Representational Format and Universal Quantifiers
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Introduction: First- & second-order meanings

Big Picture Question: How are universal quantifiers – each, every, and all – mentally represented?
Finding: Despite truth-conditional equivalence, each biases representing individuals; every/all bias representing groups
Conclusion: Even though all three universals are first-orderizable, only each has a first-order representation

First- vs. second-order quantification
There are infinitely many ways to formally specify the relation expressed by universal quantifiers, including (1)-(4)

```
(1) DxB \land \forall x \in Dx [Qx]
(2) \forall x \in Dx [Qx] \land \exists x \in Dx
(3) DxB \subseteq B
(4) \forall x \in D \land \exists x \in B
(5) ...
```

“every dot is blue”

First-order: domain = individuals; assignment = one value per variable
Second-order: genuine relation between two groups / sets

Are the universals equally well described by (1)-(4)? Or are meanings specified at a finer grain-size in the mind?

Linking Hypothesis:
People are biased toward verification strategies that transparently reflect the meaning under evaluation [1-3]

• Methodological strategy: Variation in verification that can’t be otherwise explained is due to the meaning

Second-order meaning ➔ attend to & represent sets ➔ encode those set’s cardinalities in memory (4,5)
First-order meaning ➔ attend to & represent individuals ➔ fail to encode set-based properties (e.g., #) in memory

Baseline task
When asked to estimate the cardinality of some subset, participants can be fit with an accuracy (β) and precision parameter (1/σ) [6-9]

• Result: Better accuracy & precision when given the question first

Baseline task model fits

```
<table>
<thead>
<tr>
<th>Dots First</th>
<th>Question First</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dots</td>
<td>Dot Color</td>
</tr>
<tr>
<td>Enumerated Set Defined By</td>
<td>Dots First</td>
</tr>
</tbody>
</table>
```

Adding language: most- vs. existential-statements
Participants biased to attend to groups or not based on the statement under evaluation:

• A decidedly second-order most-statement or a plausibly first-order existential-statement
• Follow-up questions probed the restrictor set (target) or a random set (distractor)

```
<table>
<thead>
<tr>
<th>Most of the big dots are blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>How many big dots are there?</td>
</tr>
</tbody>
</table>
```

Result: Participants know the restrictor set’s cardinality better following most-statements

Takeaway: Each, every, and all are represented in different formats in speakers’ minds

• Each is represented in a first-order format; every and all are represented in second-order formats
• Knowledge of group-based properties (e.g., #) following evaluation reflects this subtle difference in meaning

Testing truth-conditionally equivalent statements
Same task, but both conditions were matched in syntax, truth-conditions, and images

• Result: Participants know the restrictor set’s cardinality better following every- and all-statements than following each-statements; every- and all-statements still pattern together when tested within subjects

```
All of the
Each of the
Distractor
Target

Every
All

Every
All

n=12

<table>
<thead>
<tr>
<th>Distractor</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=12</td>
<td></td>
</tr>
</tbody>
</table>
```

Linguistic consequences of first-order each

Distributivity
While every and all can give rise to distributive interpretations, each mandatorily does [10,11]:

```
(6) a. Each student sang happy birthday (well as a solo piece / #in perfect harmony)
   b. Every student/all the students sang happy birthday (well as a solo piece / in perfect harmony)
(7) a. Determine whether each dragon is dangerous (‘for each dragon, figure out whether it’s dangerous’) & b. Determine whether every dragon is dangerous (‘figure out if it’s true that every dragon is dangerous’) &c. All birds lay eggs
(9) Usually you complain every/#each time we shop
```

Genericity
While every and all can be used to express generic thoughts, each cannot [13,14]:

```
(8) a. #Each bird lays eggs
   b. Every bird lays eggs
   c. All birds lay eggs
(10) #Generic sentences abstract away from individual entities / events and describe group properties
   • FOL considers individuals and their properties
   • The # of exceptions tolerated changes with the domain size; hard to capture in FOL (though see [15])
   • The same problem arises for statements with proportional quantifiers, like most [16]
```

References:

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