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Panel on Diagrammatic Representations and Cognitive Architectures

Organizers

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Need for Architecturally-based Tools for Modeling Cognitive Activity Involving Spatial and Diagrammatic Representations. Diagrammatic representations are ubiquitous in human problem solving. Diagrams are common in professional activities such as military planning, chemical research and engineering design as well as in everyday lay problem solving. Diagrammatic reasoning involves a combination of reasoning steps, some of which are inferences from symbolic representations, while others are perceptions on diagrams. Diagrams are often external, but they can also be evoked as mental images to help in problem solving and understanding. Memory is also at least partly diagrammatic - e.g., we recall spatial configurations in episodic events to answer questions about spatial relations. Computational modeling of phenomena involving diagrammatic and other spatial abstractions is important for scientific as well as practical reasons. Practical reasons include the need for better design of diagrams for comprehension and problem solving.

Cognitive architectures such as Soar, ACT-R, Epic, and Prodigy, to name a few of the most well-known, are computational frameworks that include several components of cognition and that can be used to build computational models of cognitive phenomena. The cognitive models built using such general cognitive architectures not only account for the phenomenon being modeled, but show how the details of performance arise from general architectural properties. This ability to cover a variety of phenomena with a common underlying architecture is the origin of Newell's use of the term "unified theories of cognition" to describe these architectures as computational theories. Soar and ACT-R share many features in common: they are both based on the basic components of cognition as composed of long-term and working memories, and a control process that brings information from LTM in response to the contents of WM, which in turn contains goals and input from external perception. They represent cognitive states, goals, and memory contents in terms of symbolic expressions, whose symbols refer to entities, their properties and relations in the domain of discourse. These architectures, especially ACT-R, have been very successful in supporting the building of cognitive models for an increasing range of phenomena, from language processing to problem solving. However, in their original designs based solely on symbolic representations of cognitive states, they are not as expressive for modeling cognitive activities involving diagrammatic and similar spatial representations. Recent research, however, has begun to explore diagrammatic components to symbolic architectures.

There are many challenges for architectural proposals that incorporate diagrammatic reasoning. A unified way of treating the use of external diagrams and imagination is one of them - when people look at graphs to get some information, they appear to operate on some of the diagrammatic elements to create a composite of the external and the imagined diagrams. Diagrammatic elements are abstracted, rotated, etc., while the agent keeps control over what is real and what is imagined. Diagrammatic memories are another area of concern - how they are abstracted and stored in memory, and since matching of diagrams is not a binary affair as is the matching of symbols, there are questions about how diagrammatic retrieval works.

The Panel. In addition to the organizers, who will participate as panelists, we propose the following panel:

- *Gregory Trafton*, Naval Research Laboratory
- *David Peebles*, Univ. of Huddersfield, UK
- *Glenn Gunzelmann*, AFRL
- *Michael Byrne*, Rice University
- *Unmesh Kurup*, RPI

The proposed panel consists of researchers who have done work across a spectrum of related interest. Some of them have developed specific extensions to cognitive architectures so that they can handle diagrammatic representations. Some have been working cognitive architectures to model spatial reasoning phenomena, from which we can obtain constraints that a principled augmented architecture should satisfy. Some have worked on modeling, not necessarily computationally, cognitive phenomena involving use of diagrams. The proposed panel is a mixture of established researchers and relative newcomers.

Some questions to be addressed:

1. What do we know about spatial/diagrammatic reasoning capabilities and limitations of the human cognitive architecture?
2. What are the range of ideas currently available for how to model spatial/diagrammatic reasoning using available architectures such as Soar and ACT-R?
3. What is missing? What augmentations do we need for these architectures to cover the range of human diagrammatic reasoning capabilities?

Length. In a break with the usual BRIMS panels, we propose a 2-session Panel, one hour each, with a short break between the sessions. We need to bring together a variety of perspectives: architecture building, modeling, and identification and study of important dimensions of phenomena.

Date. Because of family constraints of one of the organizers, we request that, if possible, the panel be scheduled either on March 30 or earlier in the day on March 31.

Abstracts

Modelling graph comprehension with an embodied cognitive architecture

David Peebles
University of Huddersfield, UK

Recent developments in cognitive architectures have endowed them with perceptual and motor capabilities that allow them to be used to model tasks requiring significant visual and manual interaction with task environments. I present a recent attempt to apply one such architecture, ACT-R, to a graph comprehension task using three-variable bar and line graphs. The task was investigated in an eye tracking study in which participants were presented with bar or line graphs and were required to describe the various relationships between the variables depicted. The study revealed significant variance in performance between individuals and also between the graph types. The ACT-R model of the task interacts with the same diagram images as the experimental participants and is able to direct visual attention to the graph elements in the course of comprehending it. Constructing models of diagrammatic reasoning tasks in an 'embodied' architecture such as ACT-R requires a precise specification of the knowledge and strategies used by participants at different levels of ability and allows rigorous testing of the model using 'end of task' behavioural measures such as task completion time and also 'during task' measures such as comparing the model's visual attention shifts and verbal output with eye movement and verbal protocol data from experiment participants. The long-term aim of this research is to develop a general model of graph comprehension that will predict novice, intermediate and expert level performance with different graphical formats, enabling graph designers to evaluate different representations and select the most appropriate ones for their particular communicative goals.

Limits on Computerized Displays

J. Gregory Trafton
Naval Research Laboratory

Over the last 30 years, there has been a huge increase in the number and type of applications that have been converted to computerized displays. For the most part, this has allowed progress in science and technology to proceed more rapidly than if computerization had not occurred. I will present data that suggests some limits of creating computerized displays of complex visualizations.

Some Differences Between External and Internal Diagrams

Unmesh Kurup, Cognitive Science Program, RPI

The power of diagrammatic reasoning lies in the idea that diagrammatic representations "inside" an agent have certain similarities with diagrams in the external world, most notably, the fact that the representation preserves the geometric aspects of space and that there are processes that allow for spatial relations to be extracted from the representation. In this talk, I will argue that there are also some important differences between external and internal diagrams. These differences include the fact that internal diagrams are fragmented and that there is dissociation between the location of a diagrammatic object and its spatial extent. Further, internal diagrammatic representations are also simplified, suffering both a loss of detail as well as a loss of location information. I will show evidence from the psychological literature for each of these differences and, using examples, show that capturing these differences can be beneficial for both building AI systems as well as cognitive modeling. These differences have also been accommodated within the constraints of the cognitive architecture Soar. Time permitting, I will provide examples of how this augmented cognitive architecture, called biSoar, performs in a cognitive modeling task.

A Theory of Human Spatial Competence and Relation to Diagrammatic Reasoning

Glenn Gunzelmann
Air Force Research Laboratory

In earlier work with Lyon, we presented a general theory of spatial competence aimed at accounting for the breadth of spatial information processing abilities exhibited by humans. In this talk, I will present the current state of this theory, and illustrate its explanatory power in complex task contexts, including some speculative comments regarding its application to diagrammatic reasoning.

A Visual Salience System for ACT-R

Michael D. Byrne, Clayton T. Stanley
Rice University

When in any visual environment, including working with diagrams, one of the decisions faced by the human visual system is where to look next. The literature contains many models of parts of this process, but few that are incorporated into any system which is capable of meaningful reasoning. However, Byrne (2006) proposed an extension to the ACT-R visual system which incorporates both bottom-up visual factors (e.g., if there is only one green object on a display of blue objects, it tends to pop out) as well as top-down factors (e.g., if the system expects the next relevant item to be on the left, the visual system is more likely to select items on the left). We will report on new experiments which test fundamental assumptions of this framework for visual salience and present ACT-R model fits to these results. The data contain important counter-intuitive results that in some cases, reducing the number of objects on the display does NOT result in faster searches; the model is able to reproduce these results. Future directions include a getting a more thorough understanding of the temporal dynamics of salience and testing the model in tasks with stronger top-down influences, such as locating information in cockpit displays and possibly in interpreting more complex visual representations such as diagrams.