ACT-R/S: A Computational and Neurologically Inspired Model of Spatial Reasoning

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The field of cognitive modeling has seen a recent push in two major areas: embodied cognition, and neurological realism. No longer is it sufficient to show that a model of cognition can produce a specific behavior without actually interacting with its environment in someway, be it a real environment or simulated. Nor can psychologists ignore the fact that for every system, representation, rule, and computation proposed there must be some underlying neurological reality behind it. With both these constraints in mind, we set out to develop an extension to ACT-R (Anderson & Lebiere, 1998) allowing it to enter into a three-dimensional world in a neurologically plausible manner.

ACT-R/S (spatial) relies specifically upon three processing modules, only two of which are new to the architecture. Each of these modules has been shown to be both behaviorally and neurologically separate. The representations and computations of each of the systems are similarly distinct.

Three Visiospatial Systems

Visual System The primary function of a visual system is to identify a set of visual features as an object. The visual system needs to be able to take fine-grained detail and through special processing, recognize an object. A feature of this system is that it is able to perform its task based off of basic two-dimensional retinotopic information. An object's depth or spatial extent is not typically necessary for its accurate identification. This functionality is currently available in Mike Byrne's ACT-R/PM (perceptual & motor extension).

Neurologically, the visual system is seated in the primary visual areas as well as the ventral visual processing stream which limits processing to fine detail, color perception, local form perception, visual scanning and visual feature analysis (see Previc, 1997 for review).

Manipulative System When it comes to grasping and manipulating objects, we need to be able to represent them in a manner that will enable us to effectively prepare the motor system for the task ahead. The manipulative system is concerned entirely with a metric, geon-based (Biederman, 1987), three-dimensional representation of objects. These representations are then typically fed to the motor system permitting the development of complex motor programs. The manipulative system can represent almost any three-dimensional object, but its primary purpose is to support actual manual manipulation.

The manipulative system relies upon the dorso-lateral visual stream as well as the parietal cortex. The involvement of the parietal cortex is not surprising given that these tasks often involve actual manipulation. However, when subjects are asked to imagine object rotations, the parietal cortex is still often activated (see Previc, 1997 for review).

Configural System The configural system is concerned with representing objects in space to facilitate navigation. It represents the world around us as spatial blobs that need to be navigated around, above, or below. Its representations are nowhere near as precise as those found in the manipulative system. It encodes the locations of objects in terms of egocentric vectors that are continuously updated through path-integration. The utilization of multiple landmarks allows the system to uniquely position itself in space and return to locations at later points in time.

The discovery of "place-cells" in the rat hippocampus has been viewed as the definitive location of cognitive-maps in the brain (O'Keefe & Nadel, 1978). Recent research has shown that the parahippocampal regions are more important in primate navigation but they still represent some form of a map of the environment. Our own meta-analysis brings the "egocentric" assumption of "place-cells" into question, hence our usage of egocentric vectors in the configural representations.

Summary

With the proposal of two additional processing systems that specialize specifically in three-dimensional processing, it is hoped that we will be able to expand the range of phenomenon that computational cognitive models can represent. We present this not only for the ACT-R architecture, but also so that other architectures might get a foothold in three-dimensional embodiment.

References

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