From Spatial Perception to Cognitive Mapping: How is the Flow of Information Controlled?

W. K. Yeap
Centre for Artificial Intelligence Research
School of Computing and Mathematical Sciences
Auckland University of Technology, New Zealand

Abstract

Most models of cognitive mapping would suggest that the process begins by constructing some form of a structural representation of the environment visited. From the latter representation, one develops a conceptual view of the environment. The flow of information in the process is almost unidirectional, from perception to conception. In this paper, I argue that this process is inappropriate for a human cognitive mapping process. The latter process should begin with some symbolic notions of places and never needed to construct explicitly a structural representation of the environment visited. Humans' ability to visualise the structural details in a familiar environment comes from the increasingly detailed grounding of its symbols to the real world as a result of familiarisation and attention to details.

Position Statements

Humans' cognitive map is a rich repository for spatial knowledge. It is not only rich in the quality and quantity of information it holds but also in the varied sources from which it derives its initial input. Yet, the map is not just a place to record information. Information from different sources at the perceptual level is entered selectively, possibly combined, and finally encoded as part of a highly conceptual and personal view of one's spatial world.

This symposium raised a question concerning how the construction of spatial representations is controlled in both cognitive and artificial systems. Within a cognitive mapping process, researchers have proposed a varied number of spatial representations that are created within it (see for example, (Poucet 1993; Chown, Kaplan, & Kortenkamp 1995; Yeap & Jefferies 1999; Kuipers 2000)). The most detailed model is that of Kuipers' (Kuipers 2000) Spatial Semantic Hierarchy (SSH model) which suggested a lattice structure for holding much of the information found in one's cognitive map. Five different levels of information were proposed: sensory, control, causal, topological and metrical. However few, if any, of these researchers have discussed how the construction of these representations is controlled. This is because intuitively, information which is relevant for constructing a cognitive map, extracted at the sensor level and at subsequent levels in the cognitive mapping process, is simply passed on from one stage to the next. The influence of one's existing knowledge about the environment on the process has often been noted but seldom been studied or modelled. The control level in the SSH model describes the necessary "laws" for a particular agent to interact with its environment. It is thus a different kind of control mechanism; not one that is concerned with controlling the construction of spatial representations themselves. In both my own work in this area and with my students (Yeap 1988; Yeap & Jefferies 1999), we have also proposed several representations to be computed from the senses to the concepts level. In a recent implementation on a robot (Wong, Schmidt, & Yeap 2007), a simple control law was introduced, namely one that instructs the robot to move "forward" when it encounters an obstacle. No other control was put in place and information flows from one end to the other.

It is thus timely to ask in this symposium: is the flow of information in a cognitive mapping process unidirectional whereby information at the perceptual level simply gets assimilated into a cognitive map? Or, are there some control mechanisms to decide what is to be assimilated and what is not? If so, where lies the control and what might it be? Is it purely some top-down influences on the early stages of processing or some decision making that is far more significant?

Since I began my study on cognitive mapping, I have always been bugged by the observation that humans remember only poorly their experience of a new environment. Of primary concern here is that most, if not all, cannot reproduce, in reasonably good details, the spatial layout of the path just traversed in a new environment. Such poor performances have generally been explained away by claiming that we either cannot remember everything that we perceived or that the information perceived during our initial experience has not been entered into our "long-term" memory. Yet, on the contrary, most models of cognitive mapping have suggested that such a representation should be computed from the sensor data and furthermore, to compute it is not a straightforward process and rather expensive computationally. If so, why do humans forget?

On reflection, I now put forth the following position statements for discussion at this symposium. The human cognitive mapping process does not begin with the computation of

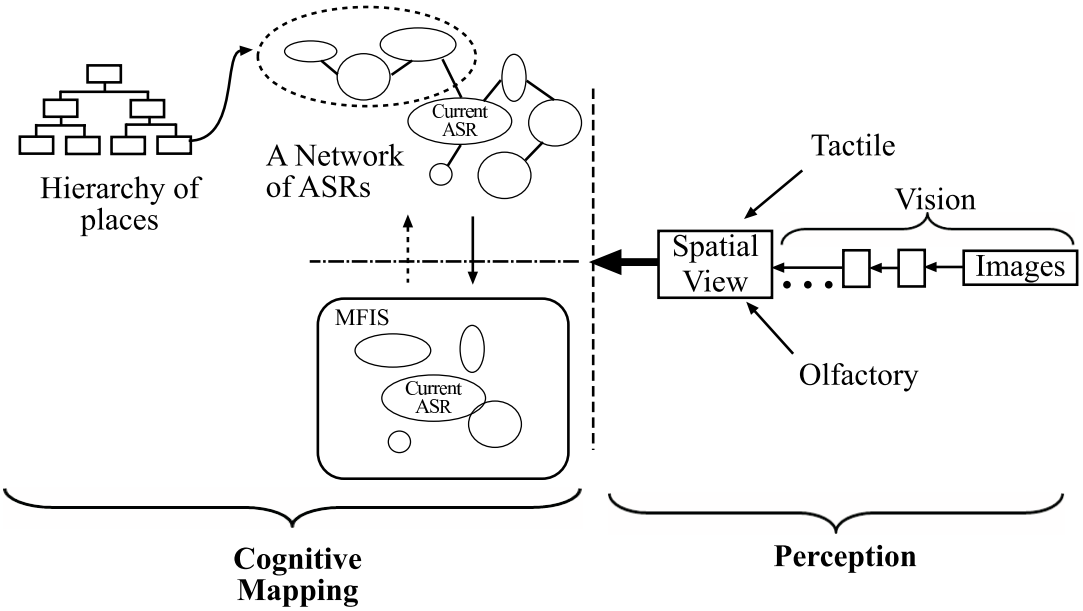

Figure 1: Yeap's model of cognitive mapping: Three key representations were proposed – a network of ASRs, an MFIS, and a hierarchy of Place Representations

a structural description of its environment as it moves from one point to another. The flow of information from perception terminates at a structure which I have referred to in my earlier work as the MFIS (see the next section). Instead, the process begins with some abstract notions of places to visit. As it moves from one point to another, this representation could be enriched in many ways. More symbols could be introduced and some are grounded to the information extracted from the MFIS. It is the result of detailed grounding of the symbols that enable one to visualise clearly the physical layout of the environment.

Yeap's Model of Cognitive Mapping

Before I provide the arguments for the above position on human cognitive mapping, I will first present a summary of the key features of Yeap's model of cognitive mapping as it now stands (see Figure 1). For details, see (Yeap 1988; Yeap & Jefferies 1999). The key features of the model are:

1. At the perceptual level, the primary sensor delivers its output as input to the cognitive mapping process. Outputs from other sensors might be added to it whenever they become available.
2. The cognitive mapping process takes each spatial view as input and constructs a description of a local space into which the cognitive agent resides. This local space is referred to as an absolute space representation (ASR).
3. Using the ASRs computed, two representations are maintained in parallel. One is known as a Memory for one's Immediate Surroundings (MFIS) and the other, a network of ASRs visited.
4. The MFIS maintains a global co-ordinate system centred upon the current ASR to describe the positions of some ASRs adjacent to its current ASR. When the individual moves out of the current ASR into another ASR, the MFIS will be refreshed to show a new display of ASRs centring on the ASR just entered. It is expected that the actual number of ASRs displayed will be affected by factors such as individual's memory capacity, processing capacity, complexity of individual ASR computed, and others.
5. Together with the MFIS, a network of ASRs is also being computed. The network shows how ASRs visited are connected locally. In other words, the network is not described using a global co-ordinate system. Each ASR has its own local co-ordinate system and ASRs are connected usually via the exits the agent used to move between them. Consequently, some of the ASRs re-visited might not be recognised and perceptual induced errors could result in not knowing the correct locations of most ASRs that are not adjacent.
6. An abstraction process will group ASRs in the network to form a conceptual description of a place. Such place representations are then organised as a hierarchy of places to indicate different levels of abstractions. Note that the nodes in the hierarchy do not need to be restricted to spatial ones alone.

Discussions

In Yeap's model, the control of the flow of information lies at the interface between the place representations and the network of ASRs. One or more ASRs within the network could be grouped or recognised as a single conceptual place. When one is in a known place, one will have expectations of which ASR one might be moving into prior to entering it. When one is in a known type of place, one's expecta-

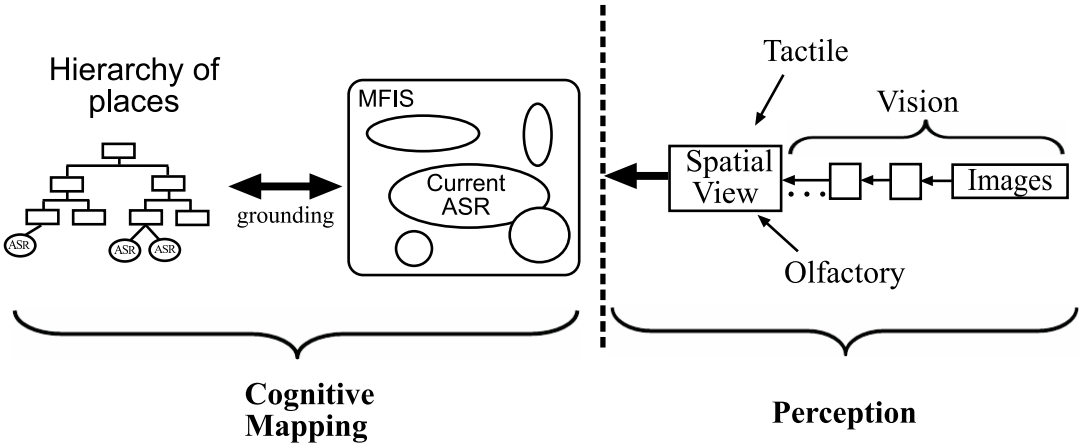

Figure 2: A human cognitive mapping process?

tions could also influence the way one constructs incoming ASRs. For example, in an office environment, ASRs of rooms would have their boundary straightened to create an ASR with the expected rectangular shape, even though the room encountered might not be rectangular.

One could ponder upon how and when ASRs are grouped into place representations and how and when one's expectations could influence the computations of ASRs themselves. However, as noted in the beginning, one difficulty with the above idea is that humans are unable to recall much of the network that is supposedly computed from one's initial experience of a new environment. If so, how could one be sure that such a network is ever computed? As I indicate in my position statements, such a network is not computed. I now discuss why.

My argument is centred around the following three observations. First, I assume that any structure proposed as part of a cognitive mapping process is for a very good reason. Thus, the spatial view is proposed to hold information directly in front of the agent. The MFIS is proposed to hold information from more than a single view. When humans move forward, they do not forget what lies behind, even though that information is no longer in view. An ASR indicates the extent of each local space and more importantly, where the exits are. The network of ASRs is proposed to hold information about the path traversed. If humans are unable to reproduce much of the information about the path just traversed, this casts doubt as to the existence of such a network (or any similar structure proposed in other models).

Second, if remembering how to return home is most important, humans would have developed specific algorithms for solving this problem. Animals have shown to have developed some amazing abilities to do so and these include some well-known discussions of how ants could measure the distance they travelled accurately, how bees could dance to orient and how birds could use position of sun to navigate. There is no reason why humans could not do likewise and computing a network of local spaces would be one highly possible algorithm, as it is favoured by many researchers working on cognitive mapping.

If humans did not develop such an algorithm, then they must be some important reasons not to do so. I hypothesize that the reason is that humans have evolved to do symbolic reasoning. Unlike lower animals, humans reason about the world. I believe that once an infant grasps the notion of a location and moving between locations, then the cognitive mapping process begins with the idea that one is always moving between different locations. During the journey one reasons about the places visited and when desired, ground the concepts to the information made explicit in the MFIS.

Figure 2 shows a change in my model of cognitive mapping to accommodate this viewpoint. Note that if we consider the MFIS as part of the perceptual system, then cognitive mapping, in humans, is very much to do with spatial reasoning about the environment. The grounding of its symbols produces the spatial layout and not the reverse. Shouldn't that be the case?

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