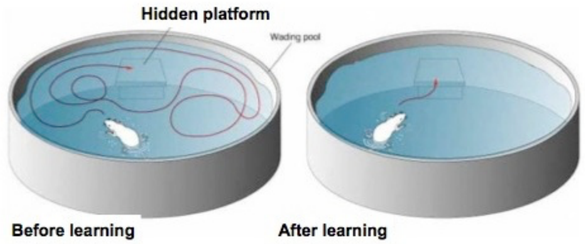
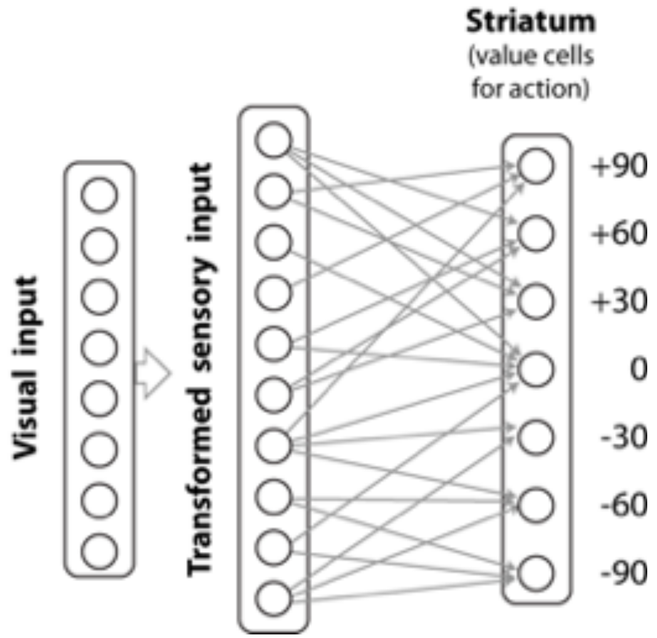
# Artificial spatial learning in the Morris water maze task

$$G = \sum_{t=0}^{\infty} \gamma^t r_t$$




## Striatum: Response learning



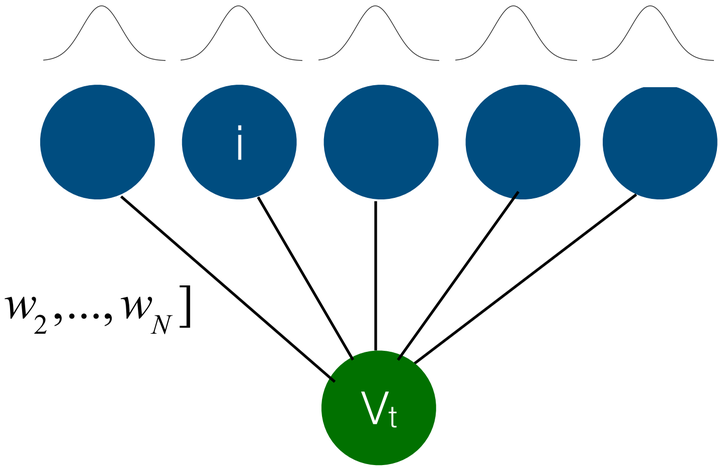

$$Q_a = v_a^{striatum} = \phi\left[\sum_{i=1}^{N} v_a^{sensory} W_{i,a}\right]$$

$$\Delta Q_{s_{t-1},a_{t-1}} = \alpha\left[r_t + \gamma \max_{a'}(Q_{s_t,a_t}) - Q_{s_{t-1},a_{t-1}}\right]$$

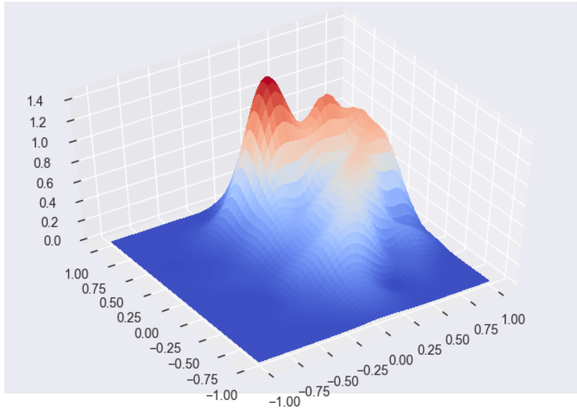
$$\Delta W_{i,a_{t-1}} = \Delta Q_{s_{t-1},a_{t-1}} v_i^{sensory} \left(\sum_{j=1}^{N} v_j^{Sens}\right)^{-1}$$

## Hippocampus: Place learning

$$f_i(p) =$$

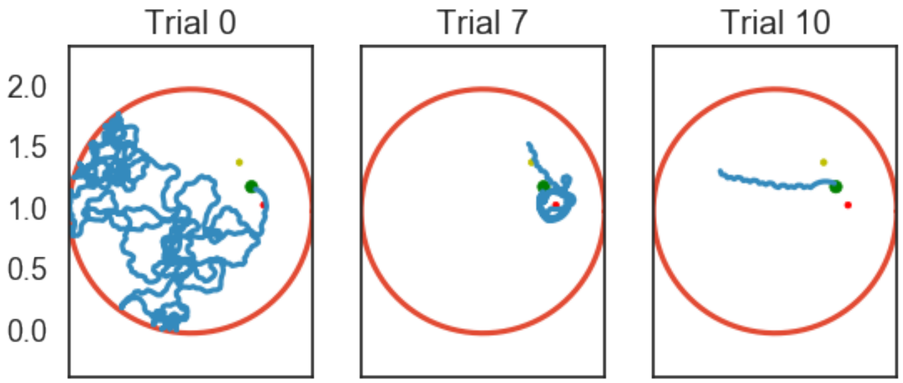


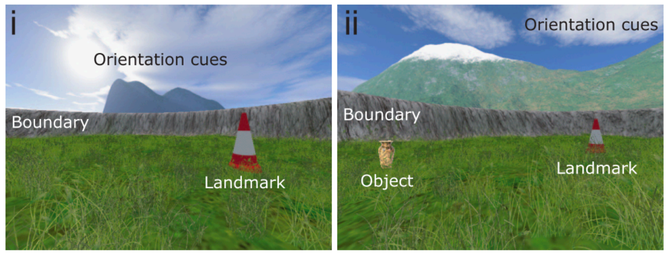

$$\vec{w} = [w_1, w_2, \ldots, w_N]$$



# Striatum learning strategy is sensitive to blocking

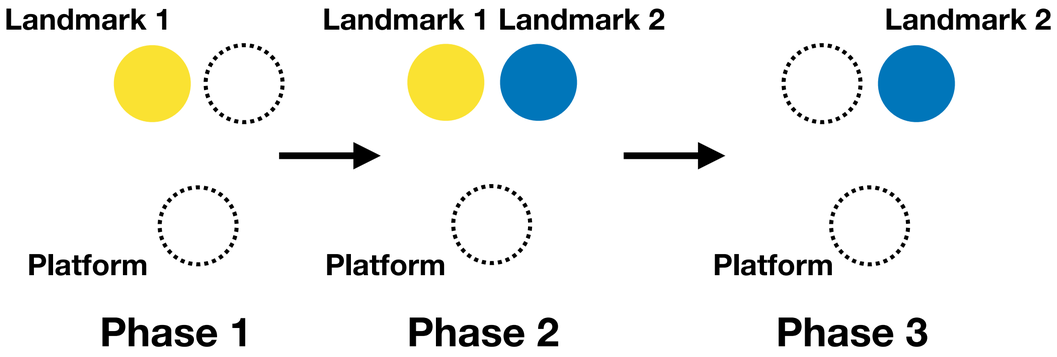
## Striatum learning trajectories




See Doeller & Burgess (2008)

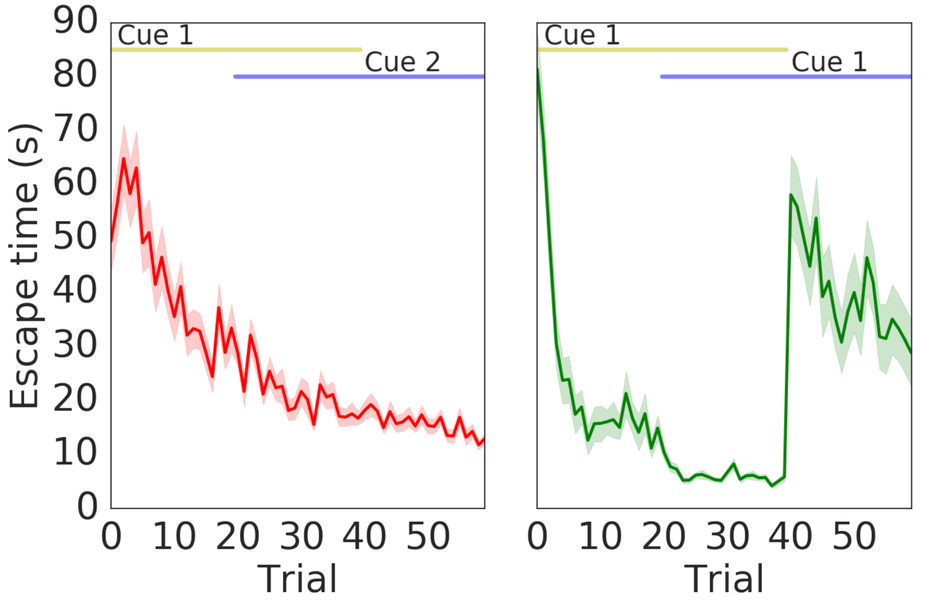
## Blocking paradigm




Prediction error = 0

Hippocampus learning

Striatum learning (hippocampal lesion)



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# Successor representation: a model for place cell firing?

$$\Delta\hat{V}(s) \propto \delta_t$$

$$T(s'|s,a)$$

$$R(s,a)$$

**Model-free** ⟷ **Model-based**

↓

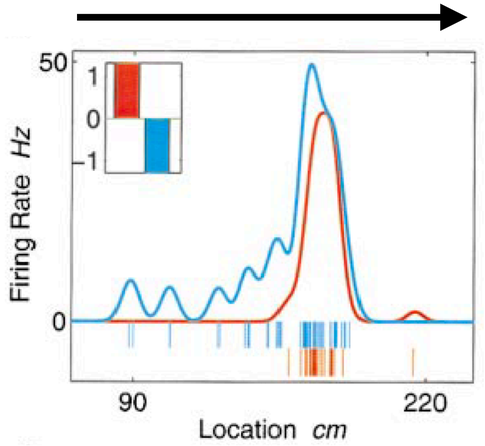
***Successor representation***

$$V(s_t) = \sum_{s'} M(s_t, s') R(s')$$

$$M(s_t, s') = E_\pi\left[\sum_{k=0}^{\infty} \gamma^k I(s_{t+k} = s')\right]$$

$$M(s_t, s') = E_\pi\left[I(s_t = s') + \gamma M(s_{t+1}, s')\right]$$

$$\Delta\hat{M}(s_t, s') \propto \delta_t^M(s') = I(s_t = s') + \gamma \hat{M}(s_{t+1}, s') - \hat{M}(s_t, s')$$

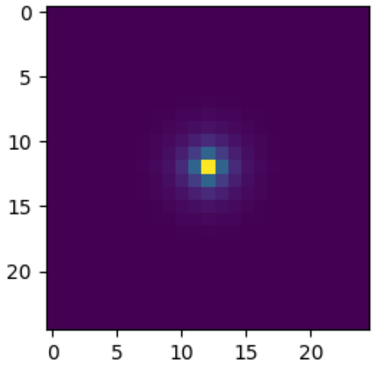



No directional bias

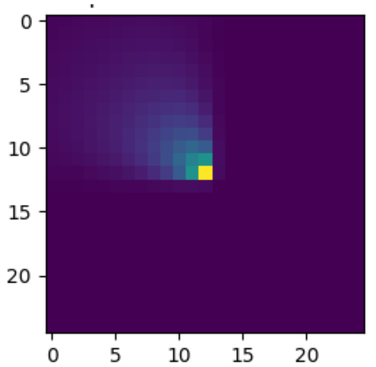
Bias to the right

Mehta et al. (2000)

**SR place field**



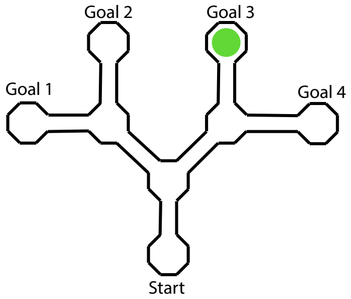

**Biased SR place field**



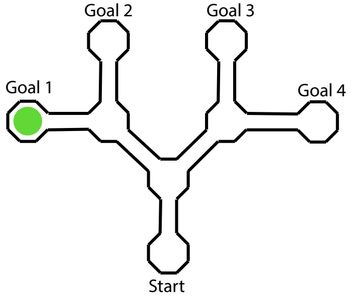

Dayan (1993); Stachenfeld et al. (2017)

# The successor representation is sensitive to changes in reward contingencies

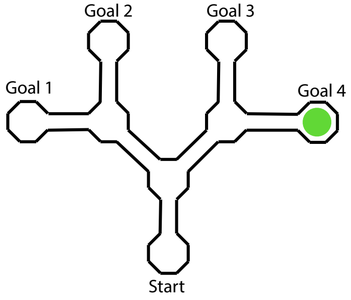
**Block 1**

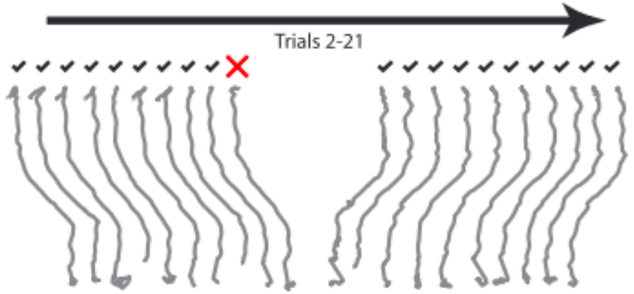



**Block 2**



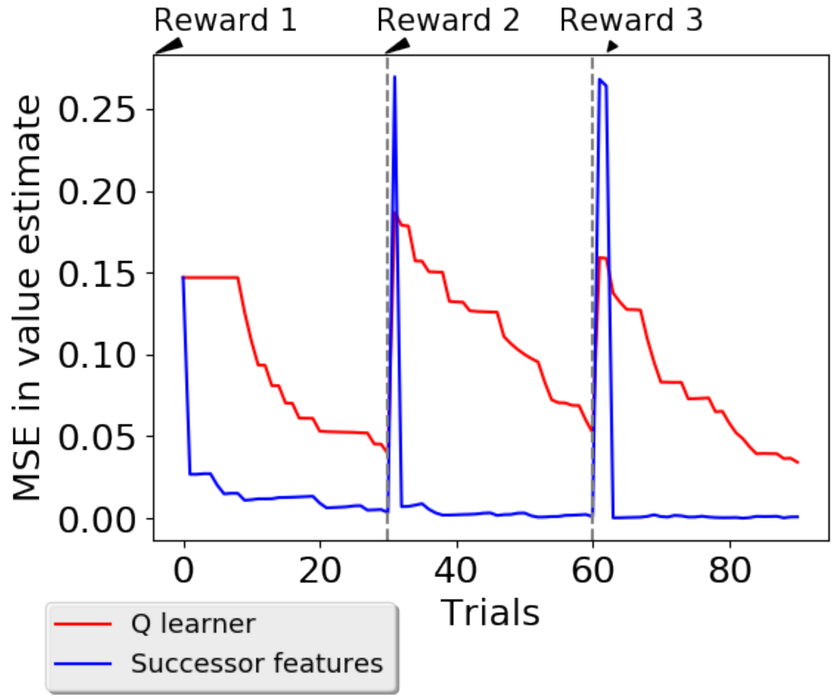

**Block 3**



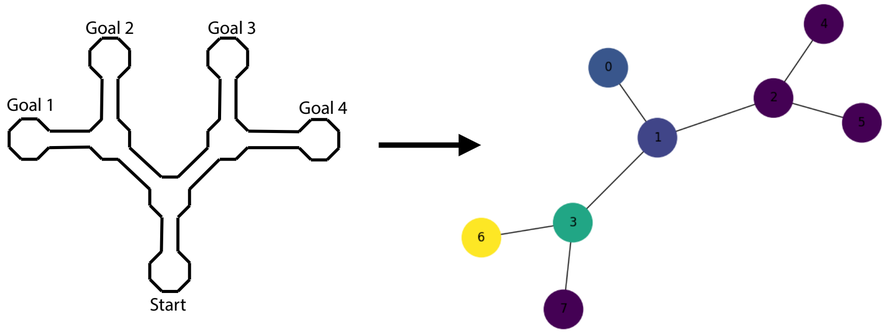




Ainge et al. (2007)

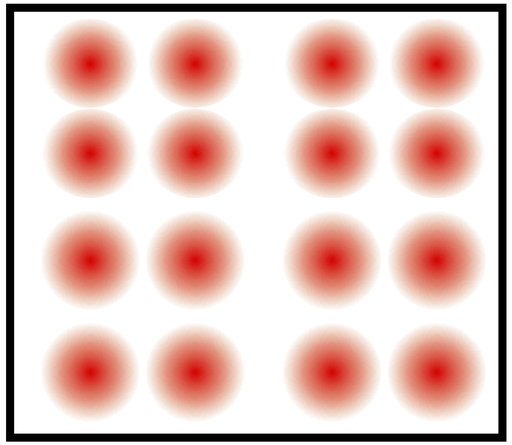
Reward changes to different box



# Successor features: extending the SR to large or continuous state spaces




$$\phi(s_t) = \left[\phi_1(s_t), \phi_2(s_t), \ldots, \phi_N(s_t)\right]^T$$



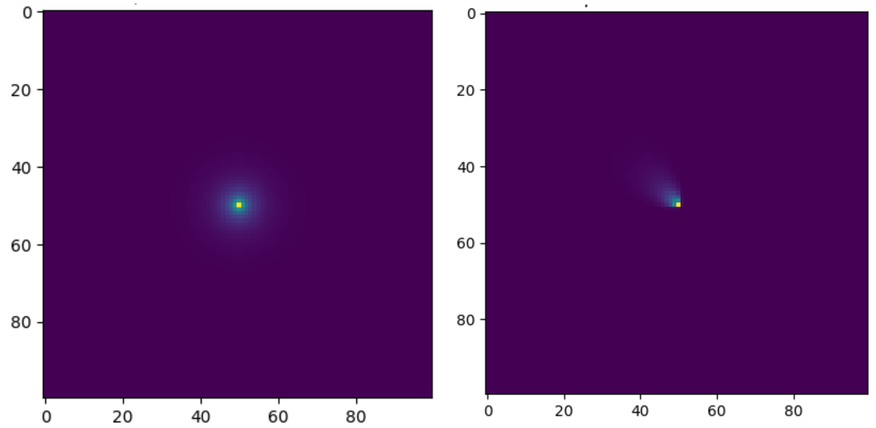
**Successor features:**

*Expected future occurrence of a feature*

$$\psi^{\pi}(s) \equiv E^{\pi}\left[\sum_{k=0}^{\infty} \gamma^{t+k} \phi_{t+k+1} \middle| s_t = s\right]$$

$$\hat{\psi}(s_t, j) = \sum_i \phi_i(s_t) W_{ij}$$

**SF place fields**




Ongoing work…

Barreto et al. (2017)

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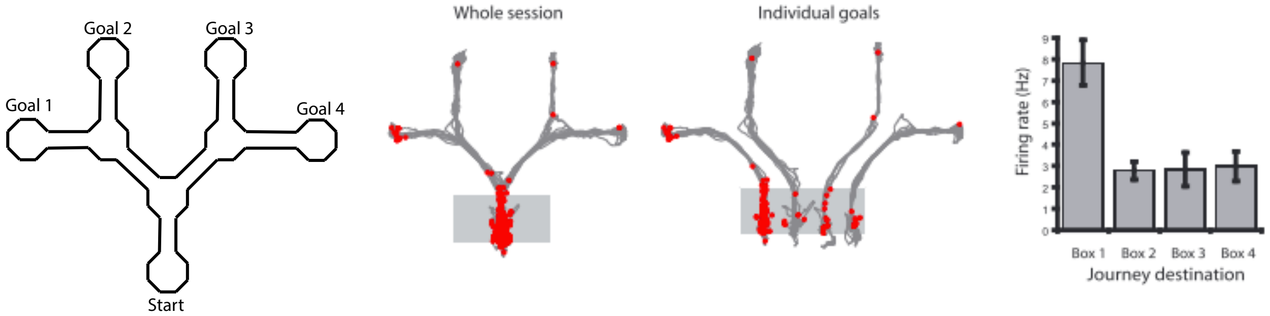
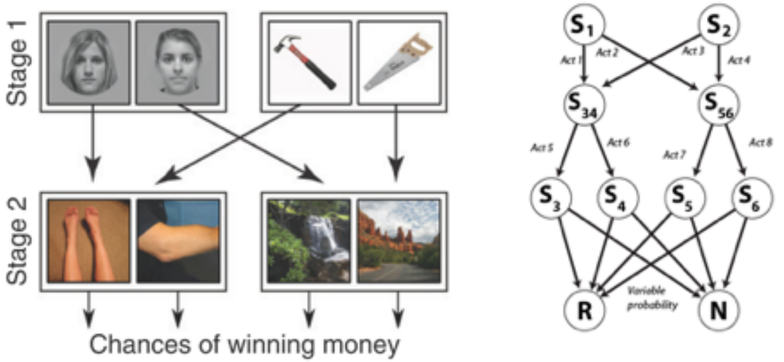
# Plans for the near future

- Investigating the role of ‘splitter cells’ in trajectory planning and reinforcement learning




Ainge et al. (2007)

- Investigating the role of the hippocampus in solving non-spatial tasks




Daw et al. (2011)

# Thanks for listening

And to…

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