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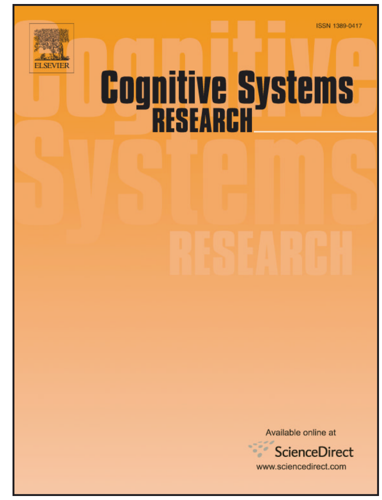

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A computational cognitive framework of spatial memory in brains and robots

Tamas Madl[a,b,*], Stan Franklin[c], Ke Chen[a], Robert Trappl[b]

[a]*School of Computer Science, University of Manchester, Manchester M13 9PL, UK*
[b]*Austrian Research Institute for Artificial Intelligence, Vienna A-1010, Austria*
[c]*Institute for Intelligent Systems, University of Memphis, Memphis TN 38152, USA*

Abstract

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. Here, we describe a computational framework for robotic architectures aiming to function in realistic environments, as well as to be cognitively plausible.

We motivate and describe several mechanisms towards achieving this despite the sensory noise and spatial complexity inherent in the physical world. We tackle error accumulation during path integration by means of Bayesian localization, and loop closing with sequential gradient descent. Finally, we outline a method for structuring spatial representations using metric learning and clustering. Crucially, unlike the algorithms of traditional robotics, we show that these mechanisms can be implemented in neuronal or cognitive models.

We briefly outline a concrete implementation of the proposed framework as part of the LIDA cognitive architecture, and argue that this kind of probabilistic framework is well-suited for use in cognitive robotic architectures aiming to combine spatial functionality and psychological plausibility.

Keywords:
spatial memory, Bayesian brain, LIDA, cognitive architecture, computational cognitive modeling

1. Introduction[1]

Spatial memory encodes, stores, recognizes and recalls spatial information about the environment and agents' orientation within it. Representing spatial information accurately in the real world is hard, for several reasons. Sensors and actuators are limited, erroneous and noisy (in the sense of noise interfering with the signal). There are additional sources of uncertainty or unknown information, such as external events, actions of other organisms, unperceived or currently unperceivable objects or events. Furthermore, physical environments can be highly complex, and yet cognitive resources (amount of memory, processing power, time and energy available) are necessarily limited by biological and physical constraints.

In artificial intelligence (AI) and robotics research, probabilistic models have provided key tools for dealing with such challenges, facilitating the quantitative characterization of beliefs and uncertainty in the form of probability distributions, and the machinery of Bayesian inference for updating them with new data. They have also inspired the 'Bayesian brain' (Knill and Pouget, 2004) and 'Bayesian cognition' (Chater et al., 2010) paradigms in the cognitive sciences. These paradigms have been successful in explaining human behaviour in tasks as diverse as the integration of sensory cues (Ernst, 2006) including spatial information (Cheng et al., 2007; Nardini et al., 2008), sensorimotor learning (Körding and Wolpert, 2004), visual perception (Yuille and Kersten, 2006) or reasoning (Oaksford and Chater, 2007). Their success suggests an answer to what biological cognition might be doing to cope with the above-mentioned challenges: approximate Bayesian inference.

Despite of this success and of the suitability of

*tamas.madl@gmail.com

[1]Some of the arguments in this paper have been published before in the first author's PhD thesis (Madl, 2016)