Modelling mental imagery in ACT-R

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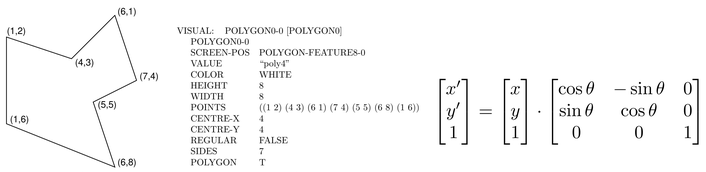
Key points

- This work aims to model spatial mental imagery within the ACT-R cognitive architecture.
- ACT-R is augmented with (a) additional coordinate representations of visual objects and (b) a set of linear and affine transformation functions to allow the manipulation of internal spatial representations.
- The modified ACT-R is tested by using it to model two classic mental imagery phenomena: mental scanning (Kosslyn, Ball & Reiser, 1978) and mental rotation (Shepard & Metzler, 1971).

Representing objects in ACT-R

- ACT-R represents visual objects as *chunks* containing symbolic information about their shape, colour, location etc. (Fig. 1b).
- In the adaptation, the coordinate locations of vertices are explicitly represented in visual objects and encoded in visual chunks when ACT-R 'sees' them (Figs. 1a and 1b).
- These vertex coordinates can be used to represent the outline shape of the object.



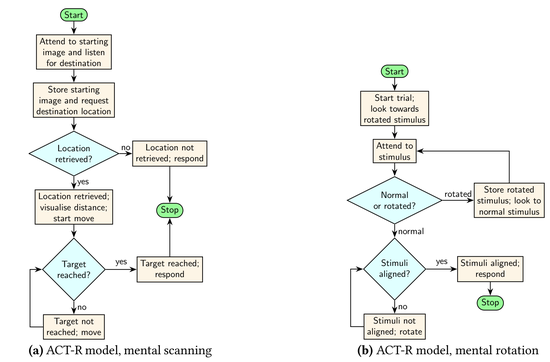
(a) **(b)** **(c)**

Figure 1: ACT-R's mental imagery mechanism: (a) explicit representation of object vertex coordinate locations, (b) encoding of the vertex locations in the visual buffer, (c) manipulation of the coordinates via matrix transformations.

- The coordinate locations are transferred to ACT-R's *imaginal* buffer where they can be manipulated using linear and affine transformation functions via matrix multiplication (Fig. 1c).
- Transformations include translate, scale, skew, zoom, reflect and rotate together with composition functions such as intersection, union and subtraction.

Strategies for scanning and rotation

- The strategy adopted for both mental scanning and mental rotation is one employed by Just and Carpenter (1985).
- For both, the process is a series of discrete steps in which the mental image is repeatedly manipulated and compared to the target to determine whether they are sufficiently close to stop (Fig. 2).

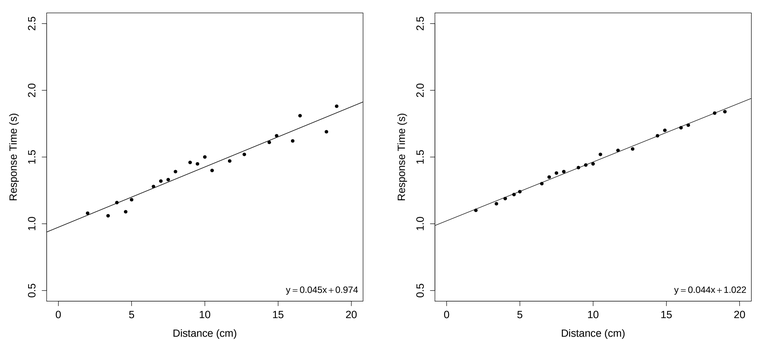


(a) ACT-R model, mental scanning **(b)** ACT-R model, mental rotation

Figure 2: Control structures of the ACT-R models for a single trial of (a) the mental scanning experiment (Kosslyn, Ball & Reiser, 1978) and (b) the mental rotation experiment (Larsen, 2014). Each rectangle corresponds to one production rule.

Mental scanning

- The modified ACT-R was applied to the 'island' experiment developed by Kosslyn, Ball & Reiser (1978) to investigate mental scanning.
- Using a *translate* function, the model was able to produce the linear relationship between distance imagined and time taken to reach the destination (Fig. 3) and provide a close fit to the human data (R^2 = .97, RMSD = 0.07).

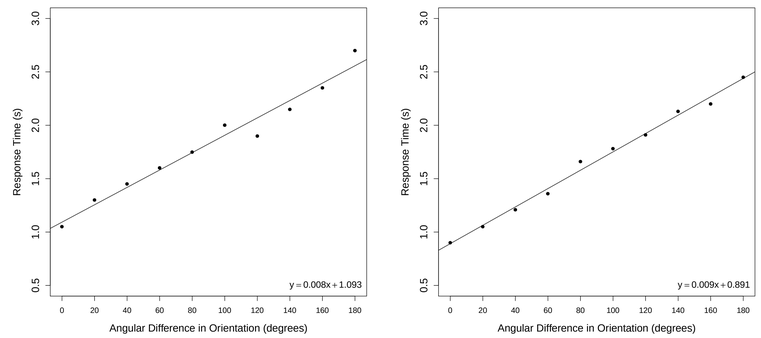


(a) Human data from Kosslyn, Ball & Reiser, (1978) **(b)** Data from the ACT-R model

Figure 3: Mean scan time for different distances in the mental scanning task.

Mental rotation

- To further test the approach, the modified ACT-R was applied to a recent replication of Shepard and Metzler's (1971) mental rotation study conducted by Larsen (2014).
- This time using a *rotate* function, the model was again able to produce the linear relationship between the degree of angular rotation between the images and response time (Fig. 4) and provide a close fit to the human data (R^2 = .983, RMSD = 0.185).



(a) Human data from Larsen (2014) **(b)** Data from the ACT-R model

Figure 4: Mean response time for different degrees of rotation in the mental rotation task.

Future work

- The mental rotation model has recently been extended (Peebles, 2019) to provide an account of the response time profiles produced two different rotation strategies (*holistic* and *piecemeal*) revealed in an experiment by Khooshabeh, Hegarty and Shipley (2013).
- The transformation functions and strategies involved in mental scanning and mental rotation are relatively simple (i.e., repeated actions producing linear RT profiles).
- The next step therefore is to produce a more stringent test of the approach by modelling more challenging tasks (e.g., Raven's Progressive Matrices (Raven, 1981), the *pedestal blocks world* or the *nonholonomic car motion planning* task (Wintermute, 2012)).