

# The psycho-logic of *each* and *every*

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LingLangLunch @ Brown

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# Big picture: Linguistic meaning in the mind



What sorts of instructions do meanings provide to cognition?

- To what extent do they constrain the thought that gets built?
- At what grain-size are they shared by speakers?

# Why *each* and *every*?

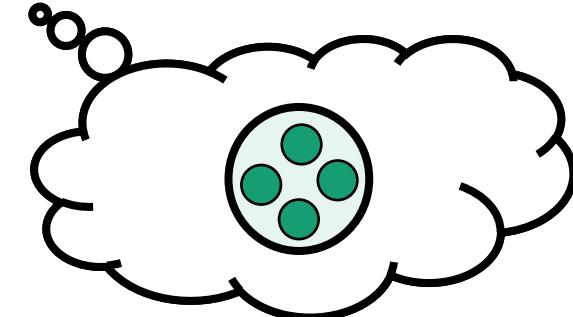
→ Can state precise hypotheses about their meaning representations

→ Can leverage an understanding of supporting cognitive systems

e.g., those for representing number, groups, individuals

“Every circle is green”

TheX:Circle(X)  
[Green(X)]



(Other case studies I'm working on:  
superlatives vs. comparatives; English & Cantonese *most*)

# Roadmap: How are *each* & *every* mentally represented?

## Three hypotheses

- Two (psycho)logical distinctions

Relational  
Second-order

Restricted  
Second-order

Restricted  
First-order

## Relational vs. Restricted

- Number cognition as a probe into which arguments are represented
- The “conservativity” universal

## First-order vs. Second-order (individual- vs. group- implicating)

- Object-files vs. Ensembles as a probe into how arguments are represented
- Consequences for language acquisition

# *Each/Every circle is green* – possible representations

The circles<sub>x</sub> are among the green-things<sub>y</sub>

$\text{TheX:Circle}(X) \subseteq \text{TheY:Green}(Y)$

The circles<sub>x</sub> are such that they<sub>x</sub> are green

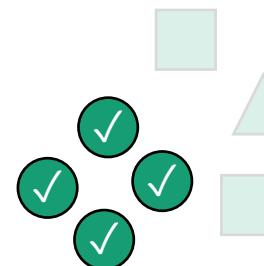
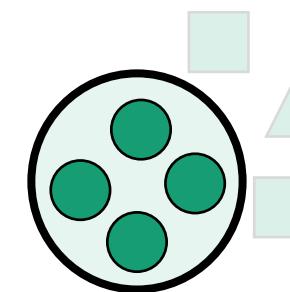
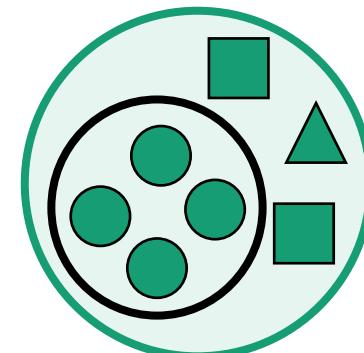
$\text{TheX:Circle}(X)[\text{Green}(X)]$

Any individual circle<sub>x</sub> is such that it<sub>x</sub> is green

$\forall x:\text{Circle}(x)[\text{Green}(x)]$

*every*

*each*



**Relational  
Second-order**

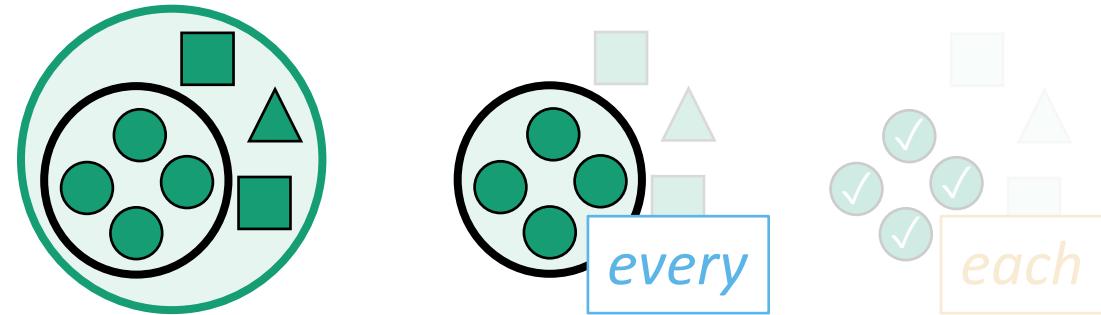
**Restricted  
Second-order**

**Restricted  
First-order**

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# Different representations & behavioral predictions

**Linking hypothesis (Interface Transparency):** In evaluating a sentence, people are biased toward strategies that **directly compute the relations & operations expressed** by the semantic representation under evaluation

## Relational

$\text{TheX:Circle}(X) \subseteq \text{TheY:Green}(Y)$

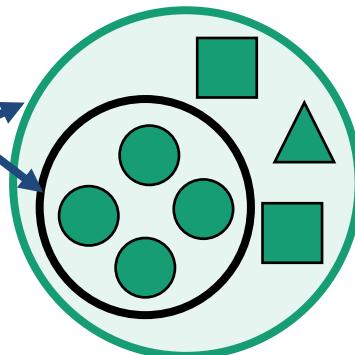
$\approx$ The circles<sub>X</sub> are among  
the green-things<sub>Y</sub>

## Restricted

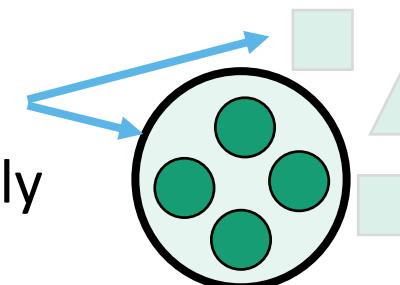
$\text{TheX:Circle}(X)[\text{Green}(X)]$

$\approx$ The circles<sub>X</sub> are such that  
they<sub>X</sub> are green

Represent &  
compare both  
arguments



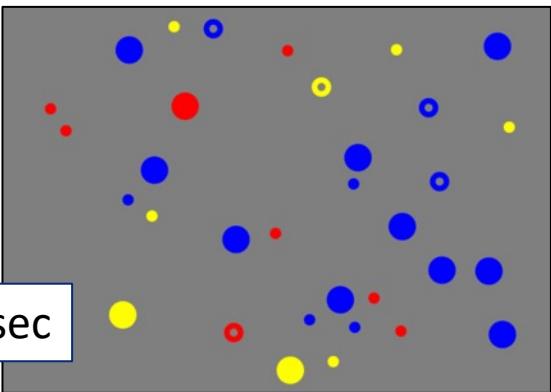
Treat  
arguments  
asymmetrically



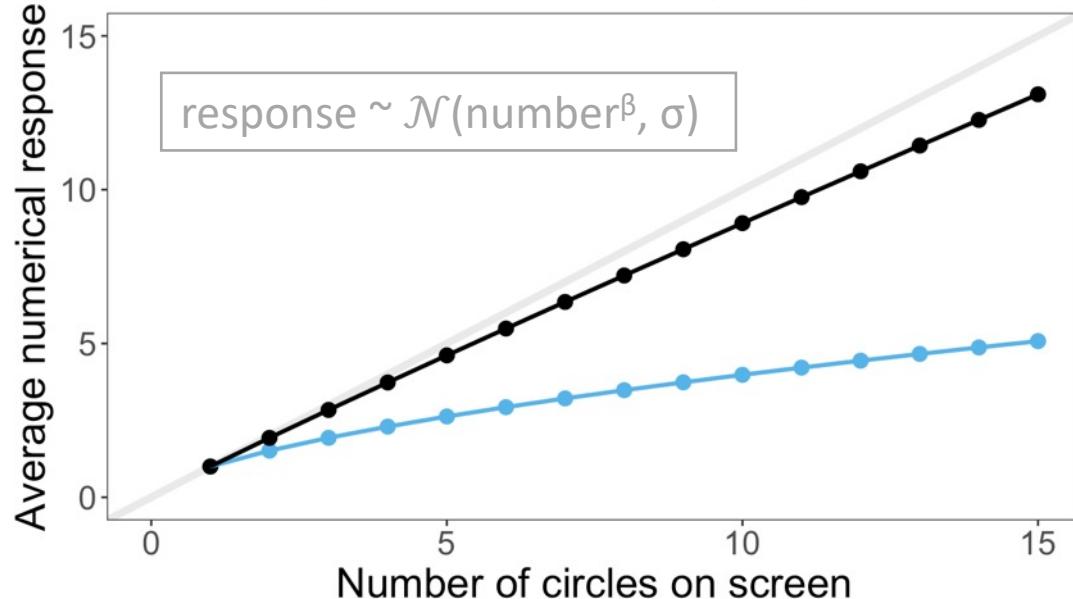
Every big circle is blue

TRUE

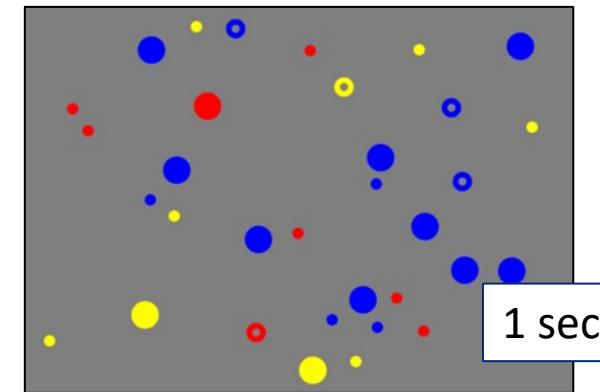
FALSE



Accuracy on “how many” question



How many big circles  
are there?



How many big circles  
were there?

#-knowledge following *every*  
vs.  
#-knowledge **baseline**

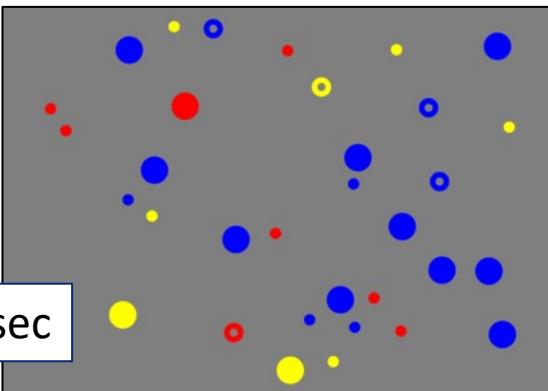
How many big circles  
were there?

Every big circle is blue

TRUE

FALSE

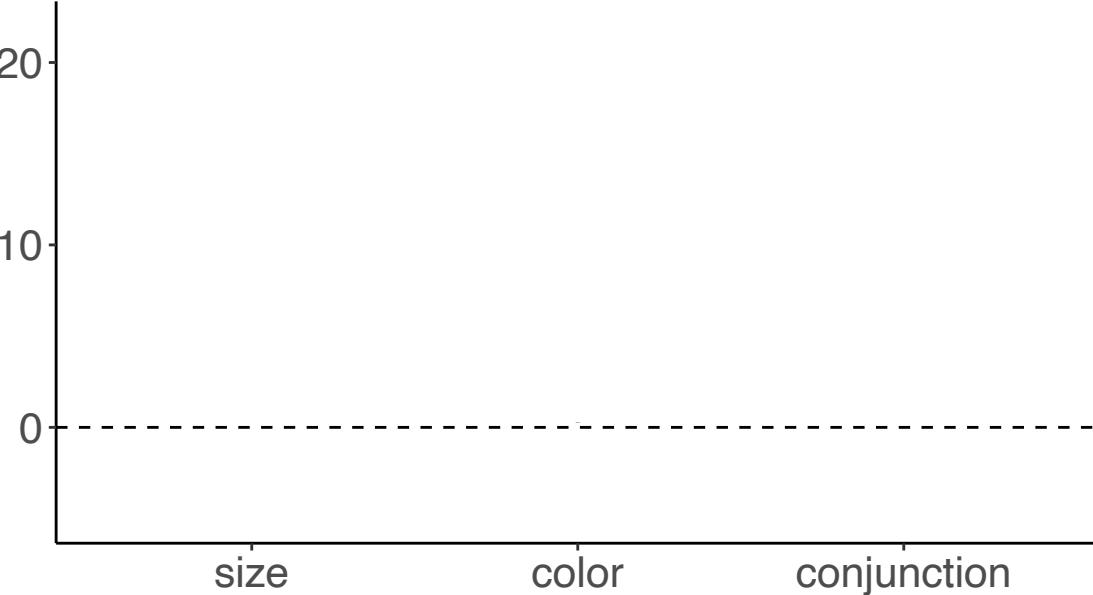
1 sec



How many  
{big/blue/big blue}  
circles were there?

Cardinality estimation error  
"Every [size] circle is [color]"

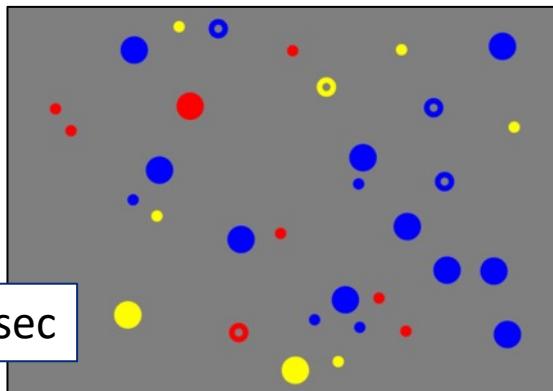
Difference in % error  
(post-verification – baseline)



Every big circle is blue

TRUE

FALSE



### Relational

*The big-circles<sub>x</sub> are among the blue-circles<sub>y</sub>*

Represent both arguments

How many  
{big/blue/big blue}  
circles were there?

Cardinality estimation error  
"Every [size] circle is [color]"

Difference in % error  
(post-verification – baseline)

size

color

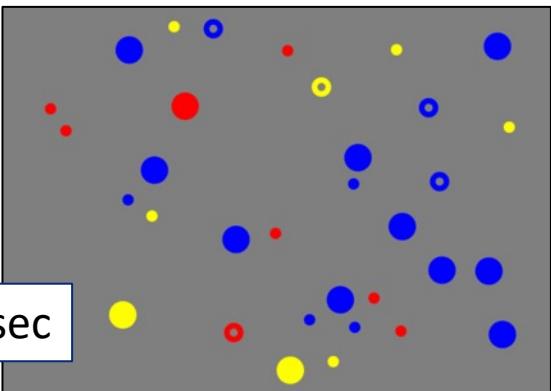
conjunction



Every big circle is blue

TRUE

FALSE



How many  
{big/blue/big blue}  
circles were there?

Relational

*The big-circles<sub>x</sub> are  
among the blue-circles<sub>y</sub>*

Represent both  
arguments

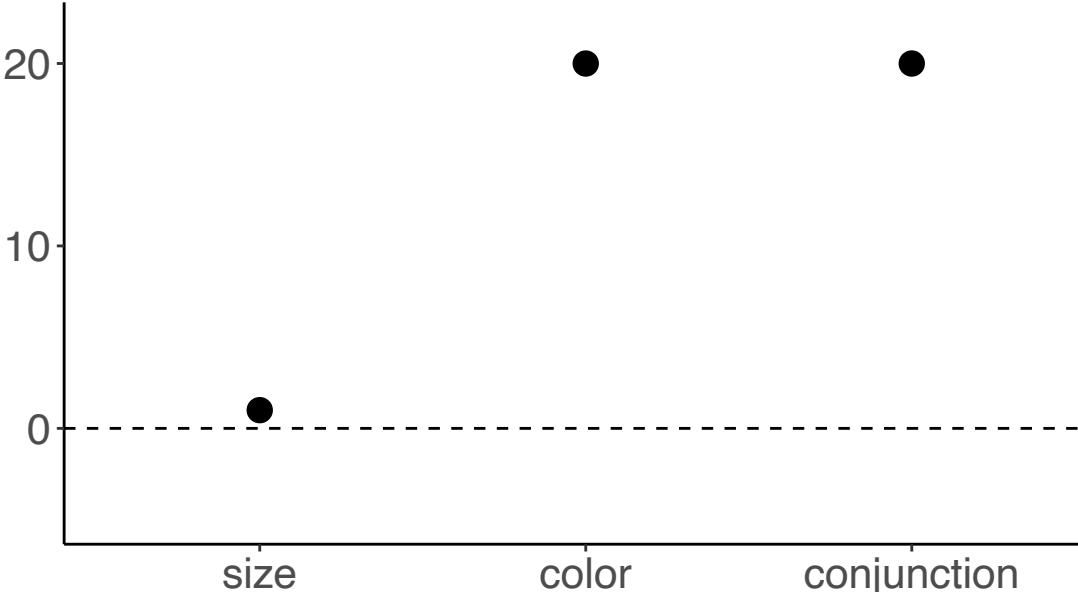
Restricted

*The big-circles<sub>x</sub> are such  
that they<sub>x</sub> are blue*

Treat arguments  
asymmetrically

Cardinality estimation error  
"Every [size] circle is [color]"

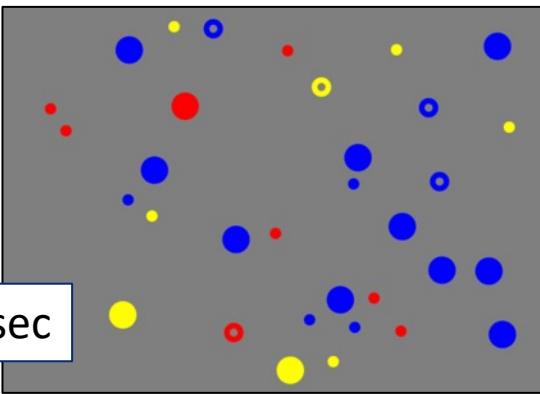
Difference in % error  
(post-verification – baseline)



Every big circle is blue

TRUE

FALSE



How many  
{big/blue/big blue}  
circles were there?

### Relational

*The big-circles<sub>x</sub> are among the blue-circles<sub>y</sub>*

Represent both arguments

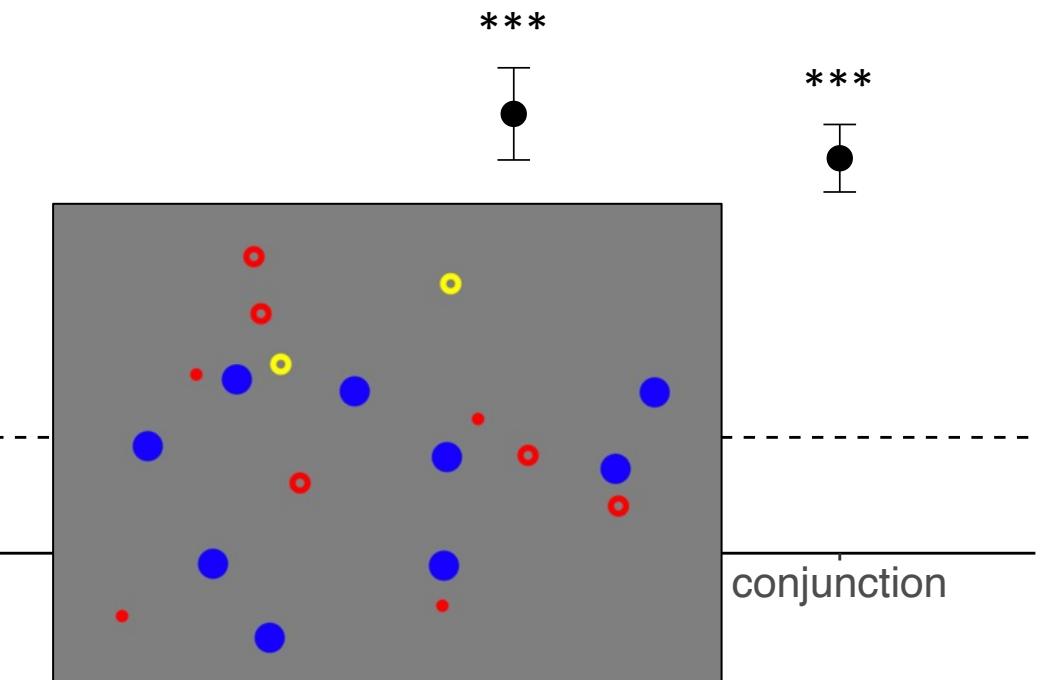
### Restricted

*The big-circles<sub>x</sub> are such that they<sub>x</sub> are blue*

Treat arguments asymmetrically

Cardinality estimation error  
"Every [size] circle is [color]"

Difference in % error  
(post-verification – baseline)



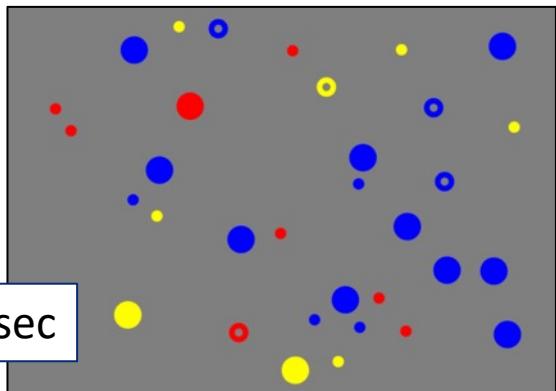
$|\text{BIG}| = |\text{BIG} \& \text{ BLUE}|$

n = 48

Every big one  
is a blue one

TRUE

FALSE



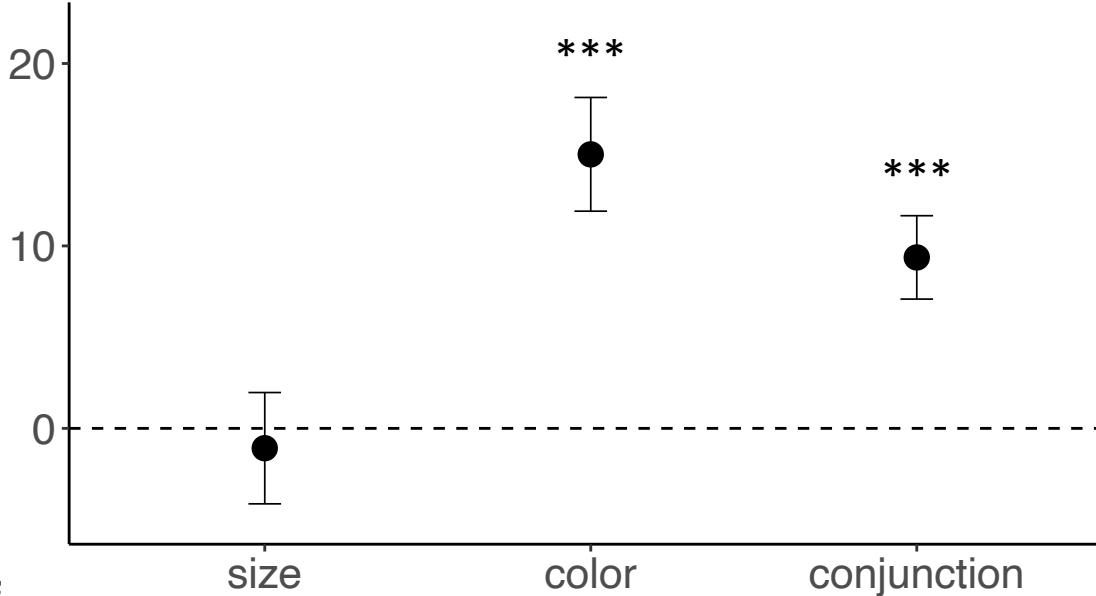
How many  
{big/blue/big blue}  
circles were there?

Does this reflect the  
two arguments being  
introduced in  
different ways?

No!

Cardinality estimation error  
"Every [size] one is a [color] one"

Difference in % error  
(post-verification – baseline)

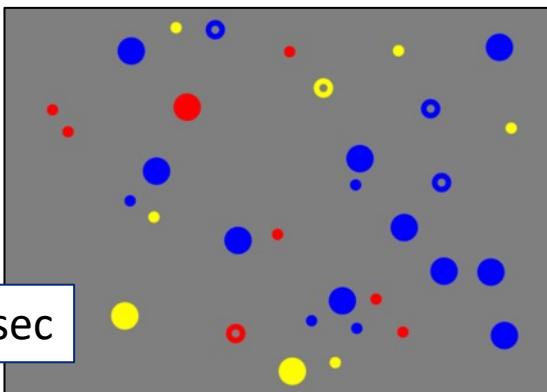


n = 48

Every circle that is big  
is blue

TRUE

FALSE



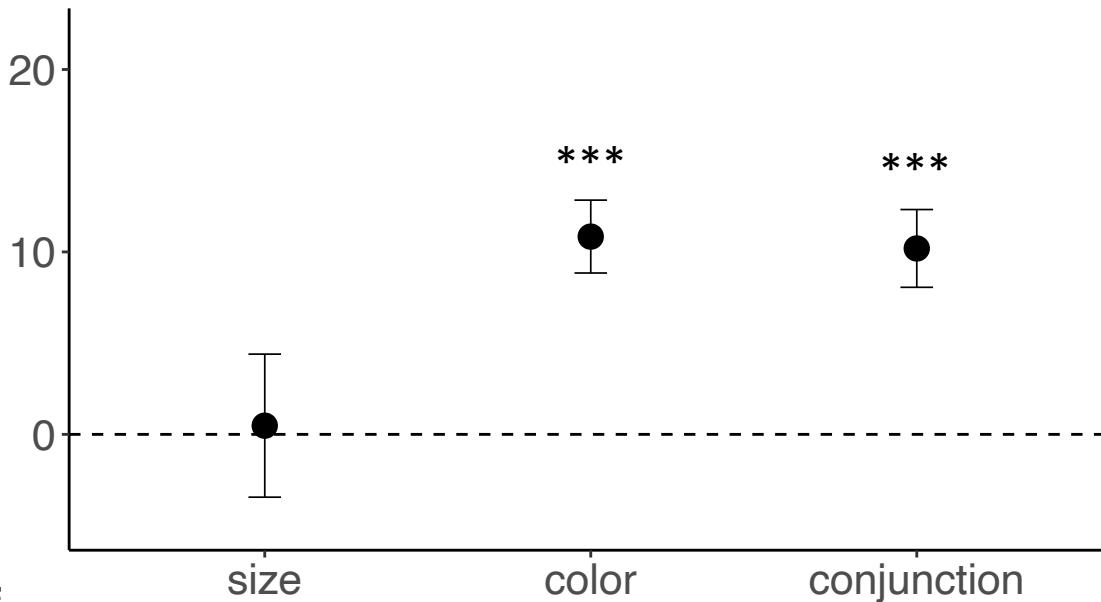
How many  
{big/blue/big blue}  
circles were there?

Does this reflect the  
two arguments being  
introduced in  
different ways?

No!

Cardinality estimation error  
"Every circle that is [size] is [color]"

Difference in % error  
(post-verification – baseline)

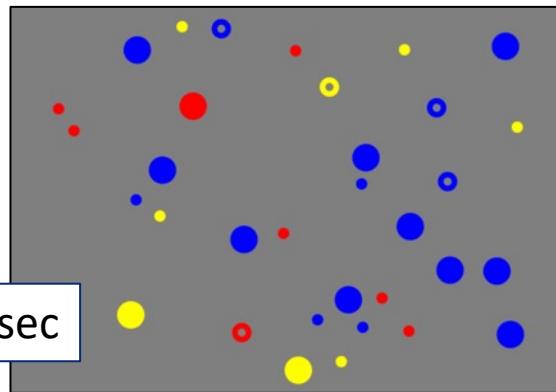


n = 48

Every big circle is blue

TRUE

FALSE



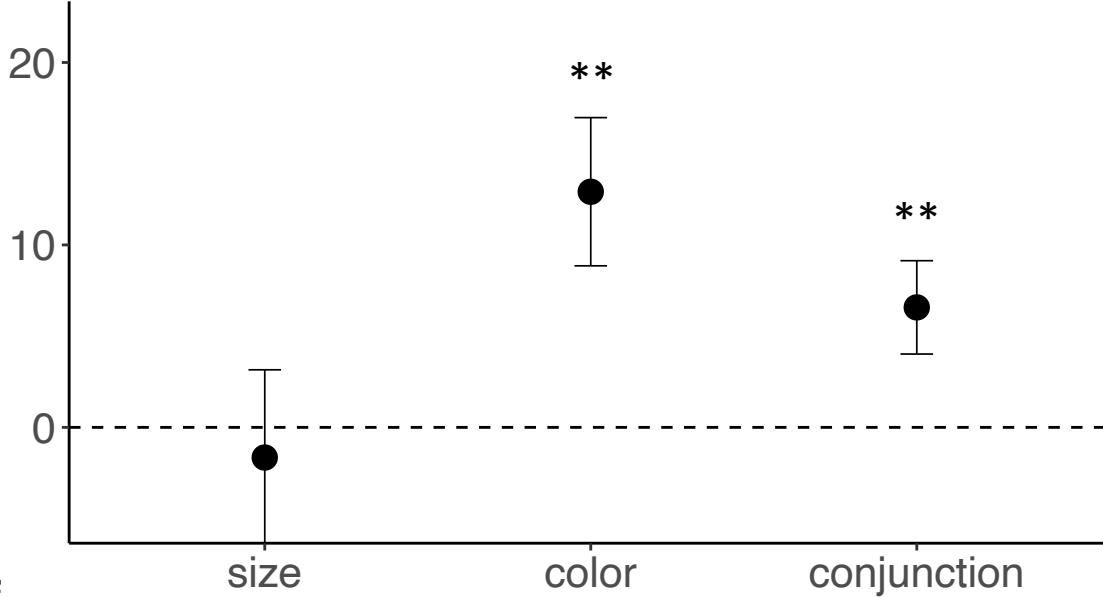
How many  
{big/blue/big blue}  
circles were there?

I don't know!

Another signature of  
the asymmetry:  
opting not to answer

Rate of pressing IDK button  
"Every [size] circle is [color]"

Difference in % Opting out  
(post-verification – baseline)

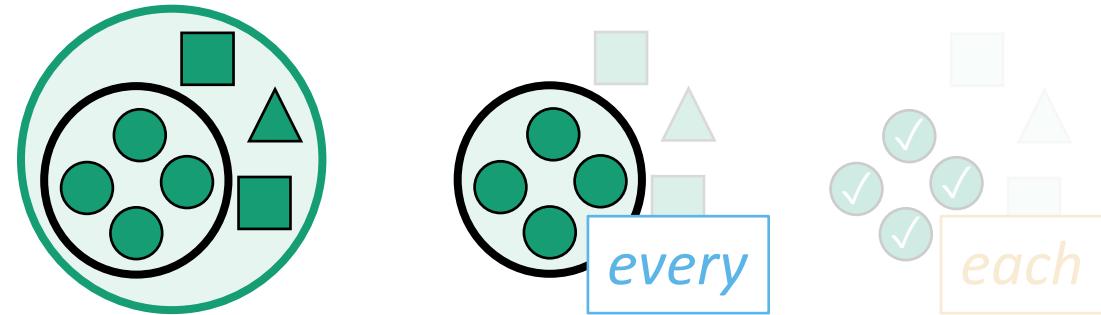


n = 48

# Roadmap: How are *each* & *every* mentally represented?

## Three hypotheses

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## Relational vs. Restricted

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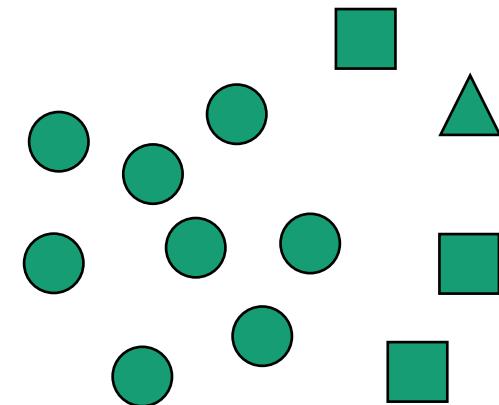
# Natural language determiners are “conservative”

A determiner **DET** is conservative iff

- (1)  $[[\text{DET } \text{NP}] \text{ PRED}] =$
- (2)  $[[\text{DET } \text{NP}] [\text{be NP that PRED}]]$

*every circle is green* (TRUE) =

*every circle is a circle that is green* (TRUE)



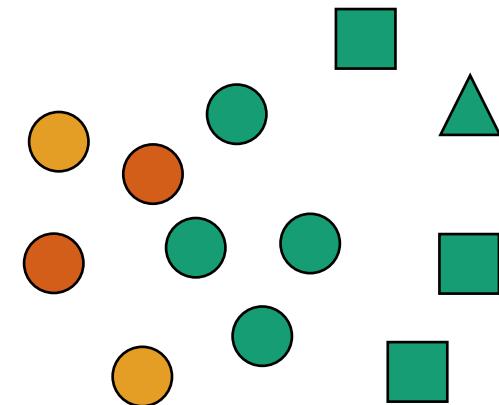
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- (1)  $[[\text{DET } \text{NP}] \text{ PRED}] =$
- (2)  $[[\text{DET } \text{NP}] [\text{be NP that PRED}]]$

*every circle is green* (FALSE) =

*every circle is a circle that is green* (FALSE)



# Natural language determiners are “conservative”

A determiner **DET** is conservative iff

- (1)  $[[\text{DET } \text{NP}] \text{ PRED}] =$
- (2)  $[[\text{DET } \text{NP}] [\text{be } \text{NP} \text{ that PRED}]]$

- Cross-linguistically, all determiners are conservative
- 5year-olds can learn novel conservative determiners  
**but not** novel non-conservative ones!

# “Conservativity” is puzzling on the relational view

What rules out all the non-conservative relations?

$$|\text{CIRCLES} \cap \text{GREEN}| > |\text{CIRCLES} - \text{GREEN}|$$

*≈ most circles are green*

$$\text{CIRCLES} \subseteq \text{GREEN}$$

*≈ every circle is green*

$$|\text{CIRCLES}| = |\text{GREEN}|$$

$$\text{CIRCLES} \supseteq \text{GREEN}$$

# “Conservativity” is entailed on the restricted view

Relative to the circles, *is green* applies to

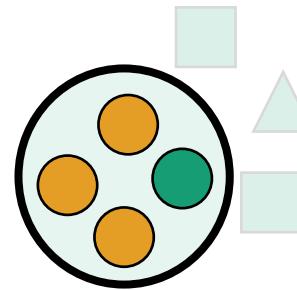
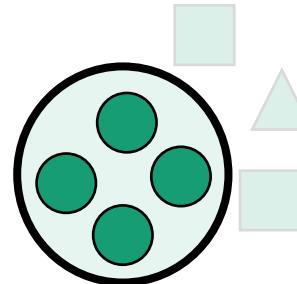
...**all** things

...**most** things

...**at least 2 & at most 4** things

...**???** things

(intended:  $|\text{CIRCLES}| = |\text{GREEN}|$ )

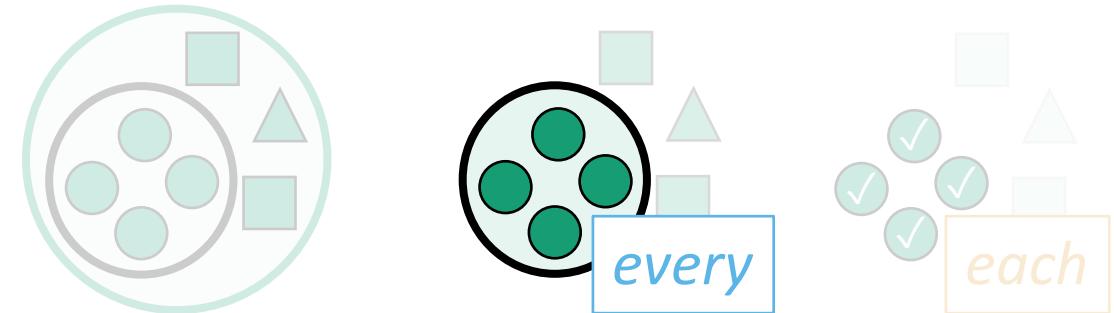


→ Non-conservative meanings are not stateable if the first argument restricts the domain of quantification

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- ➔ Consequences for language acquisition

*Each* highlights individuals more than *every*

(1) Which book did you loan to **each** student?

a. *Frankenstein* to Frank, *Persuasion* to Paula, and *Moby Dick* to Mary

(2) Which book did you loan to **every** student?

a. #*Frankenstein* to Frank, *Persuasion* to Paula, and *Moby Dick* to Mary

b. There's no one book that I loaned to every student

*Each* highlights individuals more than *every*

(3) **Each** old fashioned needs an orange peel

a. *some particular cocktails are in need of garnishes*

(4) **Every** old fashioned needs an orange peel

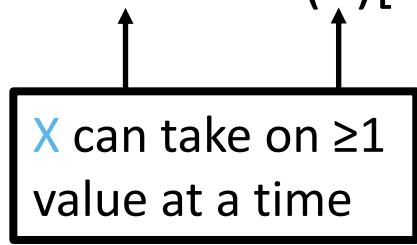
a. *some particular cocktails are in need of garnishes*

b. *in general, the recipe calls for an orange peel*

# Different representations

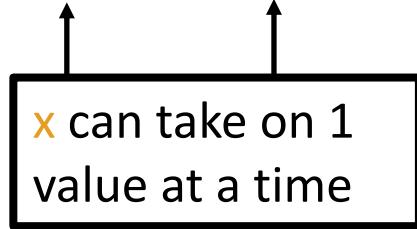
## Second-order representation (*every circle is green*)

The  $\exists x: \text{Circle}(x) [\text{Green}(x)]$   $\approx$  The circles are such that they are green



## First-order representation (*each circle is green*)

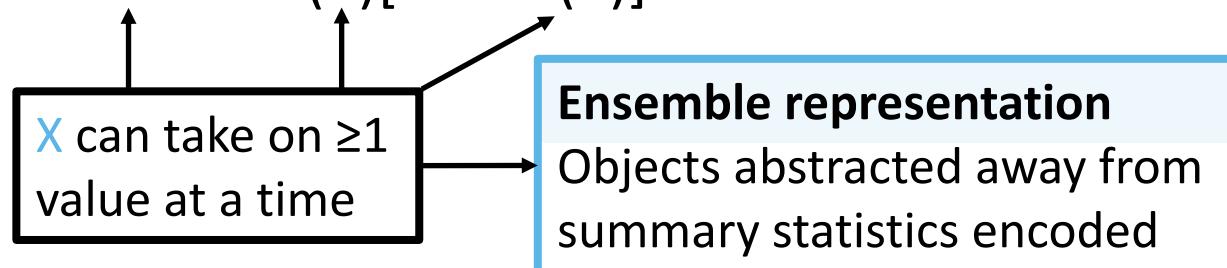
$\forall x: \text{Circle}(x) [\text{Green}(x)]$   $\approx$  Any individual circle is such that it is green



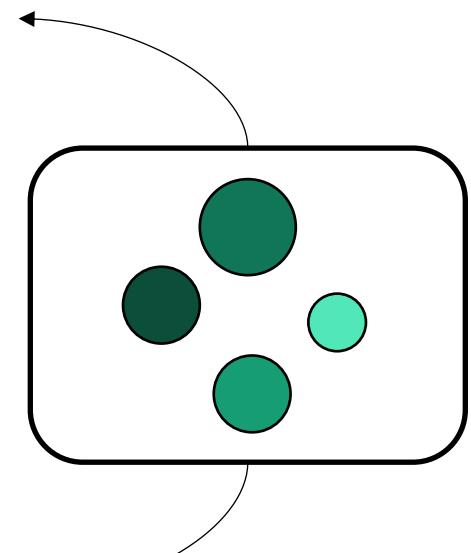
# Different representations & cognitive systems

## Second-order representation (*every circle is green*)

The  $\forall X: \text{Circle}(X)[\text{Green}(X)]$   $\approx$  The circles are such that they are green



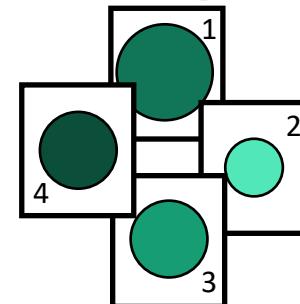
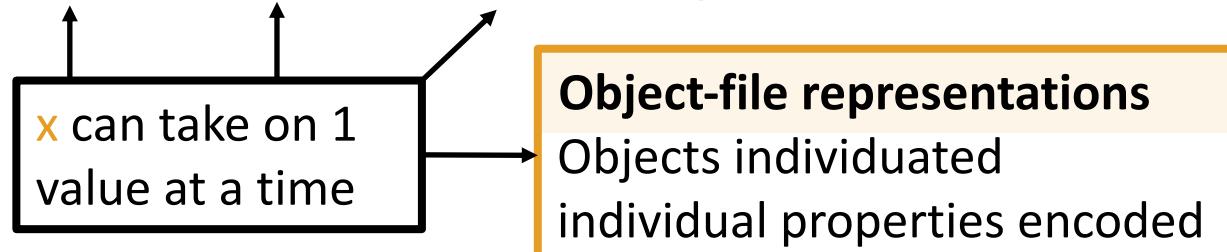
Center: (0,0)  
Avg. Hue:   
Avg. Size:



e.g., Ariely 2001; Feigenson, Dehaene & Spelke 2004; Alvarez 2011;  
Haberman, Brady & Alvarez 2015; Ward, Bear & Scholl 2016; Whitney & Leib 2018

## First-order representation (*each circle is green*)

$\forall x: \text{Circle}(x)[\text{Green}(x)]$   $\approx$  Any individual circle is such that it is green



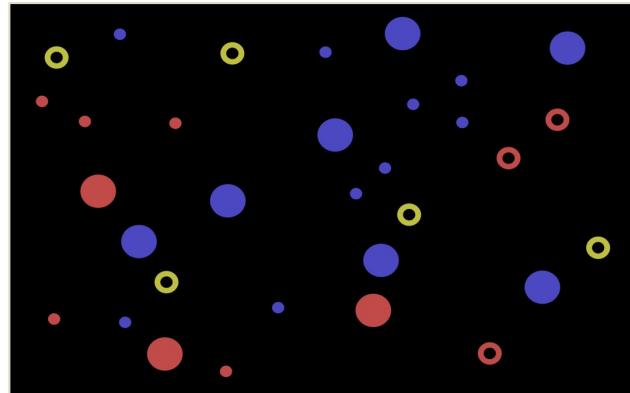
e.g., Kahnemann et al. 1992; Pylyshyn & Storm 1998; Scholl, Pylyshyn & Feldman 2001; Scholl 2002; Feigenson, Dehaene & Spelke 2004; Carey 2009

## Cardinality (group property)

{Each/Every} big circle is blue

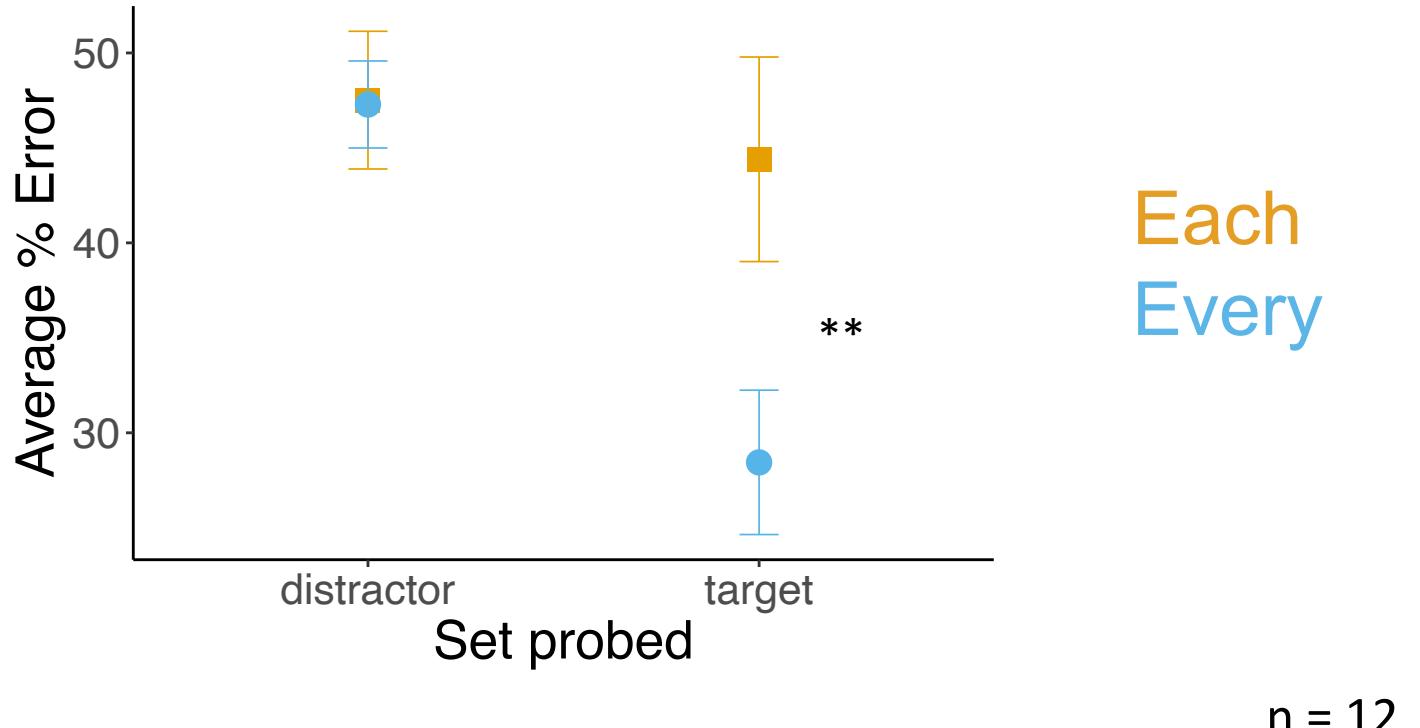
TRUE

FALSE



How many  
{big/medium/small}  
circles were there?

Percent error (initial condition "each")

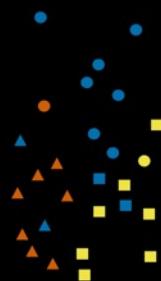


## Center of Mass (group property)

Is {each/every} circle blue?

“Yes”

“No”



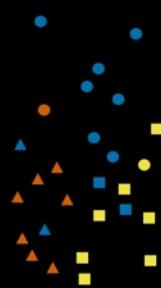
(with 3- to 8-year-olds)

Where was the middle  
of the circles?

Is {each/every} circle blue?

“Yes”

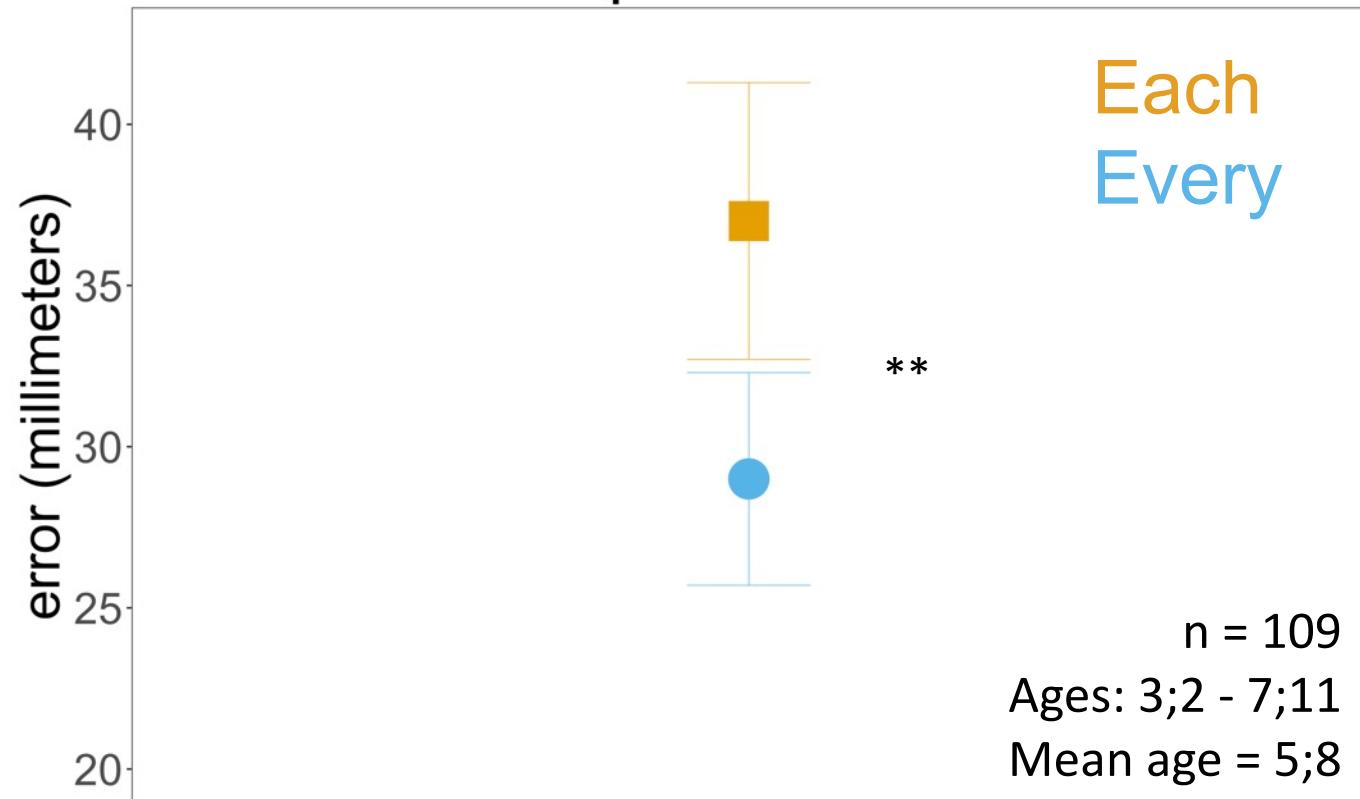
“No”



Where was the middle  
of the circles?

## Center of Mass (group property)

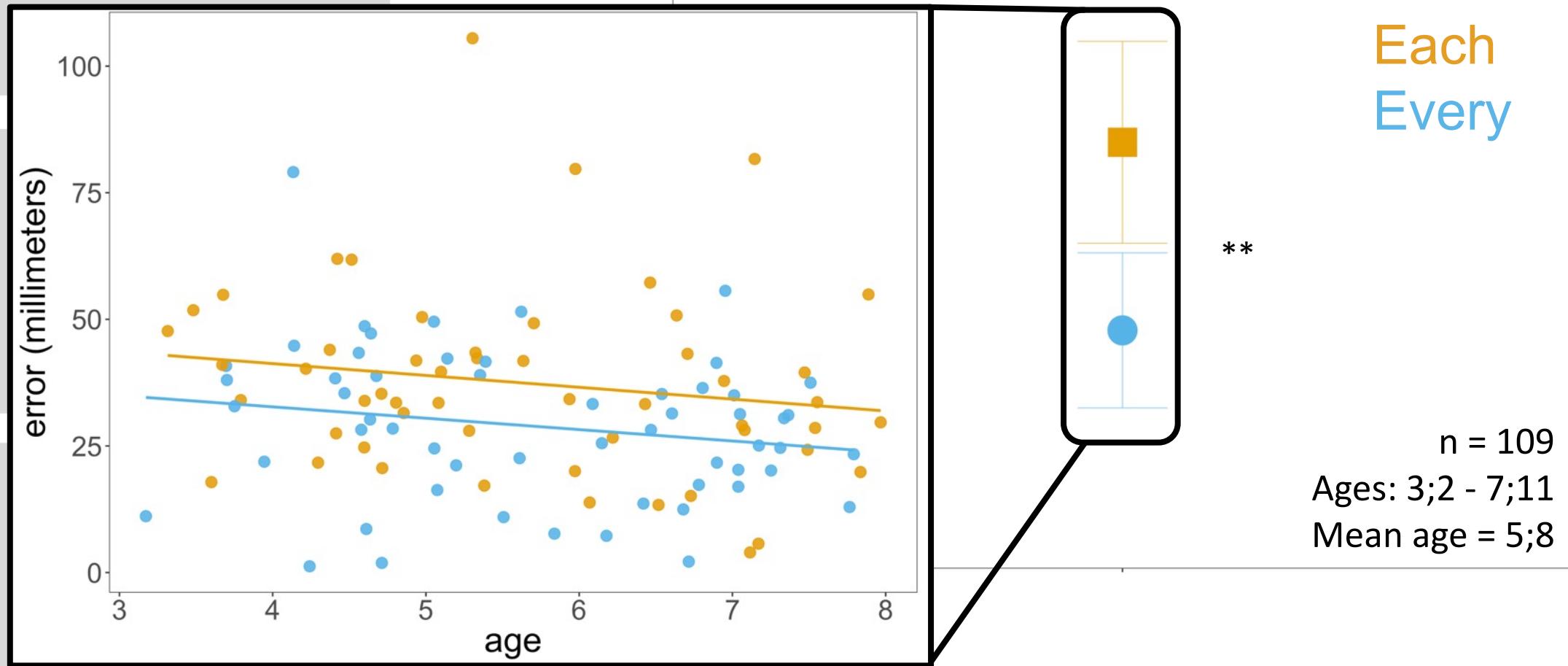
Distance from tap to actual set center



# Center of Mass (group property)

Is {each/every} circle blue?

Distance from tap to actual set center



{Each/Every}  
circle is green



TRUE

FALSE



One circle  
changed its color

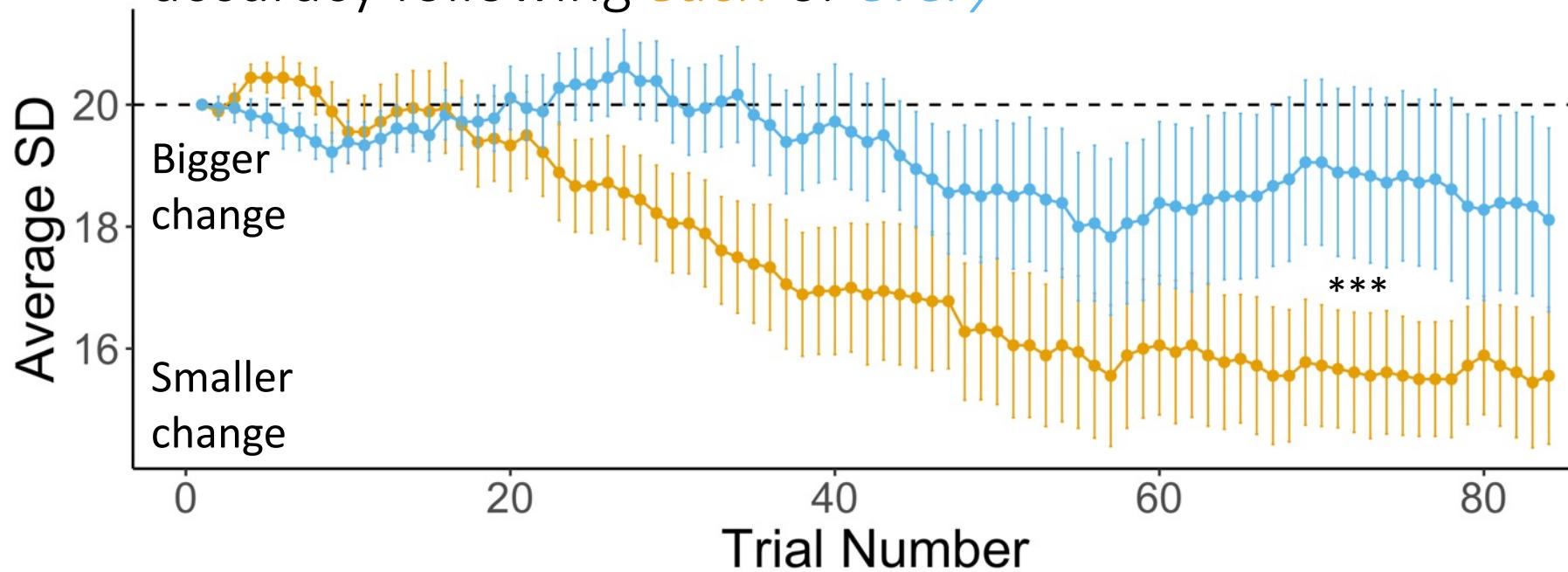


TRUE

FALSE

## Color (**individual** property)

Color change detection: difficulty required for 70% accuracy following *each* or *every*



# Different representations & cognitive systems

## Second-order representation (every)

The  $\text{X}:\text{Circle}(X)[\text{Green}(X)]$

$X$  can take on  $\geq 1$  value at a time

**Ensemble representation**  
Objects abstracted away from summary statistics encoded

## Verification strategy

Center: (0,0)  
Avg. Hue:   
Avg. Size: 

## Downstream pragmatic consequences

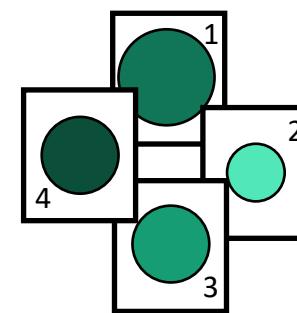
More easily supports broad generalization?

## First-order representation (each)

$\forall X:\text{Circle}(X)[\text{Green}(X)]$

$X$  can take on 1 value at a time

**Object-file representations**  
Objects individuated individual properties encoded



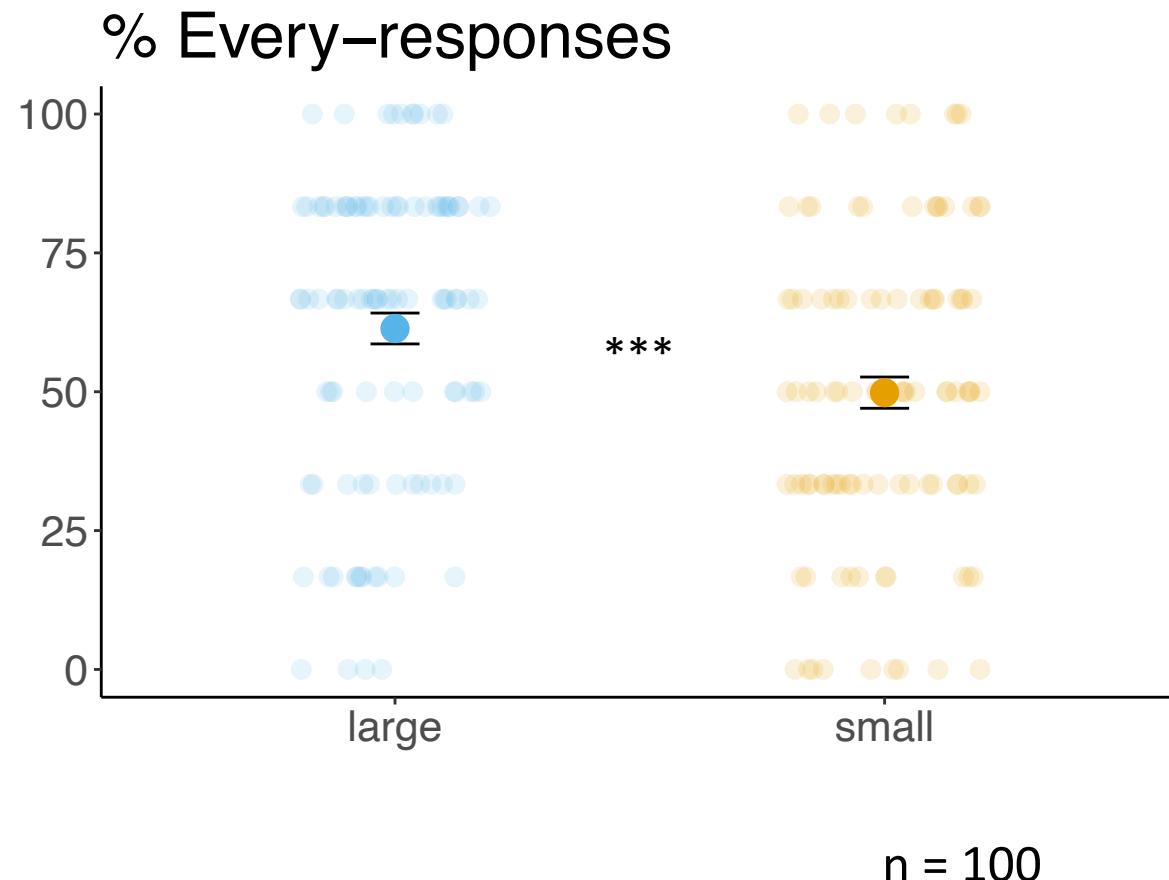
Better for smaller domains?

# *Every*: better for larger domains

An astrophysics team at NASA has been studying a cluster of {four/four thousand} stars.

(1) Based on their calculations, each star in this group has been burning for more than 20 billion years.

(2) Based on their calculations, every star in this group has been burning for more than 20 billion years.

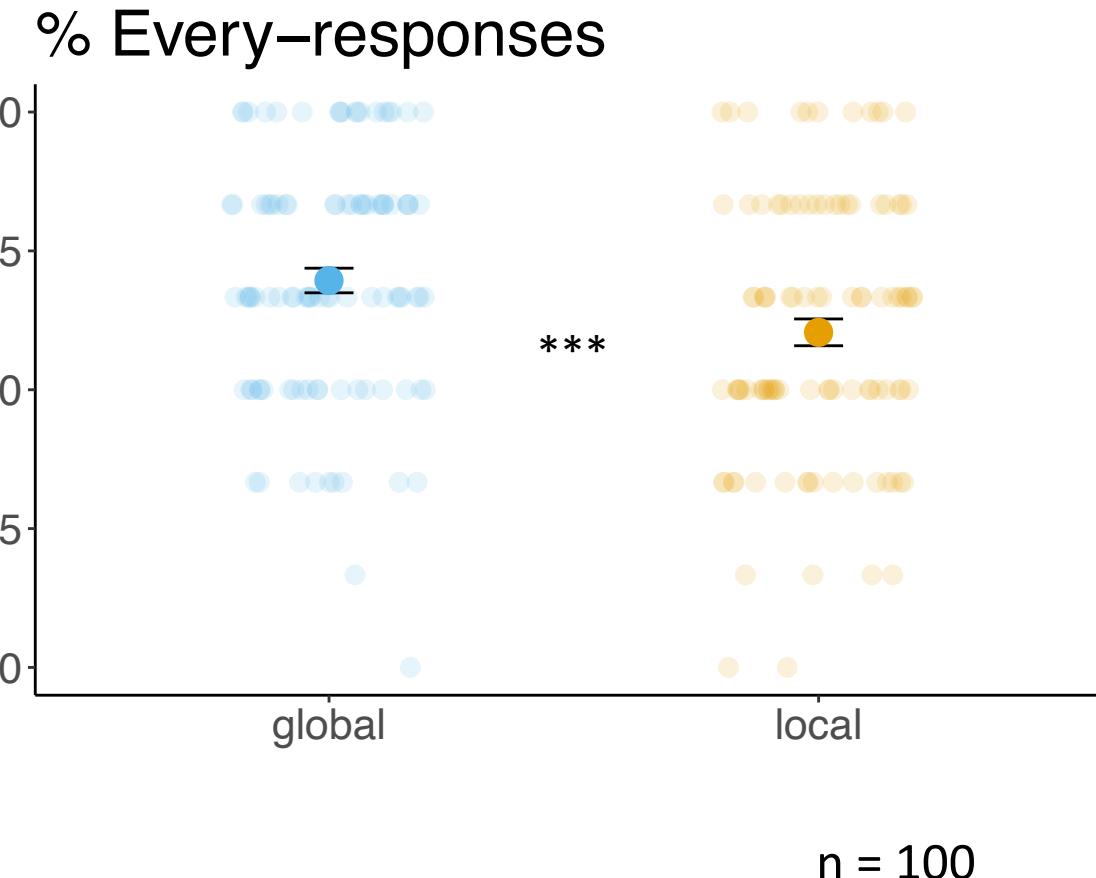


# *Every*: better for projecting beyond local domain

An astrophysics team at NASA has been studying a cluster of stars.

(1) Based on their calculations, **each** star {**in that cluster/in the universe**} has been burning for more than 20 billion years.

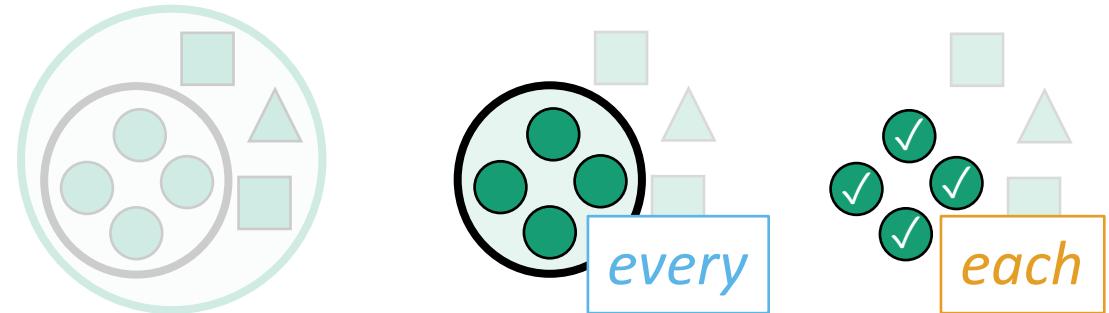
(2) Based on their calculations, **every** star {**in that cluster/in the universe**} has been burning for more than 20 billion years.



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# How are *each* & *every* acquired?

e.g., to acquire *every*, learners need to figure out its:

**Syntactic category:**

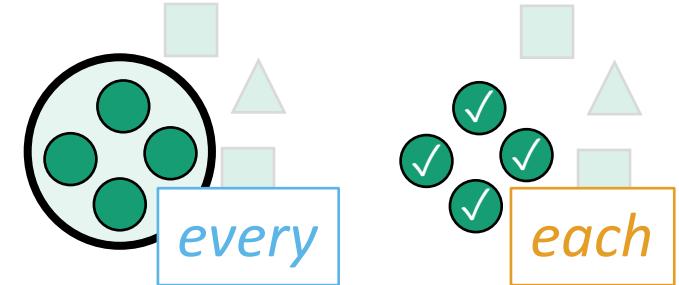
DET (not ADJ)

**Quantificational content:**

Universal (not proportional, existential, etc.)

**Representational format:**

Second-order restricted (not first-order restricted)



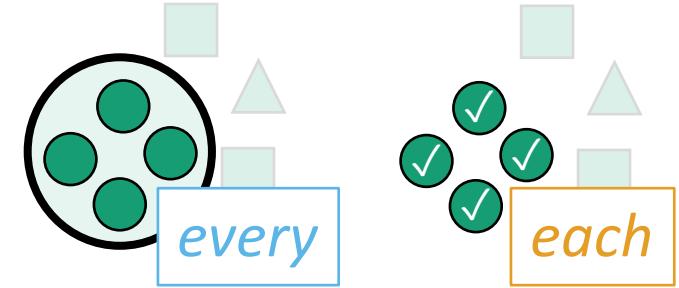
What leads learners to pair  
“each” and “every” with  
the right representations?



# What information is in learners' input?

- "You have to ring up **each** thing"
- "Could you put a flower on **each** plate?"
- "Put sugar in **each** coffee"
- "We'll put one finger on **each** thing we count"
- "We **each** have three"

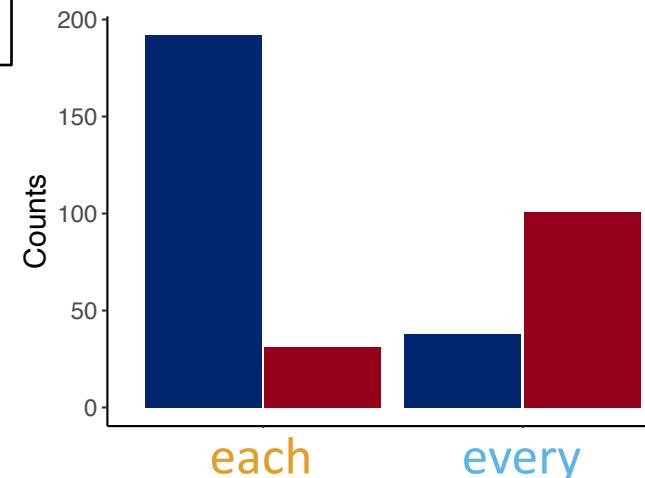
} Child ambient speech



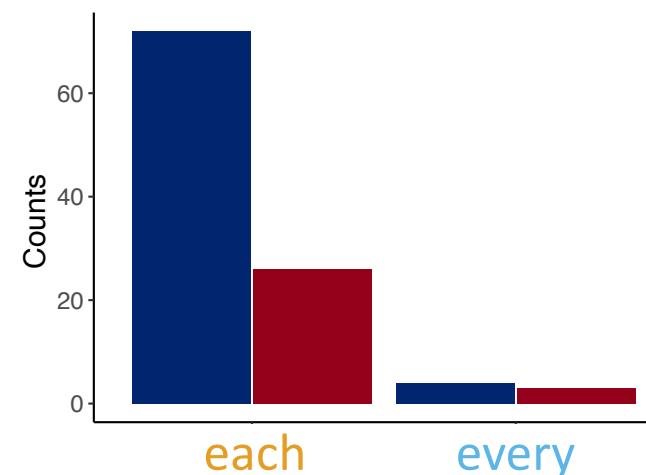
Generalize over local domain



Domain present vs. not



Within working memory limit ( $\leq 3$ ) vs. not ( $\geq 4$ )



# How are *each* & *every* acquired?



"You want one bite  
of **each** piece, huh?"

Domain present in small #s

Triggers

Object-files



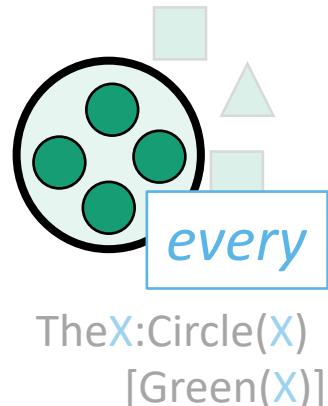
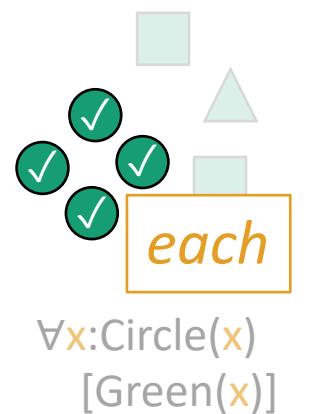
**Every** time you color,  
you get better."

Project beyond local domain

Triggers

Ensembles

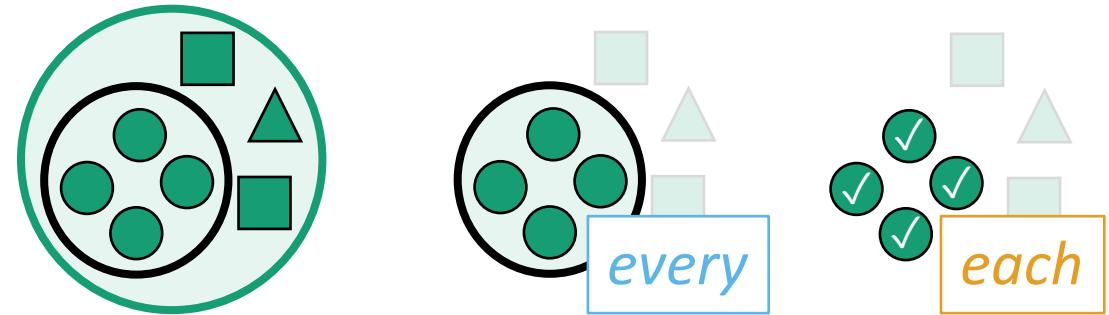
Diversity: low  
Avg. Hue: Avg. Size:



# How are *each* & *every* mentally represented?

## Three hypotheses

- ✓ Two (psycho)logical distinctions



## Relational vs. Restricted

- ✓ Number cognition as a probe
- ✓ The “conservativity” universal

## First-order vs. Second-order (individual- vs. group- implicating)

- ✓ Object-files vs. Ensembles as a probe
- ✓ Consequences for language acquisition

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Finger painting courtesy of Alex Oppenheimer (1;6)

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