Jim Davies: Research Statement

Theory

The use of multiple types of knowledge (e.g. functional, causal, spatial) is an important long-term AI problem, as well as a poorly-understood human cognitive phenomenon. The guiding theory of my research is that one function of knowledge representation change is to make explicit the similarities between two apparently disparate ideas. A reasoner might not be able to see the similarity of two similar ideas because they have different names (e.g. "revolution" and "circle"), resulting in what is known as an ontological mismatch. Re-representing the ideas with different knowledge types is one possible solution strategy. I investigate this theory by looking at how intelligent systems, both natural and artificial, use visual knowledge in analogical problem solving. I use visual knowledge to mean explicitly represented information pertinent to how a scene appears, e.g. shapes, locations, relationships, colors. In our example, visually abstracting both "revolution" and "circle" to the symbol "ellipse" allows the reasoner to see the ideas' similarity. There are two major steps in evaluating my theory for analogy and visual representation. The first is to show that solution steps can be represented visually and transferred successfully to visually-represented new problems. I investigate the use of visual representations in analogical problem solving. I have shown support for this theory for human cognition in the Proteus system, and have applied it in the area of bioinformatics with the Triptych system. The second step is part of my future work, comparing visual to non-visual knowledge in its usefulness for analogy.

Past Work

The *Triptych* system applies visual analogy to the bioinformatics field of protein structure prediction. Understanding the three-dimensional structure of proteins is an important part of molecular biology beacuse all life crucially depends on the structure of macromolecules. Triptych uses a visual representation of protein topology, called a contact map (a binary matrix showing which parts of the protein are physically close to others), to retrieve similar structures from a knowledge base using computer vision techniques. Structure information is then adapted from the retrieved sources to the unknown target protein. The Triptych system shows that for protein structure prediction, visually re-representing the query information facilitates analogical reasoning.

The *Proteus* architecture also uses visual analogy, but is domain-independent, and works for multi-step problem-solving solutions. It shows that using *only* visual knowledge, a reasoner can successfully retrieve, map, transfer, and store problem-solving strategies between analogs of various kinds. A Cognitive Visual Language (Covlan) represents problem states with visual knowledge (scenes symbolically represented with shapes and relations between them), and describes transformations of these states (e.g. *add-element, decompose*). The transformations work on many of the primitive visual elements because cases are visually encoded at the correct level of abstraction for transfer. Proteus is the only implemented model of visual analogical problem solving for multi-step procedures. By modeling human subjects in visual analogy experiments, I have shown evidence for parts of Proteus as a cognitive model.

Future Work

My future work will proceed on two tracks: automatically generating visual representations from non-visual ones, and the comparison of visual to non-visual knowledge in problem-solving. I will describe each in turn.

I will expand Proteus to be able to analogically solve problems with non-visual knowledge. Upon encountering ontological mismatches, however, it will change the non-visual knowledge into the visual language– that is, automatically generate a visual representation from a non-visual one. Proteus will use this visual re-representation to resolve mismatches. Once appropriate connections are made using visual knowledge, those inferences will be translated back into the non-visual knowledge representation for evaluation.

To show strong evidence of the value of representation change requires a comparison between two different representations. When Proteus can automatically turn non-visual representations into visual ones it can be used for a testbed to determine the conditions under which visual representations are helpful. For example, in the work of myself and my colleagues on protein structure prediction, we have used visual contact maps as the input for retrieval and adaptation. Showing that it can work is the first step; the next step is showing it under what conditions it is superior. In this example, I could compare the retrieval quality of contact map results to sequence homology results.

Since the theory is not domain specific, I plan to implement systems to work in many domains, including practical applications. For example, work with design programs (photo editing, illustration, CAD) do not facilitate working on several versions of ideas at the same time. A program able to transfer visual operations from one situation to another could apply analogous changes to several branches of the design hierarchy. Because bioinformatics applications have great practical importance, I use them for my domains when possible. These domains could include the prediction of protein pathways, stem cell differentiation pathways, and the active or binding sites of proteins. I look forward to working with collaborators in the biological and medical sciences.

My research explores the changing of knowledge through different modes of representation. My work in visual representations for analogical problem solving, in both cognitive modeling and bioinformatics, has proven fruitful and I am enthusiastic about its future for both basic science and applications.