



1 Background

A recent normative theory of hippocampal replay¹ suggests that the specific order of replay experiences is optimised for offline planning, whereby each replay corresponds to an update to a state-action value^{2,3}

The derived prioritisation scheme considers the expected improvement in the animal's immediately ensuing behaviour as a result of each potential individual replay update:

$$v_{\pi_{new}}(s) - v_{\pi_{old}}(s) = \underbrace{\sum_{i=0}^{\infty} \gamma^i P(s \rightarrow x, i, \pi_{old})}_{\text{Need}} \times \underbrace{\sum_a [\pi_{new}(a | x) - \pi_{old}(a | s)] q_{\pi_{new}}(x, a)}_{\text{Gain}} \quad \begin{array}{l} \pi_{old} \text{ Current policy [before replay update]} \\ \pi_{new} \text{ New policy [implied by a replay update]} \end{array}$$

2 Problem

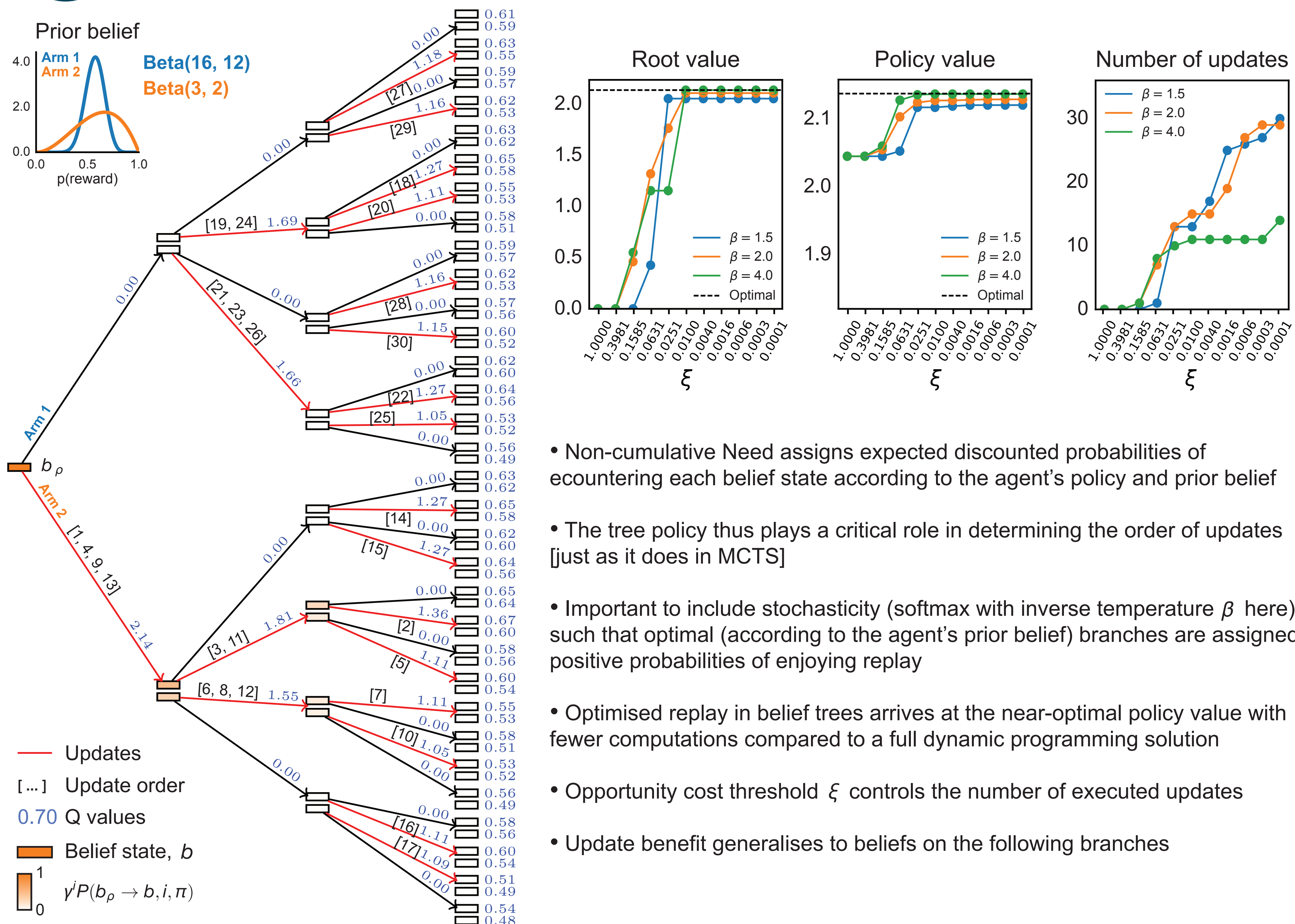
Although very successful, the theory does not extend to replay that encourages optimistic exploration in the face of ignorance

In this work, we extend the theory of replay to partially observable domains to show that optimised replay does favour uncertain outcomes whenever there is a potential long-range benefit of exploration

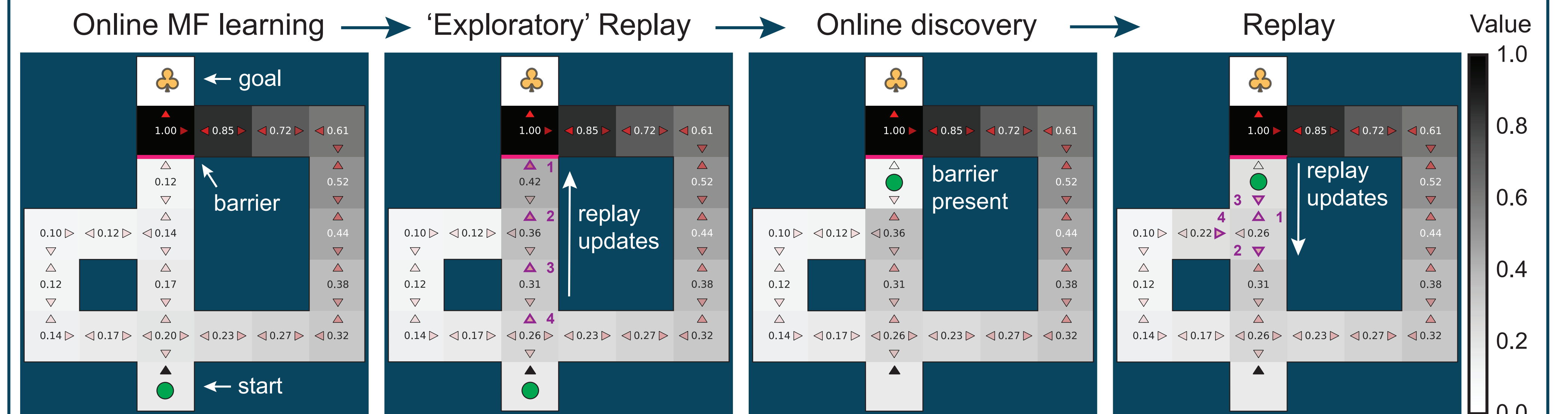
We consider optimised replay in belief MDPs where the following decomposition applies:

$$v_{\pi_{new}}(z) - v_{\pi_{old}}(z) = \sum_{z' \in \mathcal{Z}} \sum_{i=0}^{\infty} \gamma^i P(z \rightarrow z', i, \pi_{old}) \times \sum_a [\pi_{new}(a | z') - \pi_{old}(a | z)] q_{\pi_{new}}(z', a) \quad \text{where } z = \langle b \in \mathcal{B}, s \in \mathcal{S} \rangle$$

3 Prioritised sweeping in Bayesian bandits



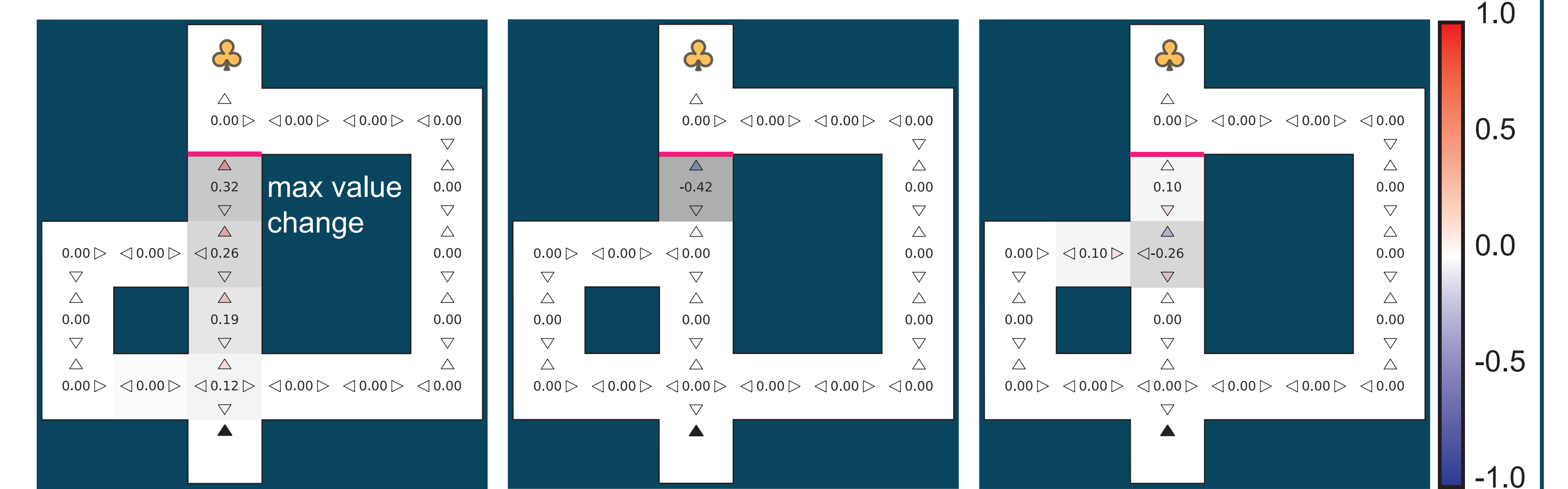
4 Offline replay drives directed exploration



Tolman's⁴ detour maze treated as a POMDP

The agent is uncertain about the barrier configuration

Offline replay in belief space can give rise to directed exploration

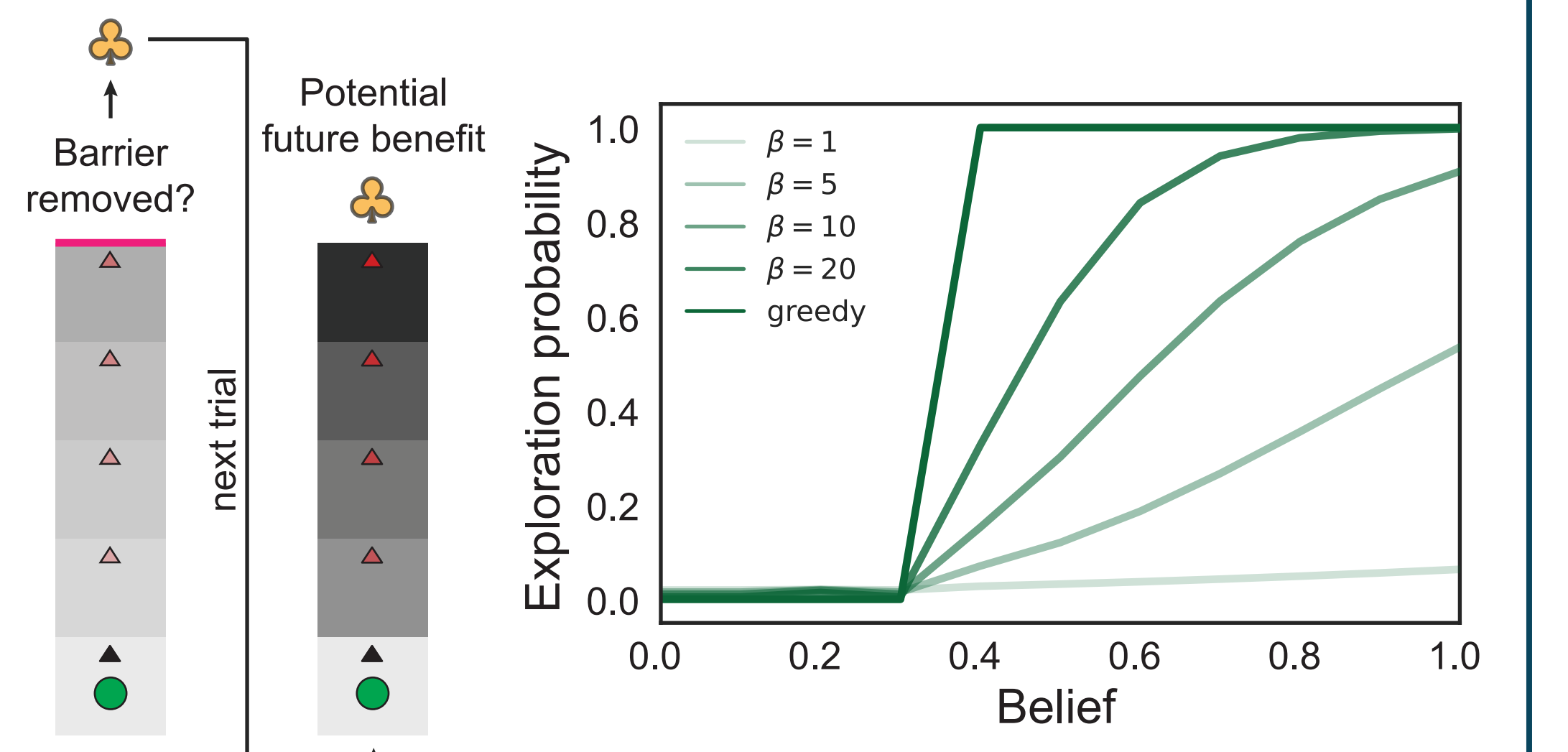


The agent maintains a belief over the presence of one of the barriers from the original Tolman's experiment

At the end of each trial, the belief is updated according to:

$$b_{t+1} = \begin{cases} \kappa \phi + (1 - \kappa) b_t & \text{if the shortcut was not attempted} \\ 1 - \kappa(1 - \phi) & \text{if the shortcut was successful} \\ \kappa \phi & \text{if the shortcut was unsuccessful} \end{cases}$$

and is set to what was actually experienced during the trial



5 Summary

- Belief-space formulation of optimised replay facilitates directed uncertainty-guided exploration
- Such replay propagates the value of the future use of potential information gain (deep exploration)
- Broad generalisation across belief states
- Predictions for the role of replay in rodent & human exploration

6 References

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