Proposing a lazy generalised model of visual working memory to promote theory building

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Australian Mathematical Psychology Conference 2025

Two questions in this talk

How do we promote better theory building in psychology?

By showing a model best fits one instance of a specific phenomena?

Or with a lazy model that directs attention to interesting mechanisms and parameters?

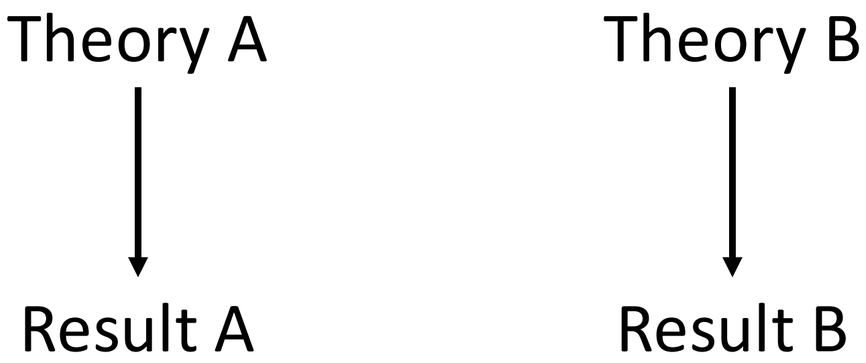
How do we model visual working memory in a way that respects its complexity?

Are we addressing the wide variety of phenomena and mechanisms of the system in the model?

The part where Philip Smith convinces me that the sample-size model is everything.

Playing 20 questions with nature

It is often assumed that:



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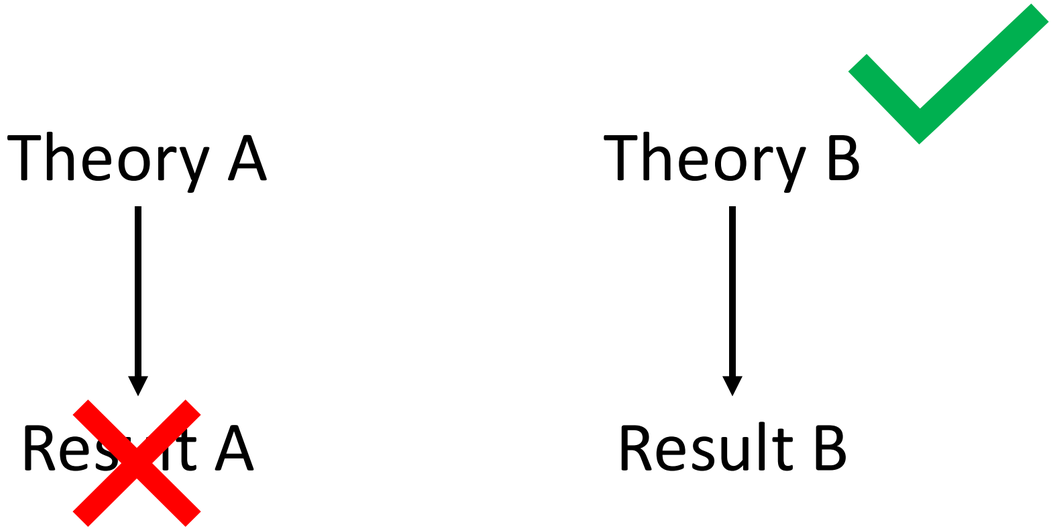

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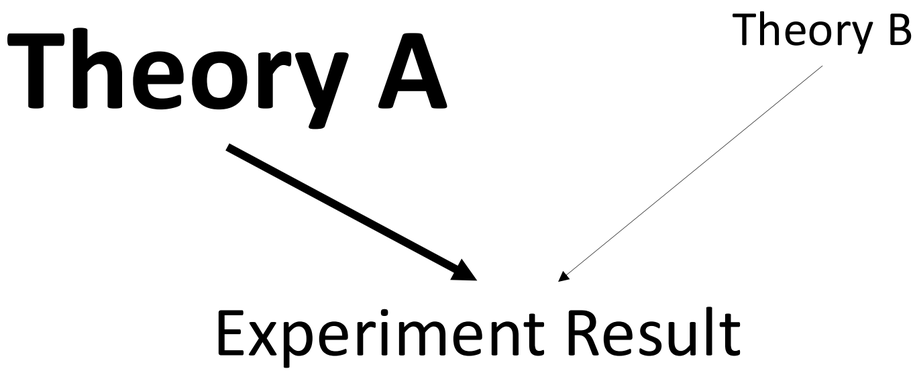
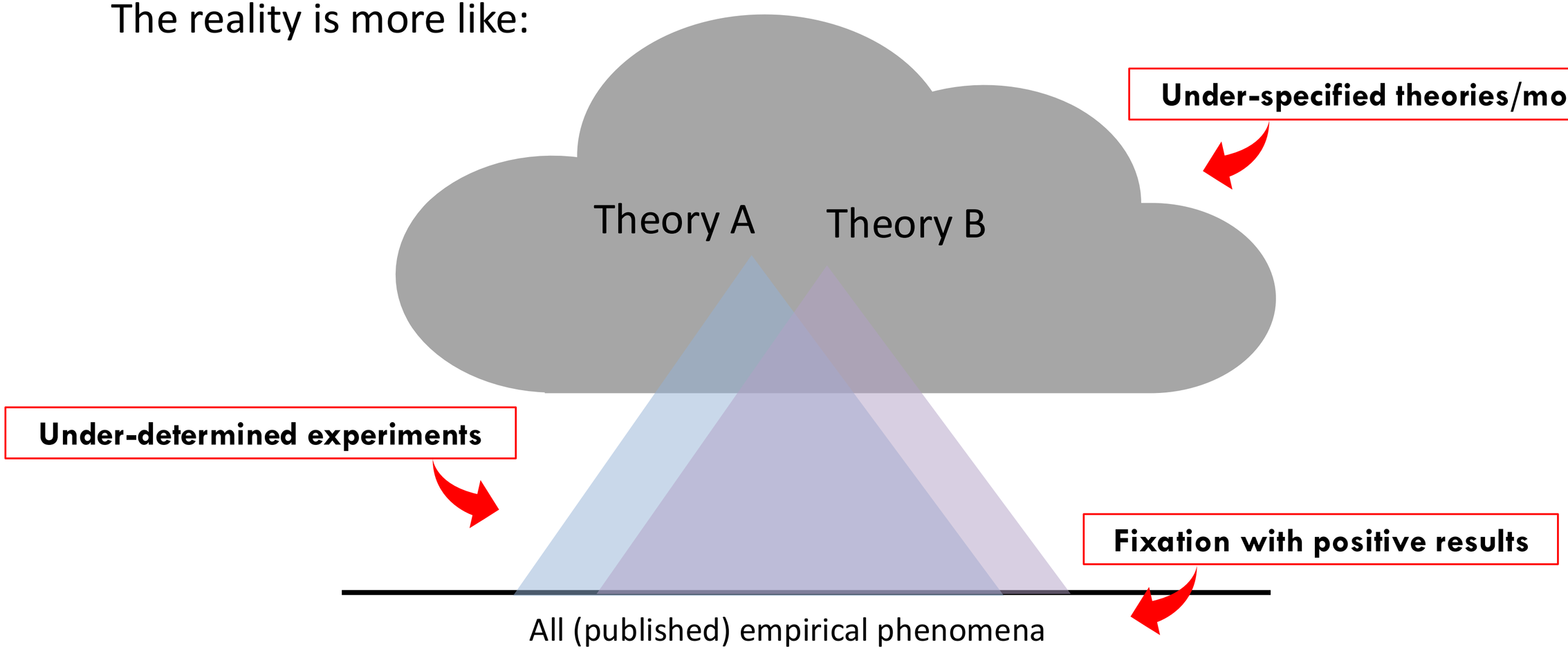


Newell, A. (1973). You can't play 20 questions with nature and win: Projective comments on the papers of this symposium.

Playing 20 questions with nature

The reality is more like:



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A “theory crisis” in psychological science

Under-specified theories
Ad-hoc changes to models

Under-determined experiments
Blunt instruments

Straw-man of competing models
Models as toothbrushes

Overgeneralisation of models
A lack of intellectual humility…

What is visual working memory?

Object-based theory
"slot models"

Luck and Vogel (1997);
Zhang and Luck (2008)

Feature-based theory
"resource models"

Alvarez and Cavanagh (2004);
Wilken and Ma (2004)

What is visual working memory?

Object-based theory
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Feature-based theory
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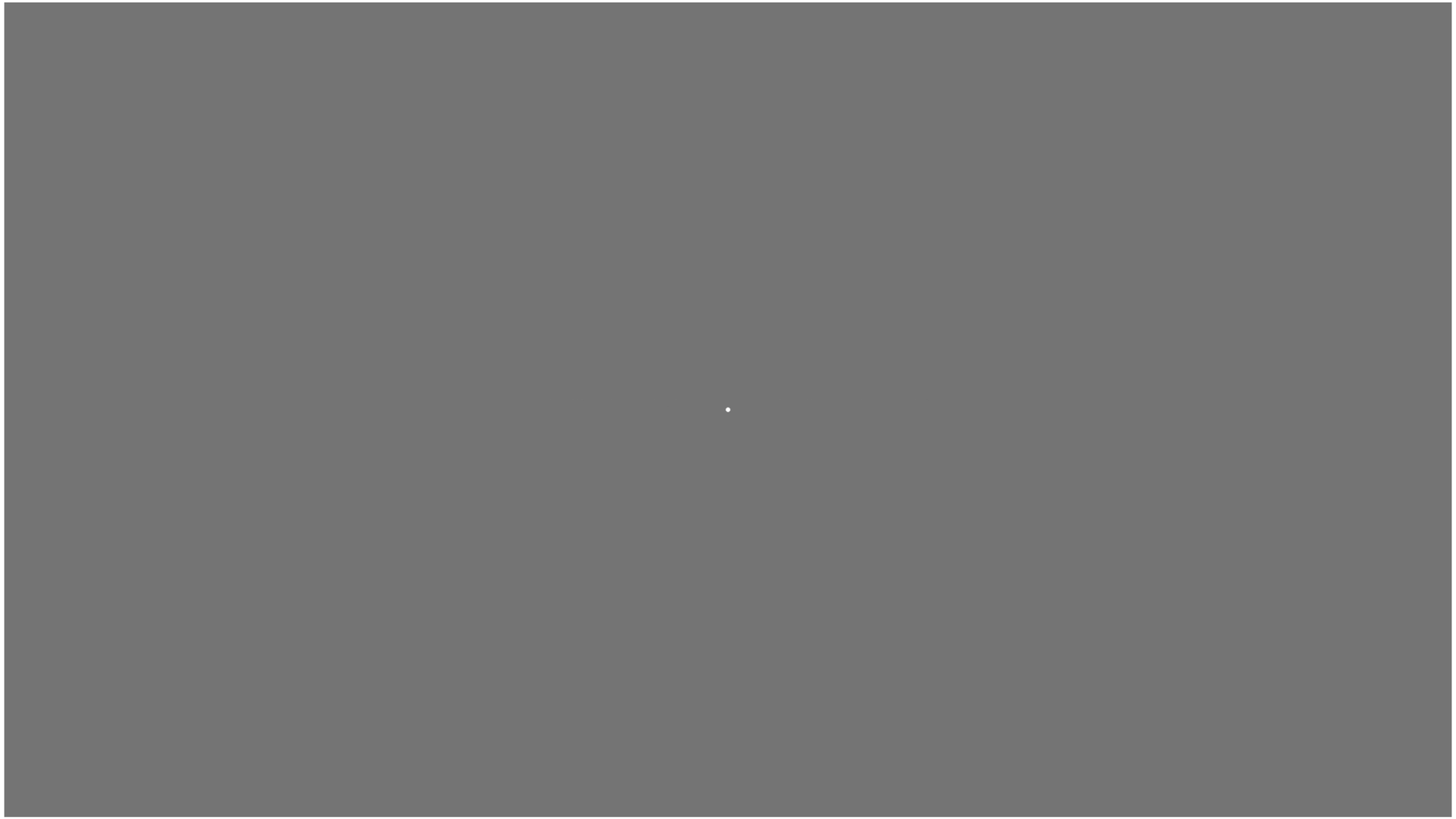
versus

A false dichotomy coupled with straw-manning leads to weak experimentation and one-sided model comparisons

Conjunction whole-report task



Ngiam, W. X. Q., Loetscher, K. B., & Awh, E. (2024). Object-based encoding constrains storage in visual working memory. *Journal of Experimental Psychology: General*, *153*(1), 86.

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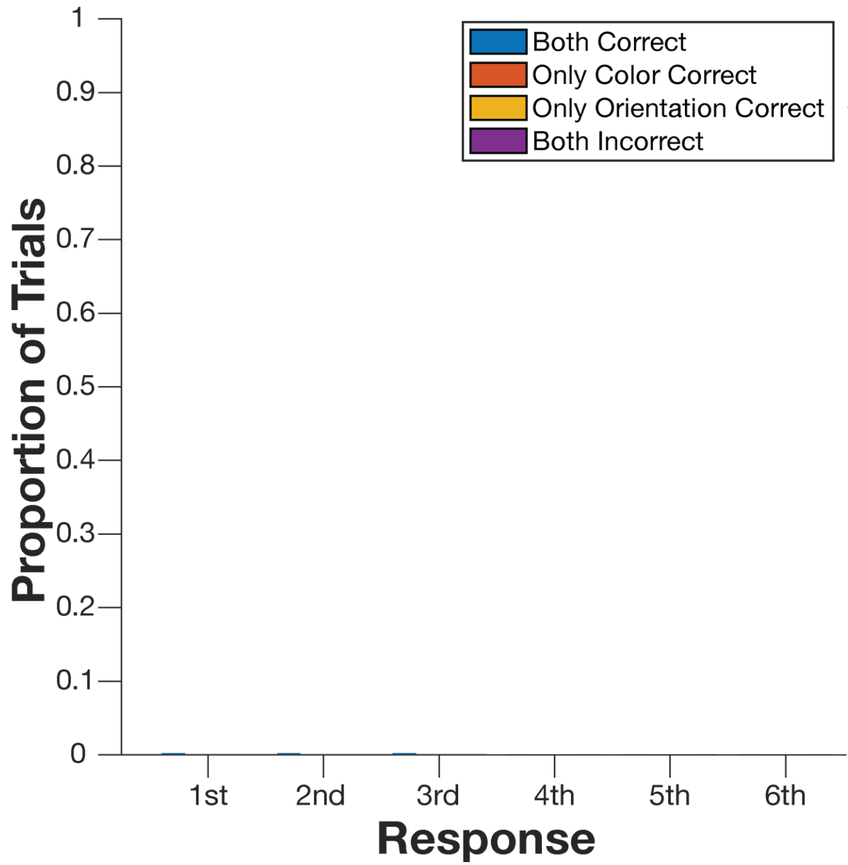
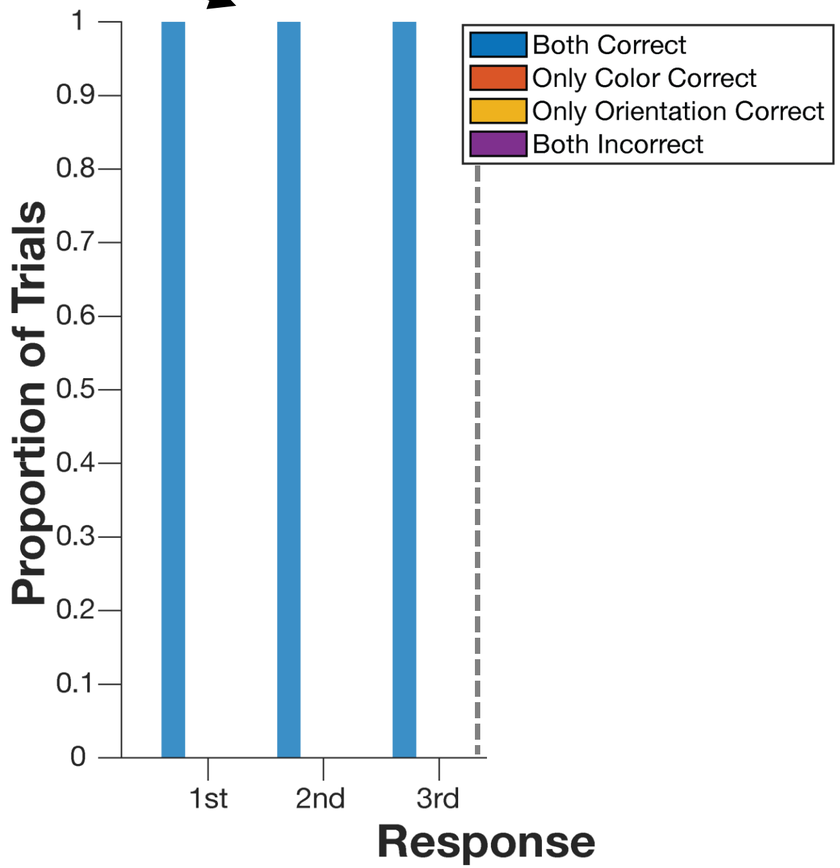


Possible types of recall

Ordered by responses

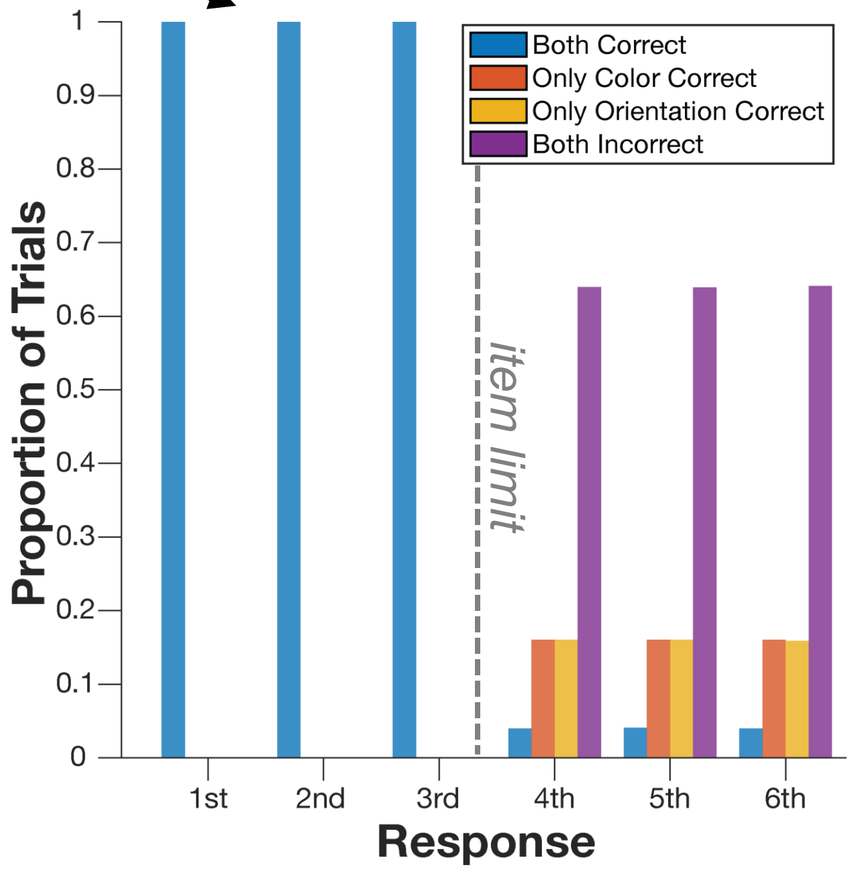
A strong object model

Perfect recall within item limit (*Kmax*)



A strong object model

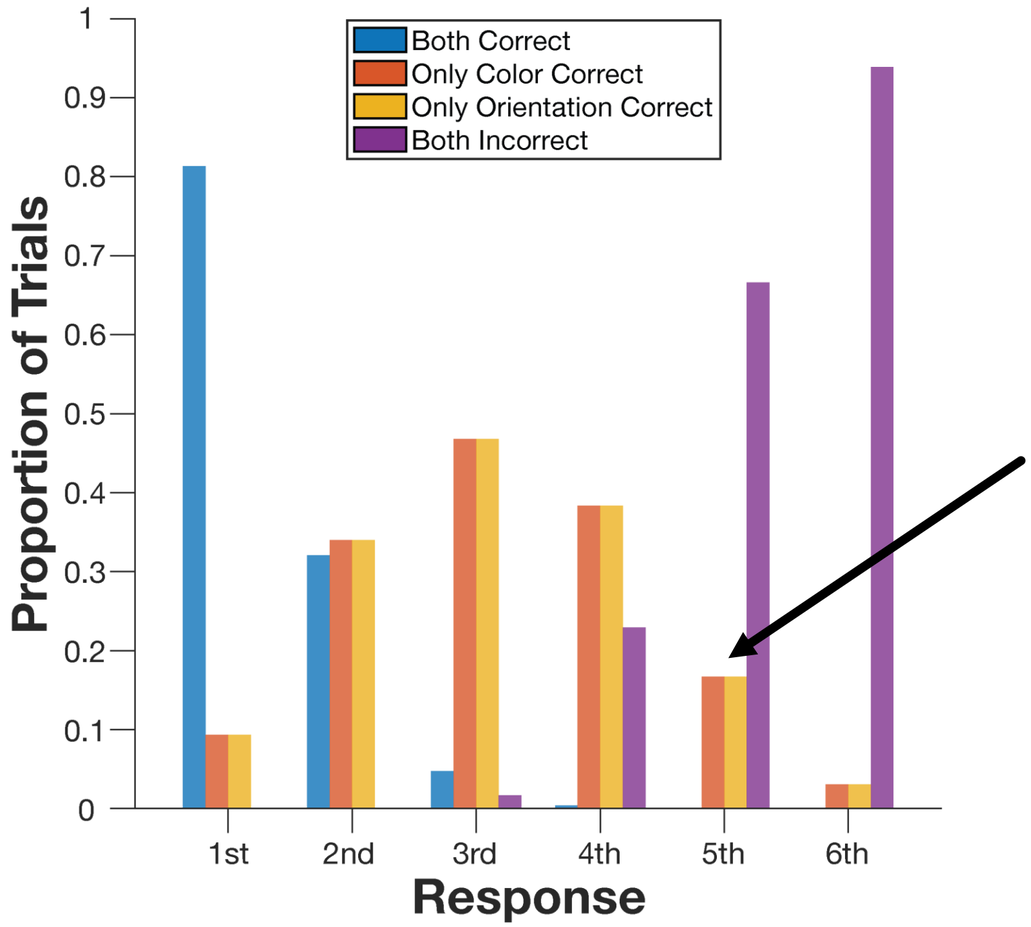
Perfect recall within item limit (Kmax)



Guessing for remaining responses

A feature-based resource model

Feature storage independent of objecthood



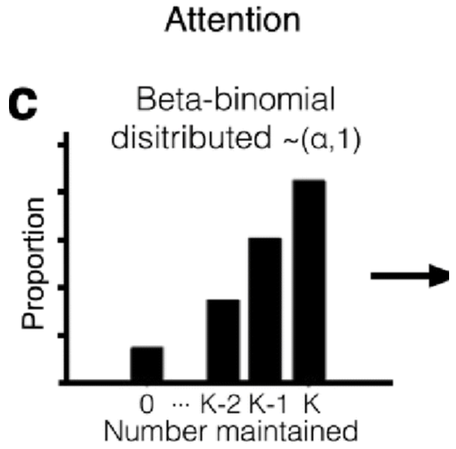
Accurate recall distributed across *all* responses

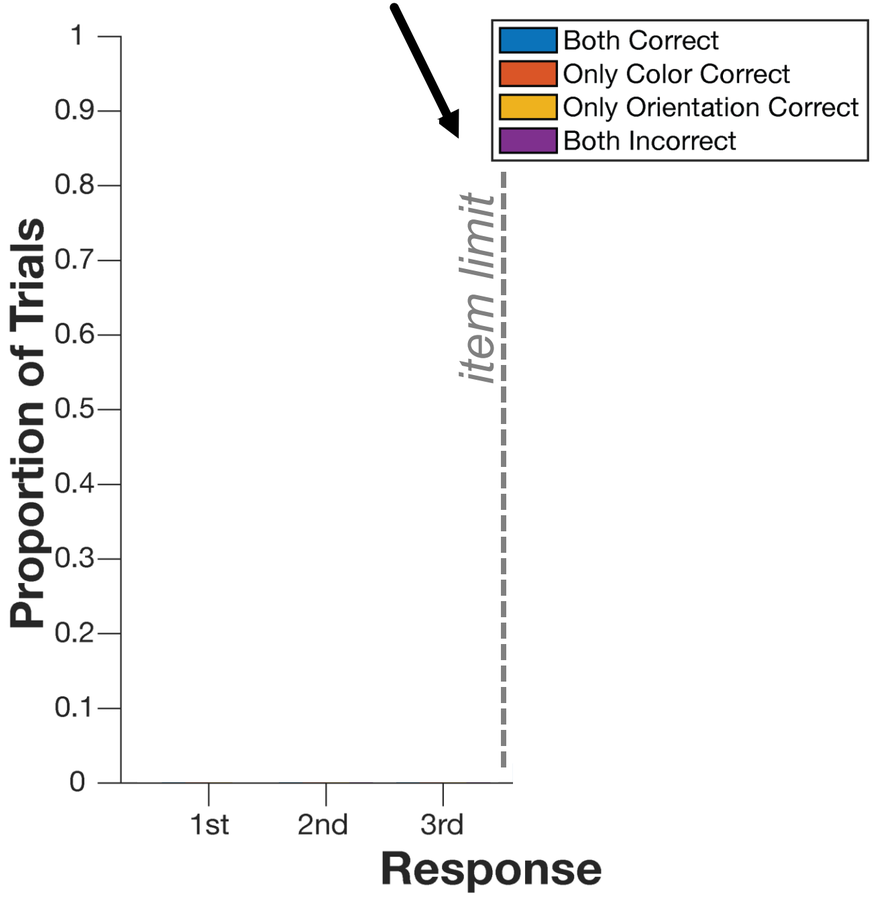
$f(x, i) \sim Bernoulli(p)$

A combined object and features model

Accurate recall constrained within an item limit

But attention fluctuates so maximum capacity is not always achieved



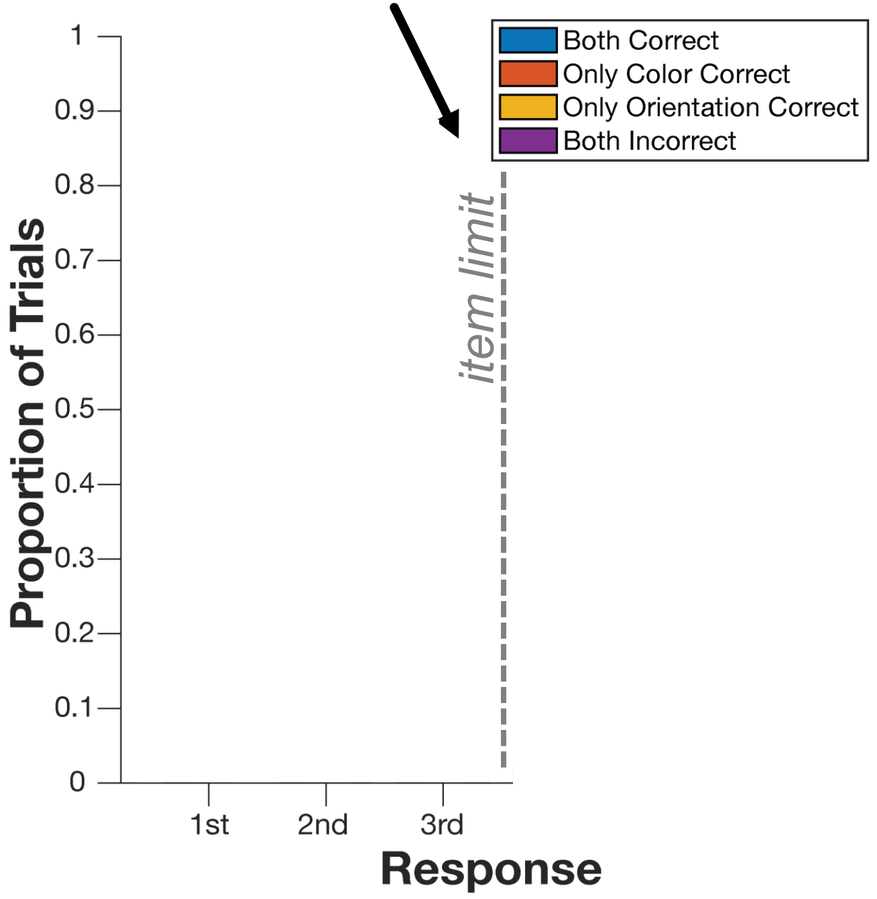


A combined object and features model

Accurate recall constrained within an item limit

But attention fluctuates so maximum capacity is not always achieved

And features are forgotten independently and probabilistically



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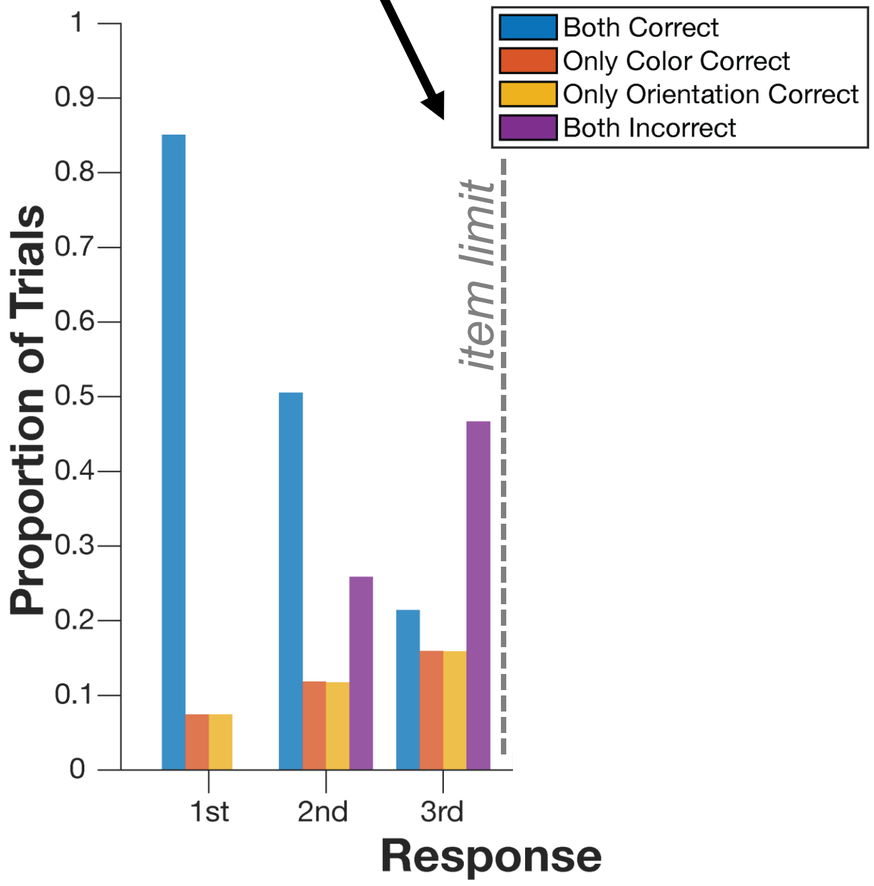

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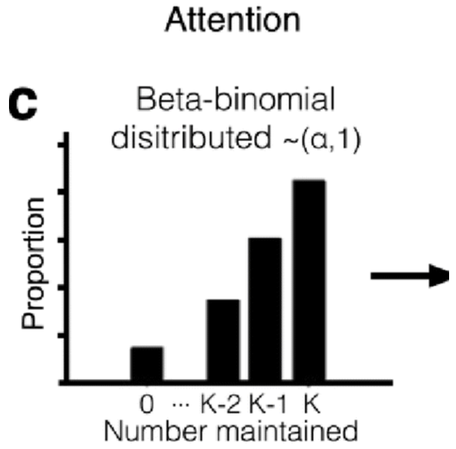
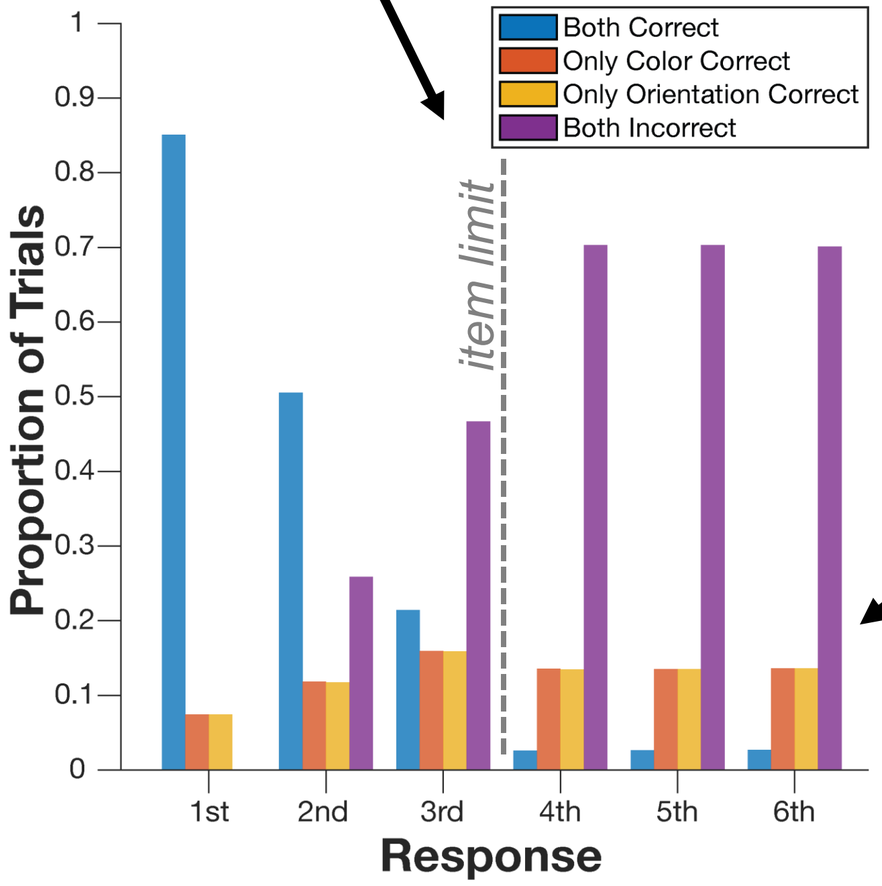
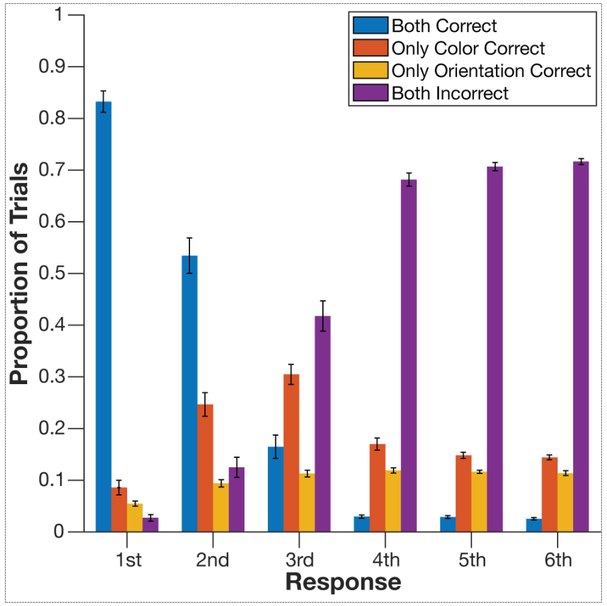


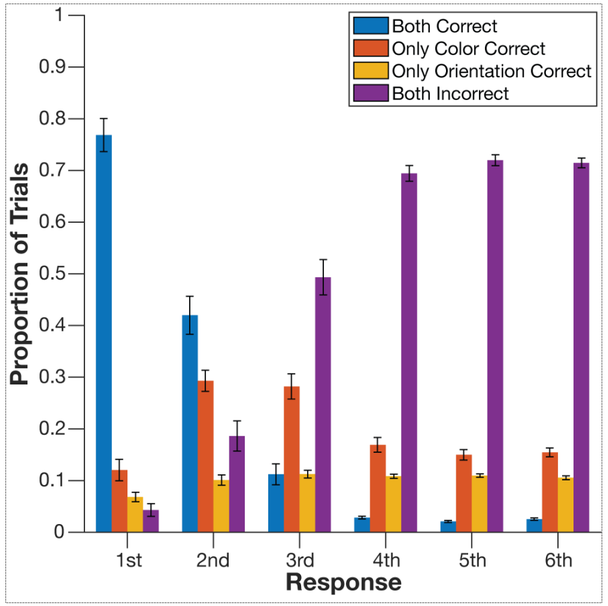


Guessing beyond the item limit

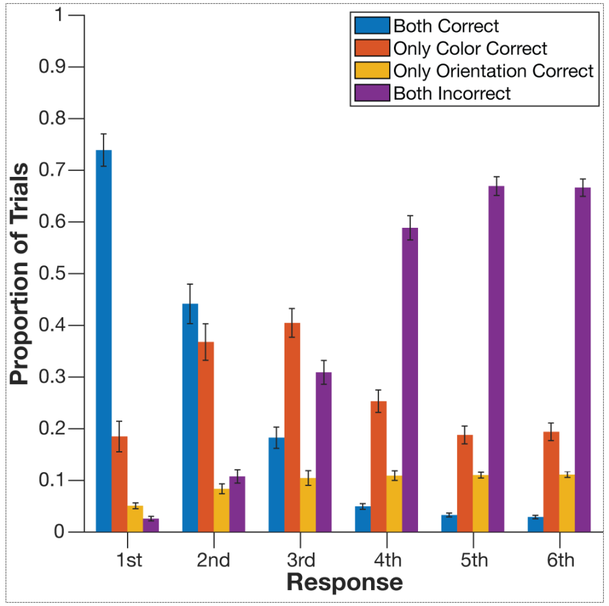
Experiment 1



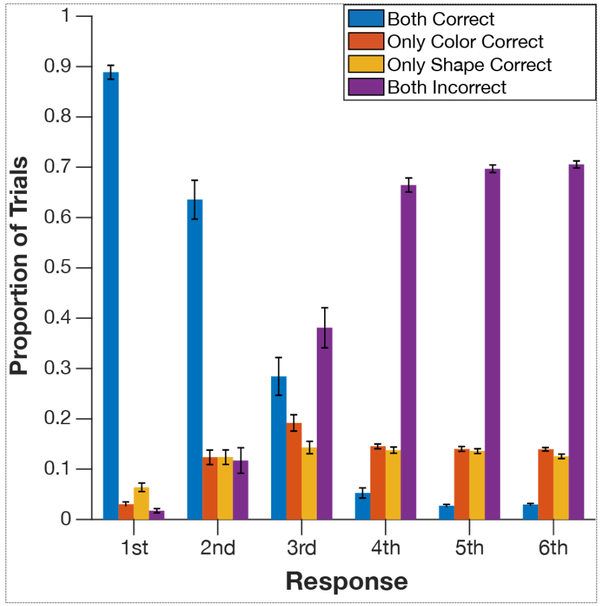
Experiment 2



Experiment 3

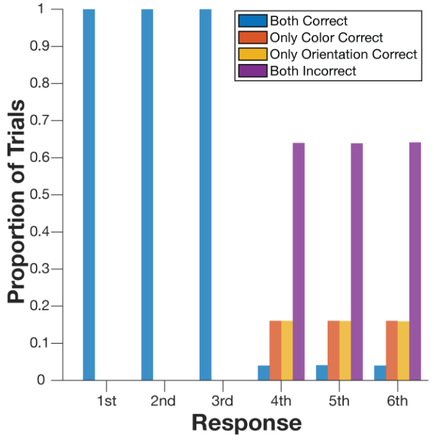


Experiment 4



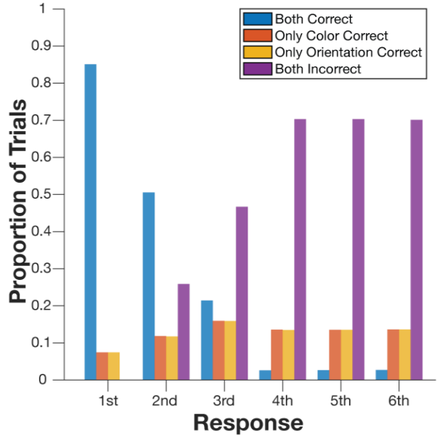
Strong Object Model

Accurate storage of three objects



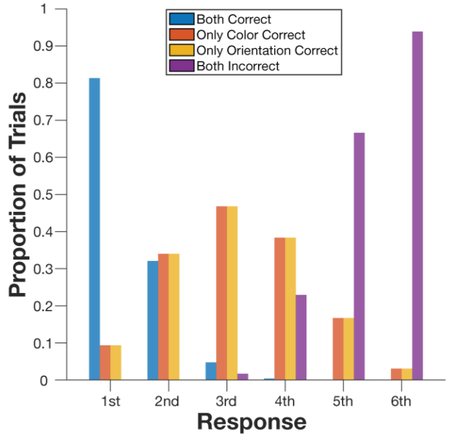
Pointer Model

Item-based storage with feature loss



Independent Feature Model

Feature storage independent of objecthood



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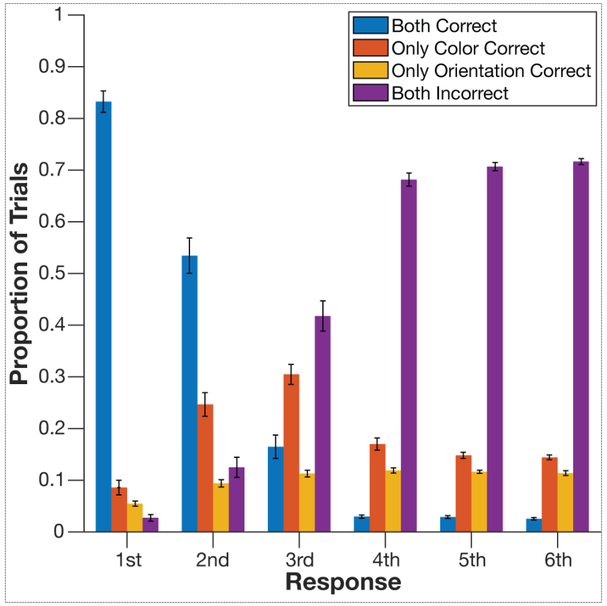
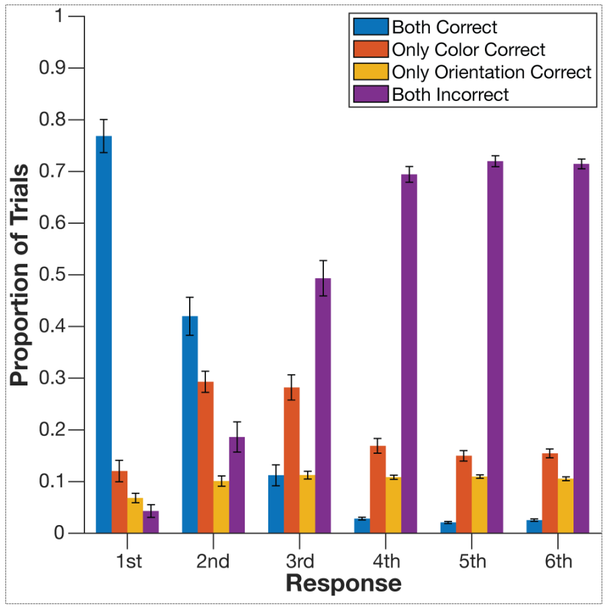


Experiment 2



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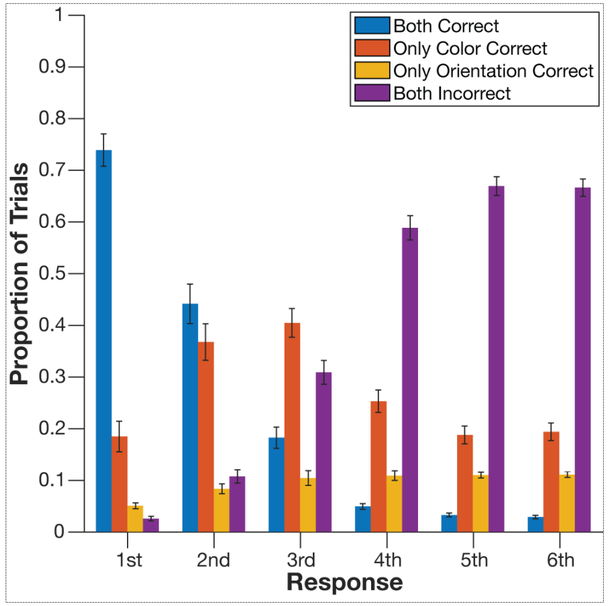

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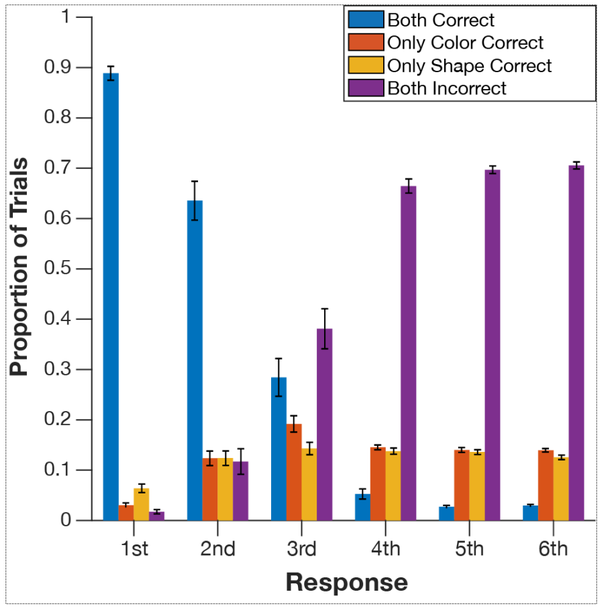

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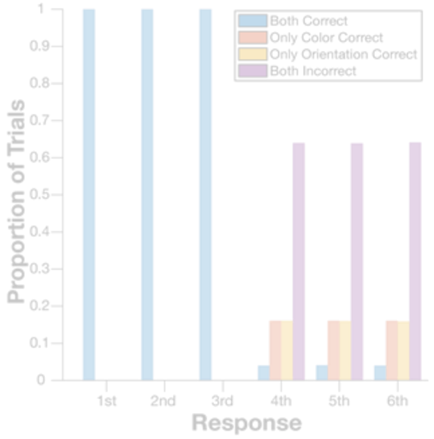

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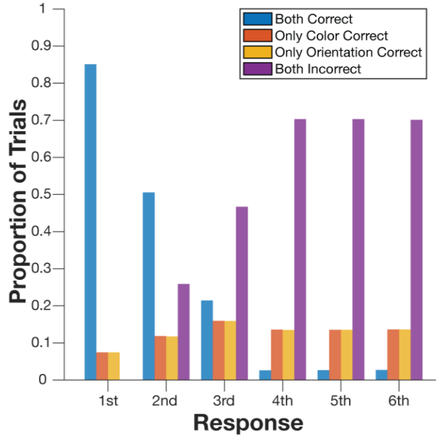

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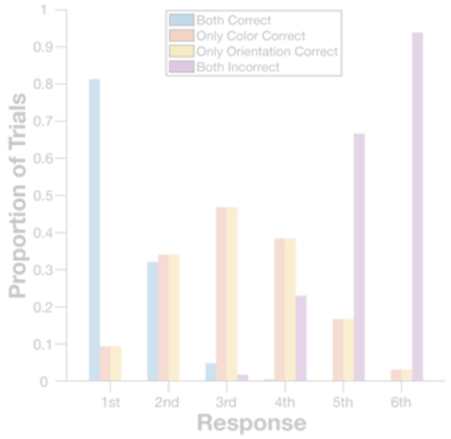
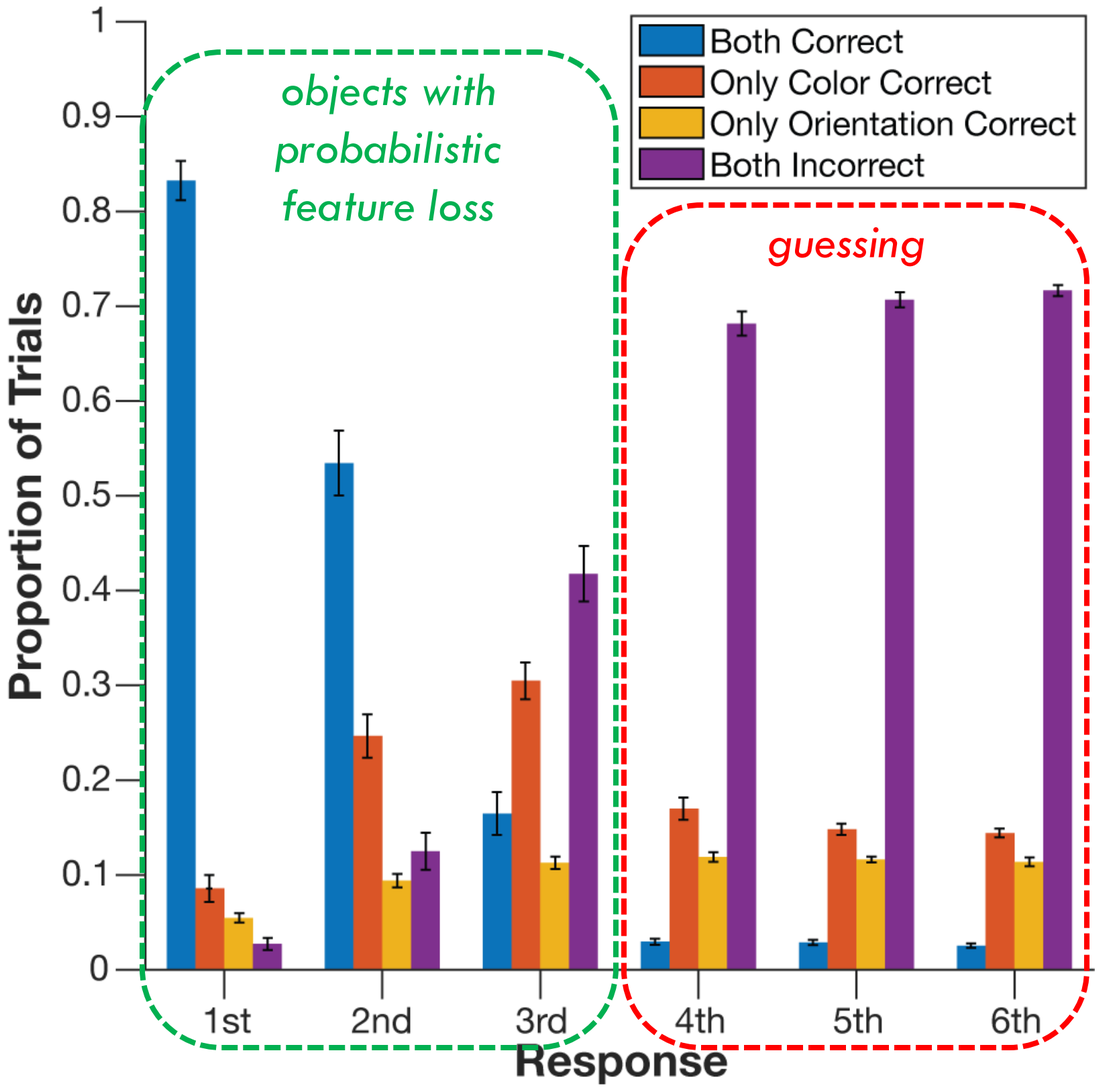


Not simply objects or features

We see object-based encoding and feature-based loss occurring in concert

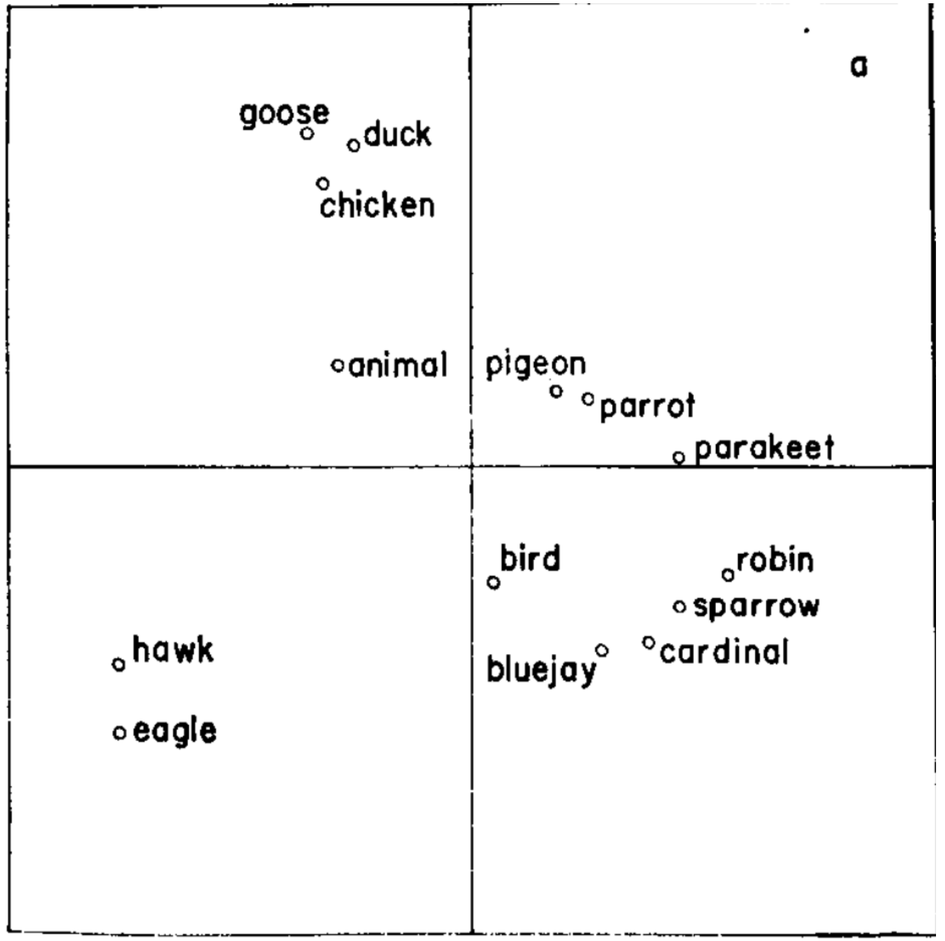


Ngiam et al. (2024) *JEP:G, 153*(1), 86.

Can there be both object- and feature-based representations?

What if an object is an *abstracted* representation of its features?

Measuring category membership

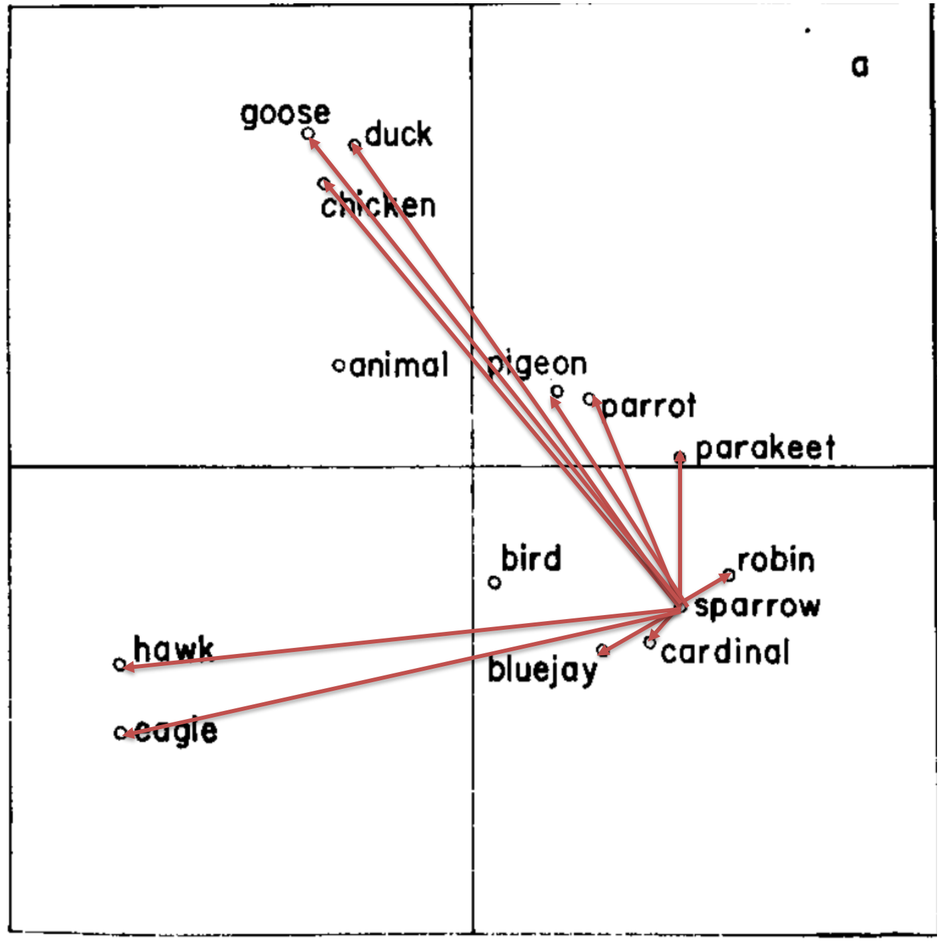


Multidimensional scaling plot of bird similarity

Measuring category membership

Generalized Context Model (GCM)

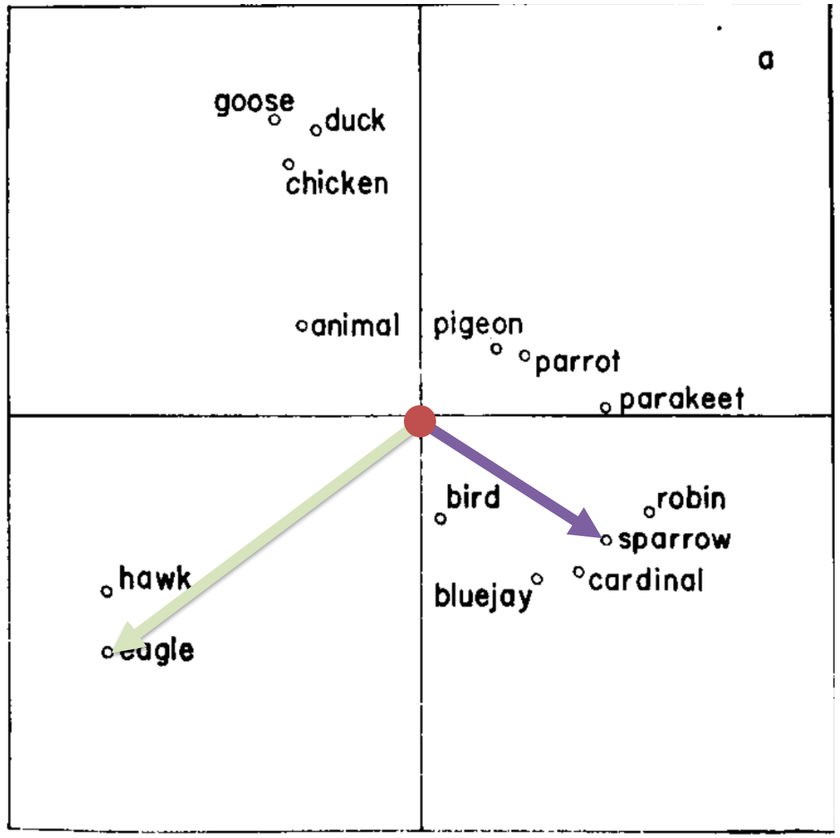
The probability of a stimulus being categorized as a member of a given category is a weighted function of the distance between the target stimulus and the members of the two categories in the space



Measuring category membership

Multiplicative prototype model (MPM)

The probability of a stimulus being categorized as a member of a given category is a weighted function of the distance between the target stimulus and the prototypes (central tendencies) of the two categories in the space



The Contrast Model (Tversky, 1977)

The similarity between the i^{th} item and j^{th} item

$$s_{ij} = \alpha f(I \cap J) - \beta f(I - J) - \gamma f(J - I)$$

A weighted function of the intersection between item *I* and item *J* (i.e. common features)

Minus a weighted function of the featural differences in *I* but absent in *J* *and* in *J* but absent from *I* (i.e. distinctive features)

The Generalized Contrast Model (Dry and Storms, 2010)

Common features

Distinctive features

$$s_{ij} = \left[\theta \sum_k v_{ik} v_{jk}\right] - \left[(1-\theta) \sum_k v_{ik}(1 - v_{jk})\right]$$

The Generalized Contrast Model (Dry and Storms, 2010)

A parameter that balances common and distinctive features

$$s_{ij} = \left[\theta \sum_k v_{ik} v_{jk}\right] - \left[(1-\theta) \sum_k v_{ik}(1 - v_{jk})\right]$$

A lazy generalised model of visual working memory

A parameter that balances feature-based and object-based memory

$$WM = \theta[f(I) + f(J)] - (1 - \theta)[f(I \cap J]$$

Feature-based memory (exemplar)

Object-based memory (prototype)

The lazy general model of working memory

$$WM = \theta[f(I) + f(J)] - (1 - \theta)[f(I \cap J]$$

Forces researchers to address possibility of both feature-based and object-based representations

A dynamic model that allows changes in feature-based and object-based effects

A parameter measuring feature binding or abstraction or other interesting potential mechanisms

What might shape the θ parameter?

$$WM = \theta[f(I) + f(J)] - (1 - \theta)[f(I \cap J]$$

Object-based encoding

Gestalt factors, expectations, grouping

Failures in feature binding

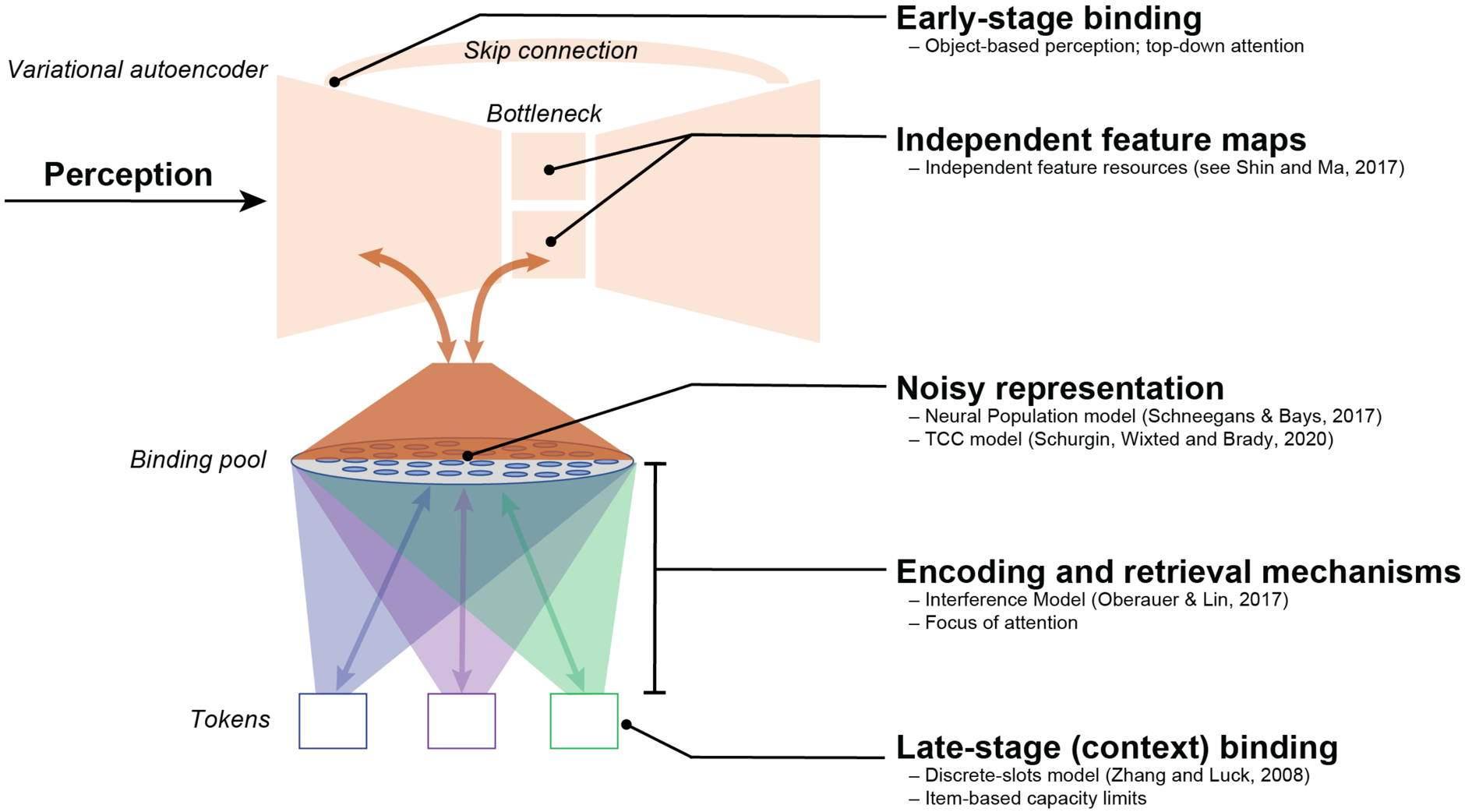
Swap errors, feature dropping

Correlated signals in two- or multi-dimensional signal detection

Shifts of interference

Less interference at an object-level?

A theory map of visual working memory



Ngiam, W. X. Q. (2024). Mapping visual working memory models to a theoretical framework. Psychonomic Bulletin & Review, 31(2), 442-459.

Questions (or perhaps answers)?

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