Finding your way: The Cognitive Science of Navigation

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Motivation

One overarching research question in cognitive science concerns how information from perception and memory is processed and integrated in order to achieve robust, efficient, and adaptive behaviour in space, as is necessary in wayfinding. Examining this integration is quite complicated, entailing an understanding of learning strategies, spatial memory representations of static and dynamic relations, perceptual and attentional processes that direct the encoding and maintenance of select information, reasoning and planning processes, communication of spatial information via language or other representational media, the influence of background knowledge, and the development of navigation plans. Due to the complexity of the problem, research in navigation cuts across a diverse set of disciplines, including cognitive psychology, linguistics, computer science, robotics, environmental psychology, developmental psychology, and geography, and ranges from basic research questions to practical applications. This symposium presents research from across these disciplines, and provides a diversified overview of the range of issues involved.

Multiple Ontologies for Spatial Mapping and Navigation
Benjamin Kuipers

Wanting to develop computational models of spatial knowledge including perception and action grounded in the physical world, we found ourselves compelled to build robots. Inspired by the structure of the human cognitive map, we created the Spatial Semantic Hierarchy (SSH), showing how several different ontologies can be used together to represent knowledge of large-scale and small-scale space [1]. The basic SSH uses hill-climbing and trajectory-following control laws to explore the environment even with very limited prior knowledge of sensor semantics, but its knowledge of local space is quite limited. The Hybrid SSH (HSSH) exploits prior knowledge of the sensors to build local metrical maps of small-scale space. These can be abstracted to capture the qualitative decision structure of local space, making it possible to build a global topological map, which can be used as a skeleton for building a global metrical map when resources permit [2]. These multiple ontologies naturally support robust representation and learning of spatial knowledge, as well as multiple levels of human-robot interaction.

1. The Spatial Semantic Hierarchy. B. Kuipers, 2000. Artificial Intelligence, 119, p. 191-233.
2. Factoring the mapping problem: Mobile robot map-building in the Hybrid Spatial Semantic Hierarchy. P. Beeson, J. Modayil & B. Kuipers, 2010. Int. J. Robotics Research 29(4), p. 428-459.

The Neural Mechanisms of Spatial Navigation
Neil Burgess

Single unit recording in the hippocampal and entorhinal cortices of freely moving rodents provides detailed information regarding the neural mechanisms of spatial navigation. I will describe some of these experiments and the computational mechanisms they imply, which emphasize the how two types of information are combined to inform self-location. These are sensory or imagined representations of environmental boundaries and path integration via intrinsic temporal oscillations in the theta band. I will then describe the implications of these findings for the mechanisms supporting human memory for spatial locations and the spatial context of events, and provide examples of behavioral, neuropsychological and functional neuroimaging experiments designed to test the resulting predictions.

From Scenes to Maps: Coding of Large-Scale Environments in the Human Brain
Russell Epstein

Human neuroimaging studies have identified a network of brain regions involved in spatial navigation, including parahippocampal cortex, retrosplenial cortex, and the medial temporal lobe (hippocampus and entorhinal cortex). However, the distinct cognitive functions supported by each component of this network are still unknown. One approach to this problem is to identify the representational distinctions made within each brain region. I will discuss recent work that uses advanced fMRI techniques to identify neural codes that support the coding of landmarks and locations within a familiar campus environment. Results from these experiments suggest that parahippocampal and retrosplenial cortices encode information that allows individual vistas and landmarks to be distinguished. The medial temporal lobe, on the other hand, appears to encode a map-like representation of spatial coordinates that allows distances between locations to be calculated.

Way-finding in Birds: Spatial Cognitive Processes and Their Neural Bases
Verner P. Bingman

Birds are nature's supreme navigators, which is attributable to a range of compass-like and map-like spatial representational mechanisms. Looking at homing pigeons, two map-like mechanisms are of interest. The "navigational map" enables pigeons to determine the direction home from distant, unfamiliar locations, can be understood as an algorithm based on two intersecting stimulus gradients and is hippocampal independent. The "familiar-area map" enables pigeons to determine the direction home from areas experienced before, has properties resembling a cognitive map and is hippocampal dependent. There is also evidence that the familiar-area map includes the representation of both discrete landmarks, e.g., wind turbines, and extended landscape features, e.g., coastlines, the latter serving perhaps as boundaries defining a pigeon's geometric, working space. The importance of the hippocampus for the familiar-area map is revealed by hippocampal-lesioned pigeons re-orienting poorly following a navigational error and the path-like response properties of some hippocampal neurons.

The Role of Subjective Factors and External Aids in Affecting Spatial Learning
Francesca Pazzaglia

During navigation individuals focus on different types of environmental information, and that is related to the mental representation they derive and to their ability to navigate successfully through familiar and unfamiliar environments. In this talk a set of studies will be presented examining whether and at what extent the presentation of schematic maps, spatial descriptions, and instructions focused on landmarks or intersections influence spatial representation and navigation. Individual differences in cognitive style of spatial representation will be considered, as well, in the idea that subjective factors (strategies, spatial ability, spatial memory) interact with external aids in affecting spatial learning.