Paying Attention to Function Words

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Introduction

Two major types of linguistic expressions [4]:

- Content words: nouns, verbs, adjectives
- Function words: determiners, tense, conjunctions, prepositions, complementizers, ...

> Twas brillig, and the slithy toves
> Did gyre and gimble in the wabe;
> All mimsy were the borogoves,
> And the mome raths outgrabe.
> — From 'Jabberwocky', Carroll [1]

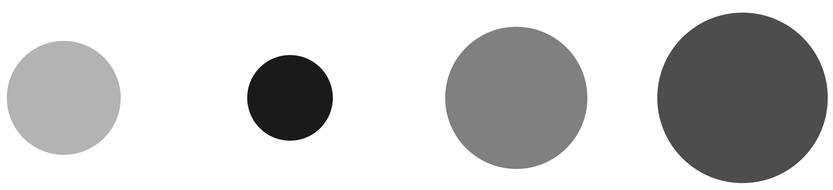
Crucial questions for explaining the emergence of *compositional* communication:

- Why have human languages evolved to exhibit this division of labor between content and function words?
- How could such a distinction have emerged in the first place?

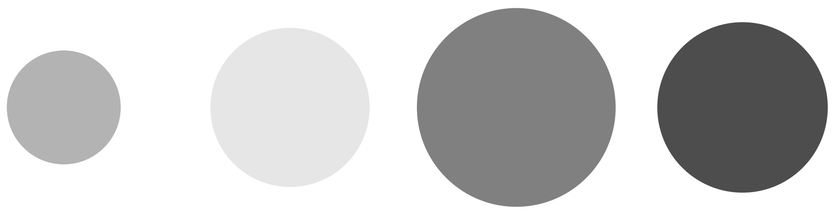
Contributions

1. Why existing approaches don't explain this distinction [longer version]
2. A new signaling game [3, 5], with variable contexts and gradable properties
3. The emergence of function words by reinforcement learning and *attention*

A Signaling Game with Varying Contexts



Refer to the circle on the left as "the lightest one".



Refer to the circle on the left as "the smallest one".

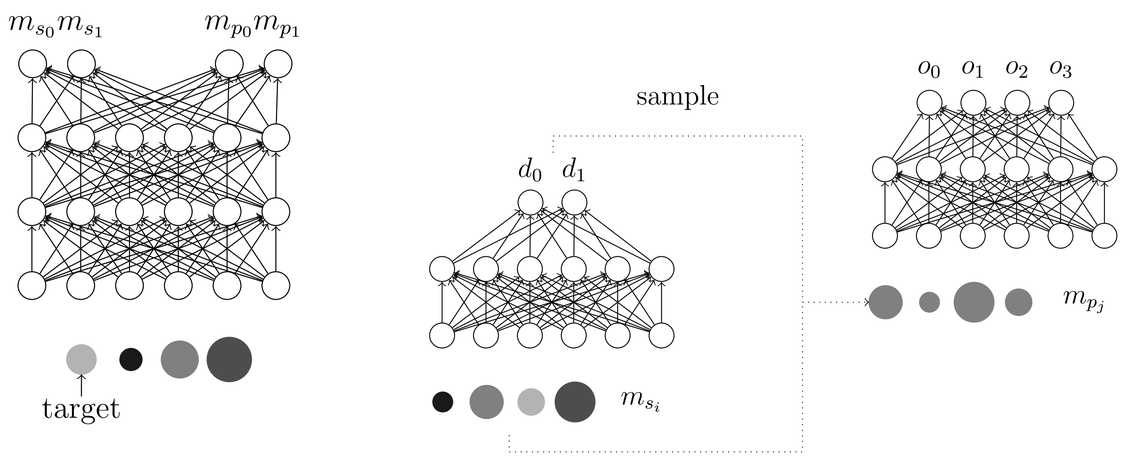
(1) A *context* c over scales S is a set of objects such that: for each $o \in c$, there is a scale $s \in S$ such that either o has the least degree on s ($o = \arg\min_{o' \in c} s(o')$) or the highest degree on s ($o = \arg\max_{o' \in c} s(o')$).

(2) Extremity Game, in general:
   a. Nature chooses a context c and a target object $o \in c$.
   b. The sender sees c and o and sends a message m from some set of messages M.
   c. The receiver sees c and m and chooses an object o' from c.
   d. The play is successful (and the two agents equally rewarded) if and only if $o' = o$.

(3) Toy semantics for a gradable adjective and superlative morphemes.
   a. $[\![\text{size}]\!] = \lambda x.s_{\text{size}}(x)$
   b. $[\![\text{-est}]\!]^c = \lambda P_{\langle e,d\rangle}.\lambda x_e.x \in c \text{ and } \forall x' \in c, P(x) \succeq P(x')$
   c. $[\![\text{least}]\!]^c = \lambda P_{\langle e,d\rangle}.\lambda x_e.x \in c \text{ and } \forall x' \in c, P(x) \preceq P(x')$

Experiment

Similar to [2], we train agents to play this game using REINFORCE [6], varying (a) number of properties and (b) receiver architecture type.
Code + data: `https://github.com/shanest/function-words-context`



(a) Basic Sender (b) Attentional Receiver

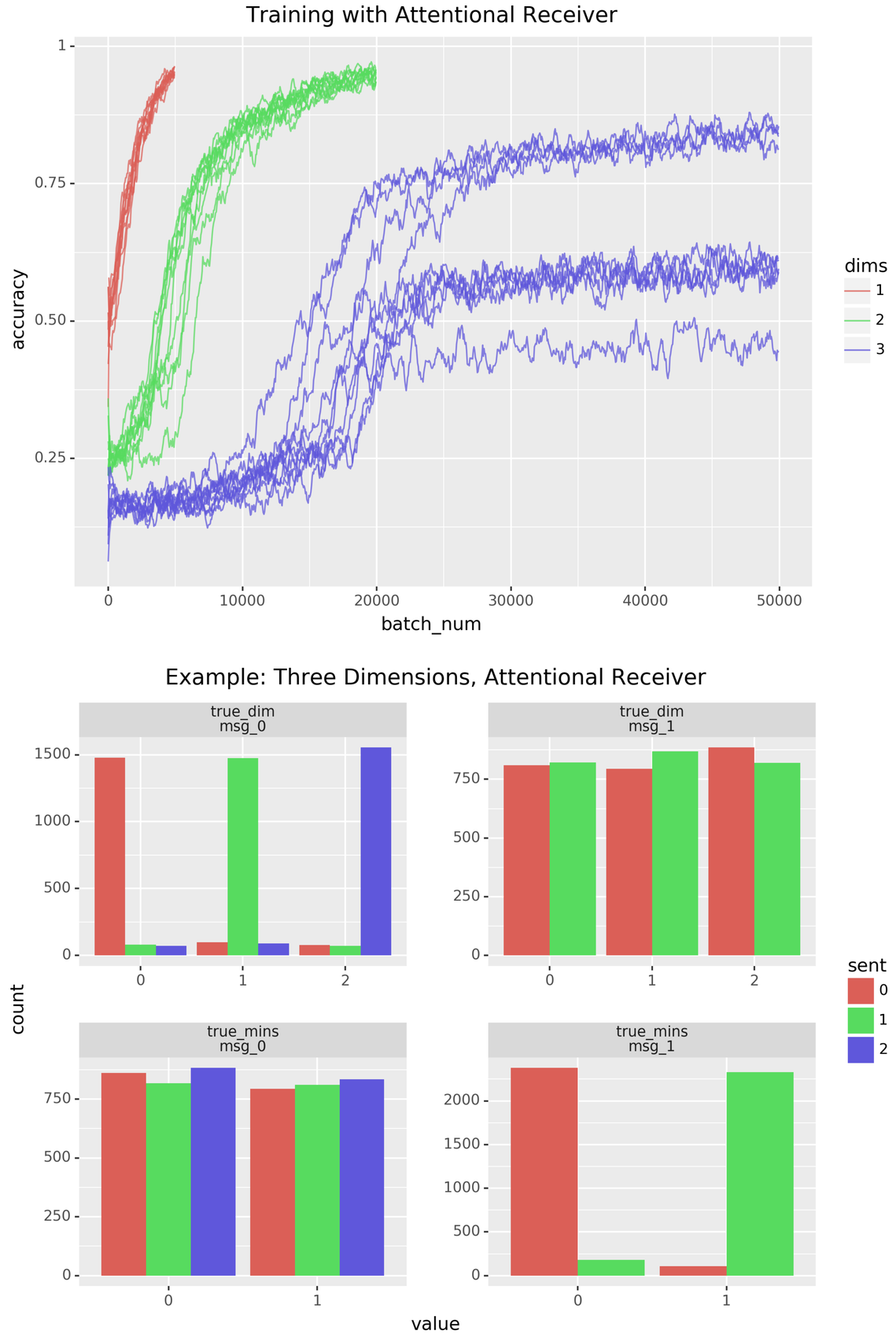
Results

dims	mean	std
1	0.975	0.006
2	0.985	0.003
3	0.731	0.062

(a) Basic Receivers

dims	mean	std
1	0.959	0.005
2	0.964	0.005
3	0.697	0.144

(b) Attentional Receivers



Future Research

- Fewer assumptions about what aspects of the input to pay attention to
- RNNs as sender/receiver, with costs for:
  - Vocabulary size
  - Length of messages

References

[1] Lewis Carroll. *Through the Looking-Glass, and What Alice Found There*. Macmillan, 1871.

[2] Angeliki Lazaridou, Alexander Peysakhovich, and Marco Baroni. "Multi-Agent Cooperation and the Emergence of (Natural) Language". In: *International Conference of Learning Representations (ICLR2017)*. 2017. arXiv: 1612.07182. URL: http://arxiv.org/abs/1612.07182.

[3] David Lewis. *Convention*. Blackwell, 1969.

[4] Luigi Rizzi and Guglielmo Cinque. "Functional Categories and Syntactic Theory". In: *Annual Review of Linguistics* 2.1 (2016), pp. 139–163. DOI: 10.1146/annurev-linguistics-011415-040827.

[5] Brian Skyrms. *Signals: Evolution, Learning, and Information*. Oxford University Press, 2010.

[6] Ronald J Williams. "Simple statistical gradient-following algorithms for connectionist reinforcement learning". In: *Machine Learning* 8.3-4 (1992), pp. 229–256.

Acknowledgements

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