A Cognitive Model of Visual Analogical Problem-Solving Transfer*

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Abstract

Complex problem solving typically involves the generation of a procedure consisting of an ordered sequence of steps. Analogical reasoning is one strategy for solving complex problems, and visual reasoning is another. Visual analogies pertain to analogies based only on visual knowledge. In this paper, we describe the use of Galatea, a computational model of visual analogies in problem solving, to model the problem solving of a human subject (L14). L14 was a given the task of solving a complex problem using analogy in a domain that contained both visual and non-visual knowledge, and was encouraged to use visual analogy. We describe how Galatea models L14's use of visual analogy in problem solving.

1 Introduction

Complex problem solving typically involves the generation of a procedure consisting of a strongly-ordered sequence of steps. These procedures have two important properties: 1) the procedure contains two or more steps, and 2) some steps cannot be executed before some other steps have already been executed. Analogical reasoning is one strategy humans often use to solve complex problems. Analogical problem solving takes a solution from a source analog and applies some version of that solution to a target problem. Visual reasoning is another strategy humans sometimes use to address complex problems.

We have used Galatea to model data on problem solving by several human subjects. This data was collected in a pyschological experiment run by Dr. David Craig. In this experiment, the human participants were given the task of solving a complex problem using analogy in a domain that contained both visual and non-visual knowledge, and were encouraged to use visual analogy in their problem solving. In this paper, we describe how Galatea models one participant's (L14's) use of visual analogy in problem solving. In the interest of space, we refer you to [Davies and Goel, 2001] for information about the Galatea modelling language.

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2 The Galatea Model of L14

Galatea is intended to be a partial cognitive model of visual analogical transfer in human beings. To support Galatea with respect to its psychological plausibility we modelled some of the visual aspects of four experimental participants' drawings, one of which we will describe in detail in this paper.

Dr. David Craig ran 34 participants in an analogical transfer experiment [Craig *et al.*, 2002]. Participants were shown a problem-solving solution about a laboratory, presented with text and a diagram. They were asked to solve an analogous problem with a weed-trimmer, presented with text only. Of these, 17 participants (in three conditions) correctly described the analogous solution. All participants were asked to draw a diagram to illustrate their suggested solutions.

The source given was a laboratory clean room problem. A single door lets in dirty air, so a vestibule is added, with two doors where one door stayed shut while the other was open. The target problem is a weed trimmer arm attached to a truck that must be able to pass through street signs. The analogous solution is to design an arm with two latching doors, so that while one is open to let the sign pass, the other stays closed to support the arm and trimmer. Participants produced diagrams describing their solutions to the problems. We modelled four of these experimental participants in Galatea, one of which, L14, we will describe in detail.

We represented the source analog as a series of `s-images` connected with `transformations`. See the top of Figure 2 for an abstract diagram of our Galatea model of the source analog.

The first `transformation` is `replicate`. The second `transformation` is `add-connections` which places the door sets in the correct position in relation to the top and bottom walls. The third and fourth `transformations` are `add-component`, which add the top and bottom containment walls. The fifth `transformation`, another `add-connections`, places these containment walls in the correct positions in relation to the door sets and the top and bottom walls.

2.1 Evaluation

We can now examine what made L14 differ from the stimulus drawing: long vestibule, rotation, line to double line, sliding doors, added objects, numeric dimensions added, and mechanisms added. Of these seven differences, our model success-

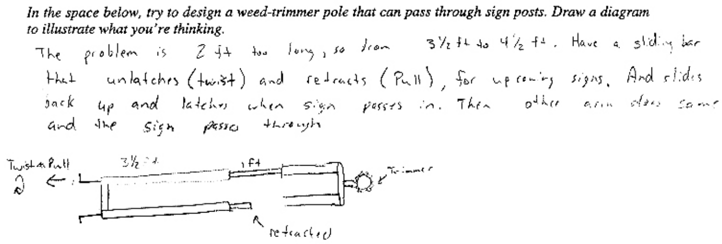

Figure 1: The source data for L14. The drawing above and handwritten text are what participant L14 produced on the experiment sheet.

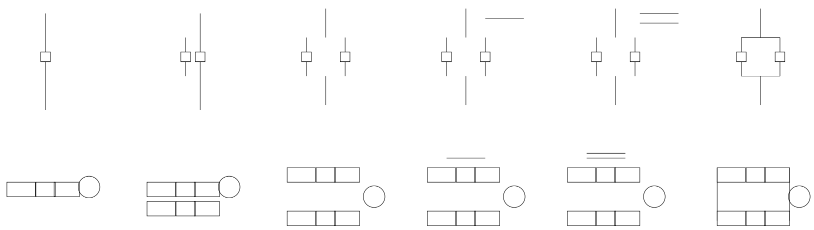

Figure 2: The implementation of L14. The top series of `s-images` represents the source analog (the lab problem) and the bottom series the target. There are six `s-images` for the five `transformations`.

fully re-creates four of them, all through manipulation of the input knowledge and by adding transformations. That is, the source Galatea code did not need to be changed.

Unaccounted for are the two bent lines emerging from the vestibule on the left side, the numeric dimensions and words describing the mechanism. Also, L14 shows one of the doors retracting, and the model does not. The model also fails to capture the double line used to connect the door sections, because the single line is transferred without adaptation from the source. This could be fixed, perhaps, by representing the argument to the `add-component` as a function referring to whatever element is used to represent another wall, rather than as a `line`.

3 Conclusion

Our initial view was that visual knowledge facilitates transfer even when non-visual knowledge might be available. In conclusion, the evaluation supported this and resulted in one unexpected discovery, for a total of two claims: **Claim one: Visual knowledge facilitates transfer even when non-visual knowledge might be available.** L14's data is an example of a cross-domain analogical problem solving that could have been represented both non-visually and visually. Our implemented model of L14 uses only visual knowledge. The level of abstraction of the visual symbols in Covlan allows the cross-domain transfer of problem-solving steps to occur, supporting our hypothesis. Further it shows that Galatea can account for human participant data.

Claim two: The successful transfer of strongly-ordered procedures in which new objects are created requires the reasoner to generate intermediate knowledge states and mappings between the intermediate knowledge states of the source and target analogs. In the course of creating this model, we discovered something about analogical transfer in general: A characteristic of strongly-ordered procedures is that components of the problem are *created* by the operations, and these components are acted on by later operations.

Our model shows how this might work for human cognition: The doorway is replicated, then moved, then sealed with containing walls. For the transfer of multi-step, strongly-ordered procedures it was necessary for Galatea to generate intermediate knowledge states and mappings.

References

[Craig *et al.*, 2002] David L. Craig, Nancy J. Nersessian, and Richard Catrambone. *Model-Based Reasoning: Science, Technology, & Values*, chapter Perceptual simulation in analogical problem solving. Kluwer Academic: Plenum Publishers, 2002.

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