# Diagrammatic Reasoning: Route Planning on Maps with ACT-R

**H. A. Dye (hdye@ttocs.org)**
U.S. Military Academy/Army Research Laboratory
MADN-MATH, 646 Swift Road
West Point, NY 10566, USA

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## Diagrammatic Reasoning

Diagrammatic reasoning, reasoning from graphical representations rather than from word-based representations, is pervasive in our society. Computers allow us to easily design and transmit diagrams that encapsulate a variety of information. Maps are specific instances of diagrams that are used to provide current and projected information (Chandrasekaran et al., 2002); for example, public transportation systems are displayed as color coded graphs. Other examples of diagrammatic reasoning include geometric problem solving in mathematics and free body diagrams in physics. Diagrams can offer cognitive shortcuts relative to verbal descriptions of certain kinds of information, notably relational and spatial information. Thus, diagrams can reduce the working memory load and make possible certain cognitive efficiencies.

### Challenges

The overall goal of this research project is to produce cognitively-congruent models of diagrammatic reasoning in the Adaptive Control of Thought – Rational (ACT-R) architecture (Anderson et al., 2004). This study investigated perception and reasoning during a problem solving task that utilizes a diagram. The model presented here uses the architecture's perceptual and motor modules; visual objects were created and placed in a virtual window on which the perceptual and motor modules could then act. There were two challenges in building the model: (1) ACT-R's visual module is text- rather than diagram-based and (2) previous vision modeling efforts (e.g., Fick and Byrne, 2003) have focused on target search where the target is identified rather than using the visual information for subsequent decision making. To validate the ACT-R model, participants performed two diagrammatic reasoning tasks.

### Diagrammatic Reasoning Tasks

Eighteen participants (U.S. Military Academy cadets) performed two simple tasks on a 5x5 grid-based map, consisting of labeled points, lines, and regions. The simplicity of these maps allowed both the isolation of the effect of specific changes in the maps and the extraction of relatively rich cognitive data. Specifically, the two tasks were (1) *"find,"* finding a target location (B) on the map (perception) or (2) *"plan,"* finding the target location (B) and executing a planned route from location (A) (perception plus decision making) (see Figure 1). The target location was positioned in one of the four corners and task difficulty was manipulated by limiting the number of direct paths to the target. For example, in Figure 1, one direct path to the target has been eliminated. Zero, one, or two (both) direct paths to the target could be eliminated.

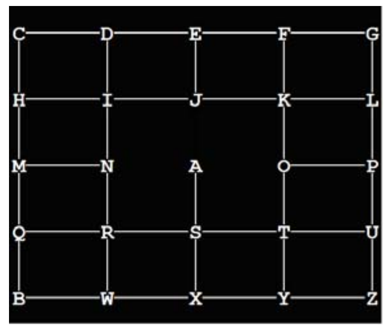


Figure 1: A sample map

Both tasks began with the participants being presented with a center-screen fixation point. In the find task, participants pressed the space bar to indicate that they had found the target location. As a check, the grid labels were then erased and the participant used the mouse to click on the target location. In the route planning task, participants found the target location and moved a red outlined box along the paths using the arrow keys to indicate the selected path. When the box was positioned over the target location, participants pressed the enter key. The search task is an assumed subtask in the route planning task. Task difficulty was manipulated by blocking direct paths to the target location (deleting paths). E-Prime was used to display and manipulate the grid and collect response data. End target location and the number and position of paths deleted were completely counterbalanced in a within-subjects design.

The average response times in msec for the find and plan tasks for target position and the blocked paths are shown in Figures 2. Find and plan times generally increased across target location according to a left-to-right upper and upper-to-lower strategy with a mixed strategy on the lower, either left-to-right or right-to-left. Plan task times increased with increasing numbers of paths blocked.

### Cognitive Modeling

Following the general strategy exhibited by participants, the ACT-R 6.0 cognitive model begins the find and plan tasks by moving visual attention away from the fixation

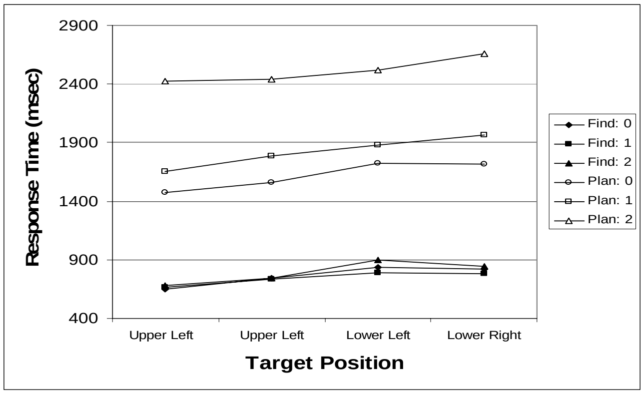


Figure 2: Averaged participant responses for the tasks with 0, 1, or 2 paths blocked and target location

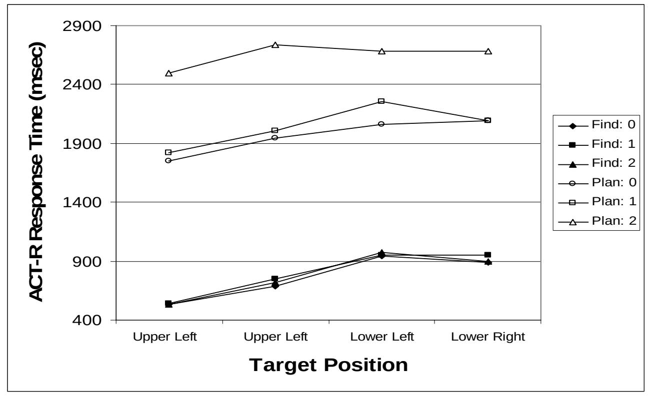


Figure 3: ACT-R model responses for find and plan tasks with 0, 1, or 2 paths blocked and target location

point, looks at the corners of the grid, proceeding from the upper left to the upper right and then lower right and lower left until it finds the target location. In the model of the find task, the model then presses a key to indicate that it has found the target location. The model of the route planning task builds on the search model. After finding the target, the model's perception focuses on the area around the starting location (A). [Note: Visual attention in ACT-R must be directed to an object and cannot be directed to an open space. To allow the model to position visual attention on the deleted paths, these paths were colored black rather than actually deleted (Cassenti, Kelley, & Ghirardelli, 2006).] The model then plans a route to the end location (B) from the start location (A) by focusing visual attention on a path in a region defined by the current location and proximity to the target location. The first arrow key is determined by the existing edge nearest the target that captures visual attention. Next, the model selects a path with the same direction as the last traversed path, causing the same arrow key to be pressed again. If no such path exists, the model shifts strategies and attempts to find any path that advances the route towards the target position. The model does not observe the labels of the intermediate locations or non-relevant paths during the find or planning processes.

The find and the plan models were run for 144 trials each or the equivalent of one participant. The mean response times as a function of complexity (blocked paths) by end target location for the two models are shown in Figure 3. The find and plan models reproduced the participants' data fairly well (see Figure 3), with r = .93 and RMSD = 0.14 and r = .97 and RMSD = 0.13, respectively.

There are some limits to the current model, even with some post-experiment adjustments. Currently, the model does not take into account the following efficiencies and errors: a decrease in response time when a participant pressed the same key repeatedly; or errors when participants attempted to traverse paths that had been deleted or mistook the target location.

## Conclusions

The correspondence between the model and participants' data was reasonably high. A largely serial ACT-R model of the search and path selection process matched participants' data with respect to the find task alone and to the plan task, which subsumes the find task. Even with this simple grid, more blocked paths resulted in greater response times and with the generally used search strategy, times varied in an orderly fashion with target location. Two questions are prompted by these results: (1) What is the effect of diagram features such as missing paths or irrelevant paths on route planning? (2) At a more detailed level than explored in this model, how are finding and planning processes interrelated in the time to the first keystroke. For the participant data, the first plan task keystroke took approximately 200 msec longer than search task keystroke, pointing to a promising window in which to explore the basics of diagrammatic reasoning.

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## References

Anderson, J. R., Bothell, D., Byrne, M. Douglass, S., Lebiere, C., & Qin, Y. (2004). An integrated theory of the mind. *Psychological Review*, *111*, 1036-1060.

Cassenti, D. N., Kelley, T. D., & Ghirardelli, T.G. (2006). Awareness yet underestimation of distractors in feature searches. In R. Sun (Ed.) *Proceedings of the 28th Annual Conference of the Cognitive Science Society* (pp. 1086-1091). Mahwah, NJ: Erlbaum.

Chandrasekaran, B., Josephson, J.J., Bannerjee, B., Kurup, U., & Winker, R. (2002). Diagrammatic reasoning in support of situation understanding and planning. *Proceedings of the Army Science Conference*, Orlando, FL.

Fick, C. S., & Byrne, M. D. (2003). Capture of visual attention by abrupt onsets: A model of contingent orienting. In F. Detje, D. Doerner, & H. Schaub (Eds.) *Proceedings of the Fifth International Conference on Cognitive Modeling* (pp. 81-86). Bamberg, Germany: Universitas-Verlag Bamberg.