

Abstract

Existing computational cognitive models of spatial memory often neglect difficulties posed by the real world, such as sensory noise, uncertainty, and high spatial complexity. On the other hand, robotics is unconcerned with understanding biological cognition. This thesis takes an interdisciplinary approach towards developing a cognitively plausible spatial memory model able to function in realistic environments, despite sensory noise and spatial complexity. We investigated how spatially relevant brain areas might maintain accurate location estimates, despite of sensory errors, hypothesizing that neurons involved in spatial representation called hippocampal place cells might perform approximate Bayesian localization and error correction. We developed computational models implementing these probabilistic mechanisms, which we argued to be psychologically plausible (producing human-like behaviour) as well as neurally plausible (implementable in brains). To support our hypotheses, we reported modelling results of single-neuron recordings from rats (acquired outside this PhD), constituting the first evidence for Bayesian inference in place cells, as well as modelling behaviour data from humans collected in experiments performed online.

In addition to dealing with uncertainty, in realistic environments, spatial representations also have to be stored and used efficiently, using structured representations such as hierarchies (which facilitate efficient retrieval search and route planning). There is evidence that human spatial memories are structured hierarchically, but the process responsible for these structures is not known. We investigated features influencing representation structure using spatial memory data from real-world and virtual reality environments collected in online experiments, and proposed a computational mechanism (clustering with subject-specific distance functions) which might give rise to human spatial representation structures, showing that they can be predicted in advance.

We have extended a general cognitive architecture (the LIDA model of cognition) by these probabilistic mechanisms for localization and map learning, correction, and structuring. We demonstrated the ability of the resulting model to deal with the challenges of realistic environments by running it in high-fidelity robotic simulations, modelled after participants' actual cities, showing that it can deal with noise, uncertainty and complexity, and that it can reproduce the spatial accuracies of human participants.