Visual Reasoning in Modeling and Design

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Introduction

Visual reasoning plays an important role in modeling in science and engineering, including science and engineering education. It also plays a critical role in engineering and architectural design. Ferguson (1992), for example, views good engineering largely as an outcome of visual reasoning (and not verbal or mathematical reasoning). Yet, there is much that we do not yet understand about visual reasoning. In fact, at present there is not even a universal agreement in cognitive science on a definition of visual representation or reasoning.

The purpose of this symposium is to bring together recent cognitive science research on visual reasoning in modeling and design. Our proposal focuses on visual representations such as sketches, drawings and diagrams. The speakers in the proposed symposium represent multiple disciplines within cognitive science, including artificial intelligence (Cheng, Goel), science education (Clement), cognitive psychology (Hegarty), architecture (Dogan), and philosophy and history of science (Nersessian). Goel will be the moderator for the symposium.

Presentations

Ashok K. Goel
Understanding Drawings by Model Construction by Compositional Analogy
Understanding sketches, drawings and diagrams is a fundamental problem in visual reasoning. I describe a computational technique for understanding engineering drawings by constructing a teleological model of the target drawing by analogy to the model of a known drawing. Knowledge of the source case is organized in a multimodal schema that contains the source drawing and its teleological model represented at multiple levels of abstraction: the lines and intersections in the drawing, the shapes, the structural components and connections, the causal interactions and processes, and the function of the system depicted in the drawing. Given a target drawing and a relevant source case, the technique of compositional analogy first constructs a representation of the lines and the intersections in the target drawing, then uses the mappings at the level of line intersections to transfer the shape representations from the source case to the target, next uses the mappings at the level of shapes to transfer the full teleological model of the depicted system from the source to the target. The Archytas computer system implements this multimodal knowledge representation and the technique for understanding drawings

by construction of teleological models by compositional analogy.

John J. Clement

Imagistic Simulation in Scientific Theory Construction; Transfer of Runnability From Specific Cases to Explanatory Models

I have been studying scientifically trained experts asked to think aloud while solving unfamiliar explanation problems. Transcripts from video tapes capture a complex set of behaviors that is difficult to parse, such as generating multiple creative analogies, explanatory models, and thought experiments. Progress has come from assigning them to three nested levels of processing: (1) mental simulations using fairly primitive physical intuitions for actions on specific cases; (2) reasoning processes such as analogy, chaining simulations, applying a model, and evaluative Gedanken experiments; and (3) abductive evolution cycles of explanatory model generation, evaluation, and modification. At level (1), subjects' use of depictive gestures, drawings, and other indicators provide evidence that they are imagining moving components in specific cases; this is modeled as an imagistic simulation process. Are these simulations simply used to 'brainstorm' a starting point for the problem, or are they involved in sophisticated modeling at level (3)? Evidence is provided for 'transfer of imagery and runnability' from cases to explanatory models, resulting in a model with enough imagistic precision, alignment, and dynamics to aid evaluation and be ready for mathematization.

Fehmi Dogan and Nancy J. Nersessian

Conceptual Diagrams in Creative Problem Solving

Studies of diagrammatic reasoning have investigated the role of diagrams in different domains in supporting reasoning, problem solving, and communication. These studies often are confined to domains that pose relatively well-defined problems, such as geometry and physics, with fewer studies in domains where the problems are ill-defined, such as scientific discovery and architectural design. Our study investigates the roles played by diagrams in concept generation and elaboration in complex, ill-defined, and creative problem solving situations as exemplified in architectural design and scientific discovery. We argue that a specific class of diagrams can be identified which structure creative problem solving in these domains – what we call "conceptual diagrams." These diagrams facilitate creativity and innovation by way of representing incipient conceptualizations of complex domains in simpler graphical representations that foster mental modeling processes. We illustrate and explicate the notion of conceptual diagrams with brief exemplars from physics, and then focus on their use in two cases of problem solving in architectural design, Daniel Liebskind's Jewish Museum in Berlin and Louis Kahn's First Unitarian Church in Rochester, NY.

Mary Hegarty

Thinking in Diagrammatic Reasoning.

Mary Hegarty will report on recent studies of diagrammatic reasoning in the domains of mechanics and chemistry, as well as studies of solution strategies in classical tests of spatial ability. These studies indicate that mental simulation can be an important strategy in reasoning from diagrammatic representations. However, reasoning with diagrams can also involve more analytic processes, such as task decomposition and rule-based reasoning, indicating that reasoning with diagrams is not necessarily a process of running and inspecting visual images in the 'mind's eye'. This paper will examine whether solution processes in "visual reasoning" are related depend on consistent cognitive styles of reasoning and/or whether they reflect adaptive strategy choice in response to task constraints.

Peter C-H. Cheng

Representational Epistemology: Beyond Visual Reasoning.

The *Representational Epistemic* approach to the study of diagrammatic cognition in complex technical domains will be summarized. The REEP approach adopts a broad perspective: (a) The rich conceptual structure of knowledge domains that encompass many levels of abstraction, scales of granularity and alternative ontologies is examined, rather than task level information. (b) *Representational systems* that govern the creation of classes of representations are analyzed, rather than the formats of particular visualizations. (c) The complex relations that codify knowledge domains as representational systems are explored, rather than mappings between informational and visual elements. The principles that appear to determine the effective diagrammatic codification of complex knowledge domains will be discussed.

Inventing new representational systems for conceptually challenging domains and contrasting them with extant approaches provides the theoretical and empirical leverage needed for the study of diagrammatic cognition under the REEP approach. Case studies of how the diagrammatic re-codification of conceptually challenging domains in science and engineering can substantially enhance reasoning, problem solving and learning will be summarized, including our recent work on diagrams for complex planning and scheduling tasks.

References

Ferguson, E. (1992) *Engineering and the Mind's Eye.* Cambridge, MA: MIT Pres