Lyon, D. R., Gunzelmann, G., & Gluck, K. A. (2004). Emulating a Visuospatial Memory Field Using ACT-R. In M. Lovett, C. Schunn, C. Lebiere, and P. Munro, *Proceedings of the Sixth International Conference on Cognitive Modeling* (pp. 368-369). Mahwah, NJ: Lawrence Erlbaum Associates.

# Emulating a Visuospatial Memory Field Using ACT-R

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## Introduction

We define visuospatial working memory (VSWM) as the set of cognitive processes used to visualize the locations of things. VSWM is not permanent visual memory; it is a temporary visual workspace used to solve spatial problems. VSWM is ubiquitous in everyday reasoning (for example, visualizing different ways of arranging furniture in a room), and is thought to be particularly important for certain occupations (for example, engineers, architects, and pilots).

Both subjective experience and empirical studies suggest that the capacity of VSWM is limited (c.f. Logie, 1994). Our goal is to model the underlying sources of this capacity limitation. To measure VSWM capacity, we use a new method called *Path Visualization* (PV, Lyon, 2004). PV is similar to some existing methods (e.g. Brooks, 1968; Attneave & Curlee, 1983; Kerr, 1987, 1993; Diwadkar, Carpenter & Just, 2000; Barshi & Healy, 2002) in which participants must visualize relative positions or movements (up, right, down…) in a two-dimensional or three-dimensional array of locations. However PV also requires participants to make continuous timed spatial judgments about intersections in a path defined by such movements. This yields accuracy and response time data that help define the VSWM representation of an imaginary path.

## Method

Four paid participants (2 female, 2 male) were each given five 30-trial sessions doing the PV task. During each trial, the participant saw a sequence of 15 text phrases presented on a CRT. Each phrase described the direction and distance (e.g. 'Left 1') of a segment of a path. There were six possible directions (Right, Left, Forward, Back, Up, Down); all distances were one. Each phrase was presented for 2000 msec, followed by a blank screen for 133 msec, then the presentation of the next phrase. As each new phrase was presented, the participant decided whether or not the endpoint of the new path segment intersected with any previously presented part of the path, and pressed a key with the right index finger to indicate 'yes', or the left index finger to indicate 'no'. In the rare event that no key was pressed during the presentation of a text phrase, the response was scored as incorrect, and the presentation of the next phrase proceeded normally. Participants were instructed to respond as accurately and quickly as possible. Small bonuses were paid for maintaining high overall accuracy and low response time.

All paths started at the center of an imaginary 5 x 5 x 5 cube (Figure 1). Segment directions were relative to a fixed frame of reference, so, for example, 'Left 1' was always toward the left side of the cube as depicted in the figure, regardless of the direction of the previous segment. No two successive segments could be on the same axis, so the path always turned to a new axis with each new text phrase. Paths were randomly generated with the restriction that a near-balance of intersection and no-intersection segments exist in the entire corpus of paths. Although a picture similar to Figure 1 was shown in the instructions, no picture was available during performance of the task. The path had to be visualized from the sequence of text phrases.

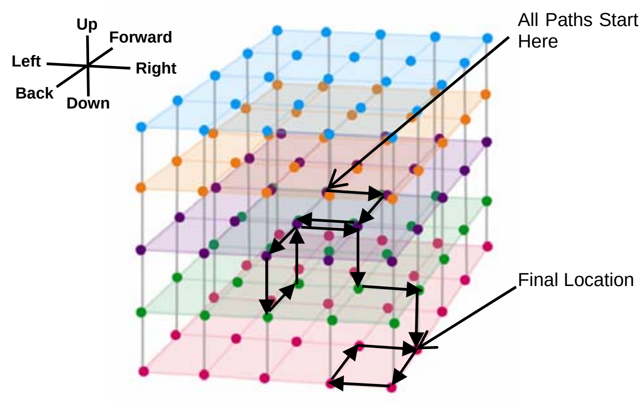


Figure 1: Depiction of a path in an imaginary space.

## Model

On the surface, this task may resemble standard verbal memory tasks in which the stimulus is a sequence of words or phrases. However since participants must make continuous spatial intersection judgments, standard models and strategies for verbal memory are insufficient. For example, a model based on serial verbal rehearsal of the text phrases would not necessarily represent the spatial information required for correct responses. Therefore we developed a model that embodies the idea of a *spatial field*. The model assumes that participants attempt to visualize the paths using some isomorphic representation in which spatial relationships between path segments are preserved.

Currently, no spatial-field-like representation exists in ACT-R. Therefore we chose to emulate a spatial field using similarity values in declarative memory. Our model performs the path visualization task as follows: First, it reads a segment descriptor ('Right 1') and generates a declarative representation of the new location. Then, using the new location as a cue, it attempts to retrieve a previous instance in which this location was generated in response to any descriptor. If anything is retrieved, the model responds 'Yes', otherwise it responds 'No'. The model predicts the following pattern of memory errors. (1) Failures to detect an intersection will increase with the number of segments presented between the initial visit to a location and the re-visit. This occurs because activation from the initial visit decays over time. (2) Incorrect 'Yes' responses (false alarms) will increase with the number of visits in the prior path to nearby locations. This is because the similarity of two locations in the model decreases as the Euclidean distance between them increases. Thus, prior visits to locations very close to the current one have a chance to be erroneously retrieved through partial matching. The more such 'near visits' there are, the greater the chance of this kind of error.

## Results and Conclusion

The two predictions of the model were tested by doing two separate partitions of the data. First we examined the segments that resulted in an intersection. Participants' responses to intersection segments were partitioned into bins based on the number of segments that intervened between visits to the location. As predicted, accuracy declined with number of intervening segments for all participants (mean $\chi^2$ = 45.8, p's < 0.05). The model captures this effect well (RMSD = 0.045).

The second partition used the segments that did not result in an intersection. These were sorted by number of near visits, that is, the number of times that prior segments visited adjacent locations, defined as one step away from the current decision location on any axis or diagonal. For example, the final location in the path depicted in Figure 1 has five near visits. Accuracy declined sharply with number of near visits for all participants (mean $\chi^2$ = 77.8, p's < 0.001). Further analysis showed that this pattern is not due to speed-accuracy tradeoff, criterion shift or aggregation artifacts. Rather, it appears to reflect interference based on proximity in imaginary space. The spatial field emulation model exhibits this interference (Figure 2) with default values for most ACT-R parameters (RMSD=0.064). We varied retrieval threshold (-0.65), and a spatial scaling factor (1.4) for scaling the function relating distance to similarity.

These results suggest that the capacity of VSWM is limited by both decay of activation and a location-based interference process that can be emulated using a spatial field. It appears that imaginary proximity has real consequences for visuospatial memory. In this respect, visualization space acts like real space.

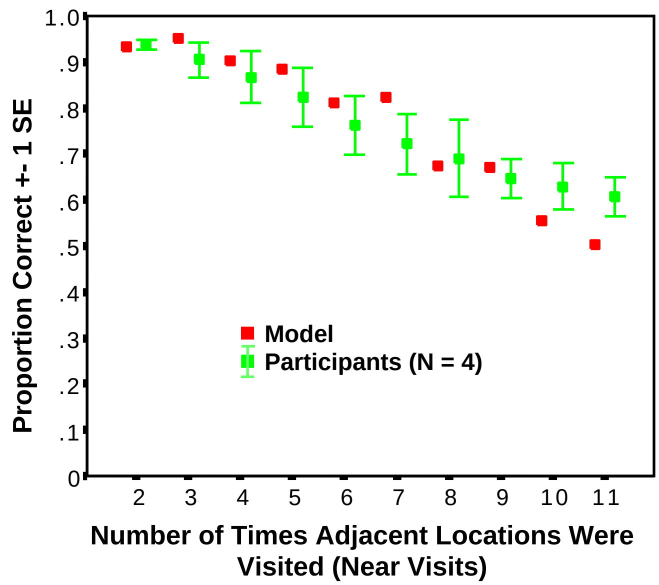


Figure 2. Effect of near visits on accuracy – Human data and model predictions.

## Acknowledgments


We thank Ben Sperry for software development, Lisa Park for research assistance, and the U. S. Air Force Office of Scientific Research for supporting this research (Grant # 02HE01COR). The second author participated in this research as a National Research Council Research Associate at the Air Force Research Laboratory in Mesa, AZ.


## References


Attneave, F., & Curlee, T. E. (1983). Locational representation in imagery: A moving spot task. *Journal of Experimental Psychology: Human Perception and Performance, 9*, 20-30.

Barshi, I & Healy, A. F. (2002). The effects of mental representation on performance in a navigation task. *Memory and Cognition, 30*, 1189-1203.

Brooks, L. R. (1968). Spatial and verbal components in the act of recall. *Canadian Journal of Psychology, 22*, 349-368.

Diwadkar, V. A., Carpenter, P. A., & Just, M. A. (2000). Collaborative activity between parietal and dorso-lateral prefrontal cortex in dynamic spatial working memory revealed by fMRI. *NeuroImage, 12*, 85-99.

Kerr, N. H. (1987). Locational representation in imagery: The third dimension. *Memory and Cognition, 15*, 521-530.

Kerr, N. H. (1993). Rate of imagery processing in two versus three dimensions. *Memory and Cognition, 21*, 467-476.

Lyon, D. R. (2004). *Measuring visuospatial working memory using path visualization.* Technical Memorandum 23-1, Air Force Research Laboratory, Mesa, Arizona.

Logie, R. H. (1994). *Visuospatial Working Memory.* Hove: Lawrence Erlbaum Associates.