# Infinite use of finite means? Evaluating the generalization of center embedding learned from an artificial grammar

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## 1 Overview

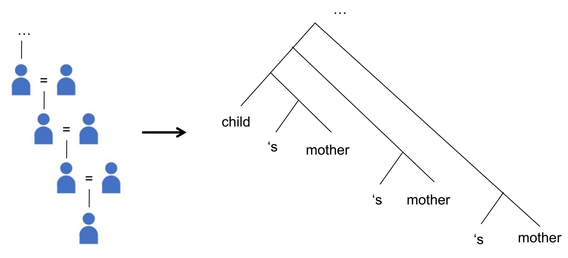
- **Question:** When people learn a syntactic pattern, do they extend it beyond the finite bounds of their training data?
- **Approach:** Train participants on a simple, synthetic language and test how they generalize it
  - Phenomenon of focus: center embedding
- **Main finding:** When participants learned the pattern for sentence sizes they had seen, they robustly extrapolated it to a greater depth of embedding.
  - Supports the hypothesis that people have an inductive bias which favors unbounded languages over bounded ones

## 2 Motivation

- Human languages are often assumed to be unbounded:

  **(1) It is raining**
  **(2) I think that it is raining**
  **(3) I think that I think that it is raining**
  **(4) …**

- Do people actually acquire unbounded languages?
- If they do: Why do they acquire an unbounded language, when the input to acquisition is bounded?
- One possibility: Unboundedness in language comes from unboundedness in the world (semantic bootstrapping)




**From unbounded family trees to unbounded syntax trees**

- Possibility we focus on: People have an inductive bias favoring unboundedness
  - Predicts extrapolation even without semantic grounding

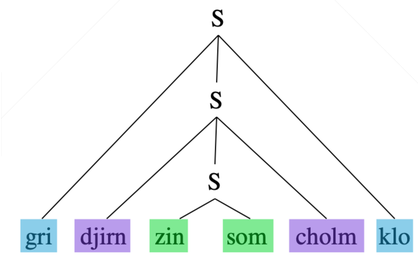
## 3 Methods

- **Participants:** 103 adult participants on Mechanical Turk
- **Materials:** Sequences drawn from a grammar featuring center embedding

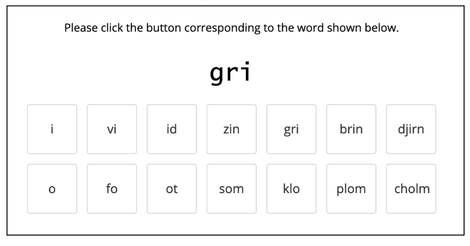
Grammar

| | |
|---|---|
| S → i S o | S → gri S klo |
| S → vi S fo | S → brin S plom |
| S → id S ot | S → djirn S cholm |
| S → zin S som | S → ε |

Example derivation



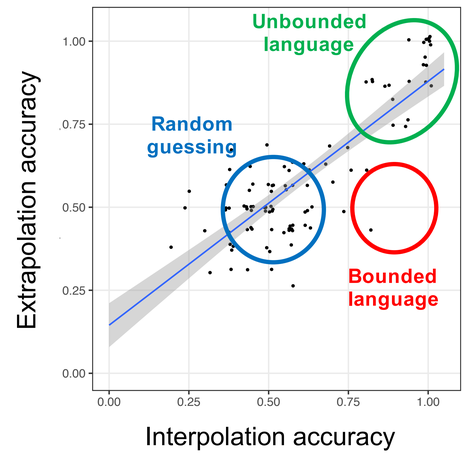

- **Training:**
  - Repeating back grammatical sequences, one word at a time.
  - Max depth of embedding: 2




- **Testing:**
  - Grammaticality judgment (given entire sequence at once)
  - Ungrammatical examples are created by swapping two words in a grammatical sequence
  - Two categories:
    - Interpolation subset: Depth of embedding = 2
    - Extrapolation subset: Depth of embedding = 3 (greater than the max seen during training)

## 4 Results

- Many participants failed to learn center embedding at all (**blue**)
- When participants did learn it, they robustly extrapolated it to a greater depth of embedding (**green**)
- Few if any participants learned center embedding in a bounded way (**red**)




## 5 Discussion

### • Unbounded generalization?

- Participants extrapolated one level beyond their experience
- Did they learn an unbounded grammar, or one that is bounded but at a level greater than the max training depth?
- A bounded grammar (e.g., 5) would likely require a rule never used in training,
- An unbounded grammar (e.g., 6) would not

  (5) $S \rightarrow \varepsilon;\ S \rightarrow AB;\ S \rightarrow AABB;\ S \rightarrow AAABBB$

  (6) $S \rightarrow ASB;\ S \rightarrow \varepsilon$

- Thus, we believe that an unbounded grammar is a simpler explanation of the results

### • Nature of the inductive bias

- These results could be explained by a bias for unboundedness or by a bias for simplicity (Perfors et al. 2010)
- A follow-up is in progress to tease these apart

## 6 Conclusion

- Participants who learned center embedding robustly extrapolated it to a greater depth of embedding
- Ongoing work:
  - Trying a harder-to-verbalize grammar
  - Disentangling whether our results are driven by a bias for unboundedness or a bias for simplicity
- Paper: https://psyarxiv.com/r8ct2

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