# Anaphoric Structure Emerges Between Neural Networks

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Anaphors are ubiquitous across human language. Almost every language uses **pronouns** and **ellipsis**, despite the potential **ambiguity** these structures introduce:

- Where did ***she*** go?
- Mary sings and John ***does too***.

Why is this? Likely because they enable more **efficient** communication – speakers can omit inferable content, the listener can still recover the intended meaning (Levinson, 2000; MacDonald, 2013; Gibson et al., 2019).

## We show how anaphoric structure can emerge between networks without any explicit efficiency pressure

## The Model

**Reconstruction** game (Lewis, 1970)

**Sender** ('speaker') and **Receiver** ('listener')


### Meanings

Concatenation of 5 roles: $(\boldsymbol{subj_1}, \boldsymbol{verb_1}, \boldsymbol{conj}, \boldsymbol{subj_2}, \boldsymbol{verb_2})$

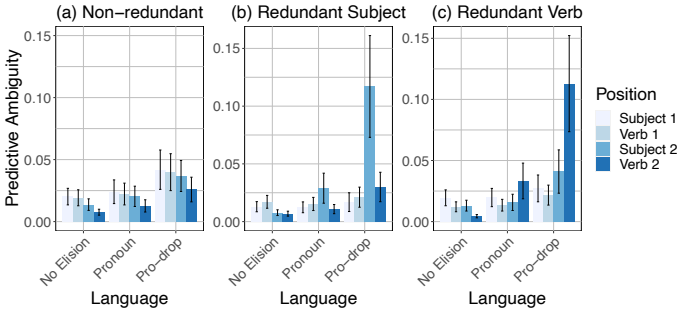
### Neural agents can learn languages with anaphoric structure

We train a listener agent on languages with:

a) no anaphoric structure ("**no elision**")
b) overt anaphoric structure ("**pronouns**")
c) elided anaphoric structure ("**pro-drop**")

All 3 are learned, but:
- at different **speeds**
- with different degrees of **ambiguity** for the listener

**Predictive Ambiguity: Listener's entropy over possible words in a role**




## How can we tell if a signal has something like an anaphor?

1) It's more ambiguous for the listener: **Predictive Ambiguity**

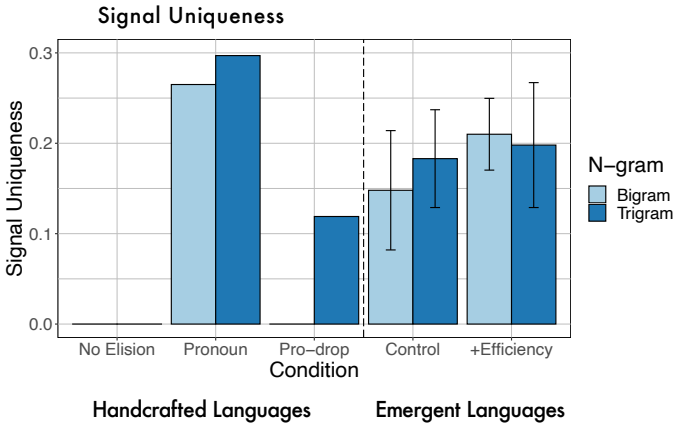
2) The speaker uses unique tokens (like pronouns) to refer to redundancy: **Signal Uniqueness**
   - Forms like *she* and *they* are used only to express redundancy
   - Look for substrings (**n-grams**) in the signals that only appear with redundant meanings

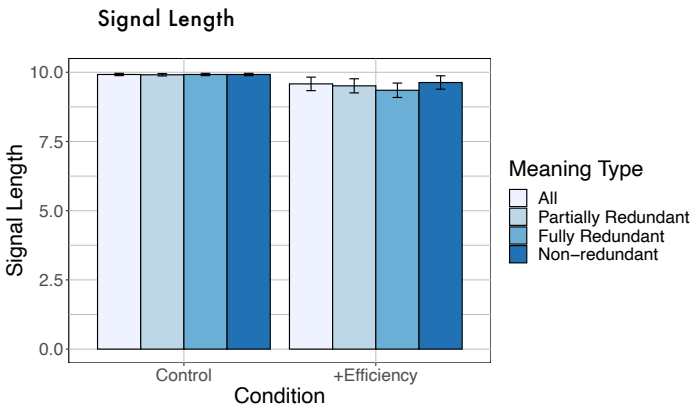
3) A signal is shorter, like ellipsis: **Signal Length**

Mary played the violin and John ~~played~~ the piano

## We find higher ambiguity and signal uniqueness for redundant meanings, consistent with anaphors like pronouns

**Adding an efficiency pressure increases the prevalence of these structures, but doesn't appear to be required for anaphoric structure to emerge**




## Future work

Will a richer semantics in the meaning space encourage the emergence of **pro-drop**?

Full paper

References

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