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Modelling immediate serial spatial recall in a macaque (*Macaca mulatta*): A competitive queuing approach

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Comparative Cognition of Serial Order

- In the field of comparative cognition, there has been much interest in the serial ordering capabilities of human and nonhuman primates
- In humans, the ability to store and retrieve novel sequences of items and events is critical for many acts of cognition
  - vocabulary acquisition (Baddeley et al., 1998)
  - learning and production of action sequences (Agam et al., 2005)
- Given its centrality to human higher-level cognition, an obvious question is how the sequence processing abilities of nonhuman primates compares

Sequence Processing In Primates

- Studies of several primate species—chimpanzees, capuchin, and rhesus monkeys—have revealed that they are capable of remembering and recalling fixed sequences of:
  - motor actions (Custance et al., 1999; Whitten, 1998)
  - visual images (Schwartz et al., 1991; 2000)
  - spatial locations (Hikosaka et al., 1999)
- Like humans, they appear to represent sequences by learning each items' ordinal position (Chen et al., 1997; D'Amato Colombo, 1988, 1989; Orlov et al., 2000)
- Non-primate species (viz. Pigeons, Rats) show no such capacity to develop ordered representations of sequences

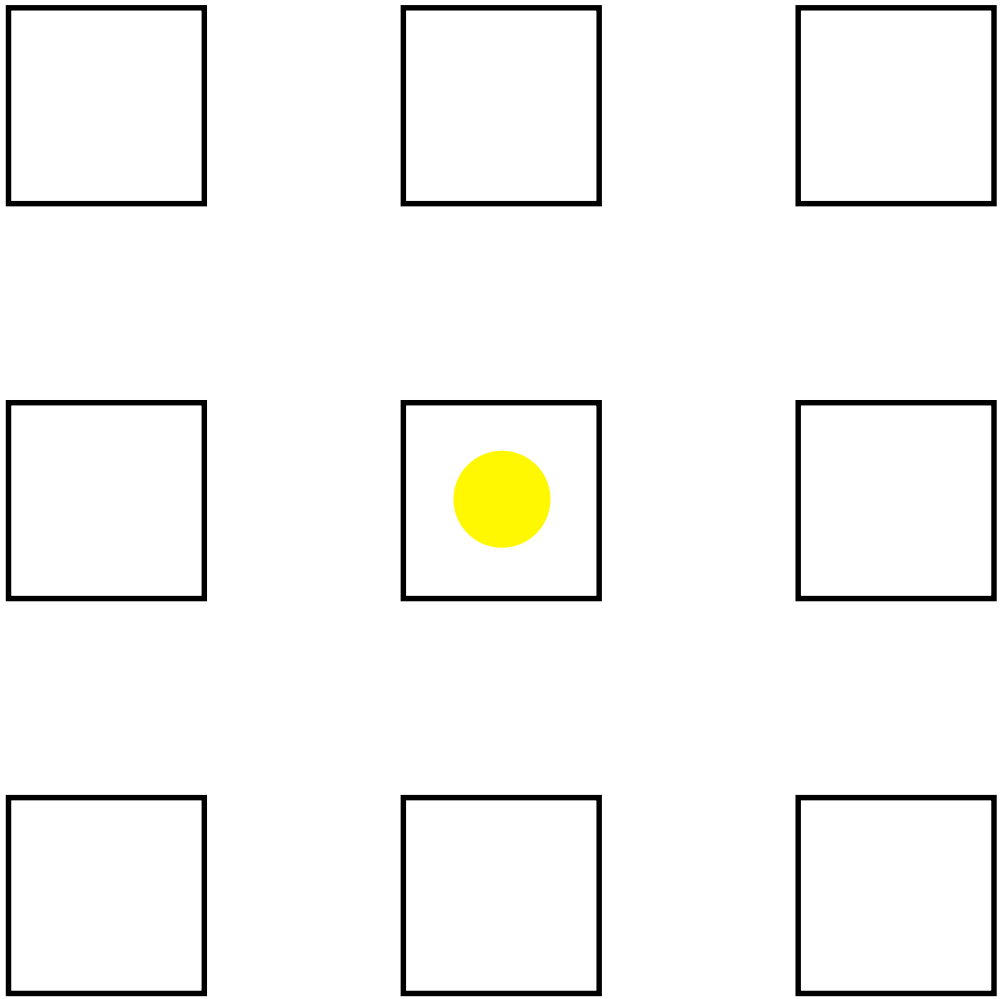
An Empirical Gap

- Despite these similarities between humans and primates, an important gap exists
- In humans, memory for serial order is examined using the *Immediate Serial Recall (ISR) task*
  - requires one shot learning
  - recall of the entire sequence
- Primate studies use paradigms in which subjects are exposed to repeated presentations of the same sequence and only a sub-set of the sequence must be reproduced
- *A recent study by Botvinick et al. (2009) has filled the gap*

Botvinick et al. (2009)

- Examined the ISR capabilities of a 6-year old rhesus monkey *Macaca mulatta* named Jelly
- Employed a spatial ISR task similar in design to spatial ISR tasks used with Humans
- The task involved a fixed set of eight locations organised in a grid
- Lists containing 3- or 4-items were constructed using random sub-sets of the locations

Serial Spatial Recall Task



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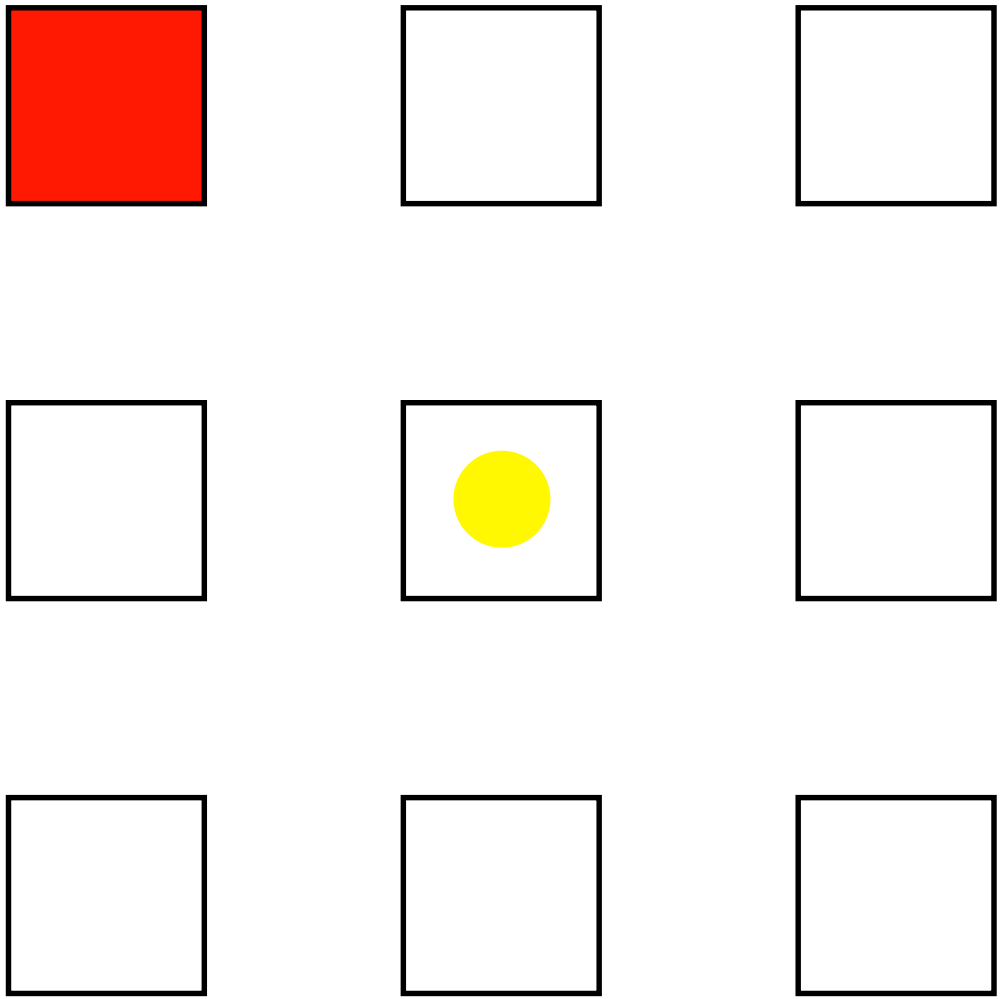

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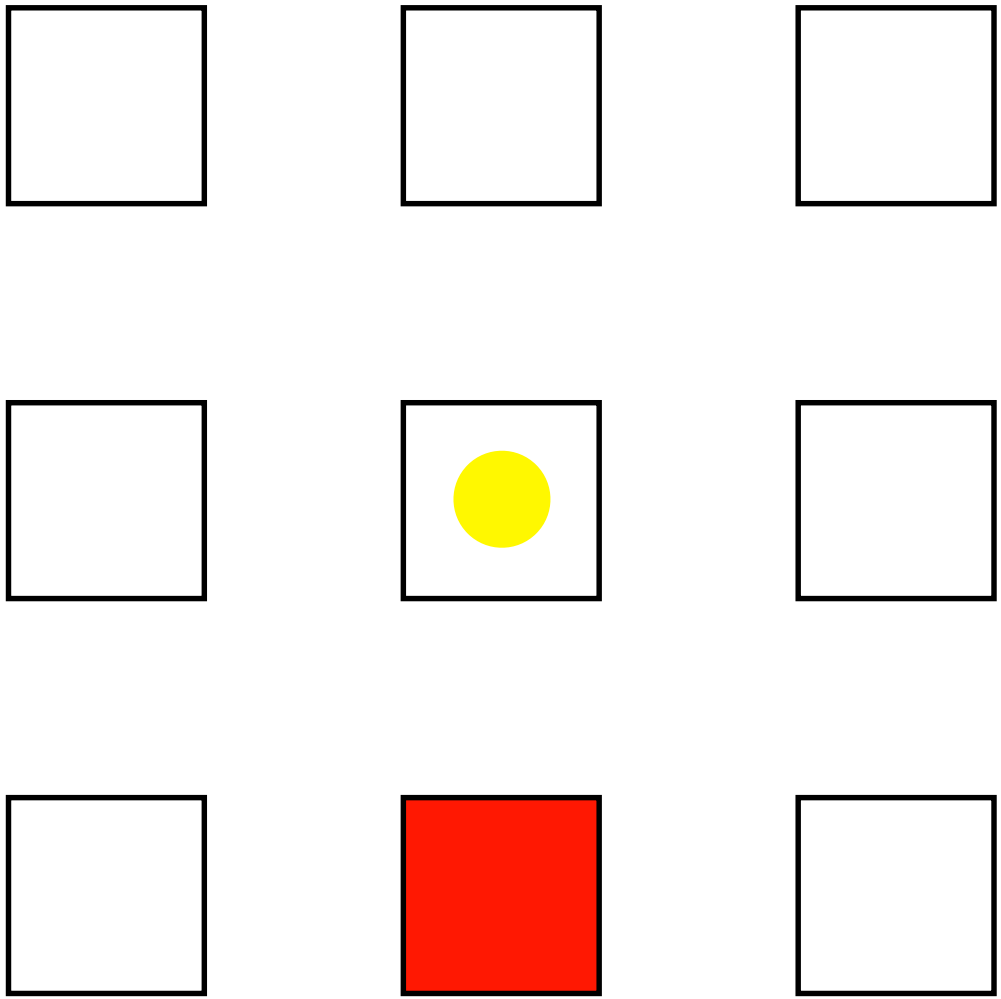

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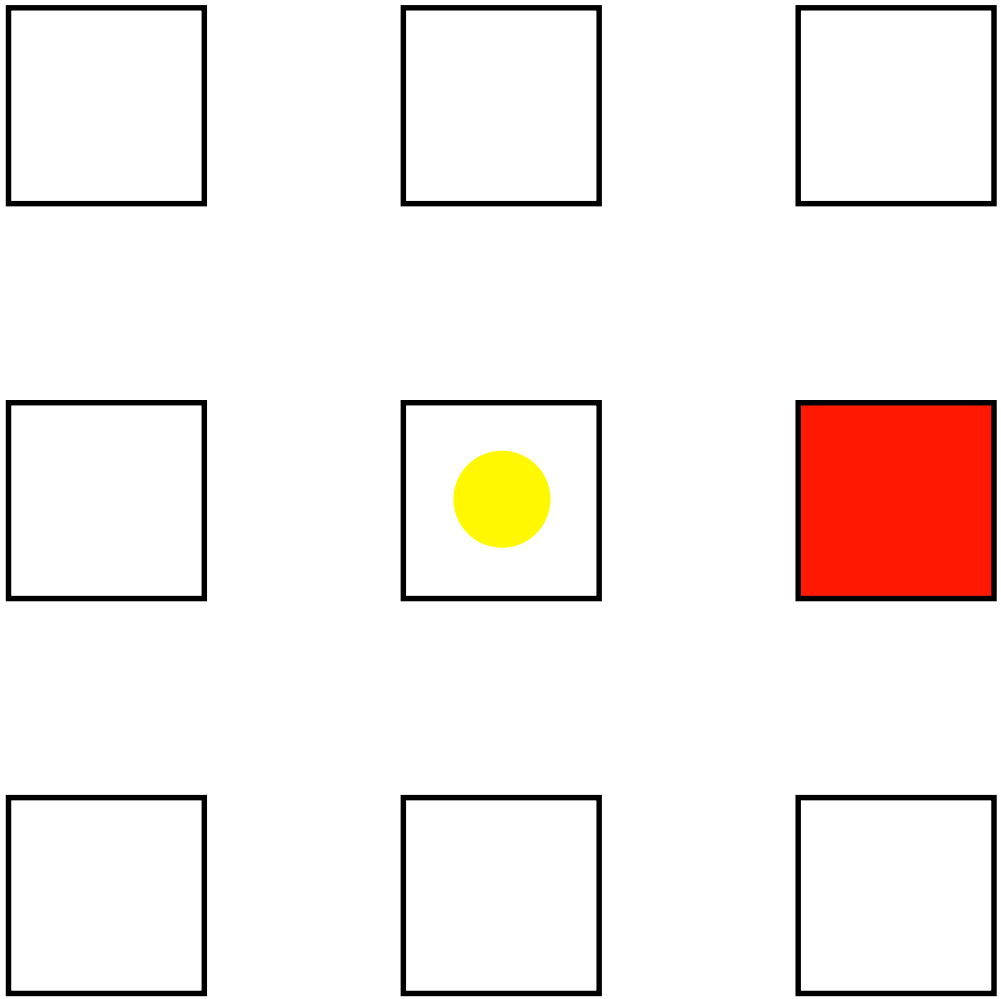

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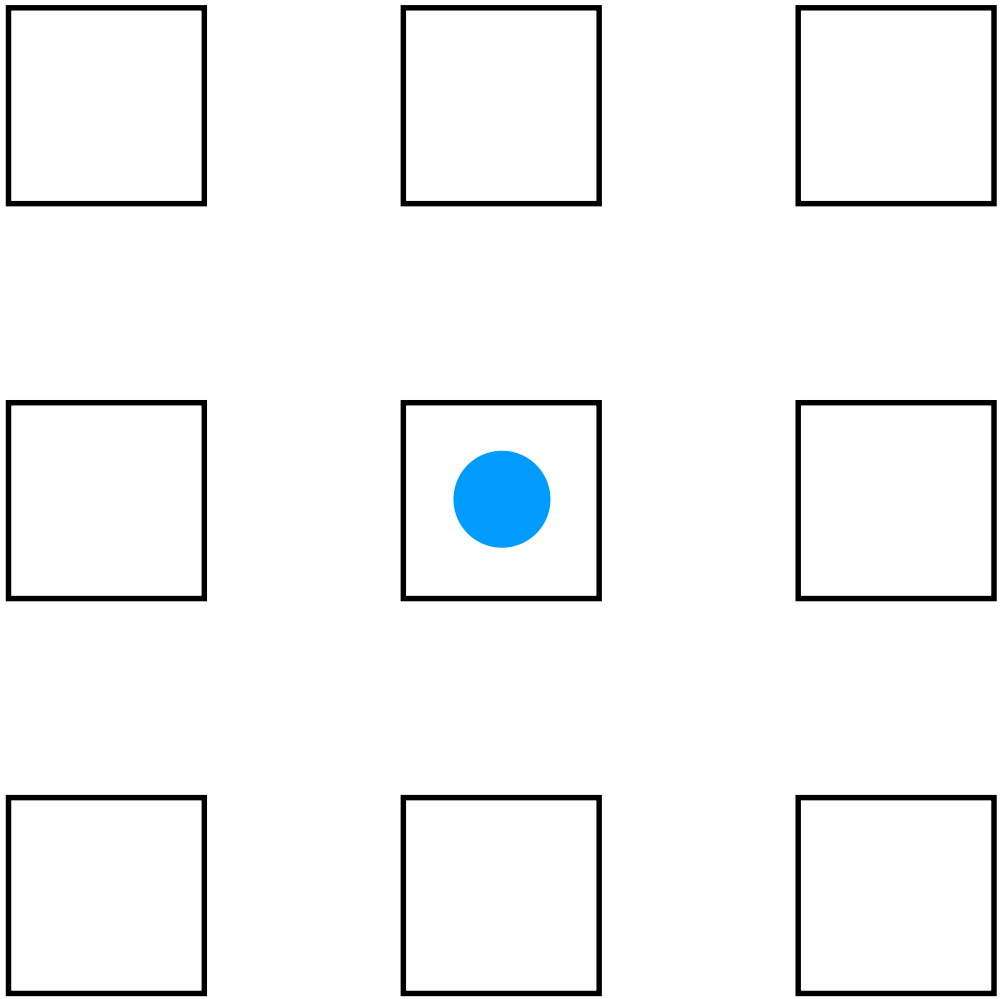

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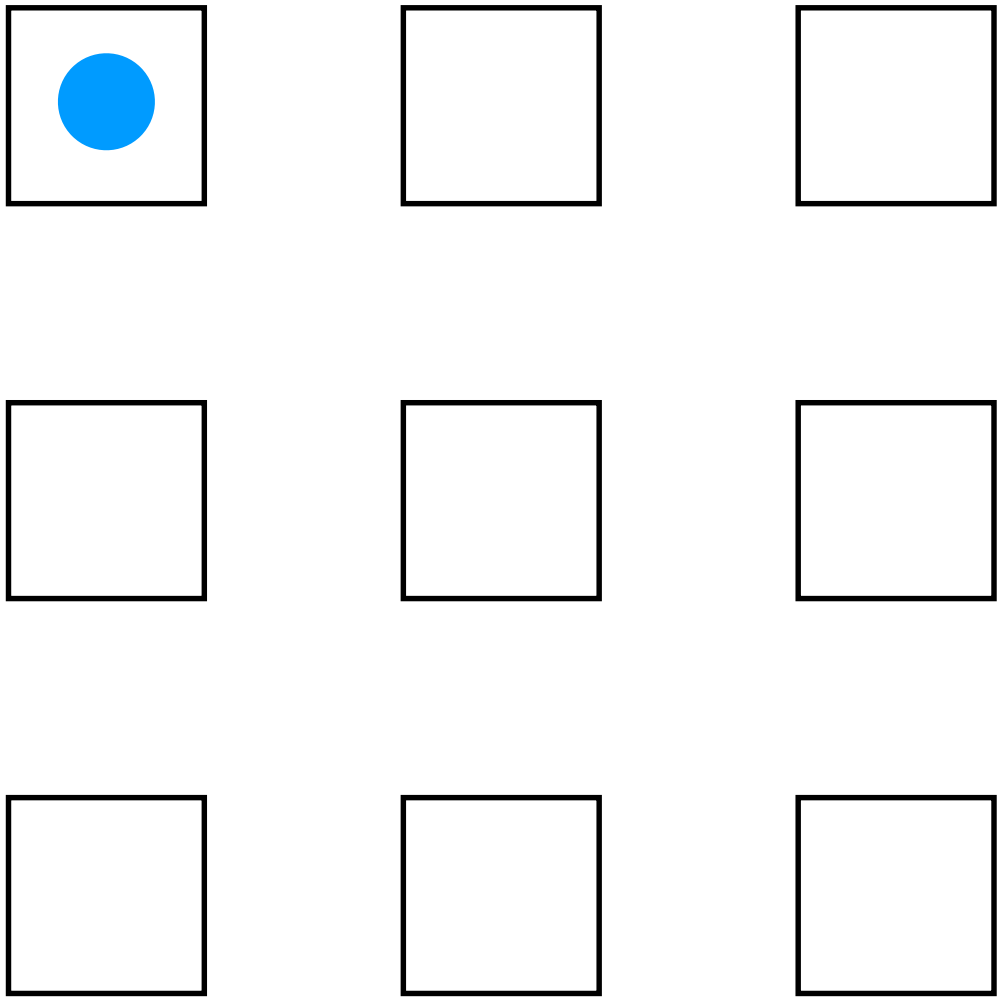

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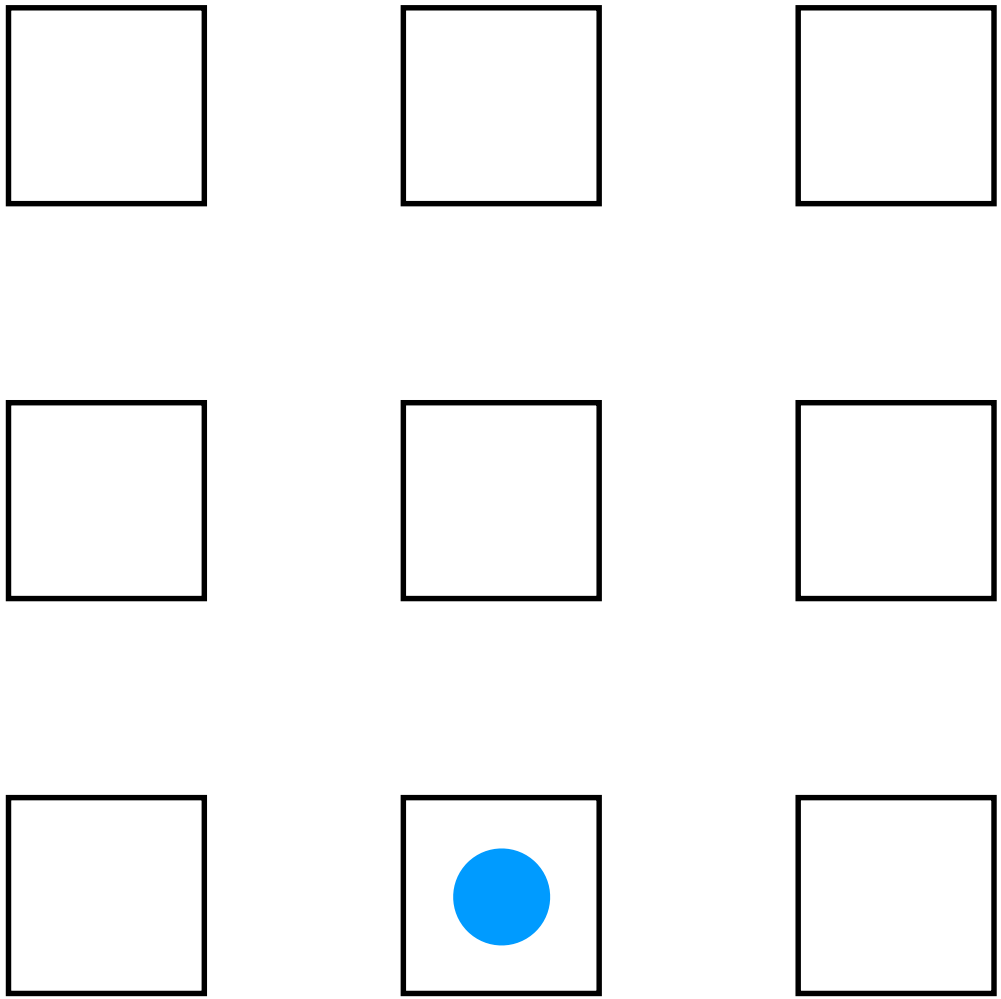

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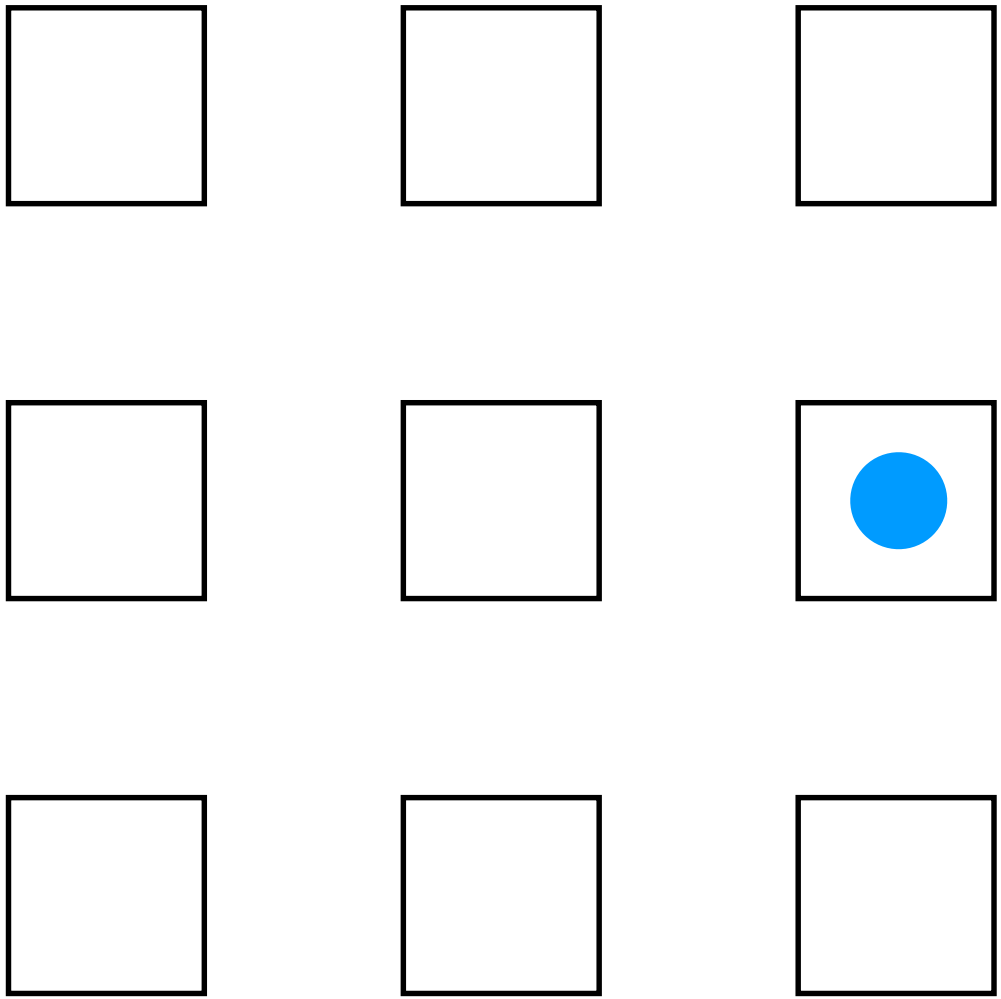

Seven Benchmark Effects of Human ISR Shown By Jelly

- List Length Effect
- Primacy Effect
- Repetition Effect
- Transposition Gradients
- Item Confusion Errors
- Fill-in
- Protrusions

Goal:

- Reproduce Jelly's data using a model based on seriating mechanisms and principles from human ISR

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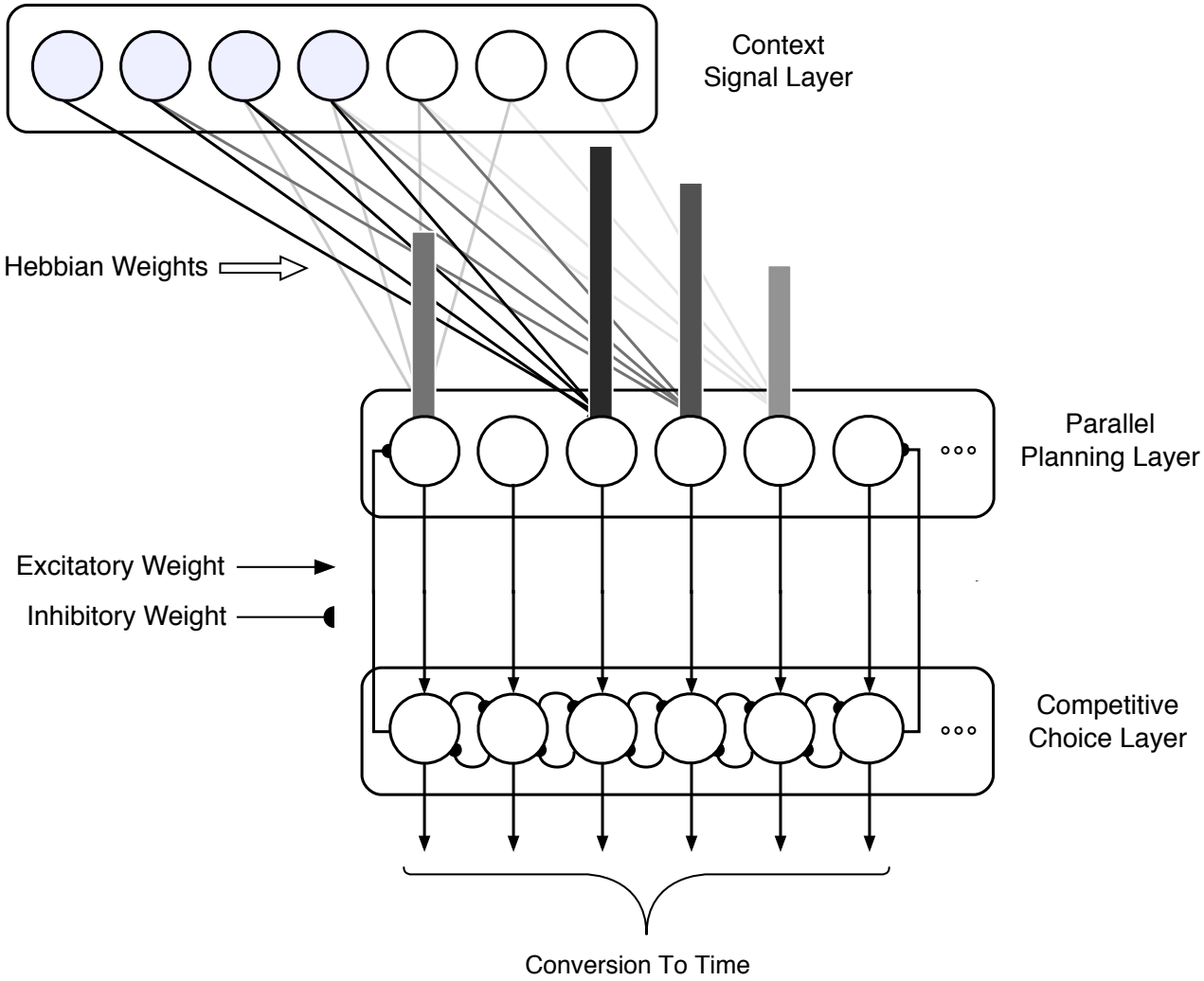
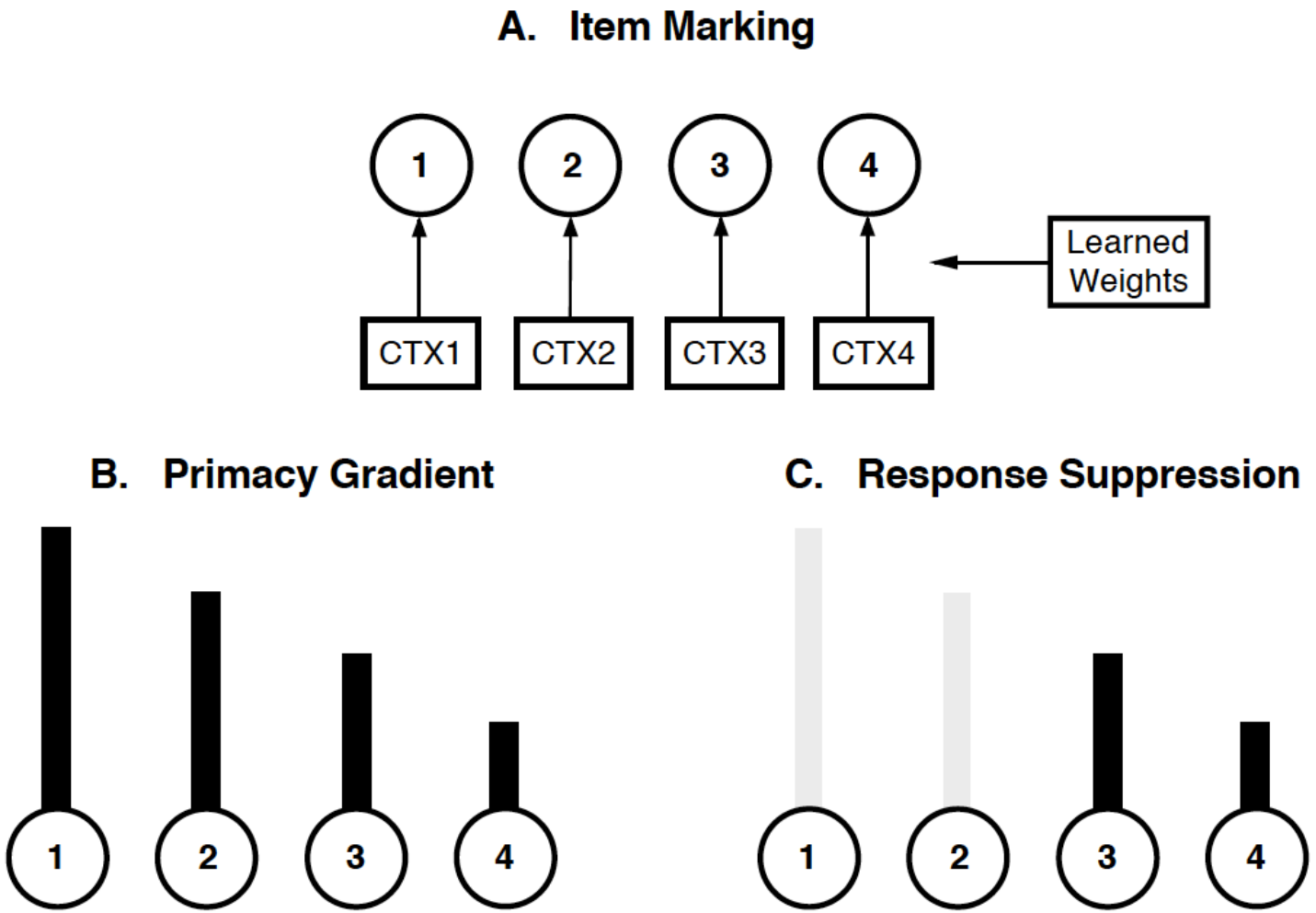
A Competitive Queuing Approach

- The architecture of the model is based on Competitive Queuing (CQ) models of serial behaviour (e.g., Grossberg, 1978; Houghton, 1990)
- Such models possess three core features:
  - fundamentally localist (refractory) representations of items
  - parallel response activation and activation gradient
  - a competitive output mechanism
- Electrophysiological recording data obtained with rhesus monkeys provide strikingly direct support for this sequence control mechanism (e.g., Averbeck et al., 2002; Averbeck et al., 2003a, 2003b)

Competitive Queuing Model



Seriating Mechanisms



Simulation Results

- Accuracy & Repetitions
- Transposition Error Gradient
- Item Confusion Errors
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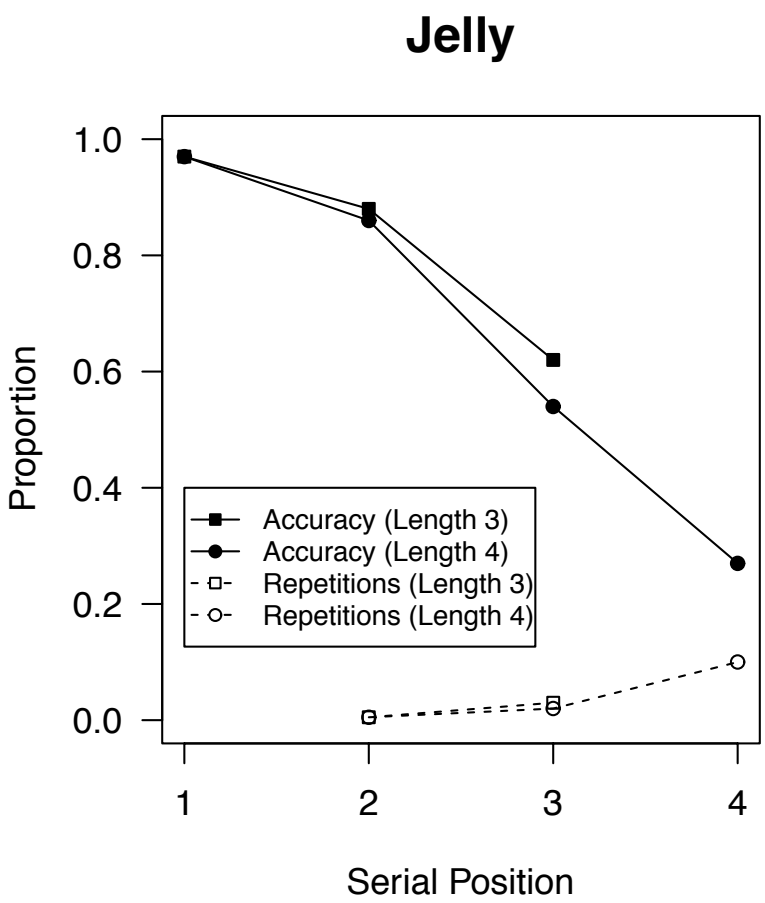
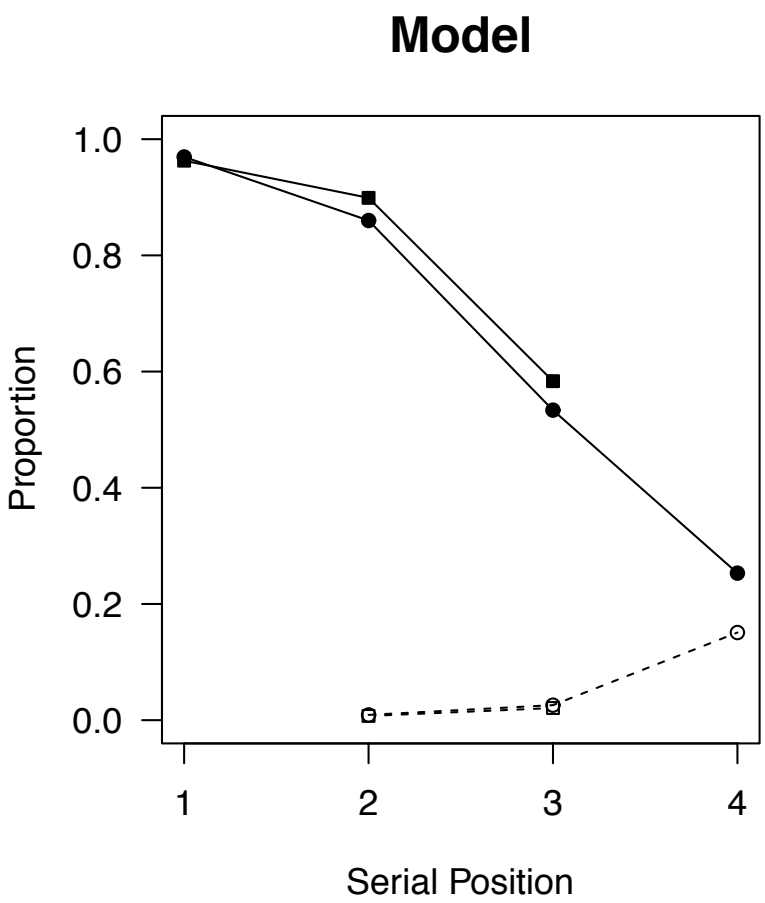
List Length, Accuracy, and Repetition Errors





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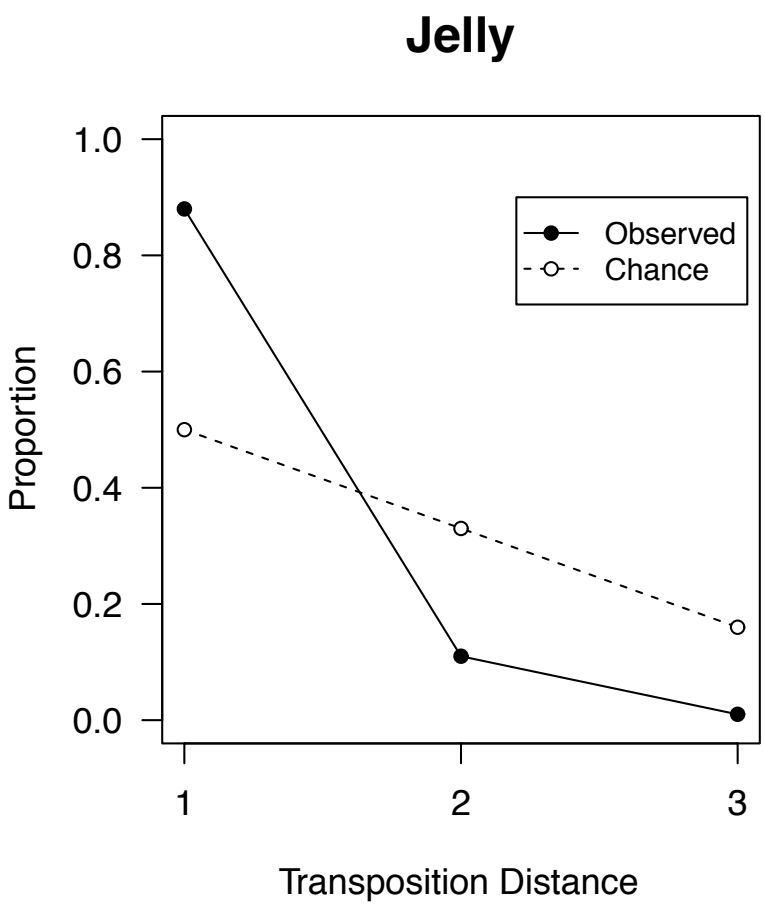

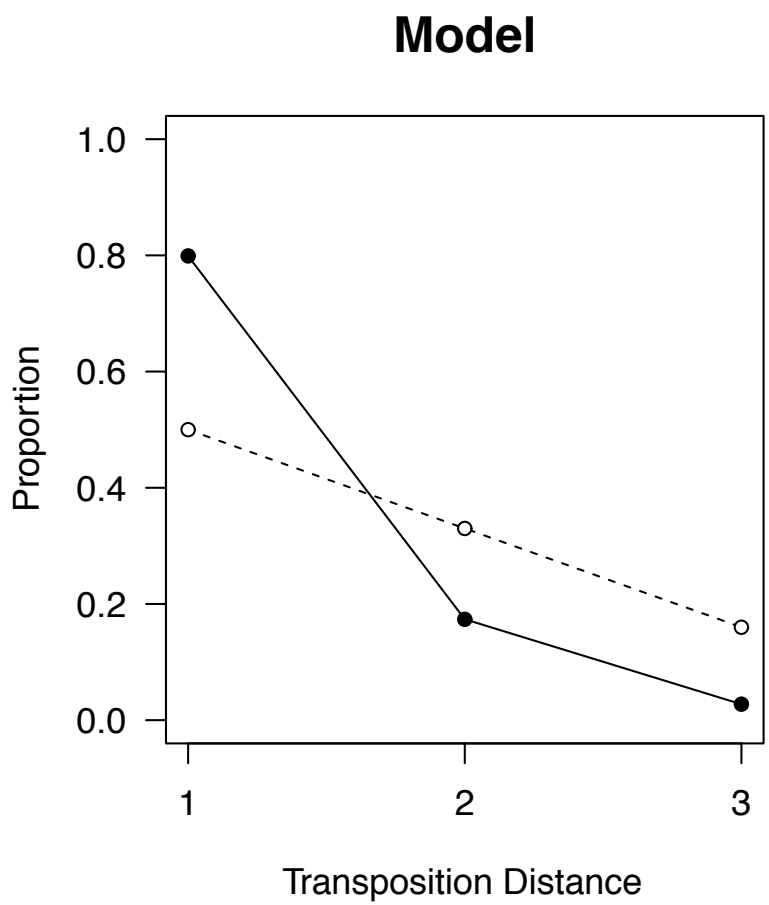

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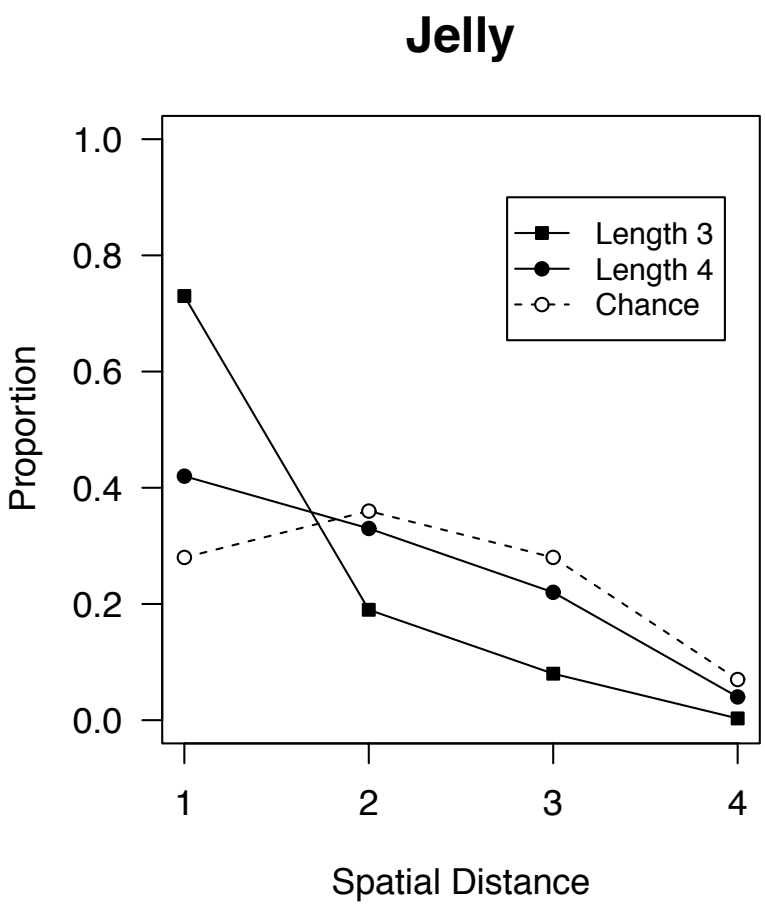
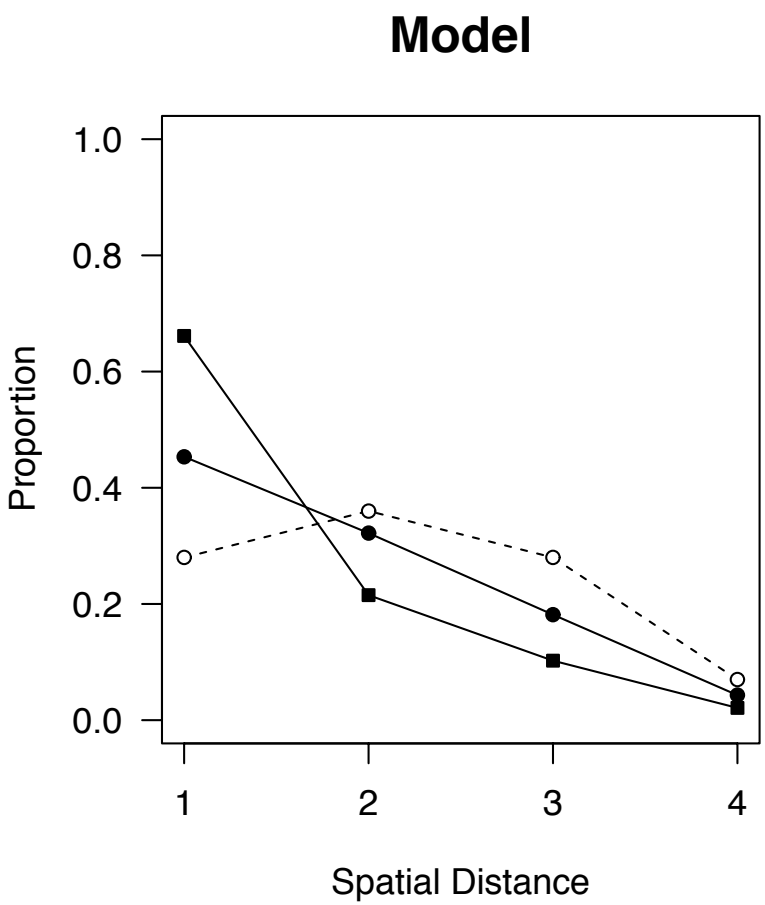
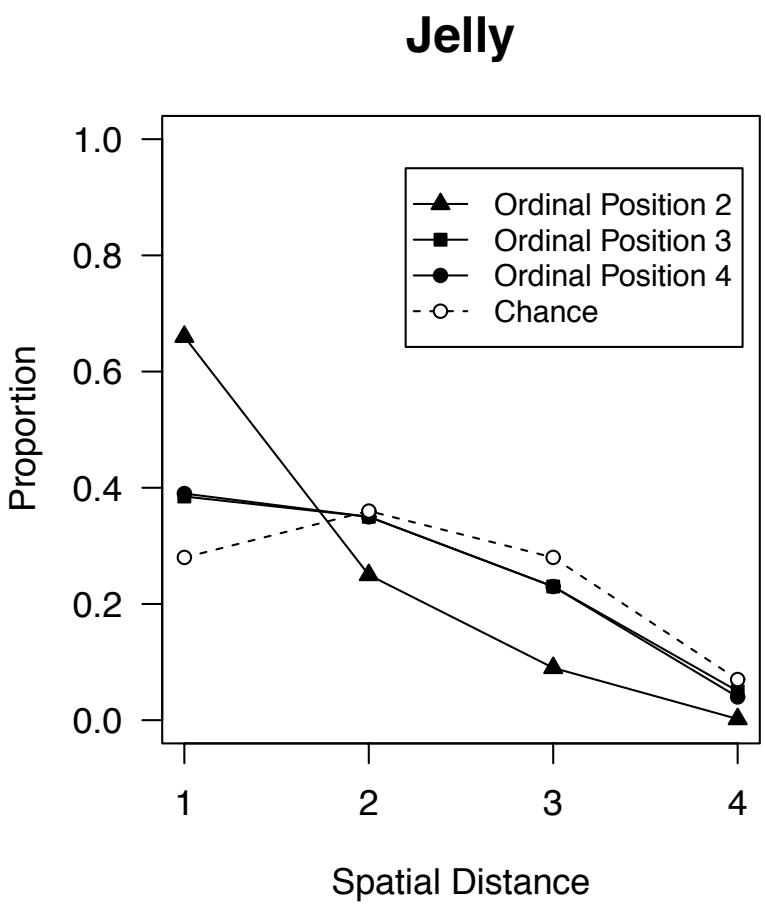
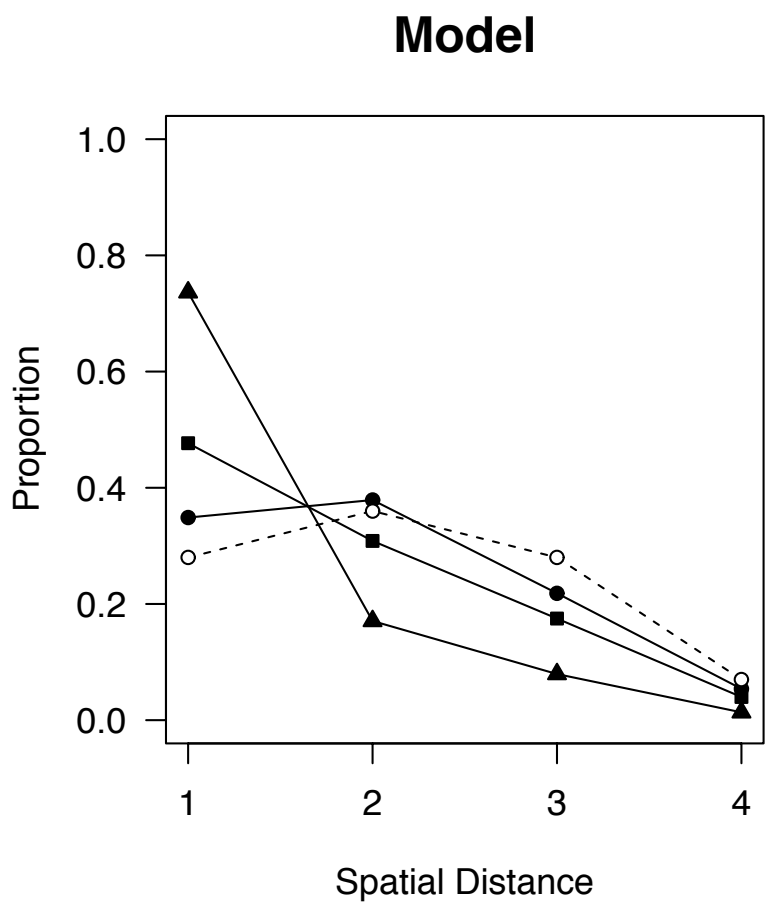




Item Confusion Errors By Ordinal Position





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Protrusion Errors

- In human ISR, when an item intrudes from the immediately preceding trial it will tend to maintain the same ordinal position that it held on that trial (Conrad, 1960; Henson, 1996)
- Such position-preserving intrusions are known as protrusions (Henson, 1996)
- Like humans, Jelly produced protrusions—33% of his intrusions preserved their position from the previous trial
- The percentage of intrusions that were protrusions in the CQ model was 31%

Fill-in Errors

- In human ISR, when people recall an item a position too soon, they tend to follow-up by recalling the item that was displaced by the error (Henson, 1996; Page Norris, 1998; Surprenant et al., 2005)
- e.g., if recall of the list ABCDE begins with the production of B, the next response is most likely to be A (a fill-in error) rather than C (an infill error)
- Like humans, Jelly produced more fill-in than infill errors—the ratio of fill-in to infill was 4:1
- The corresponding ratio in the CQ model was 2:1

Conclusions

- Results suggest that core mechanisms and principles of human ISR may be appropriate for understanding sequence processing in some nonhuman primate species
- One limitation is that the data used to infer the structure of the model are based on observations of a single animal
- It will be important to apply the model to other animals of the same species, as well as animals from different species
- Fagot and De Lillo (2012) have recently directly compared the spatial ISR performance of two baboons (*Papio papio*) with humans, and these data are a priority for future modelling efforts