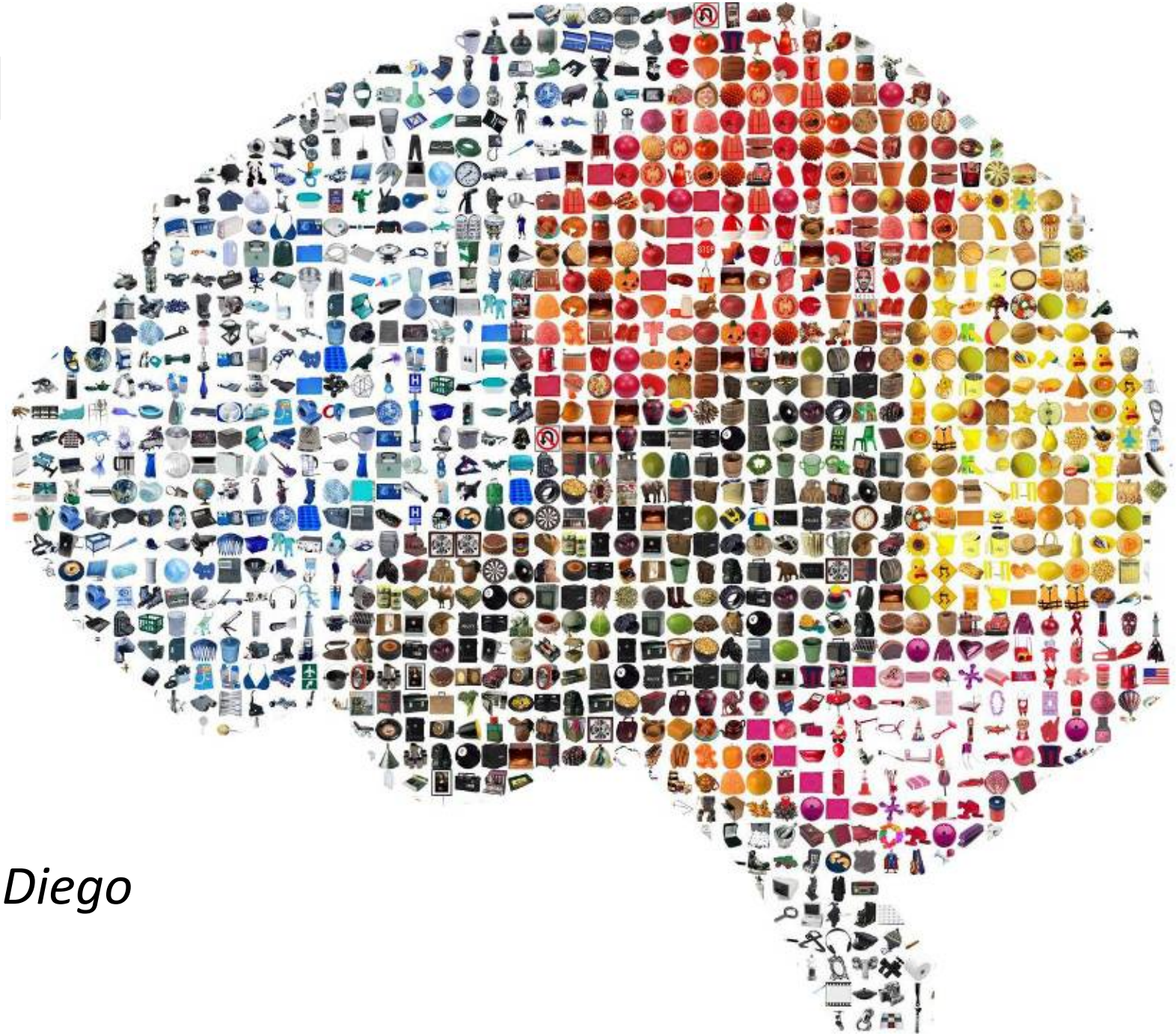
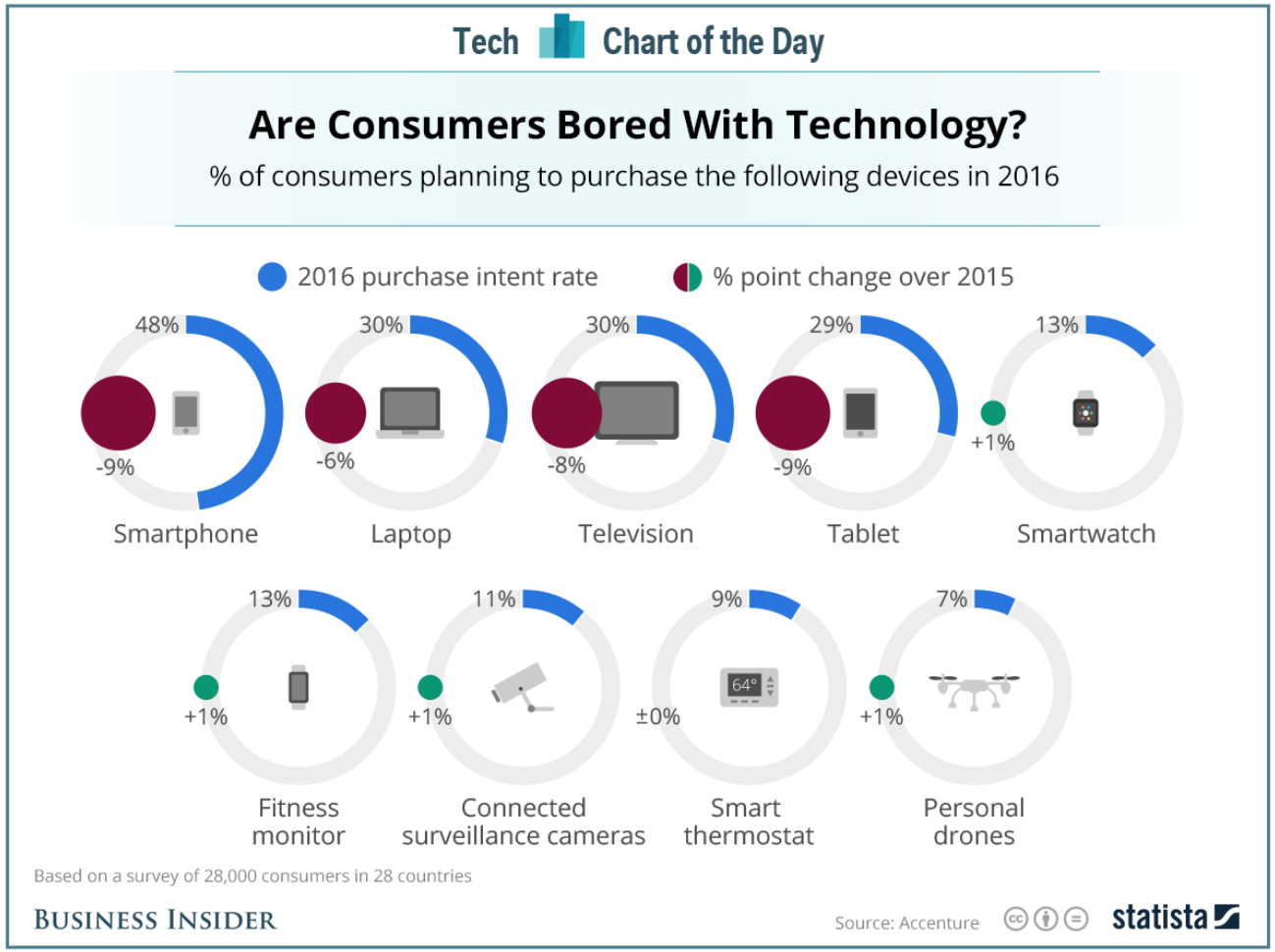
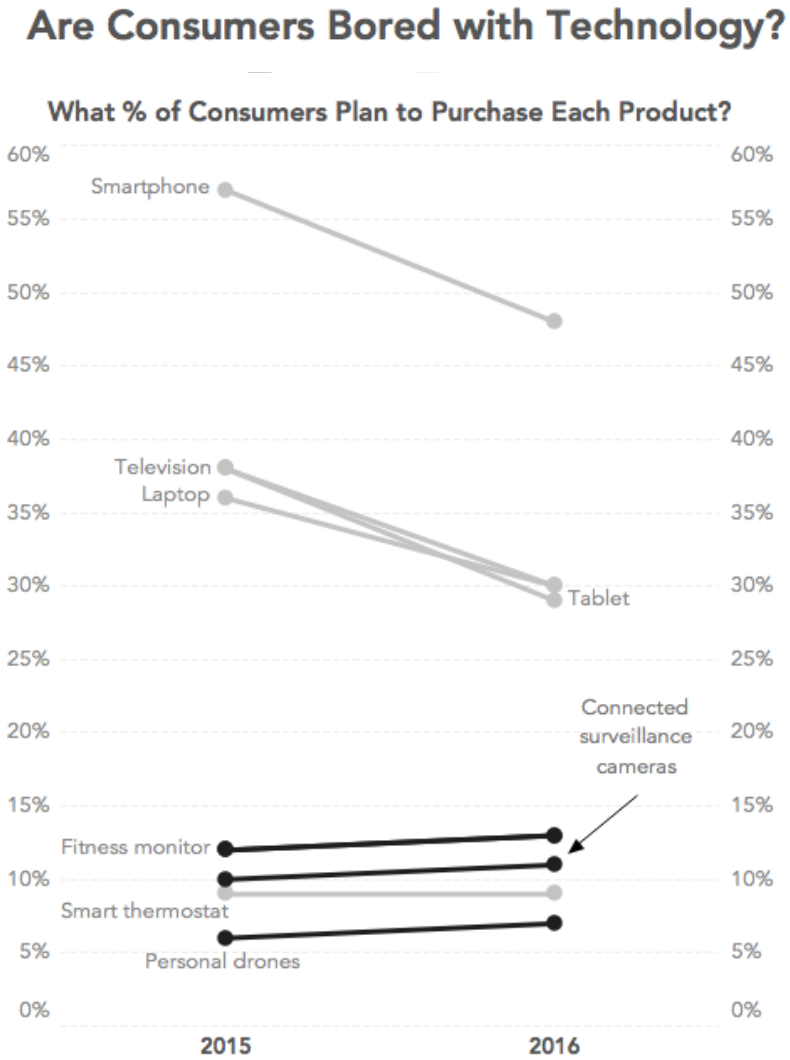
How much visual information we can hold in mind at once?



Timothy Brady
University of California, San Diego
Dept. of Psychology

We want people to be able to extract information quickly….





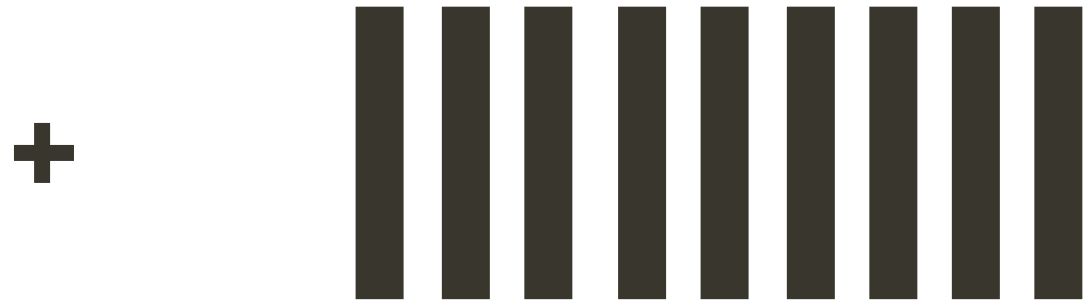
Makeover Monday submission: http://www.vizwiz.com/2016/01/are-consumers-bored.html

One reason: *Perceptual* processing limits

- Visual acuity

One reason: *Perceptual* processing limits

- Visual acuity
- Visual attention



Vision: Intrilligator & Cavanagh, 2001; etc. in vis: Haroz & Whitney, 2012

One reason: *Perceptual* processing limits

- Visual acuity
- Visual attention
- Visual working memory – Maintaining perceptual representations across delays and interruptions for comparisons, manipulations, etc.

My goals:

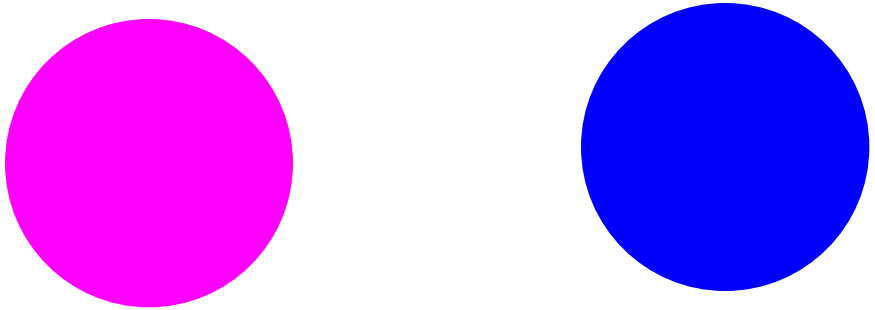
(1) Convince you working memory matters for visualization design and processing

(2) Give you a mental model for thinking about working memory limits

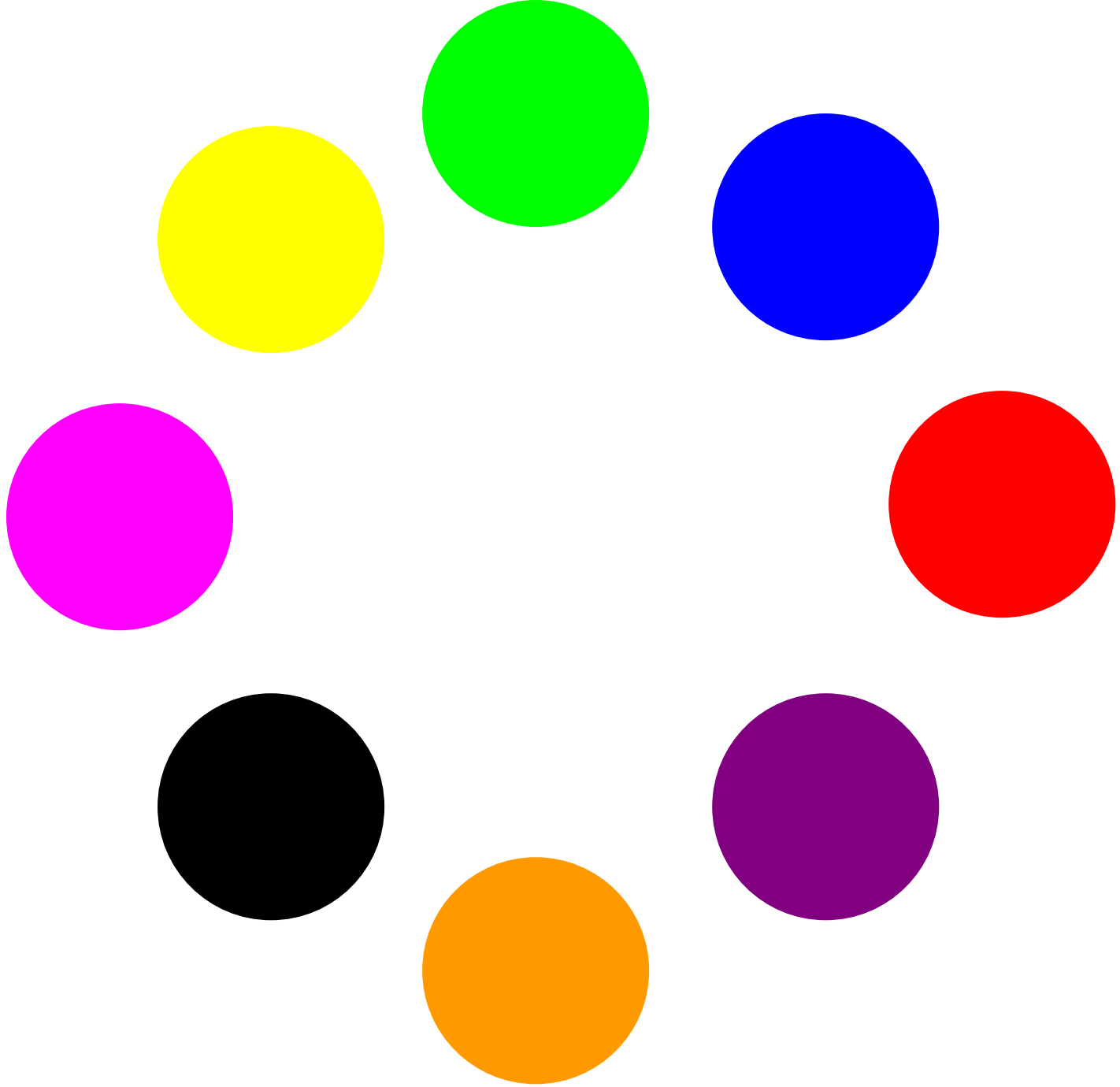
One reason: *Perceptual* processing limits

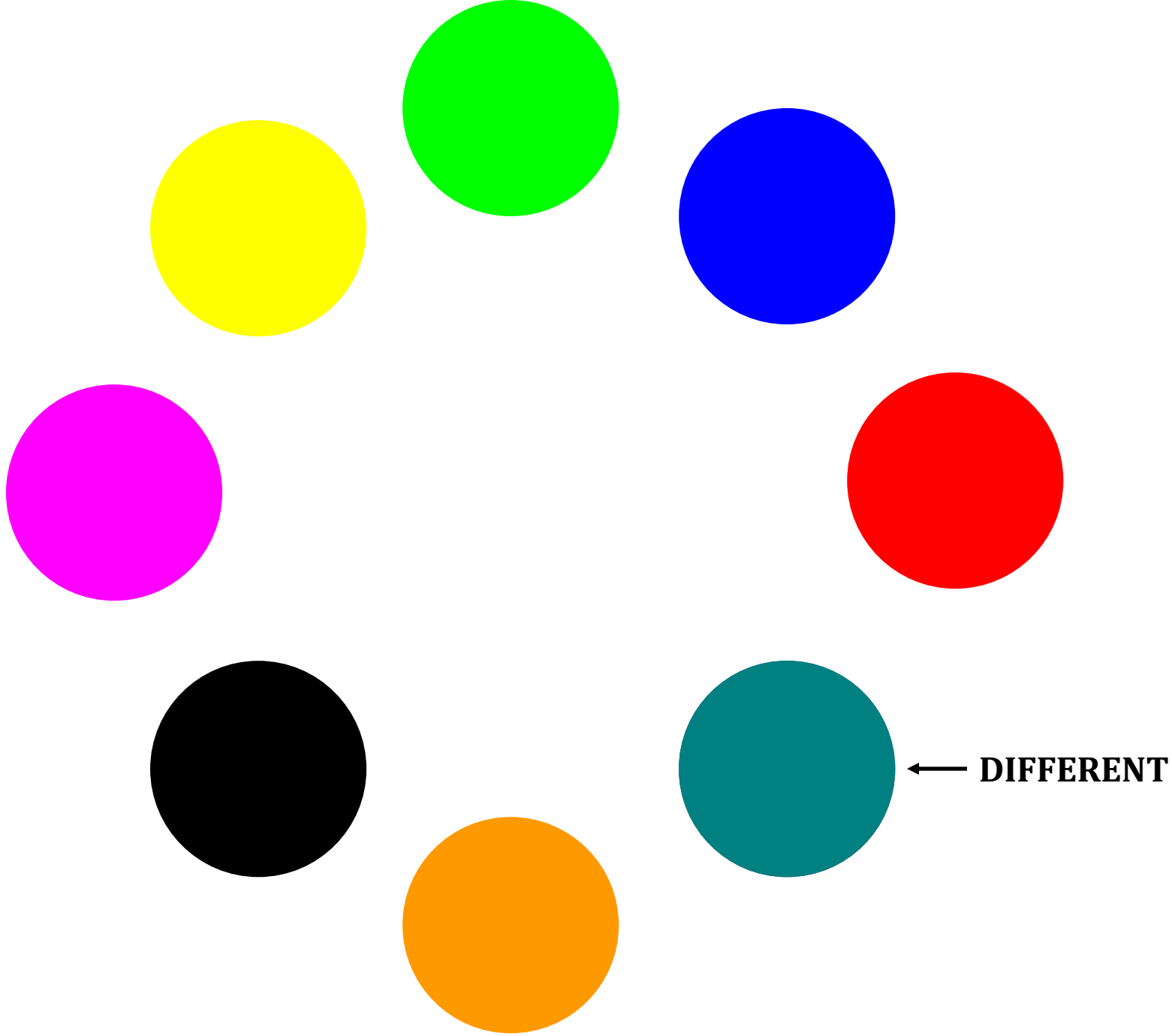
- Visual acuity
- Visual attention
- Visual working memory – Maintaining perceptual representations across delays and interruptions for comparisons, manipulations, etc.

Remember the colors on the next display…



Remember the colors

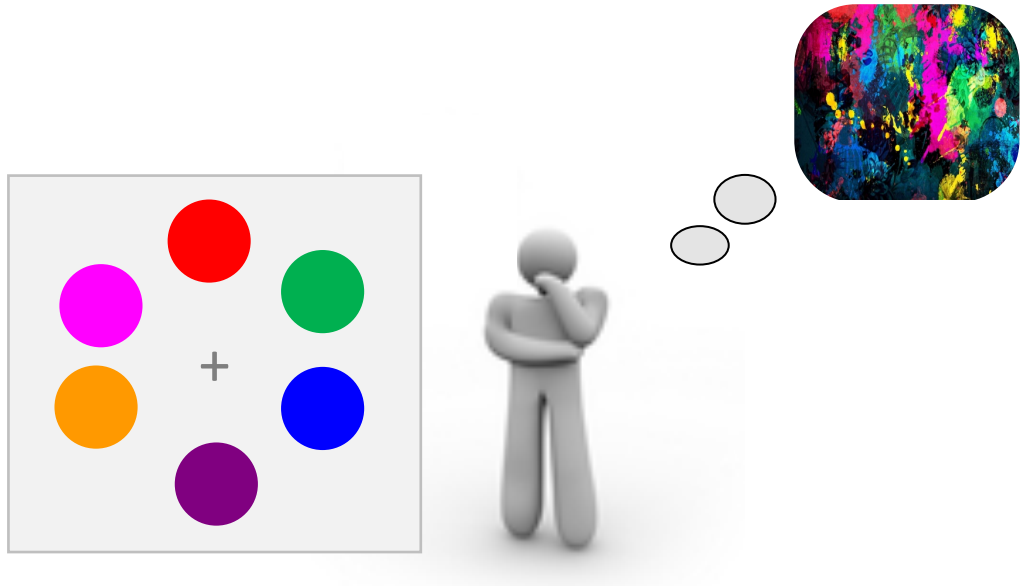



DIFFERENT

Extremely limited working memory capacity

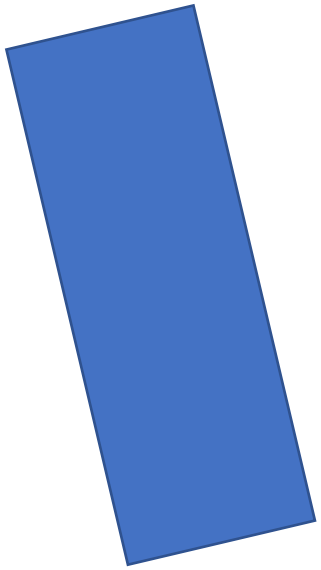
- Extremely limited capacity for holding mind information across interruptions and delays

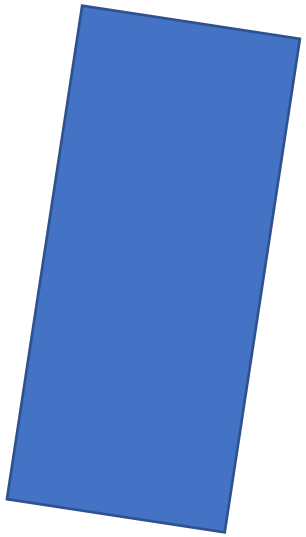
- Eye movements make this extremely relevant



Working memory strongly limits processing even for things right in front of you

Which bar is taller?

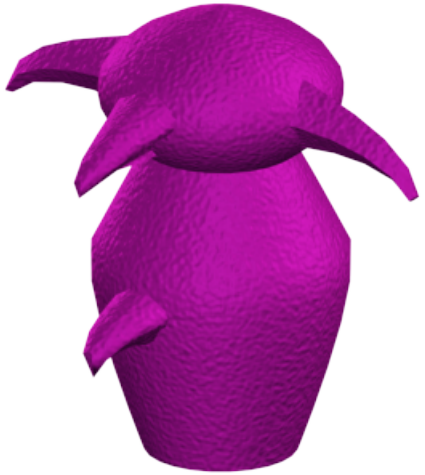


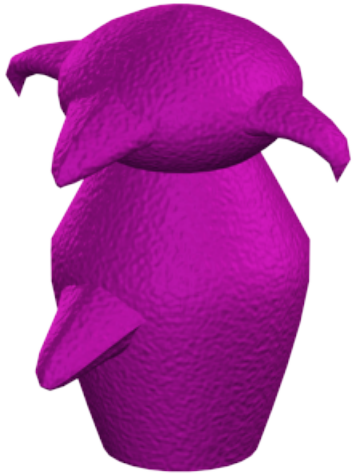


Yuan, Uttal, Franconeri, 2016; Tsubomi, Fukuda, Watanabe, Vogel, 2013; etc.

Working memory strongly limits processing even for things right in front of you

Are these two objects the same?



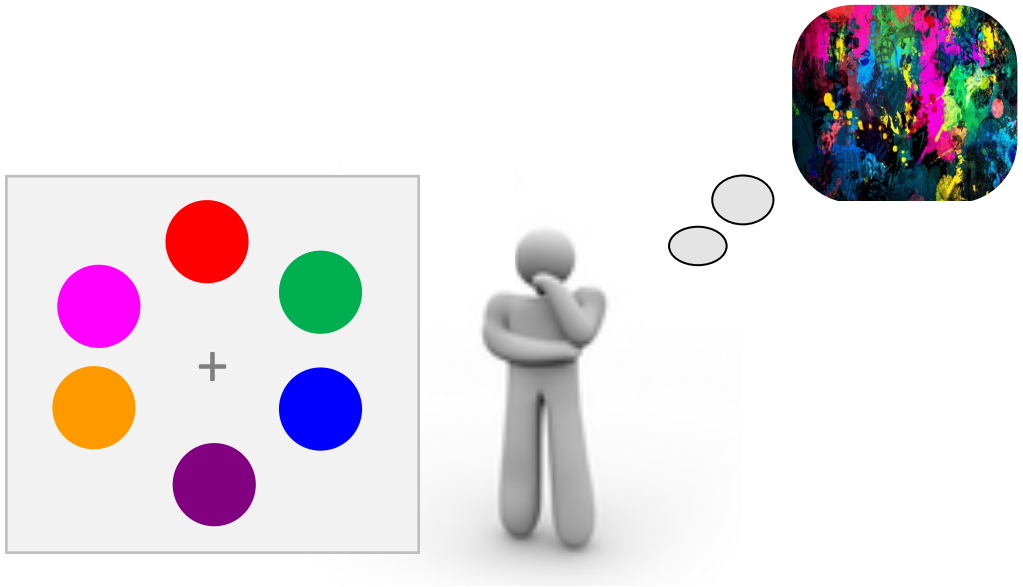


Yuan, Uttal, Franconeri, 2016; Tsubomi, Fukuda, Watanabe, Vogel, 2013; etc.

Working memory strongly limits processing even for things right in front of you

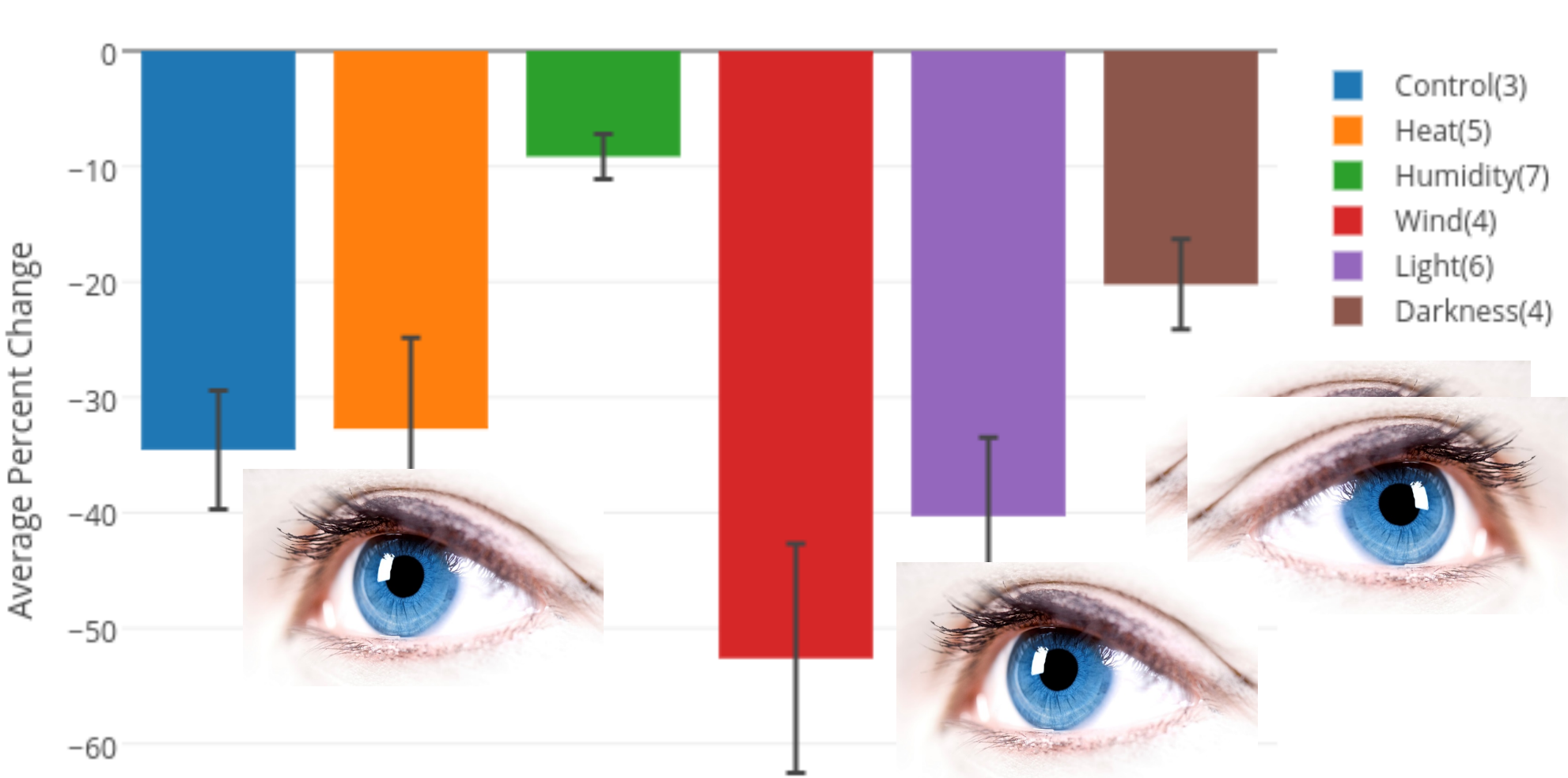
WM and eye movements: Van der Stigchel, Hollingworth, 2018. Cronin & Irwin, 2018

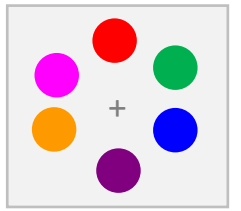
Extremely limited working memory capacity limits understanding of complex displays




PATISSIER
LA MERE MITRON
BAR
LE BISTROT

This kind of visualization is a working memory task



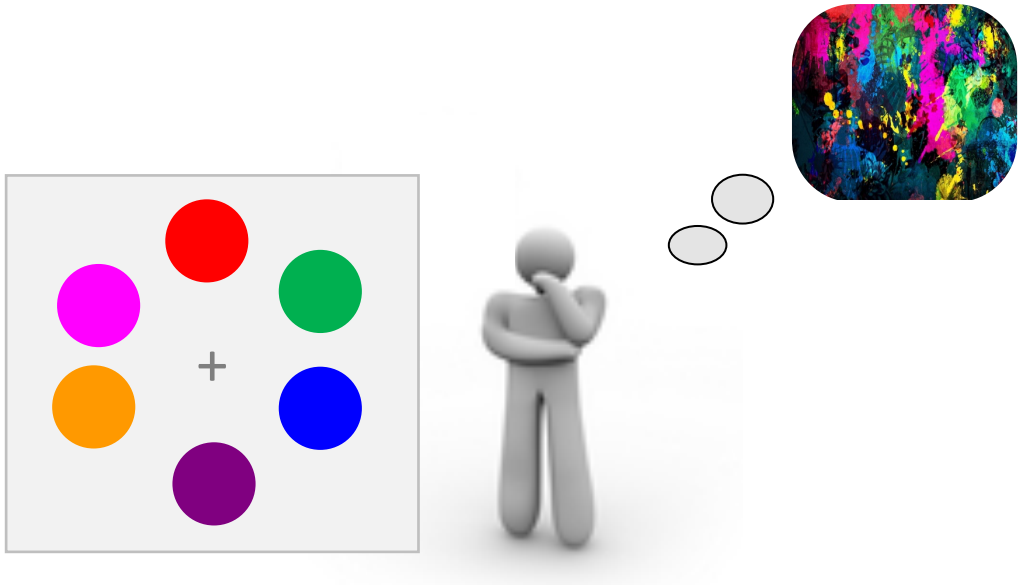


My goals:

(1) Convince you working memory matters for visualization design and processing

(2) Give you a mental model for thinking about working memory limits

How should we think about working memory limits?

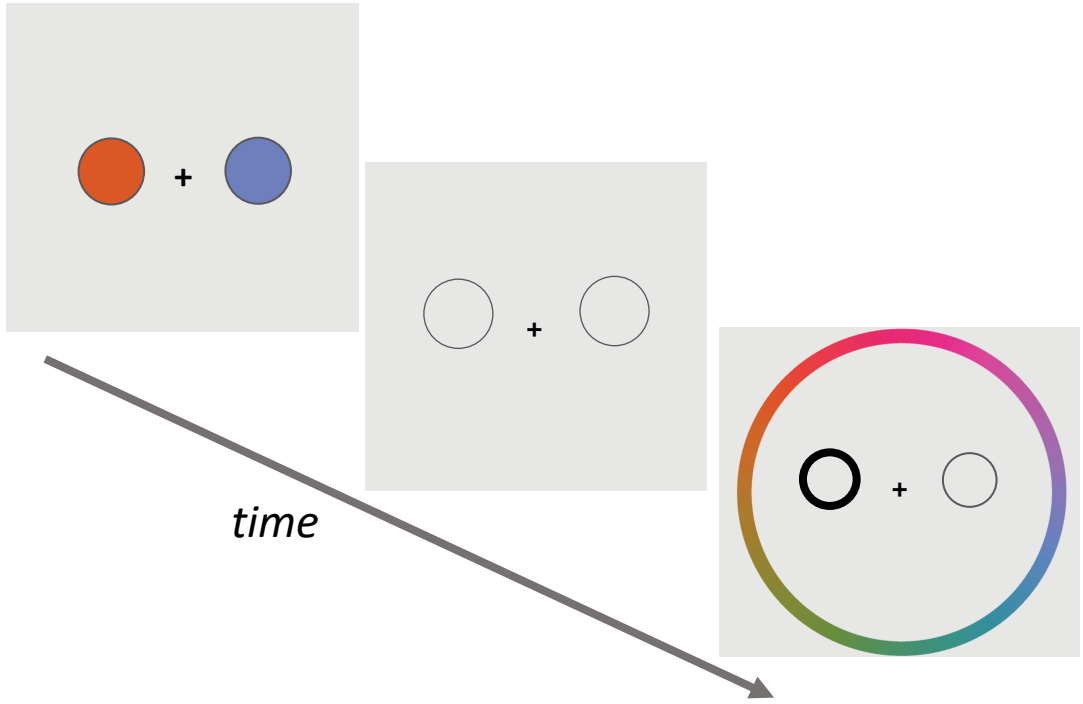


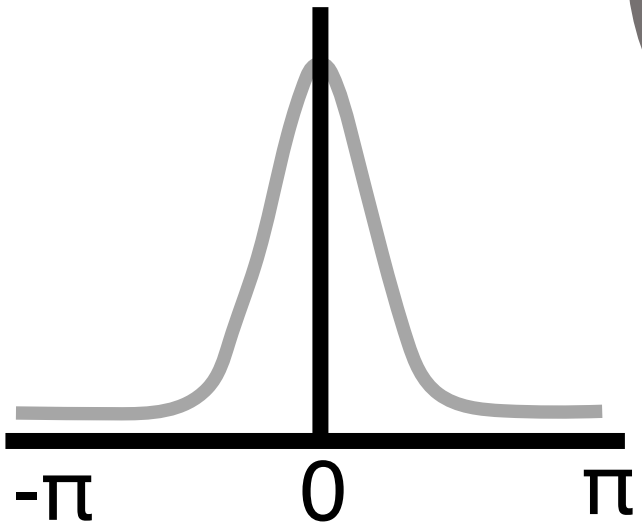
- Can we “formalize” what is limited about working memory?
- Some examples of ones you might have heard:
  - 7 +/- 2 chunks
  - People can only hold in mind 3-4 things at once

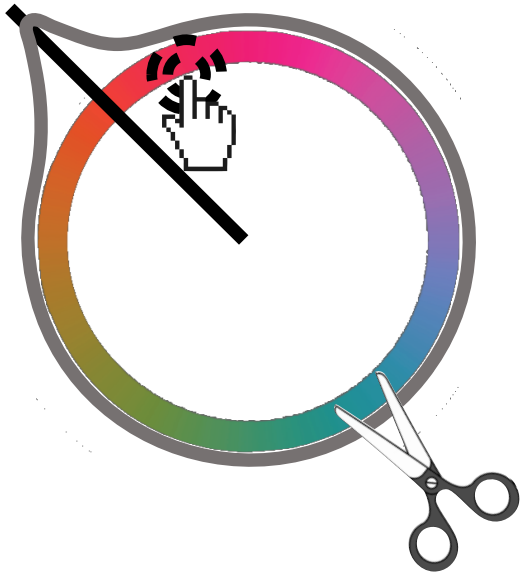
…

3-4 items: Not a good mental model.

For example, big costs even in moving from holding 1 thing to 2 things







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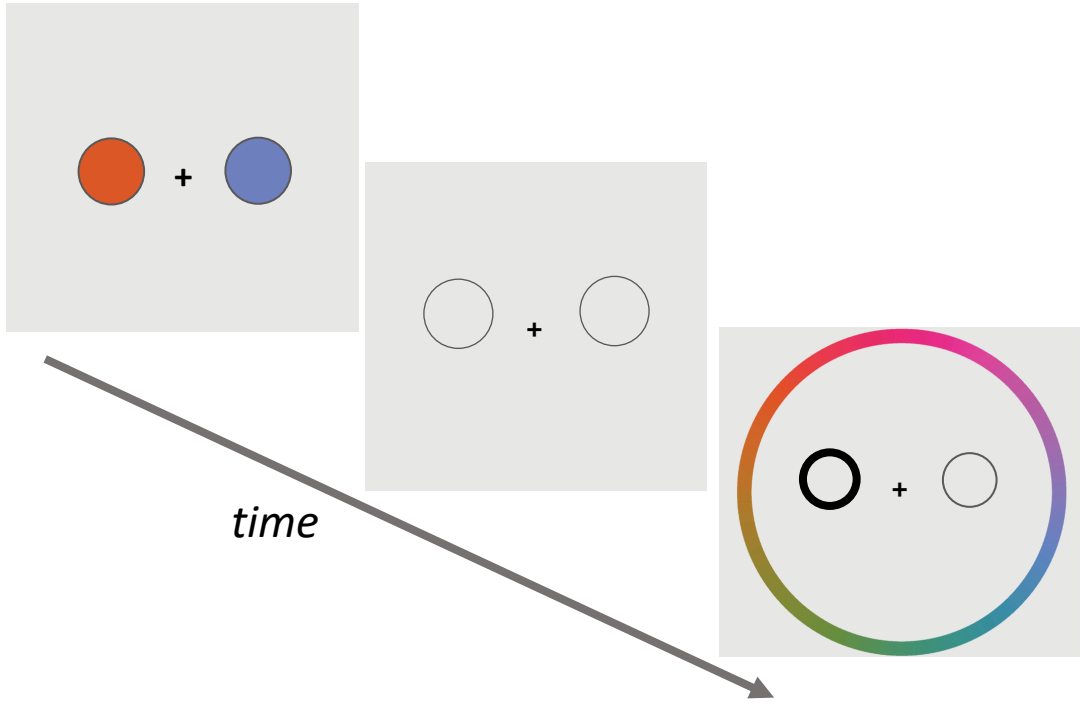
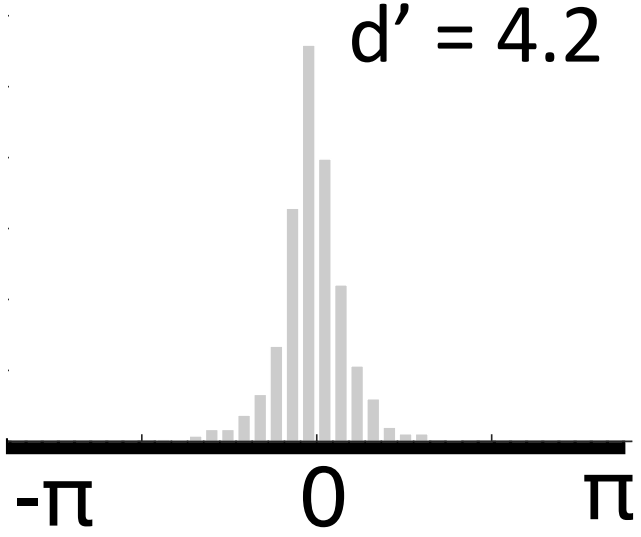


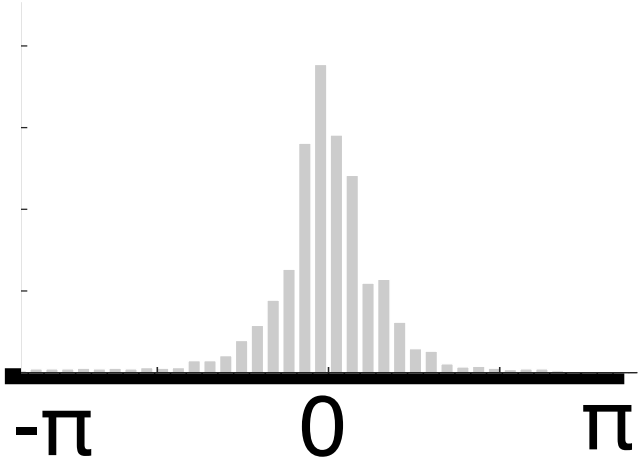
With 1 item in mind:

d' = 4.2



With 2 items in mind:

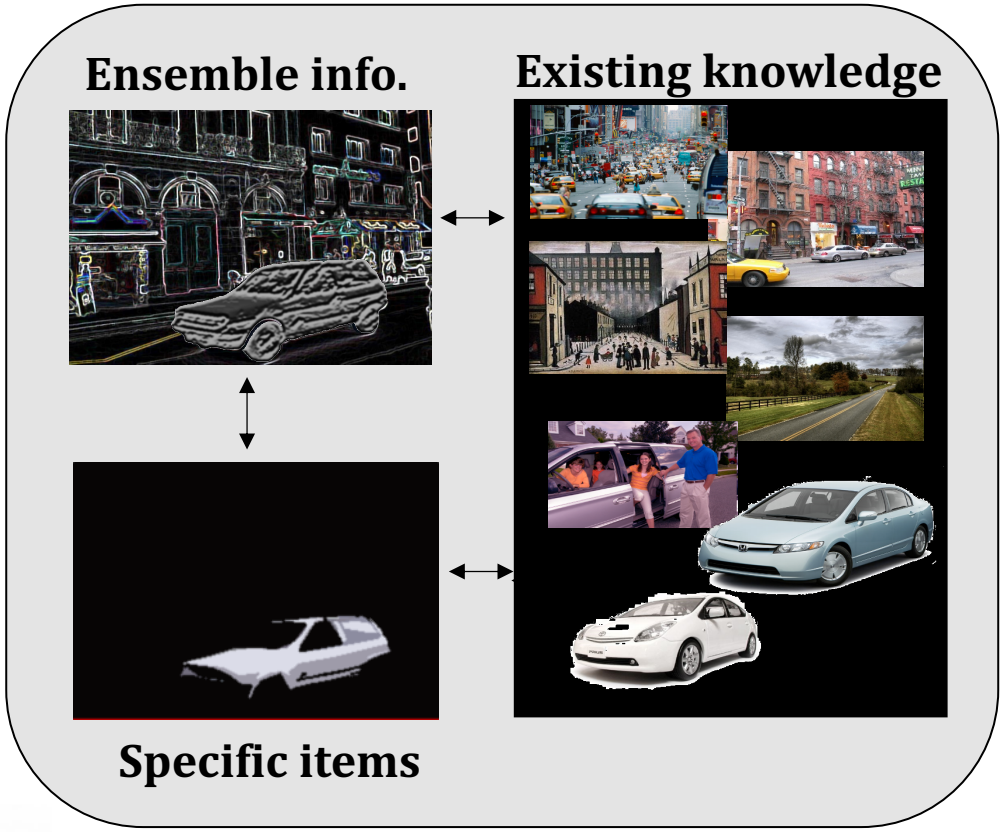
d' = 3.0



e.g., Schurgin, Wixted & Brady, 2018

Proposed mental model: hierarchical & noisy

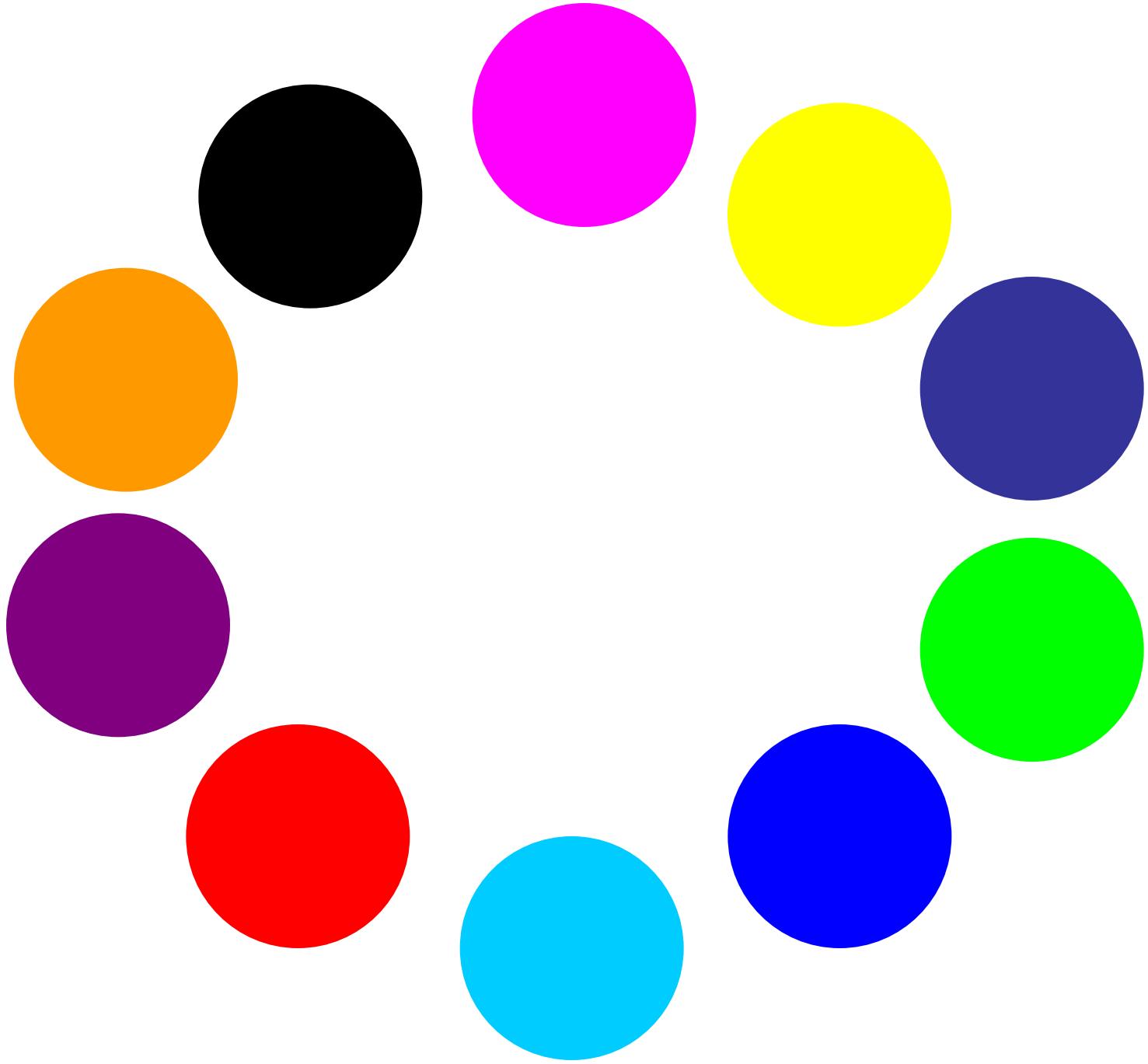
- Memories are always noisy
- Asking people to hold more in mind *always* makes them more noisy
- But items are not remembered alone. Instead, our existing knowledge and context are integral parts of our working memories.

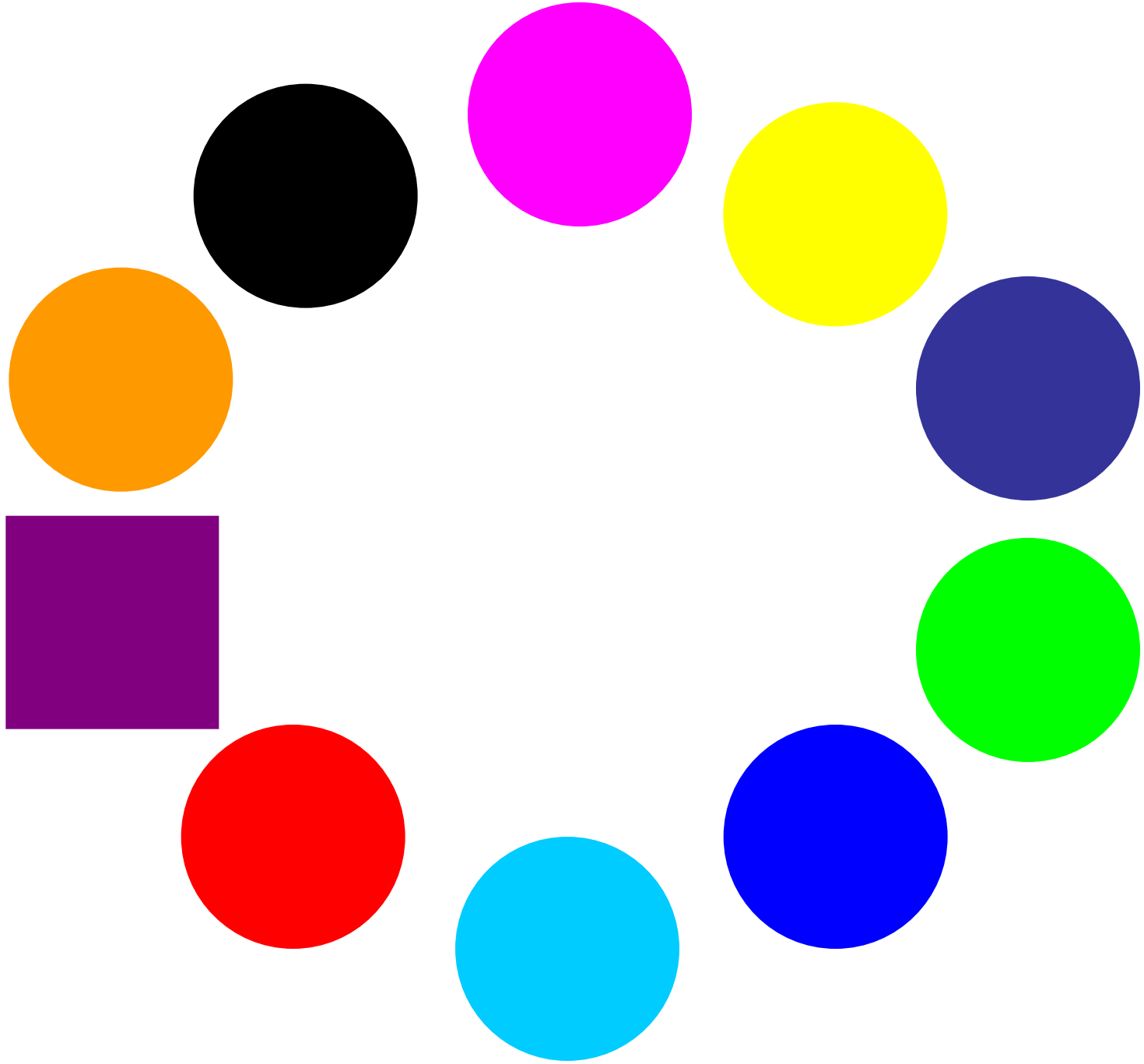


Brady & Alvarez, 2011, *Psych. Science*
Brady, Konkle & Alvarez, 2011, *JoV*
Brady & Tenenbaum, 2013, *Psych. Review*
Brady & Alvarez, 2015, *JEP:LMC*
Schurgin & Brady, 2019, *JoV*
Utochkin & Brady, 2019, *PsyArXiv*
....

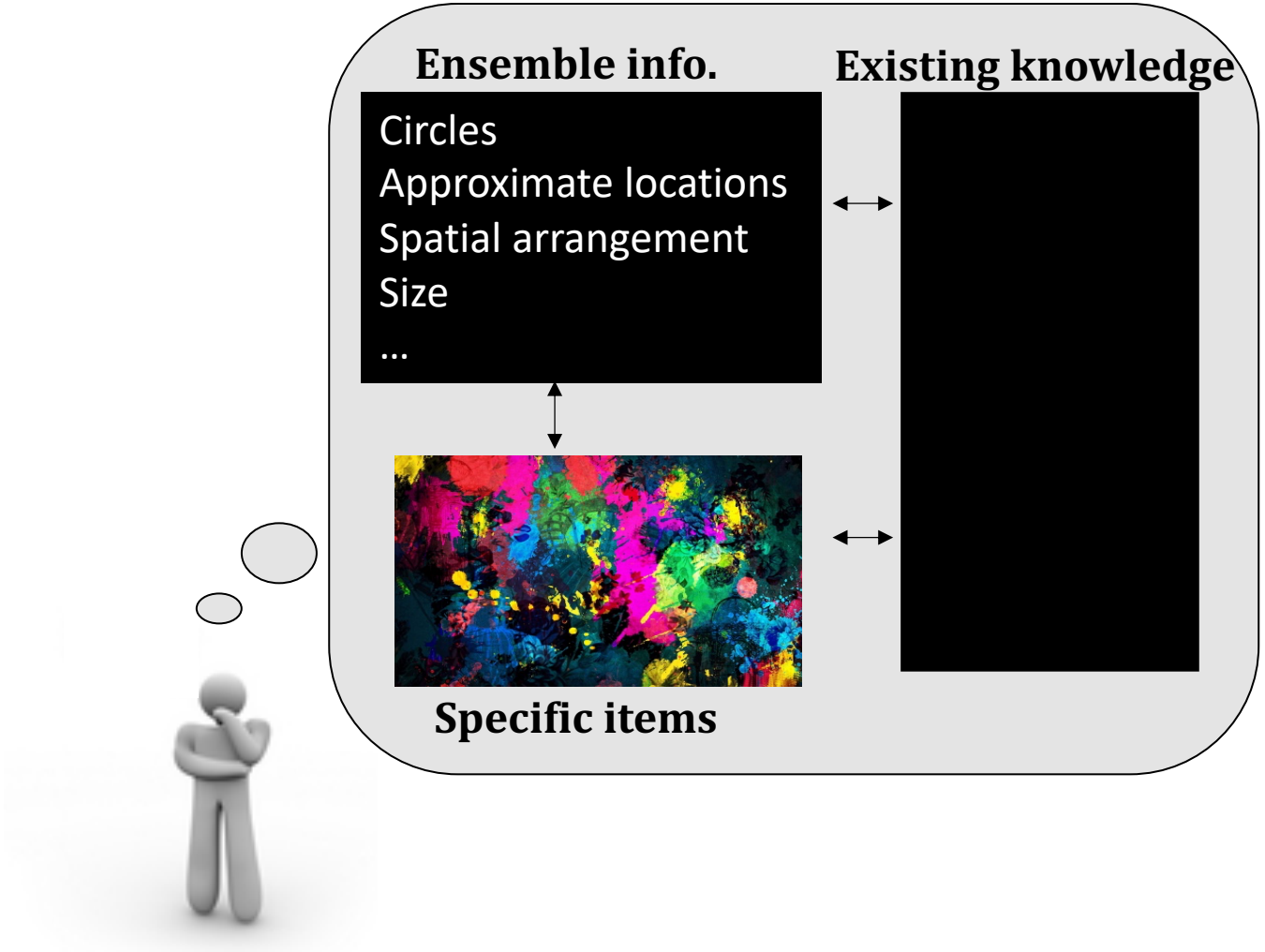
The role of context (and ‘ensembles’) in memory

Remember this display



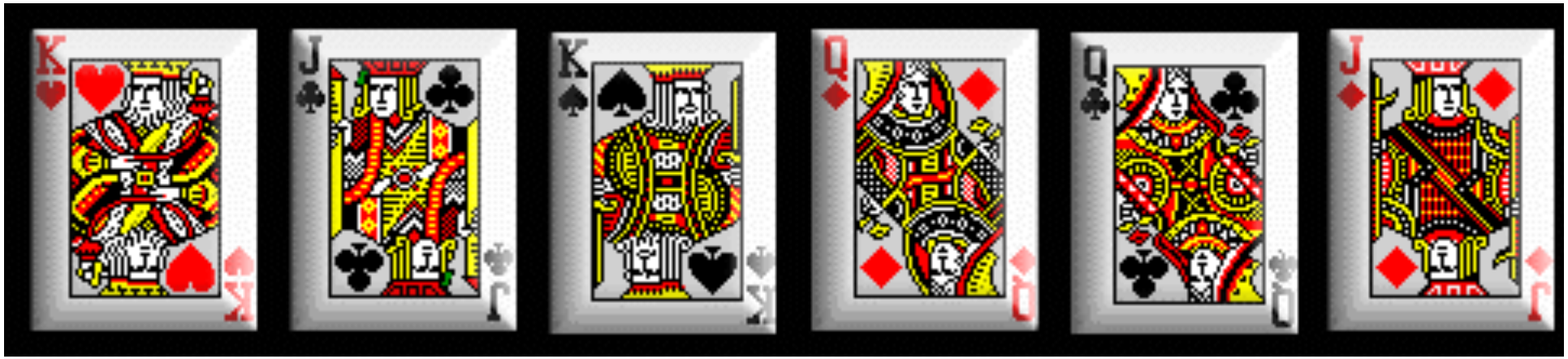


Some information about all items is stored

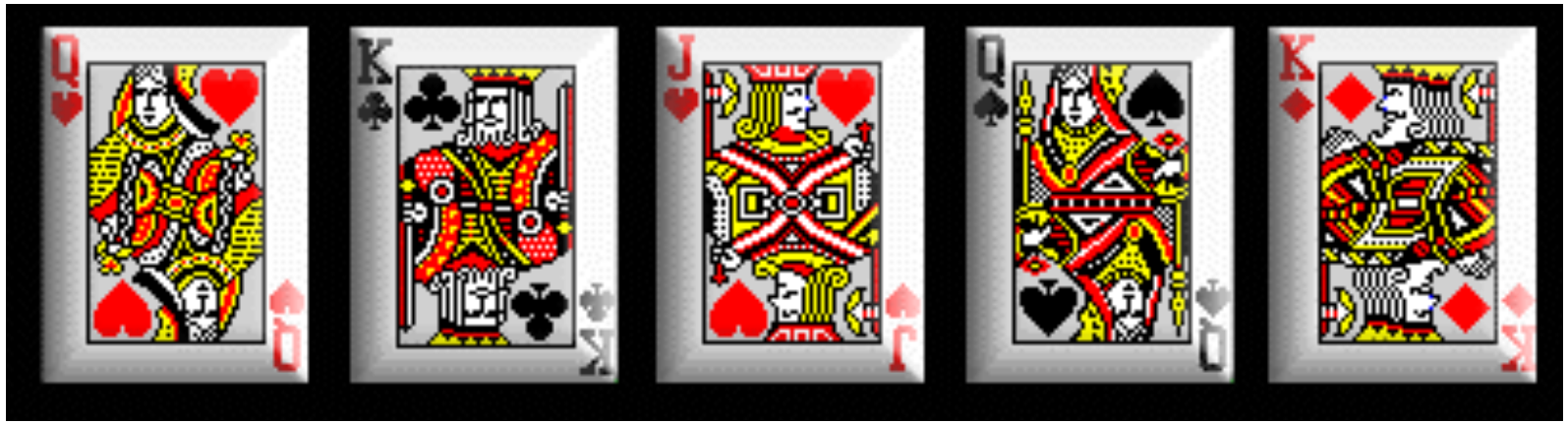


← Interacts with prior knowledge

Brady, Konkle & Alvarez, 2011, JoV



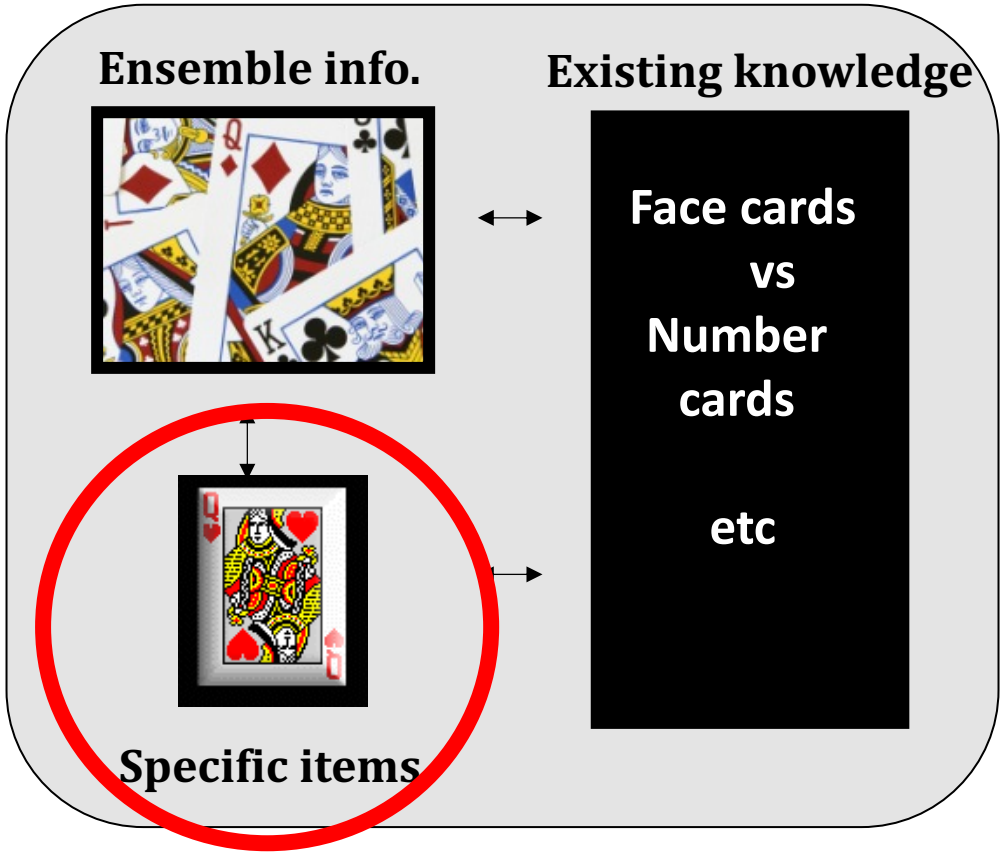
Pick a card and remember it.

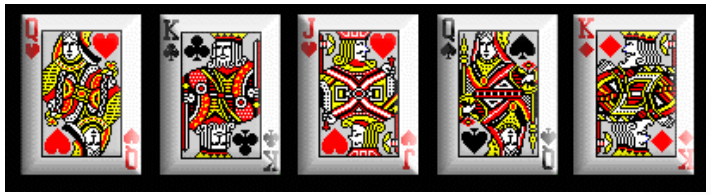


I’ve removed your card!

Proposed mental model: hierarchical & noisy

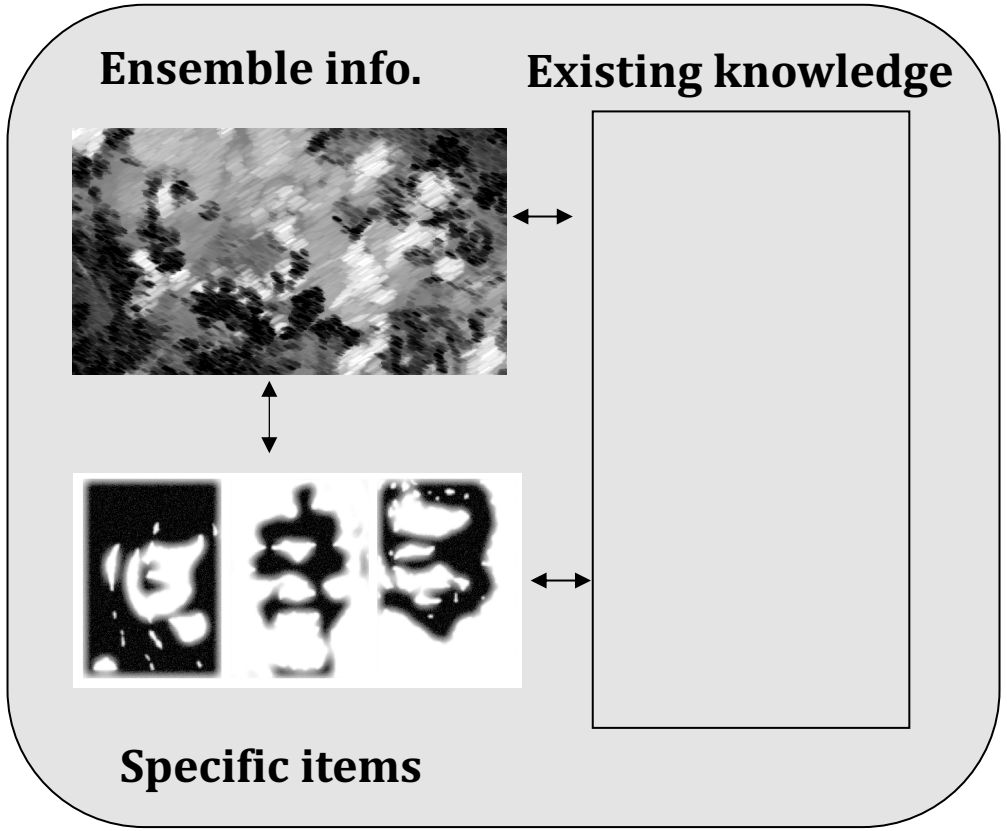
No! Existing knowledge and context are integral parts of our working memories.

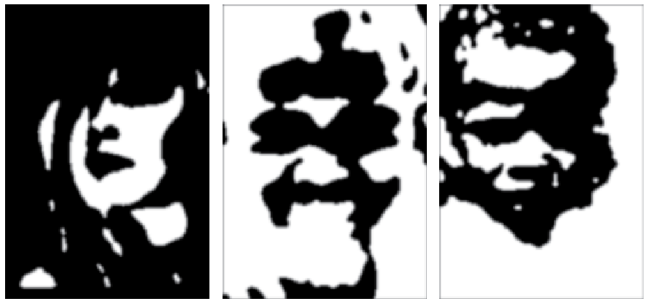




“The memory”?

Knowledge shapes individual memories

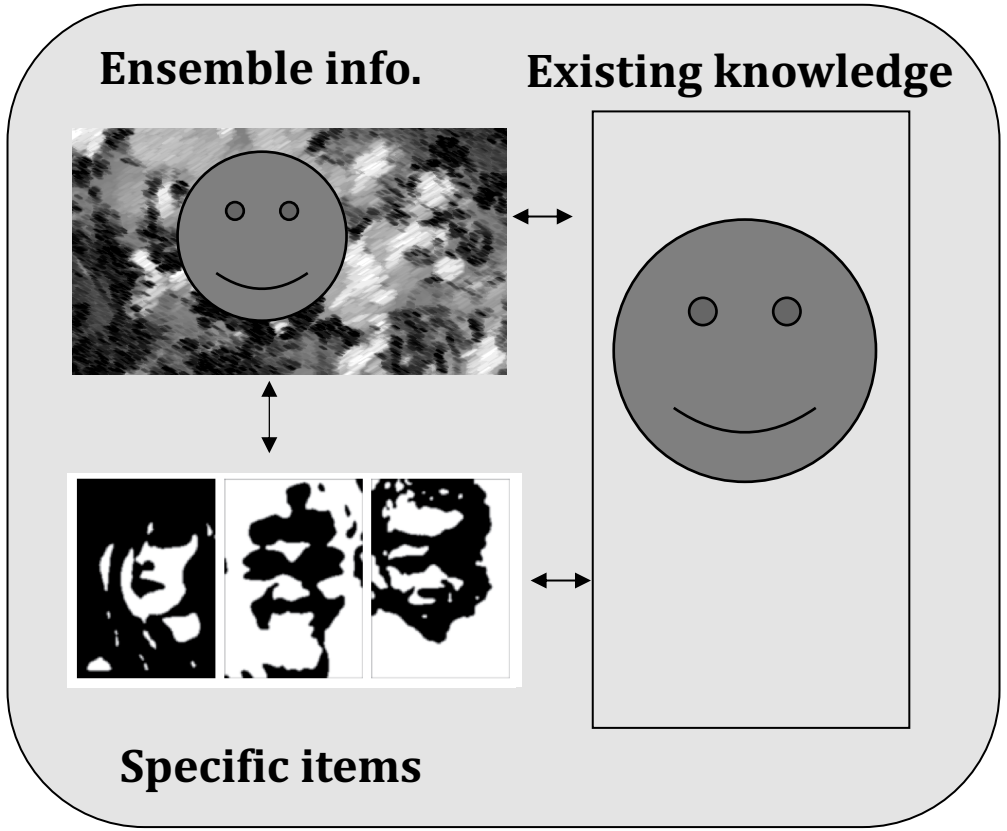


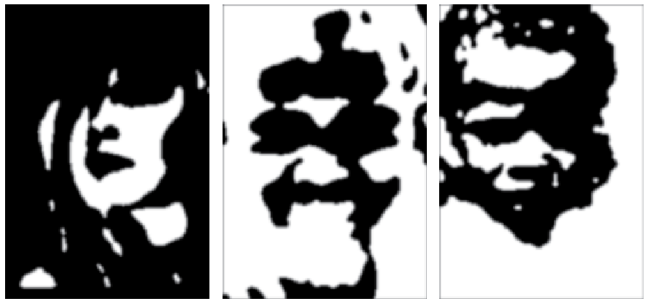


ambiguous faces

Asp, Stoermer & Brady, 2019; Brady, Stoermer & Alvarez, 2019

Knowledge shapes individual memories

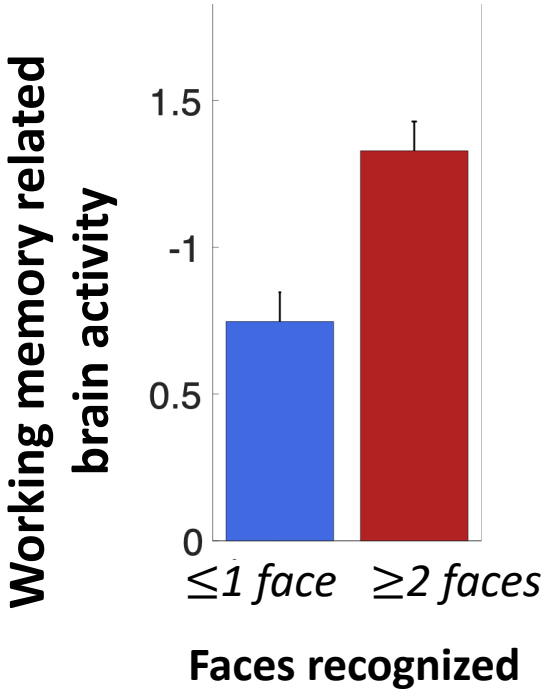


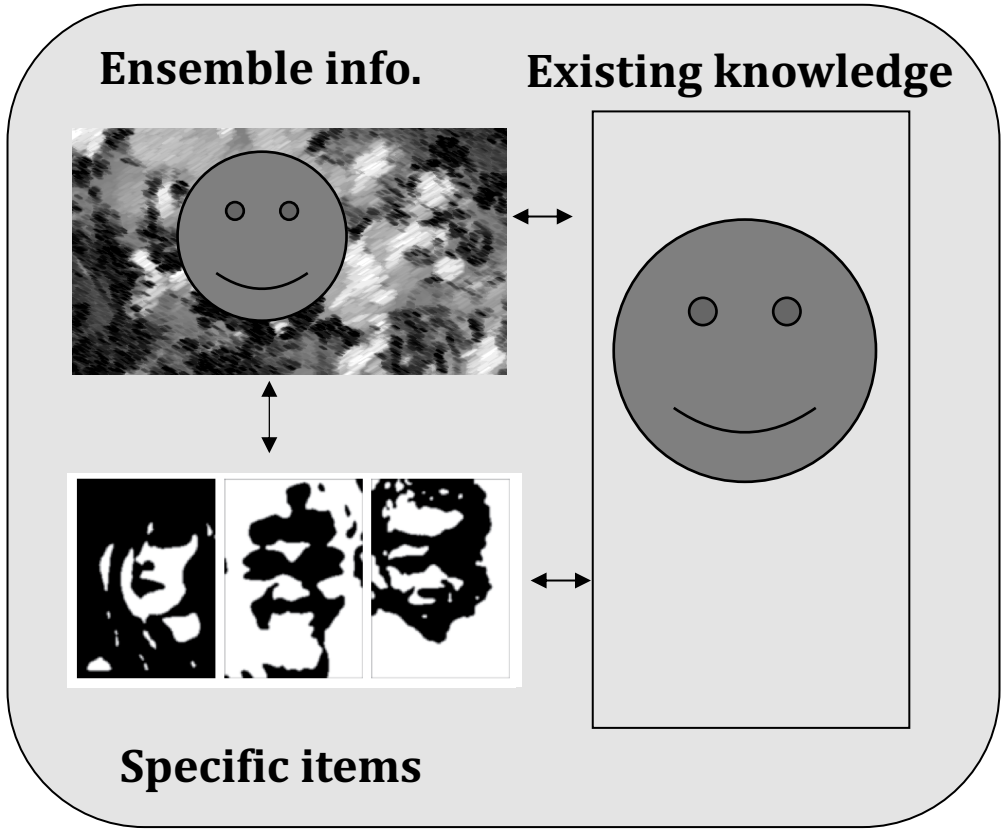


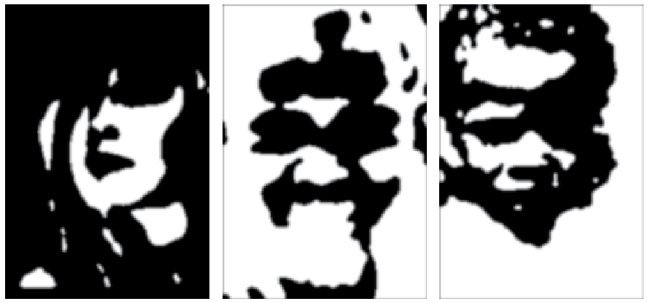
ambiguous faces

Asp, Stoermer & Brady, 2019; Brady, Stoermer & Alvarez, 2019

Knowledge shapes individual memories



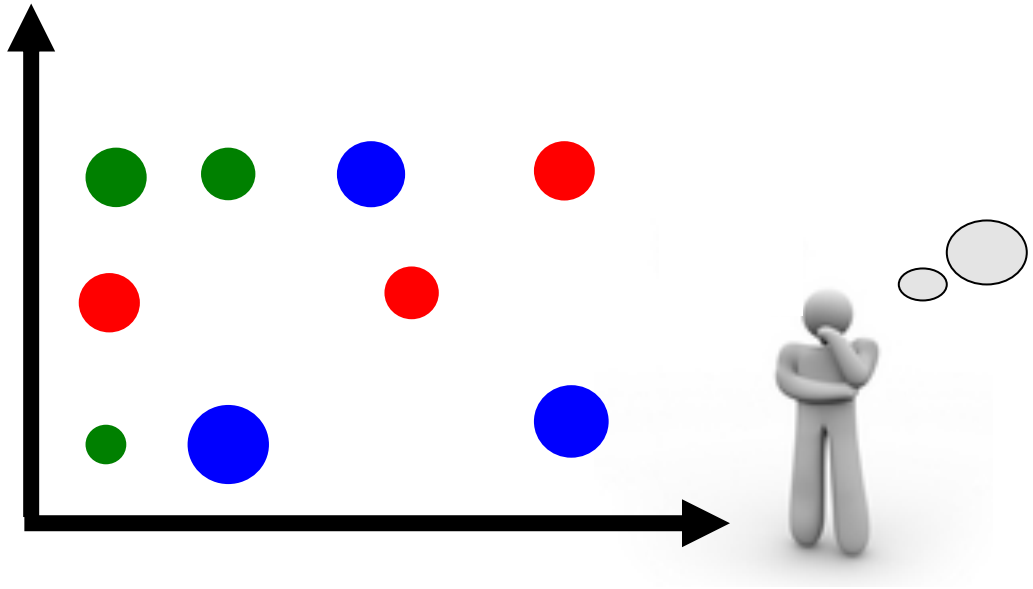


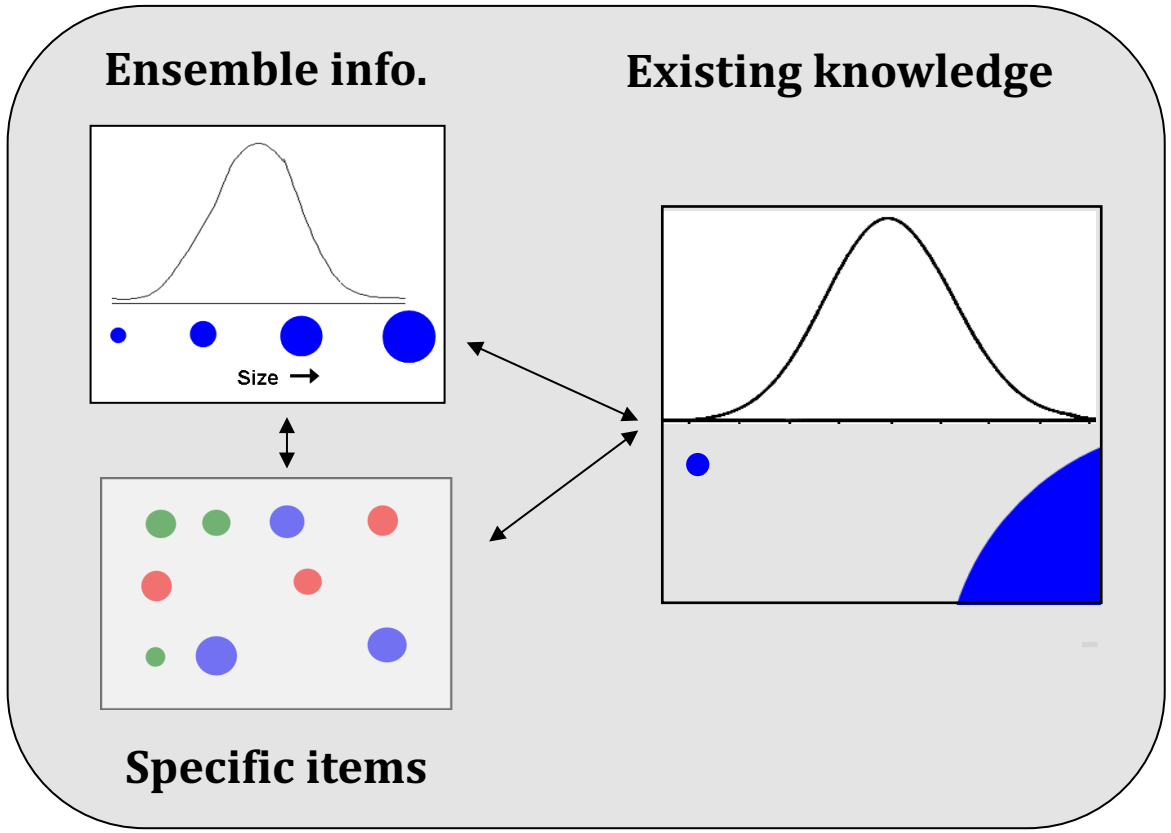


Related to ”curse of knowledge”:
e.g., Xiong, van Weelden, Franconeri, 2019.

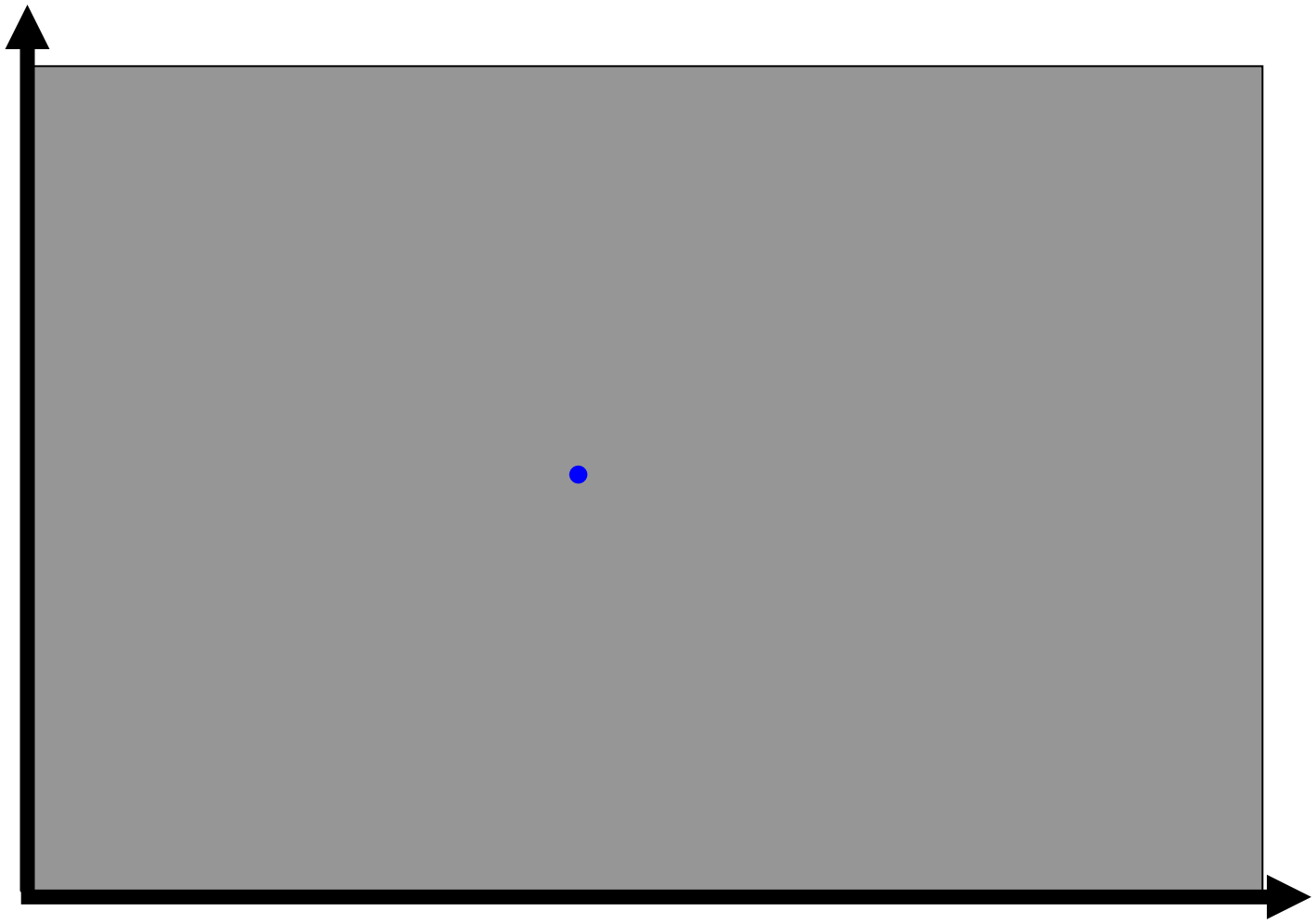
Asp, Stoermer & Brady, 2019; Brady, Stoermer & Alvarez, 2019

Ensemble information shapes individual memories





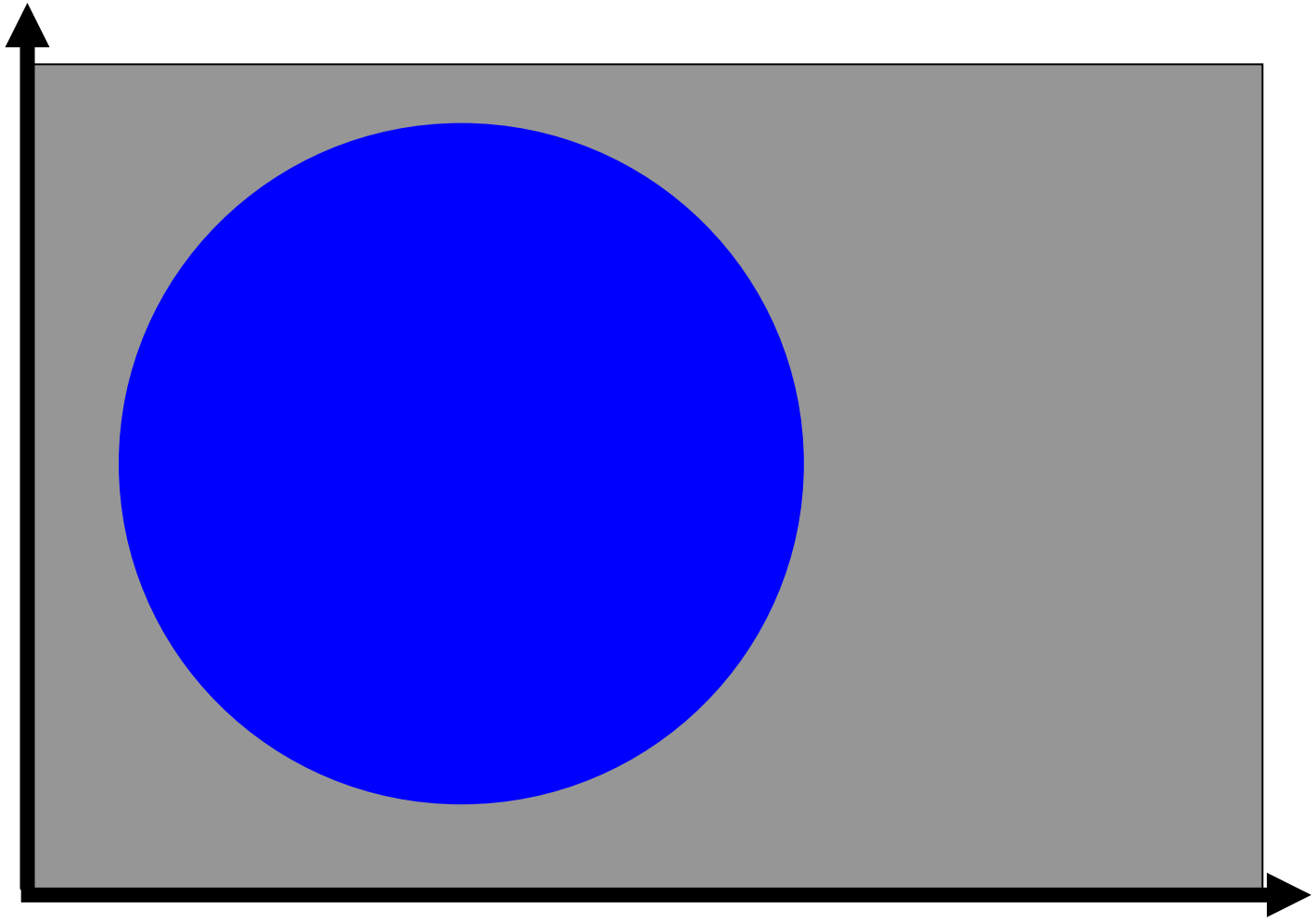
Brady & Alvarez (2011) *Psych. Science*



Imagine I put 9 dots in this display and ask you to remember the SIZE of these dots.

Imagine one of these dots. Was it bigger or smaller than **this**?

Brady & Alvarez (2011) *Psych. Science*



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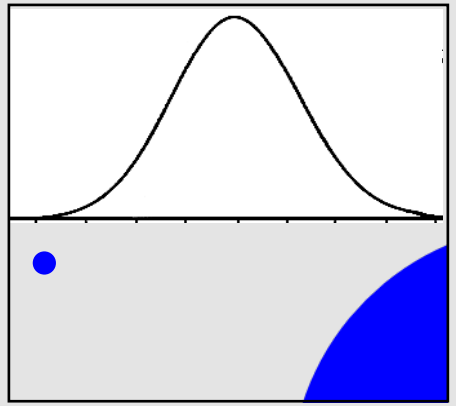
Imagine one of these dots. Was it bigger or smaller than **this**?

Brady & Alvarez (2011) *Psych. Science*

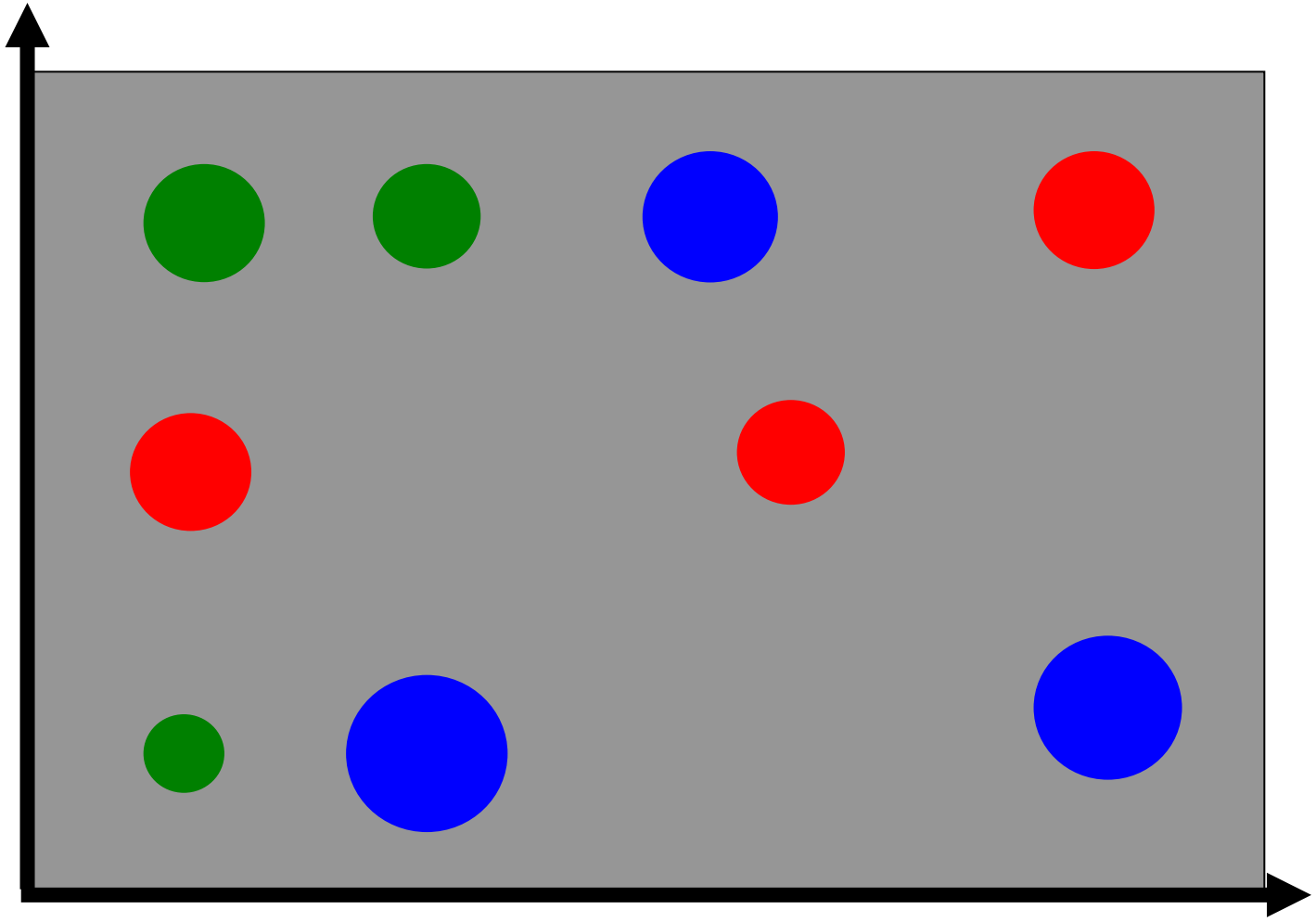
Your knowledge of the size of that dot comes from…

Ensemble info.

Existing knowledge



Specific items



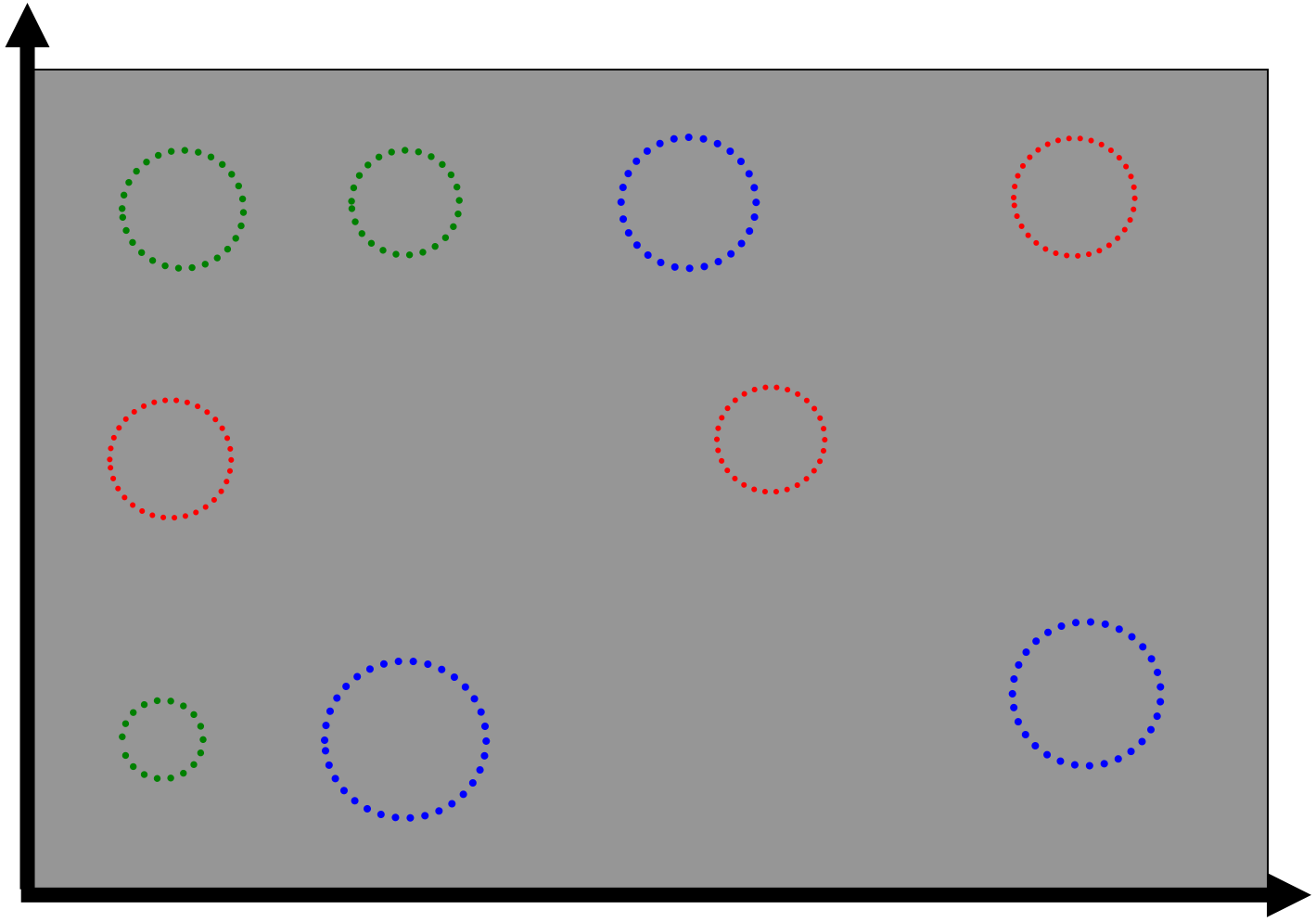
Remember the **SIZE** of the **red** and **blue** dots (ignore GREEN)

Brady & Alvarez (2011) *Psych. Science*

Were the red or
blue dots larger?

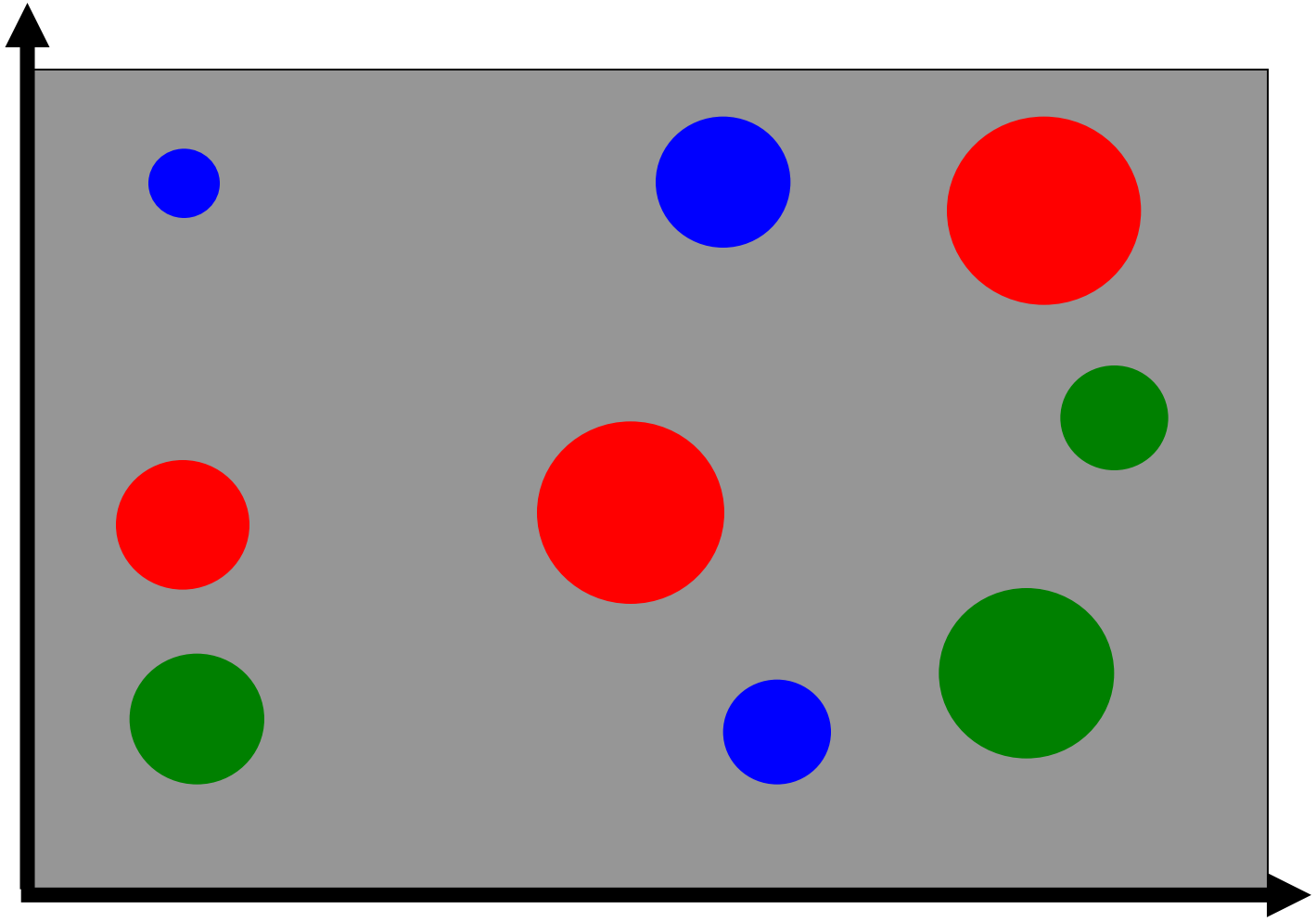
Brady & Alvarez (2011) *Psych. Science*

BLUE



Were the red or
blue dots larger?

Brady & Alvarez (2011) *Psych. Science*



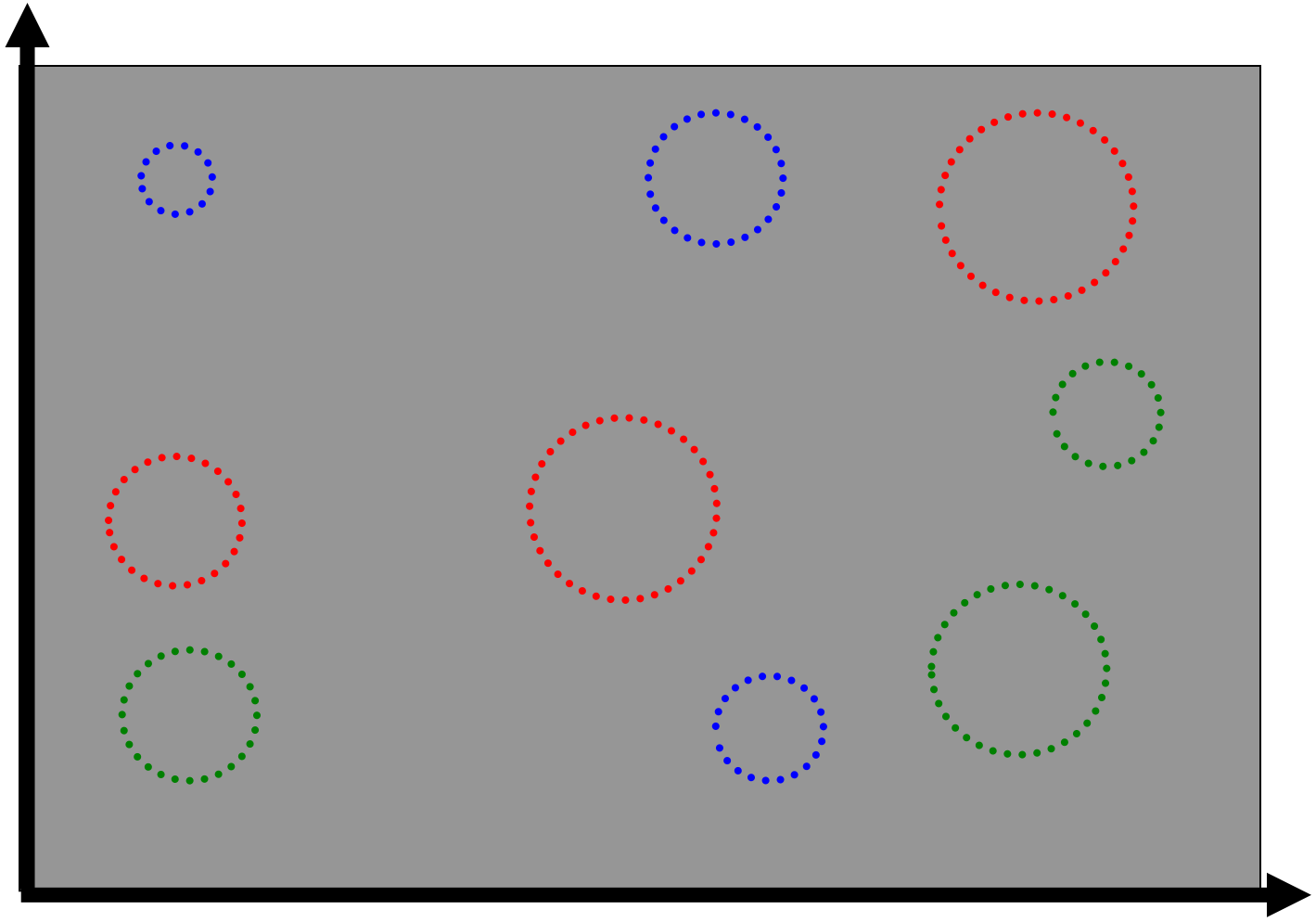
Remember the
SIZE of the
red and **blue**
dots

Brady & Alvarez (2011) *Psych. Science*

Were the red or
blue dots larger?

Brady & Alvarez (2011) *Psych. Science*

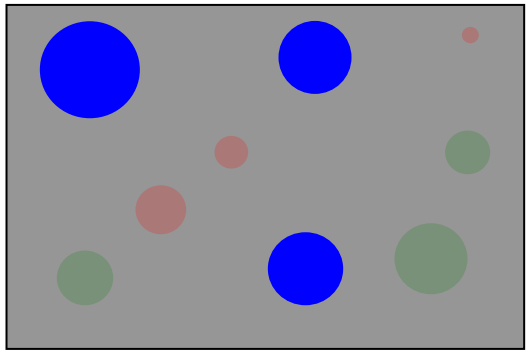
RED



Were the red or
blue dots larger?

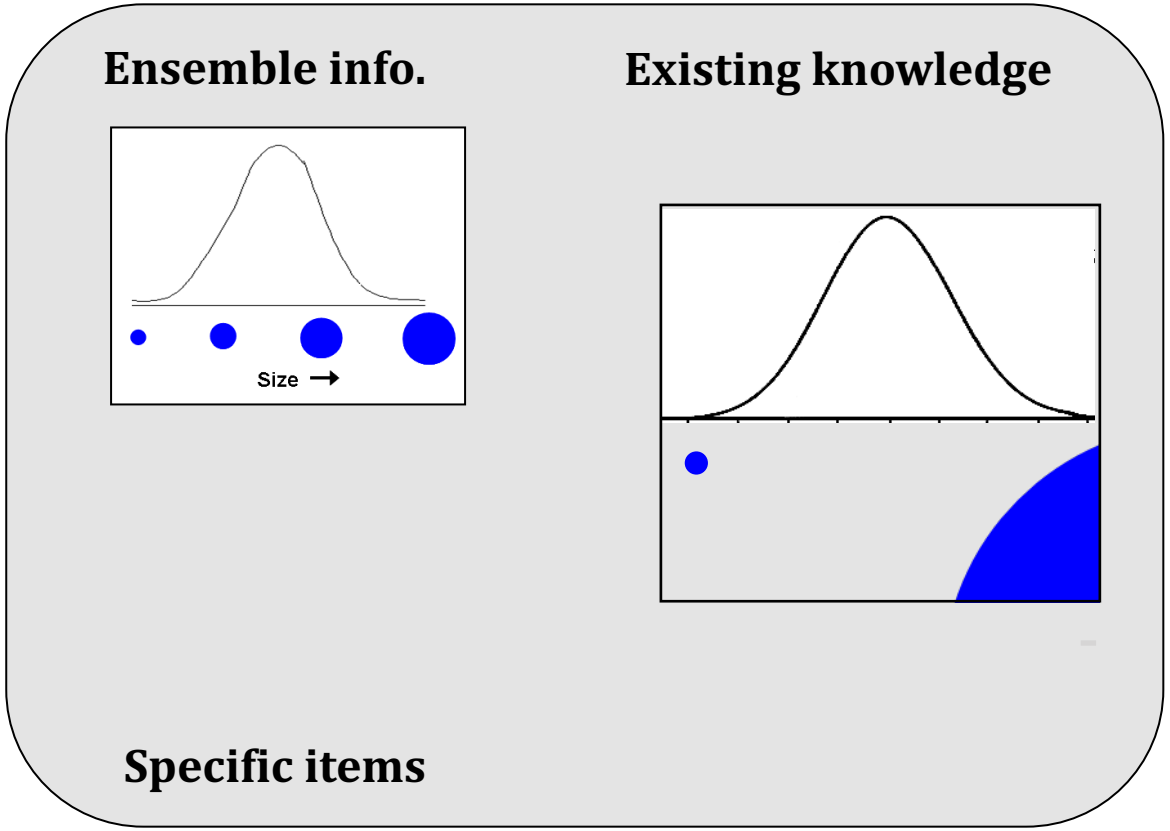
Brady & Alvarez (2011) *Psych. Science*

Your knowledge of the size of that dot comes from…



Ensemble:
Blue dots are big

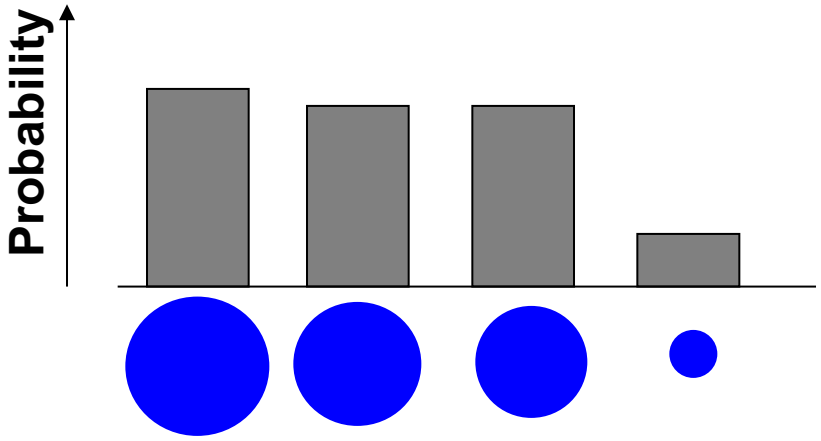
e.g., Ariely, 2001; Chong & Treisman, 2003



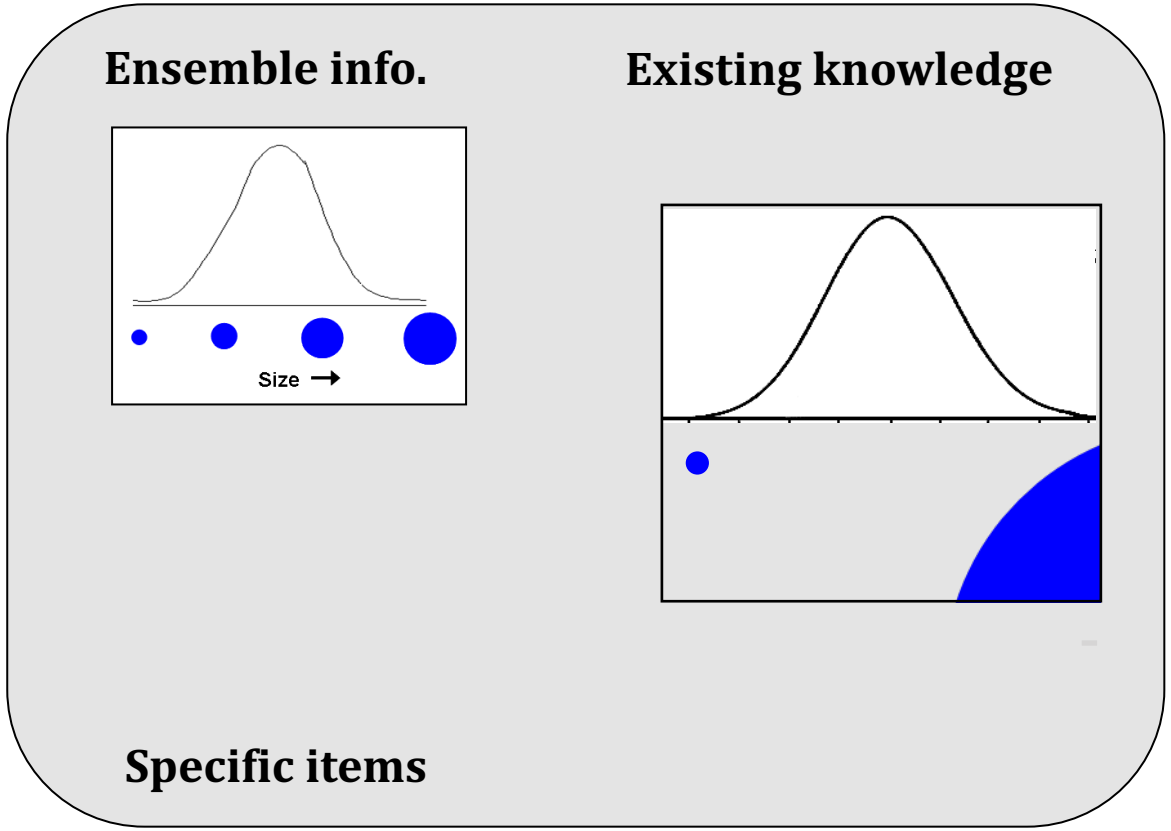
In vis context: Yuan, L., Haroz, S., Franconeri, S. (2019).

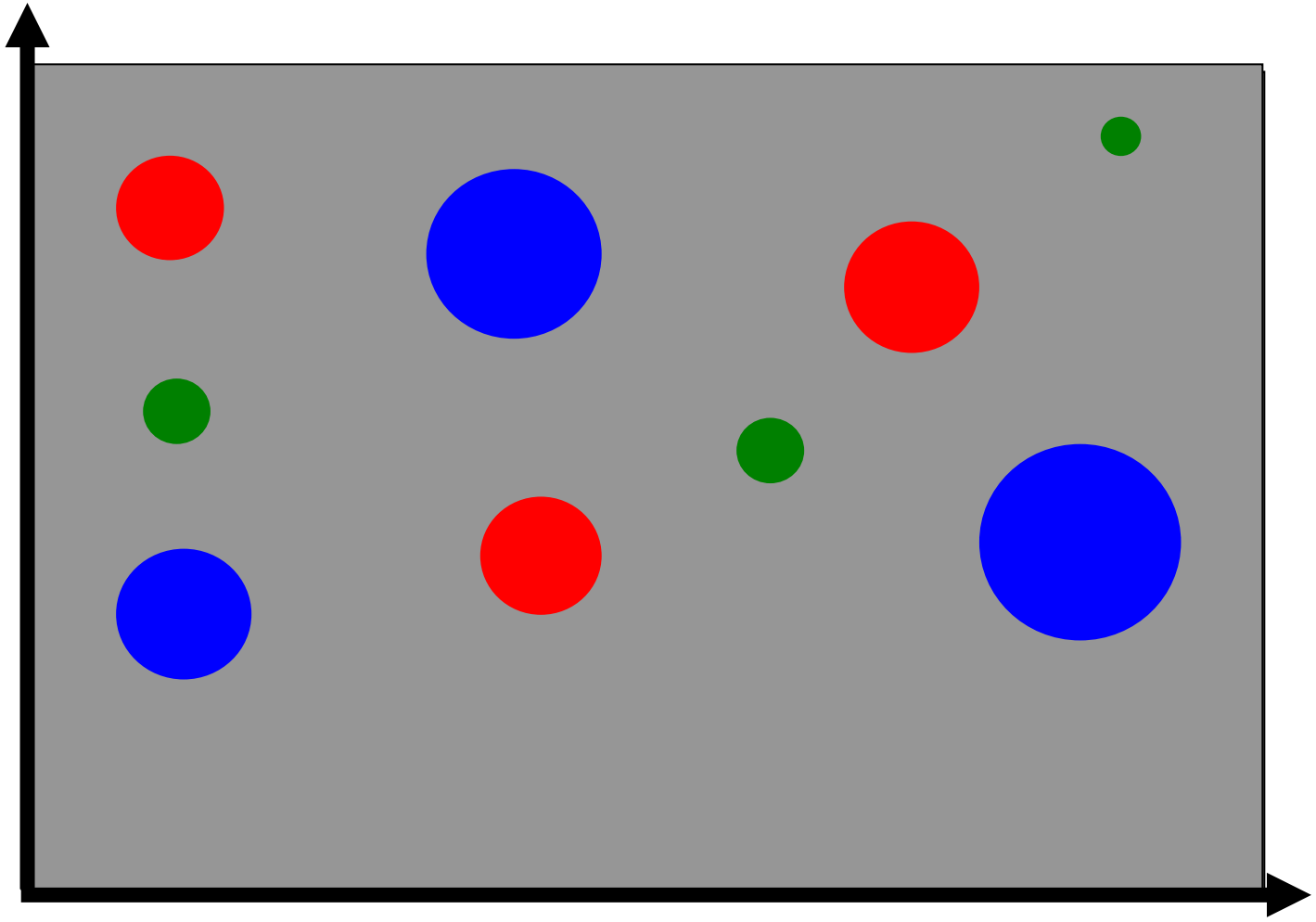
Your knowledge of the size of that dot comes from…

These knowledge sources should shape your item memory



Brady & Alvarez, 2011, *Psych. Science*

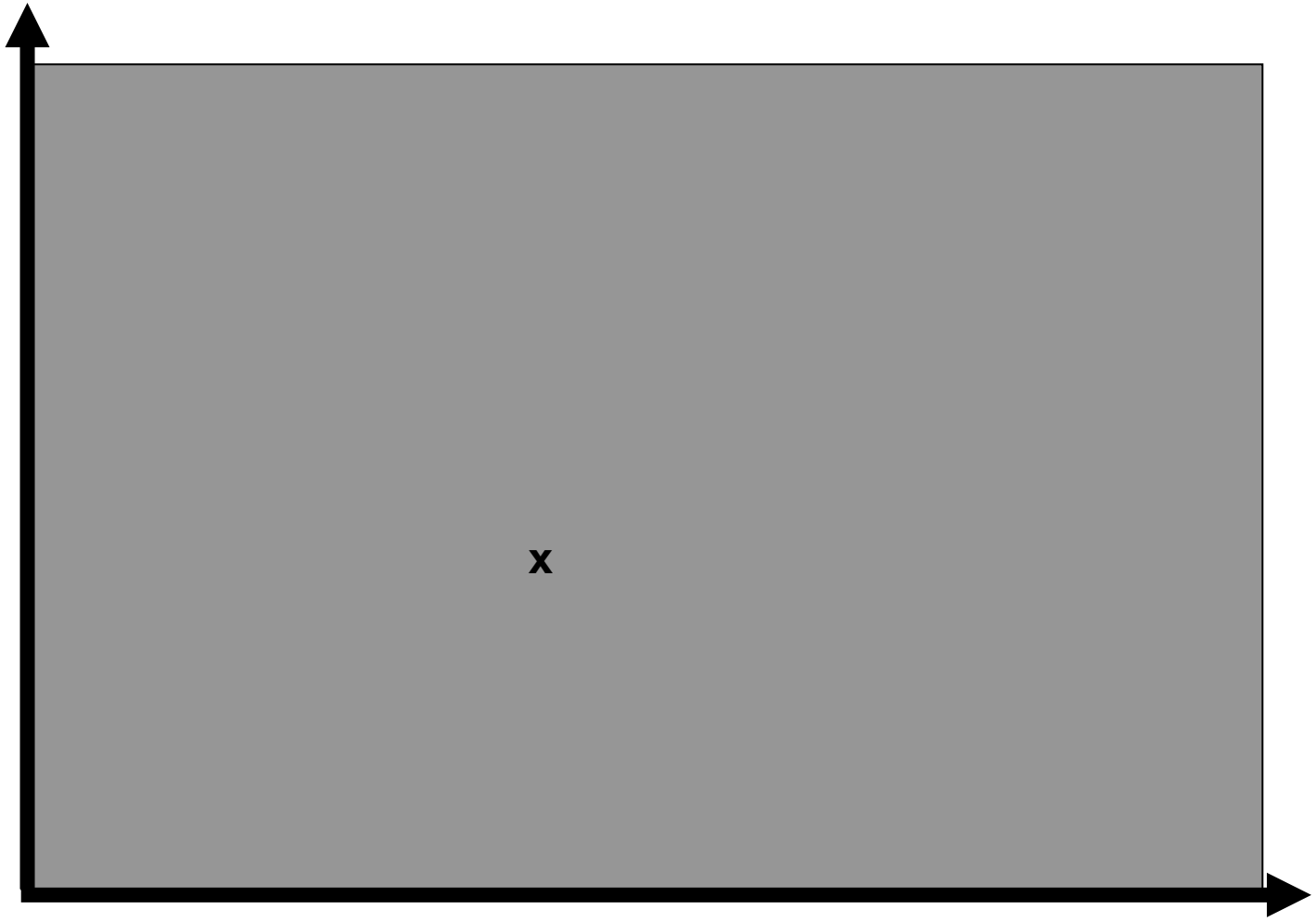




Remember the **SIZE** of the **red** and **blue** dots

Say ‘small’, ‘medium’ or ‘large’

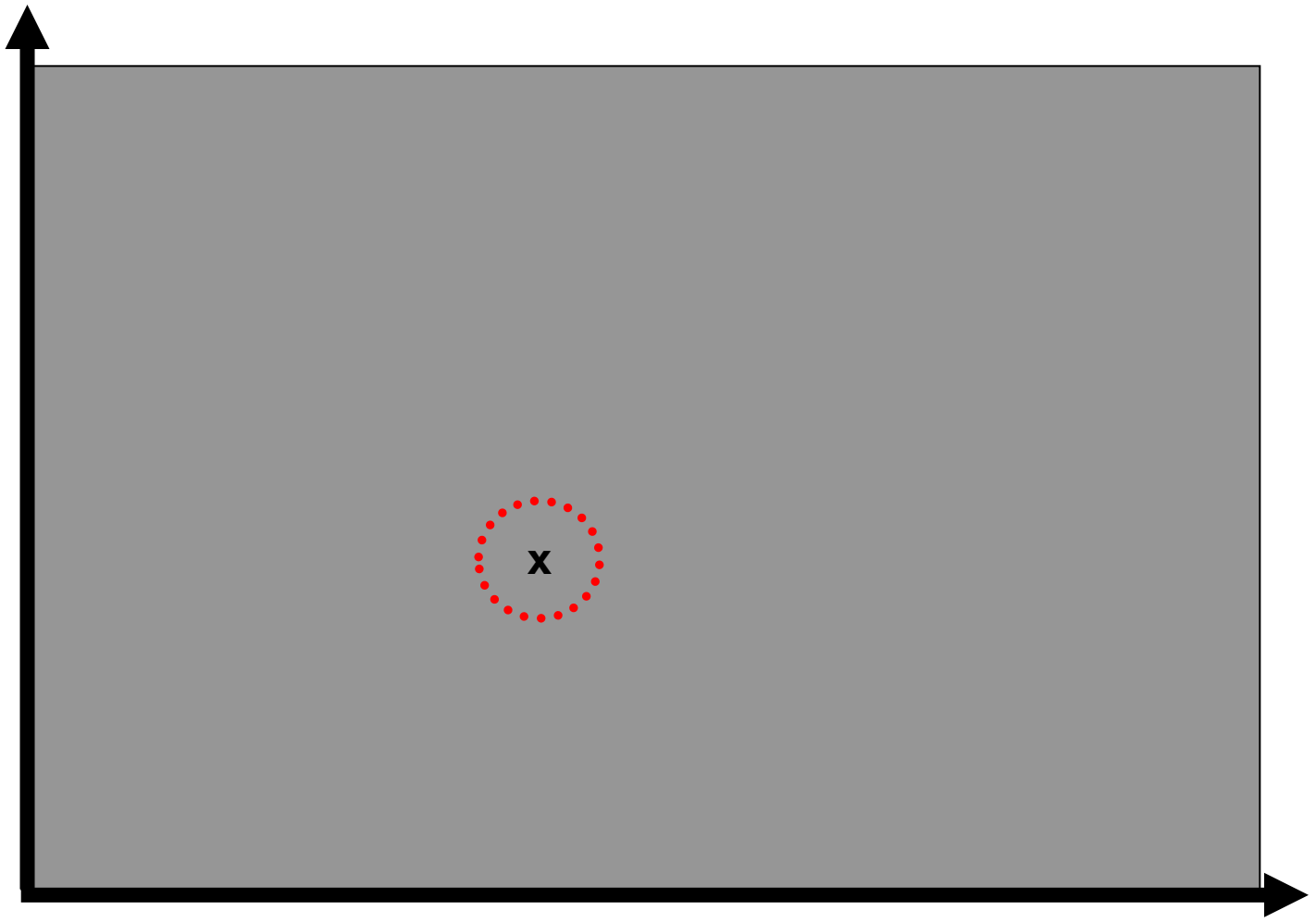
Brady & Alvarez (2011) *Psych. Science*



What size was the dot that was right here?

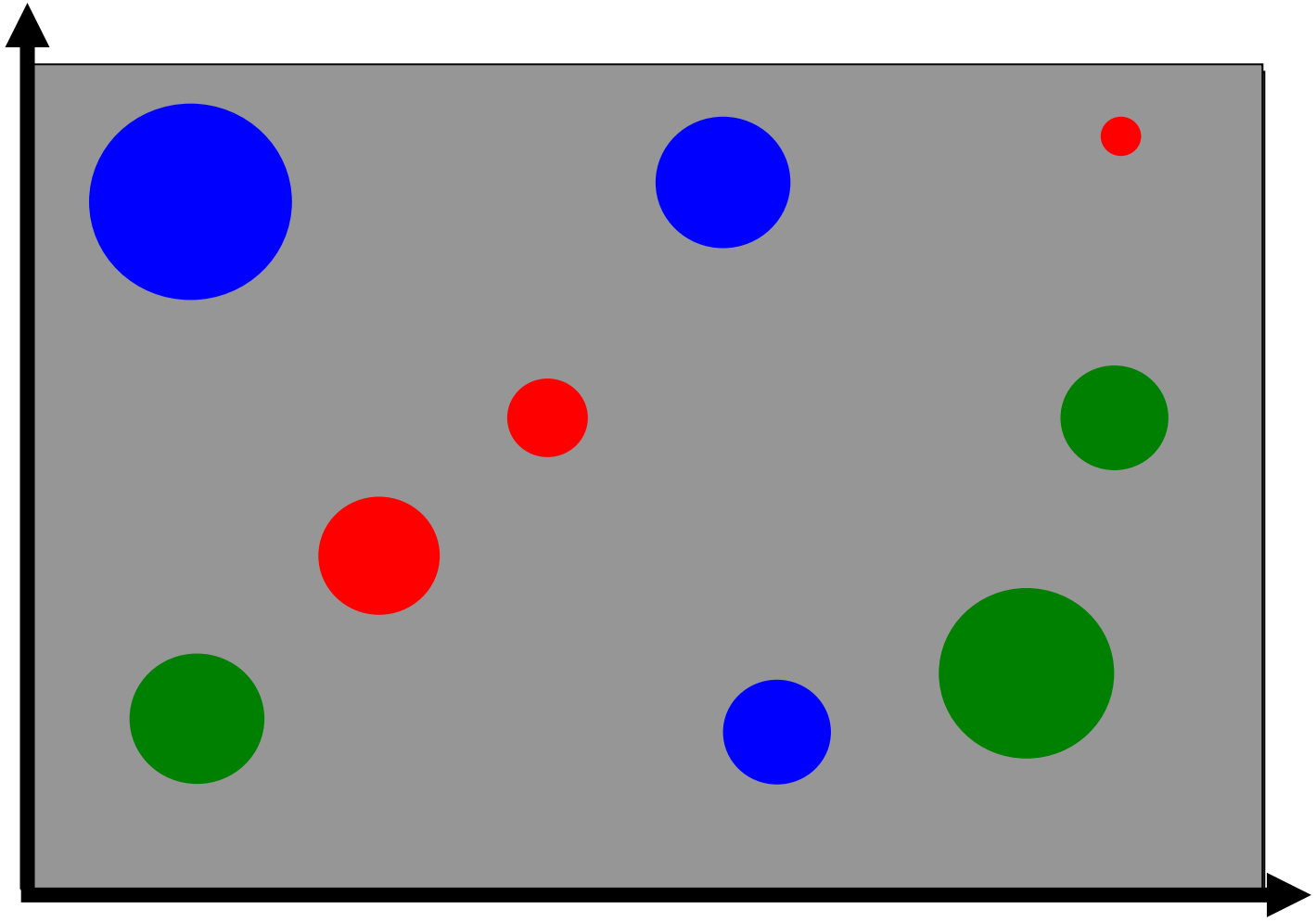
Brady & Alvarez (2011) *Psych. Science*

MEDIUM



What size was the dot that was right here?

Brady & Alvarez (2011) *Psych. Science*



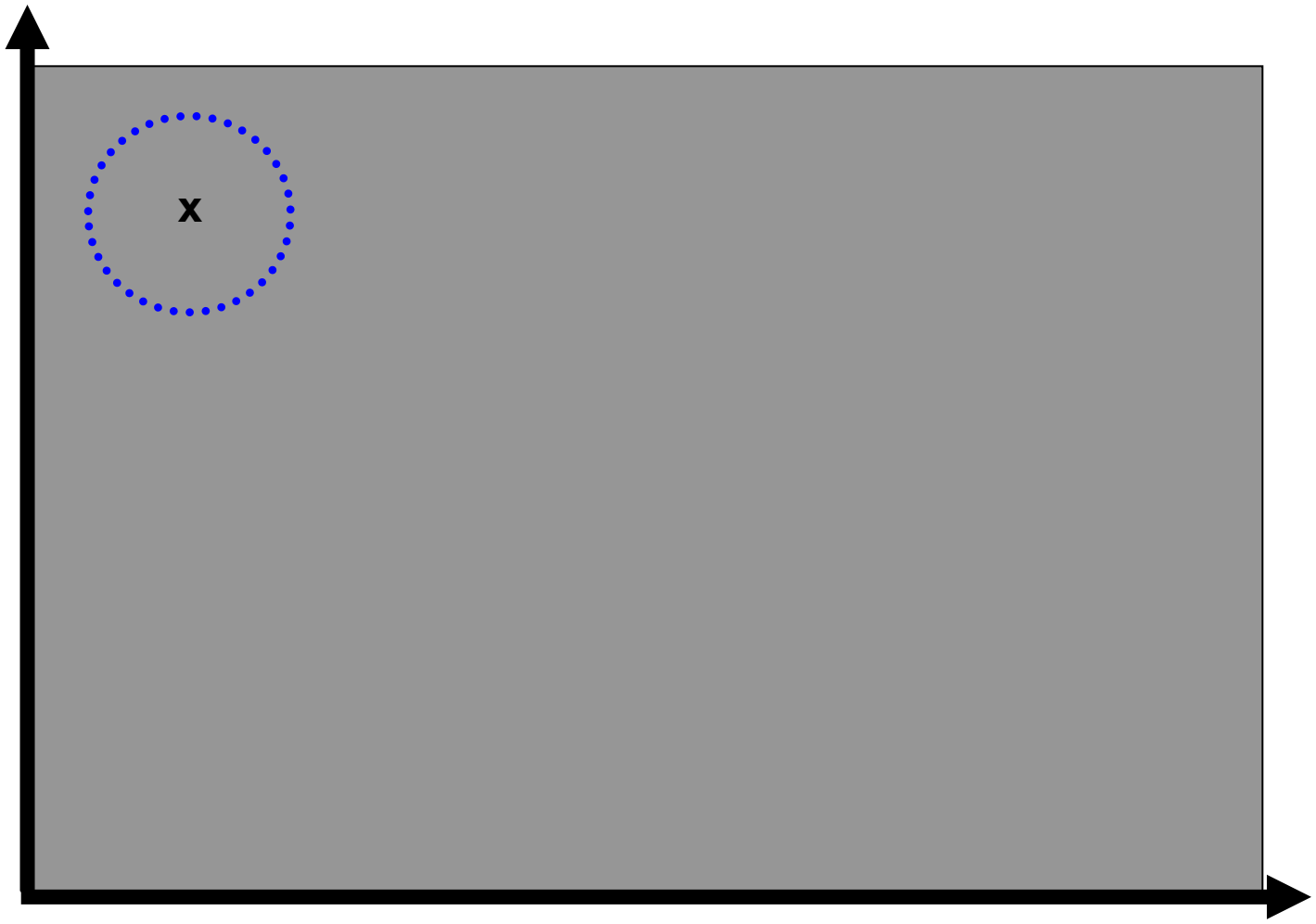
Remember the
SIZE of the
red and **blue**
dots

Brady & Alvarez (2011) *Psych. Science*

What size was the dot that was right here?

Brady & Alvarez (2011) *Psych. Science*

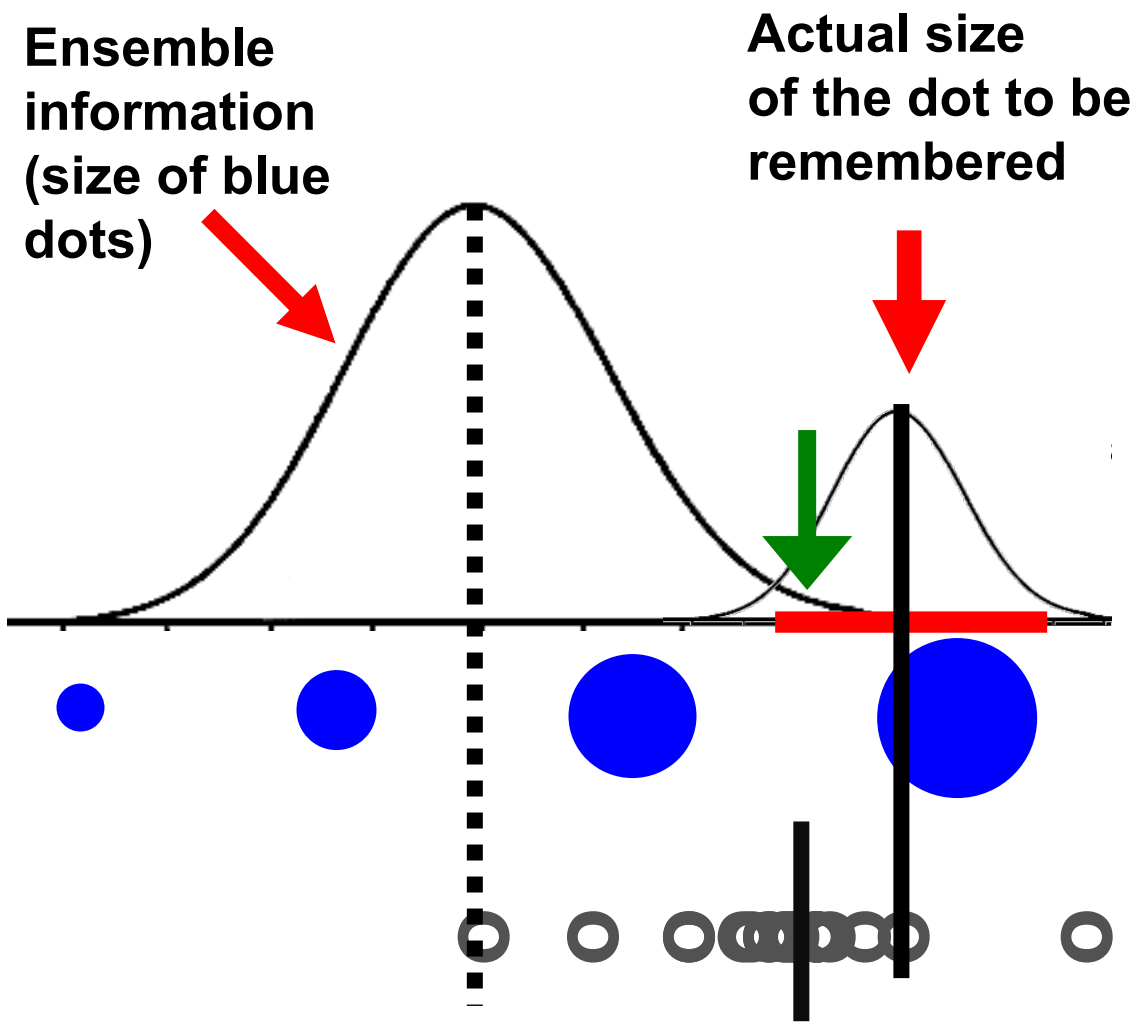
LARGE



What size was the dot that was right here?

Brady & Alvarez (2011) *Psych. Science*

What do we encode about these displays?



Optimal integration:

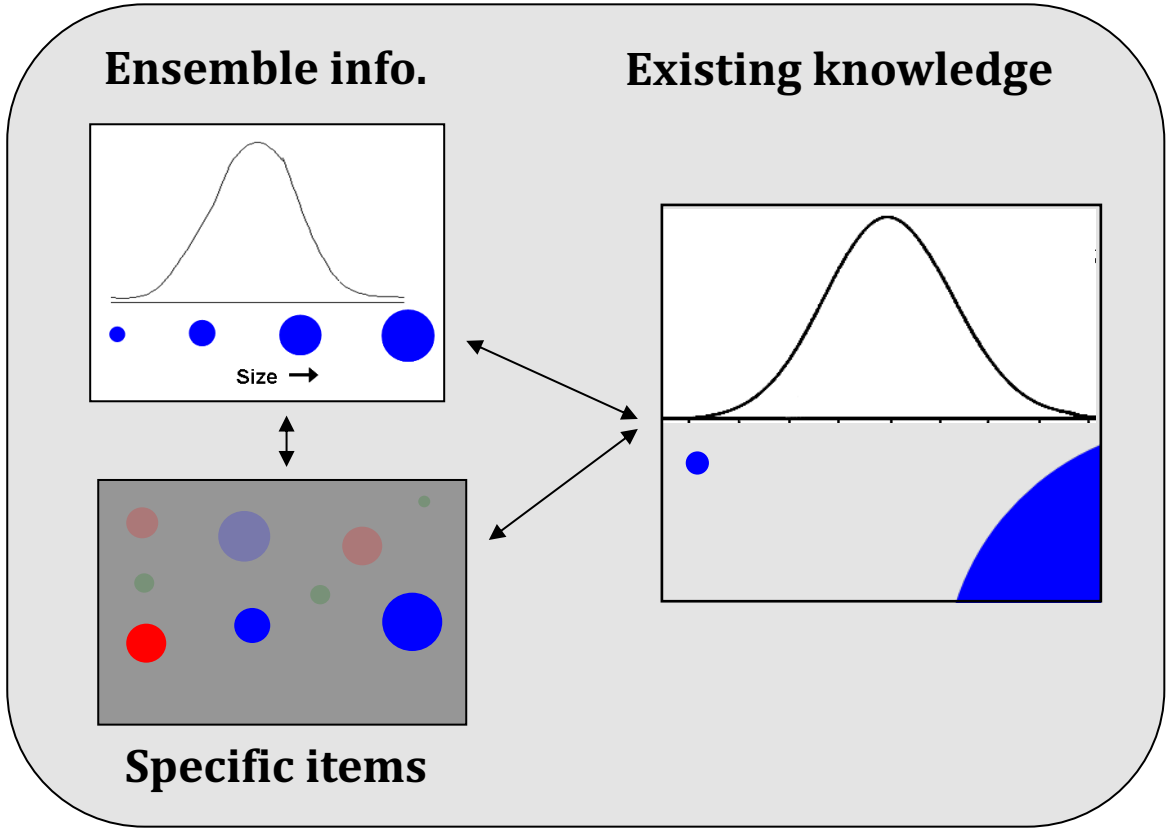
Ensemble information helps you modulate your (*noisy*) memory for the individual item to minimize error

The data

Brady & Alvarez (2011) *Psych. Science*

Proposed mental model: hierarchical & noisy

Existing knowledge and context are integral parts of our working memories.

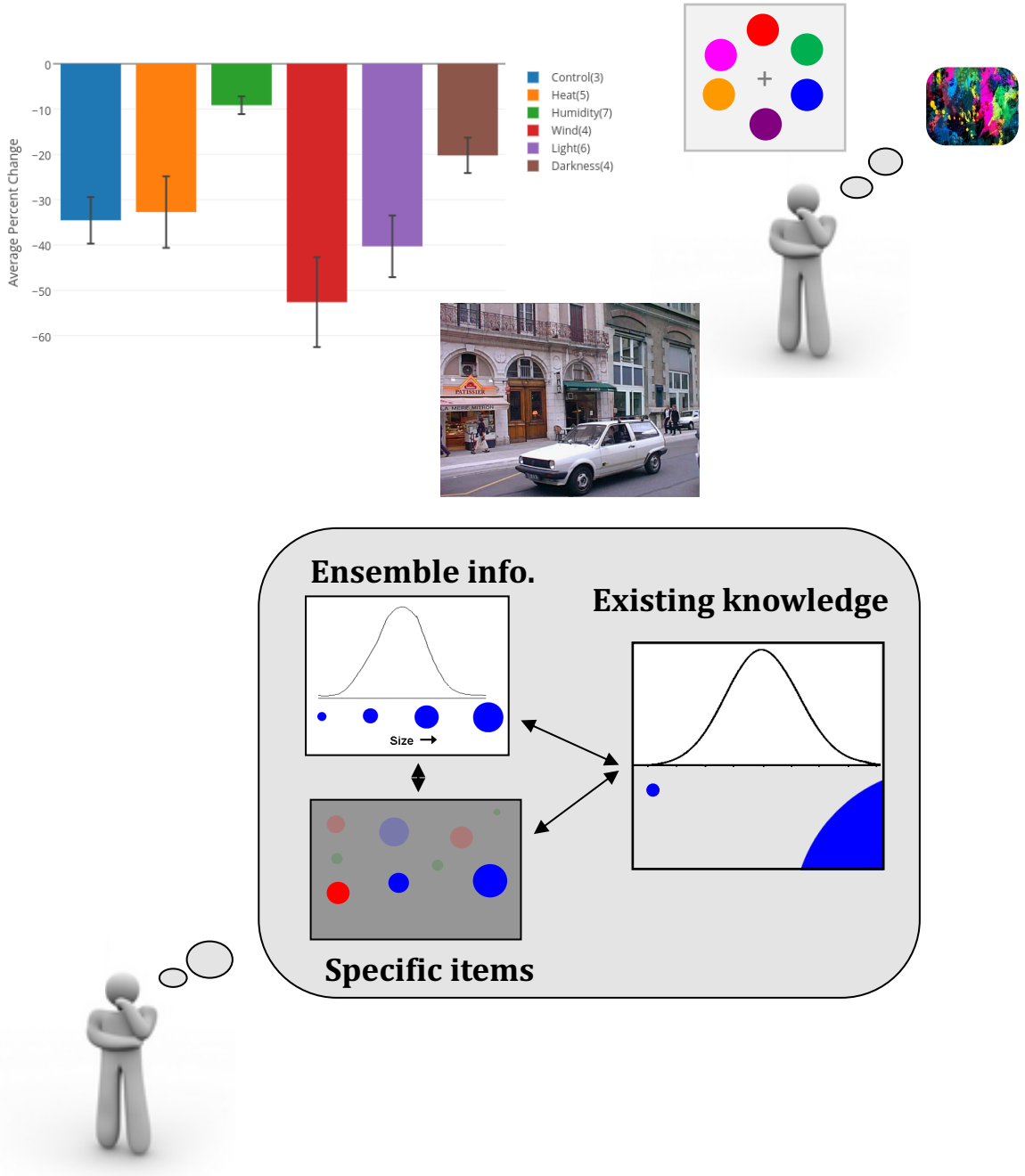


Your knowledge of the size of a dot comes from…

My goals:

(1) Convince you working memory matters for visualization design and processing

(2) Give you a mental model for thinking about working memory limits



Thanks!

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