A model of object location memory

ACT-R plays Kim's game

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Summary

Experiment

- This study starts with an experimental investigation of object location memory using the *toy test* (otherwise known as "Kim's game").
- Participants are presented with a 2D array of objects for a period of time and then asked to reconstruct the array from memory.
- Results of the experiment reveal that the accuracy of location recall is significantly affected by two factors:
  Set size. As the number of objects increases, accuracy decreases.
  Selection order. Relocation accuracy is better for those objects selected earlier.

Model

- We developed a model of object location memory using the ACT-R cognitive architecture [1].
- The model provides a close fit to the human data and is able to account for the combined effects of set size and selection order found in the experiment.
- ACT-R's explanation for these two effects is based on its declarative memory processes—in particular the similarity-based *blending* mechanism which combines the values of related memory elements to produced an aggregate response:
  Set size. As set size increases, more object locations enter into the blending process, increasing the number of influences on the retrieved x and y coordinates.
  Selection order. When each blended location is retrieved from memory, the blended location chunk remains in declarative memory and is included in all subsequent blending requests. As a result, for each additional object in the selection order, the blended x and y coordinates are comprised of an additional (blended) location chunk, thereby increasing the error.

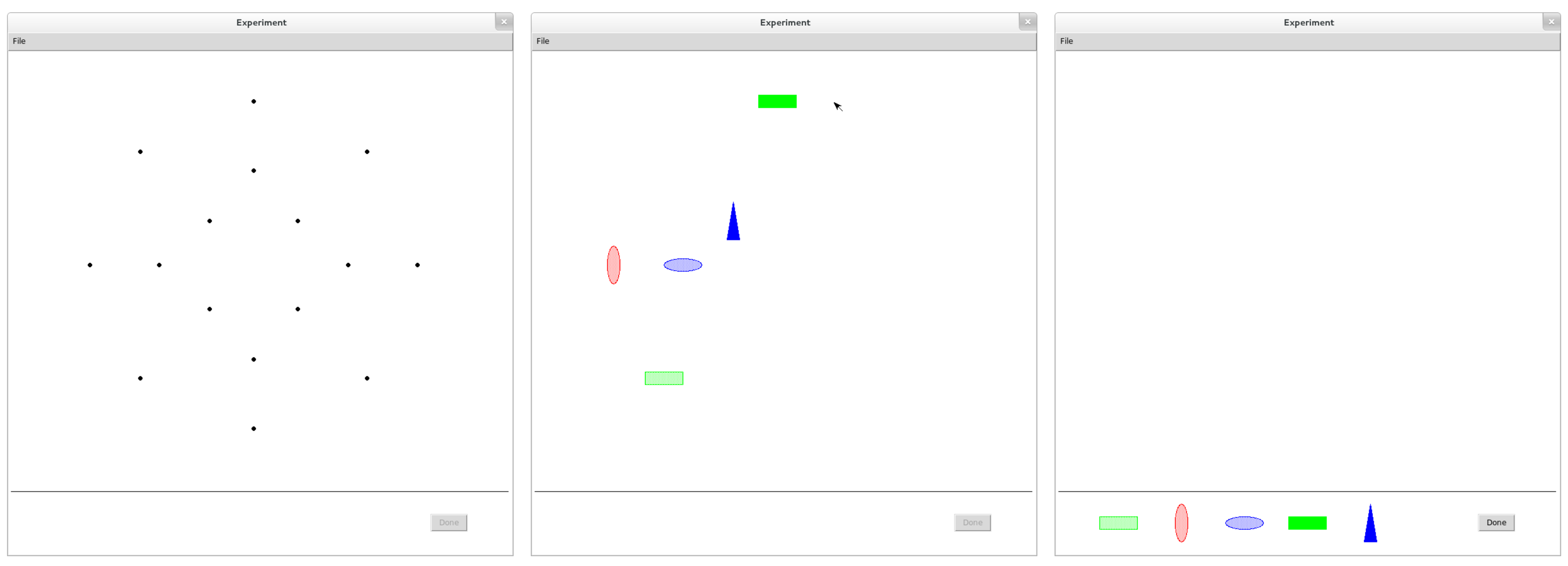
Object location memory

The ability to remember the locations of objects is a fundamental and crucial cognitive function that underlies all of our daily activities. In the laboratory, object location memory is often investigated using the *toy test* (otherwise known as "Kim's game") in which participants are presented with a 2D array of objects for a period of time and then asked to reconstruct the array from memory [e.g., 10].

Aim of the study

The aim of this research is to develop a process model of location memory that will provide a detailed, parsimonious account of the various factors affecting human performance in the toy test using established and tested memory mechanisms. In particular, the model should be able to account for the effects of *set size* [8], the relative similarity [3] or salience [4] of the objects. We also wanted to investigate whether relocation accuracy is also affected by selection order (i.e., earlier items being relocated more accurately than later ones), due to either time-based memory decay [2] or strategic factors. The model is developed using the ACT-R cognitive architecture [1],

Experiment



(a) Object locations **(b)** Encoding phase **(c)** Recall phase

Figure 1: The sixteen object locations and two phases of the experiment.

The experiment is a modification of Postma's computer-based version of the toy test [5, 8, 9]. Stimuli were 36 2D objects that differed on four features: *shape* (circle, rectangle or triangle), *colour* (red, blue or green), *size* (tall or short), and *pattern* (solid or stippled).

Objects were presented at 16 points in a 800×700 pixel *display* area. Below the display area was a 800×100 pixel *holding* area containing a button labelled 'Done'.

- **Repeated measures design:**
  IV_1: *Set size* (2, 3, 4 or 5 objects)
  IV_2: *Time delay* between encoding and recall phases (500, 1000 or 1500 ms).
  DV: *Relocation accuracy* (straight line distance between original location and relocated position).
- **Participants:**
  150 undergraduate cognitive psychology students from the University of Huddersfield.
- **Procedure:**
  Encoding phase:
  1. Fixation cross for 500 ms at display centre
  2. Between 2 and 5 stimuli displayed at random locations (Figure 1b).
  3. Participant clicks on each object with the mouse.
  4. When all stimuli clicked on, *Done* button becomes active, stimuli disappear from display area and (after delay) reappeared in the holding area (Figure 1c)

  Recall phase:
  1. Participant selects each stimulus and drags it to its original location.
  2. When all stimuli relocated, click on *Done* button, to start next trial.

Results

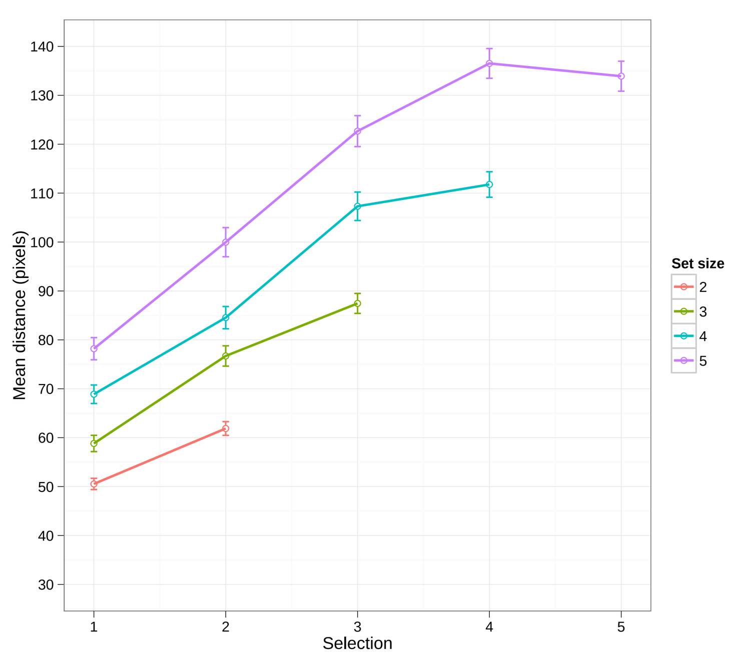


Figure 2: Mean distance (in pixels) between an object's original location and its relocation position as a function of selection order and set size. Error bars indicate standard error.

- A linear mixed effects (LME) analysis of the relationship between the mean relocation distance (log transformed) and the factors set size, selection order, and delay was carried out.
- The final model contained significant fixed effects of set size, and selection order. These factors significantly predicted the mean distance of the placed object from its original position.
- Mean distance increased as set size and selection order increased.
- There was a significant interaction between set size and selection order, but only for the 4th and 5th selections of the set sizes 4 and 5.
- Object location memory in the toy test is significantly affected by both the number of display objects and the order in which they are selected for relocation but not by the time delay between encoding and recall phases.

ACT-R, blending, and object location memory

When ACT-R 'sees' an object, its features are encoded as a chunk in memory. In addition, the location of the object is also encoded in memory as a separate chunk. When chunks are created, they have an initial level of activation which decays over time and which determines the probability that they can be subsequently retrieved for future processing.

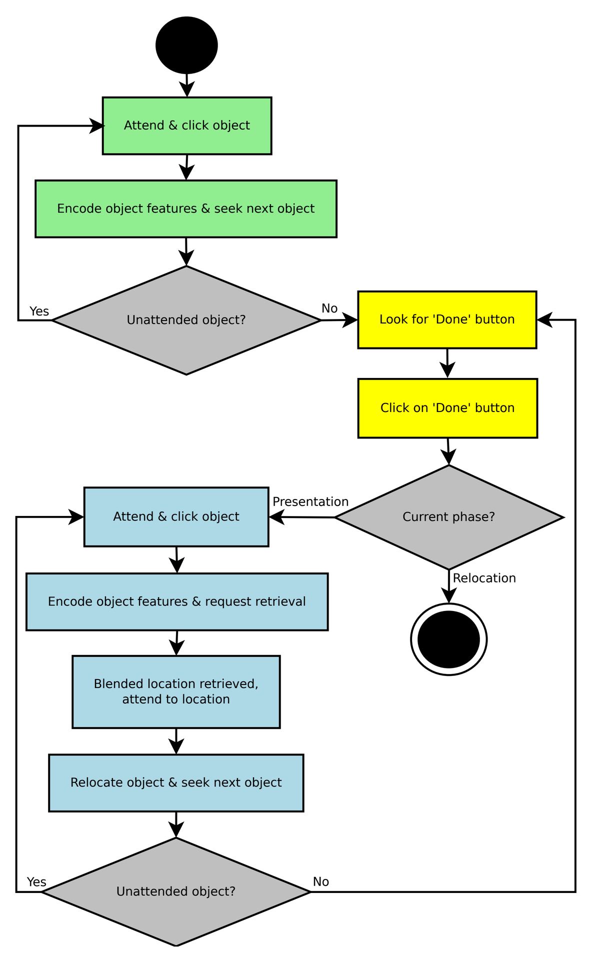


Figure 3: Control structure of the ACT-R toy test model.

Memory retrieval occurs when a production rule contains a retrieval request to the declarative memory module containing one or more cues. For example, if a production contains the features of a visual object (e.g., "tall", "green", "stippled", "rectangle") then it may probe declarative memory for a visual-location chunk using these features to retrieve a previously stored location for this object.

ACT-R's *blending* mechanism was devised to achieve capture flexible human behaviour that produces novel or continuous responses (e.g., similarity judgements or magnitude estimates) or where responses are required to reflect the entire state of a person's knowledge rather than just an individual fact. Blending combines information from several knowledge chunks during retrievals [6, 7].

In the situation where an object's location is being retrieved from its features, if blending is employed, then the x and y coordinates retrieved will be a combination derived from the location chunks of all the visual objects of the same type, with the influence of each chunk determined by its similarity to the probe, weighted by its probability of retrieval.

An ACT-R model of the toy test

An ACT-R model was constructed that was able to interact with the same experiment software as the human participants. The control structure of the model is shown in Figure 3. Like the task itself, the model is relatively simple in terms of the number of actions required and consists of only eight production rules: two to find and attend to the stimuli in the encoding phase, two to find and click on the *Done* button, and four to find, attend to, retrieve the location of, and relocate the objects in the recall phase.

The model was run 500 times and relocation accuracy compared to the human data, resulting in a reasonably close fit ($R^2 = .89$, $RMSD = 9.22$). When fitting the model to the human data, ACT-R's parameters were adjusted within conventional limits. Specifically, base-level learning was set to 0.5, activation noise was 0.2, optimised learning was 1, the blending temperature parameter was 1.9, the partial matching parameter was 1.7, and the retrieval threshold was -10.0.

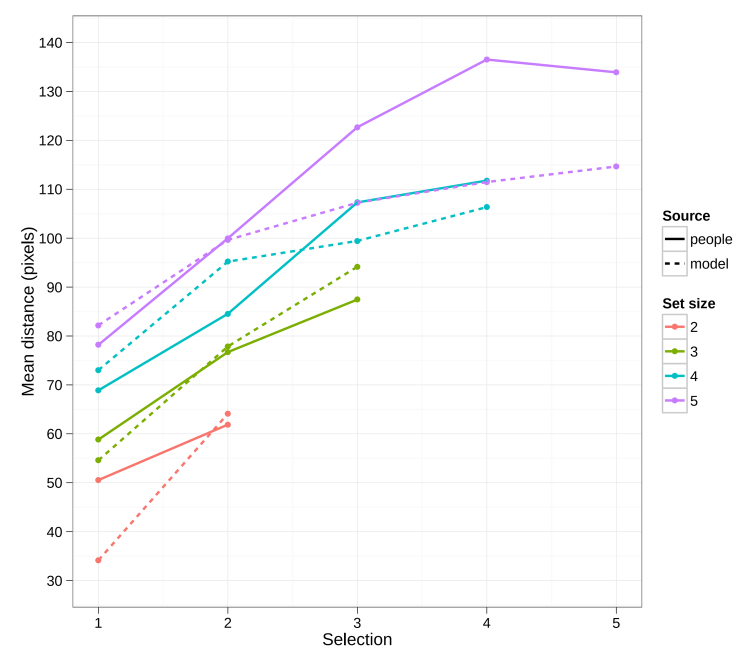


Figure 4: Mean relocation accuracy as a function of set size and selection order from experiment participants (solid lines) and the ACT-R model (broken lines).

The experiment provides strong evidence that the accuracy of object location memory is significantly affected not only by the number of objects in the set but also by the order in which the objects are selected for relocation.

The model provides a reasonably close fit to the human data and accounts for increases in relocation error with increased set size due to ACT-R's blending process; as set size increases, more object locations enter into the blending process, increasing the number of influences on the retrieved x and y coordinates. This occurs even for the first object selected.

The blending mechanism also accounts for the increase in relocation error with selection order. When each blended location is retrieved, the blended location chunk remains in declarative memory and is included in all subsequent blending requests. As a result, for each additional object in the selection order, the blended x and y coordinates are comprised of an additional (blended) location chunk, thereby increasing the error.

References

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