

Multi-agent communication and the emergence of (natural) language

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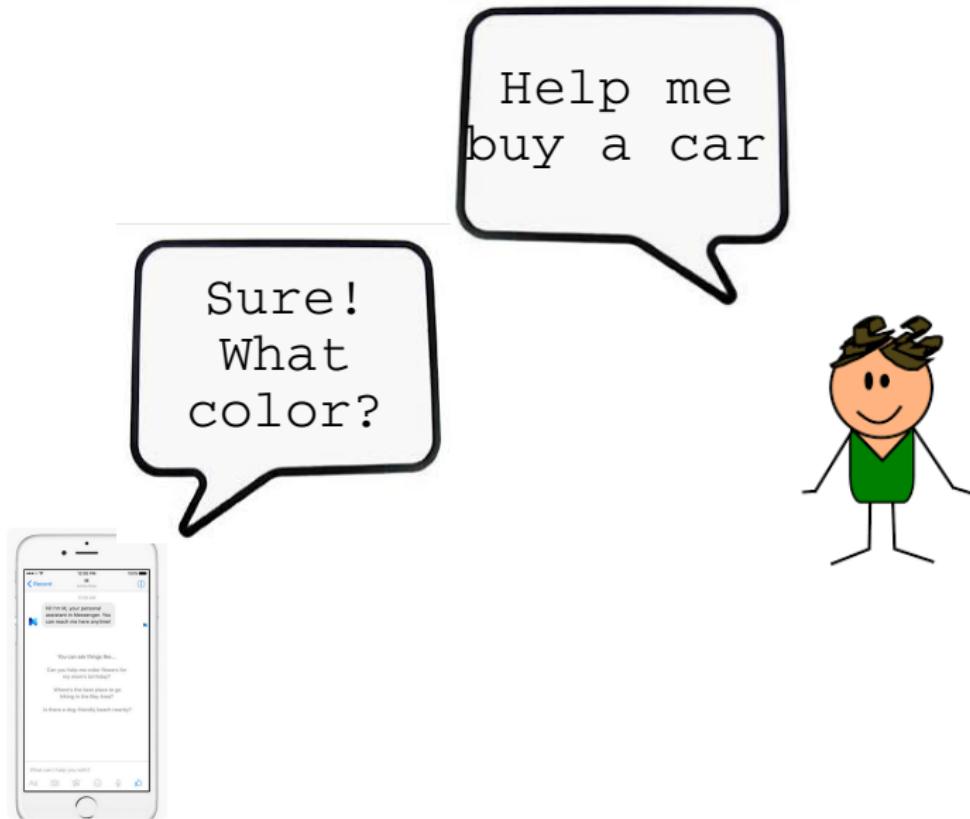
Let's Discuss
December 10th

Machines that can communicate with humans



secret AI party

Machines that can communicate with humans



Machines that can communicate with humans



Essential ingredients

communication

natural language

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communication

natural language

*basic skill of
many species*

distinct to humans

Communication first, language after

*The speed with which the chain signaling system can be learned is much improved if the sender (**AL: machine**) and receiver (**AL: human**) have pre-existing signaling systems.*

(Brian Skyrms, Signals: Evolution, Learning, and Information)

Communication first, language after

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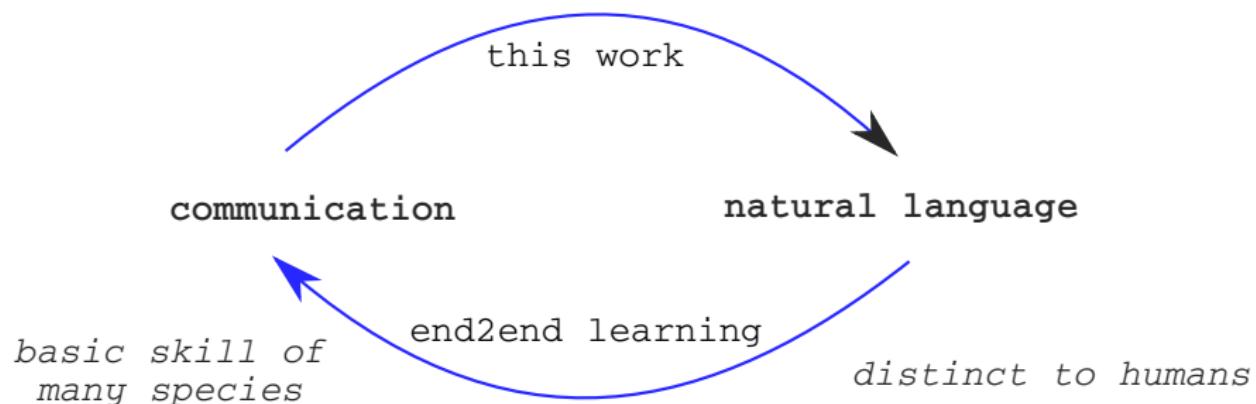
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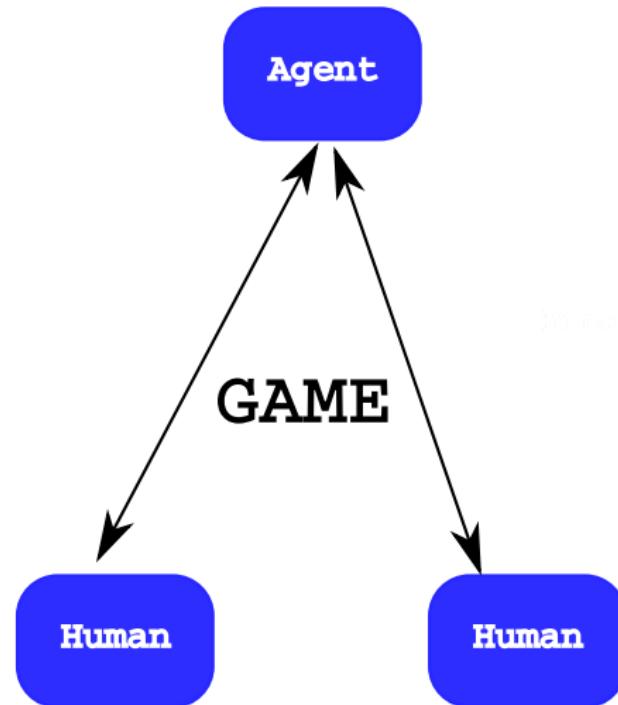
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Essential ingredients



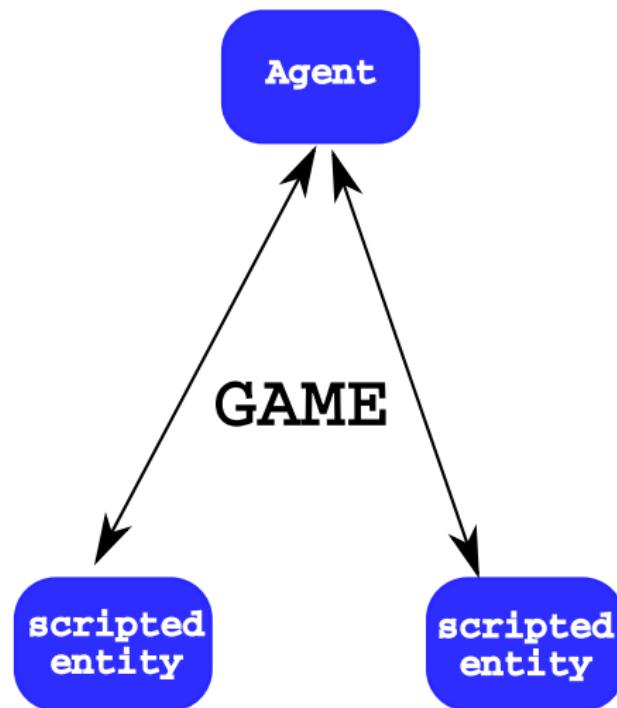
Interactive learning for language

Human-in-loop (Winograd, 1971; Wang et al., 2016)



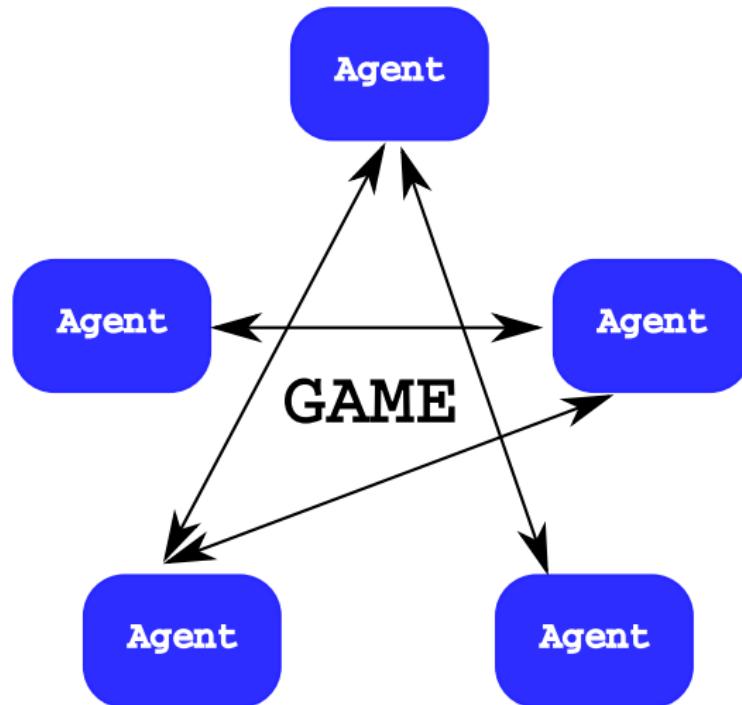
Interactive learning for language

Scripted "Teacher" (Mikolov et al., 2015; Weston, 2016)



Interactive learning for language

Multi-agent interaction



Language games

Revival of idea from Wittgenstein (1953)

- ▶ goal-oriented environment for language learning
 - ▶ emphasis on **function** rather than **structure** of language
 - ▶ *we use words to make things happen*

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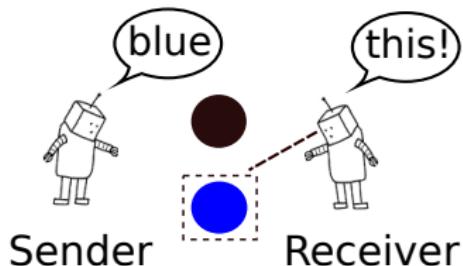
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- ▶ Conversation as joint activity (Clark, 1996) → emphasis on co-ordination/co-operative games

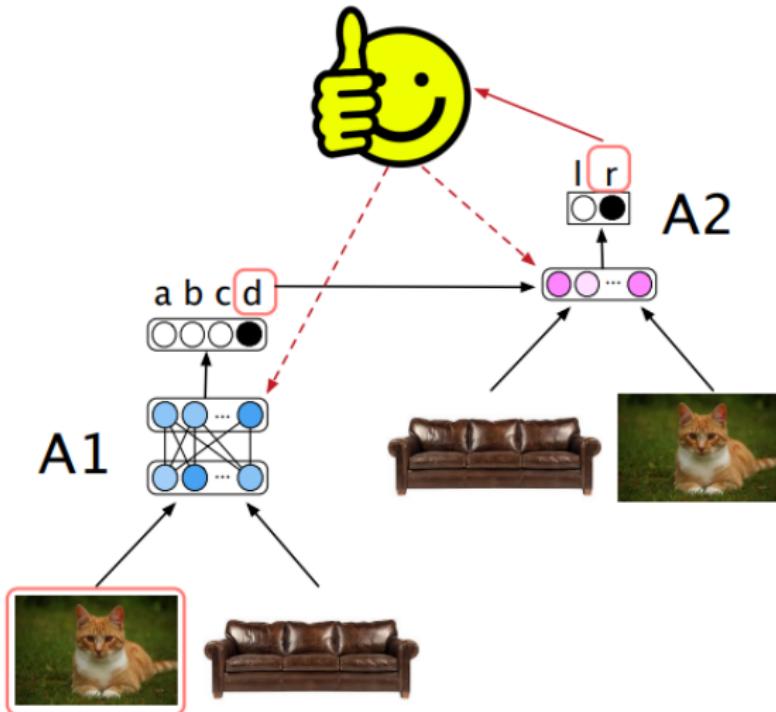
Multi-agent co-ordination games: Referential game

Reference as the basic act of communication



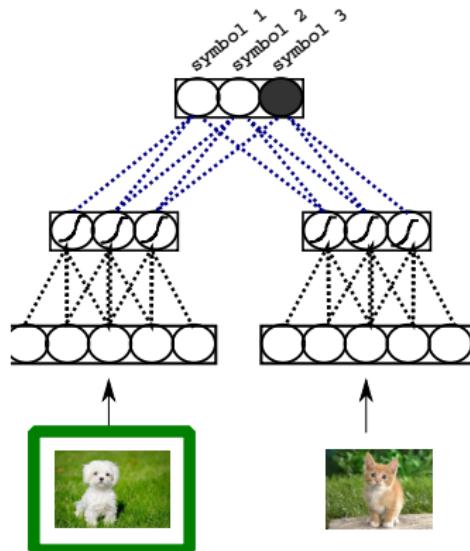
- ▶ Instance of *signaling games* studied in game theory (Crawford and Sobel, 1982) and language evolution (Wagner et al., 2003; Skyrms, 2010)
- ▶ **Sender:** Produces a *signal* referring to the object of interest
- ▶ **Signals:** Discrete units (i.e., symbols)
- ▶ **Receiver:** Interprets the *signal* and points
- ▶ **Pay offs:** +1 (*success*) or 0 (*failure*)

The game

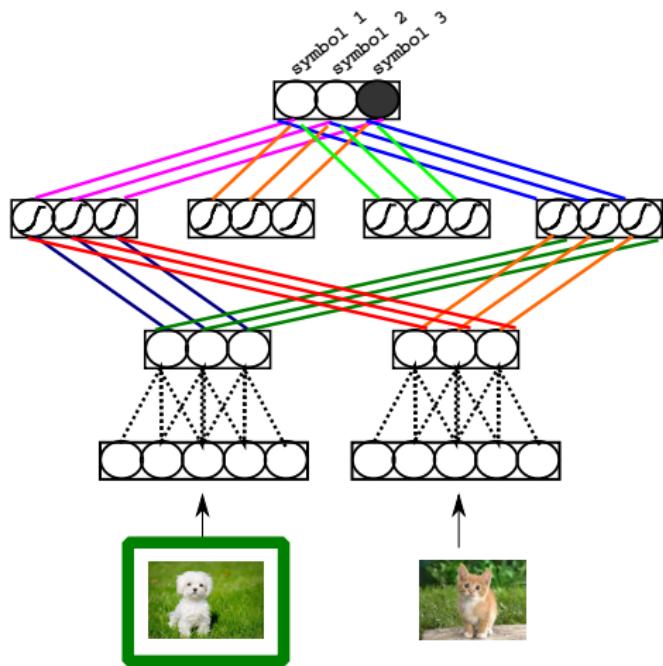


Players

Sender



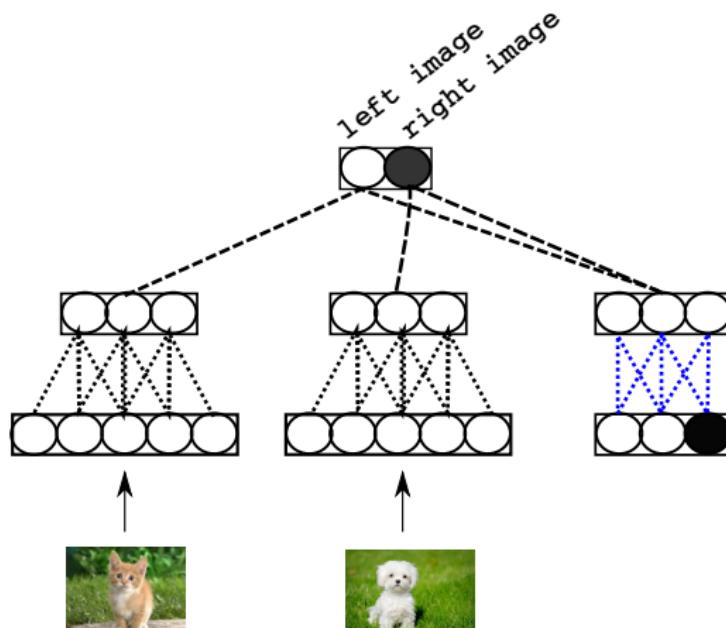
agnostic sender



informed sender

Players

Receiver



receiver

Training the agents

- ▶ learning via playing → communication success as supervision
- ▶ framework modeled with Reinforcement Learning
 - ▶ parameters define a *policy*
 - ▶ agents perform actions, i.e, Sender → *symbol*, Receiver → *image*
 - ▶ loss function:

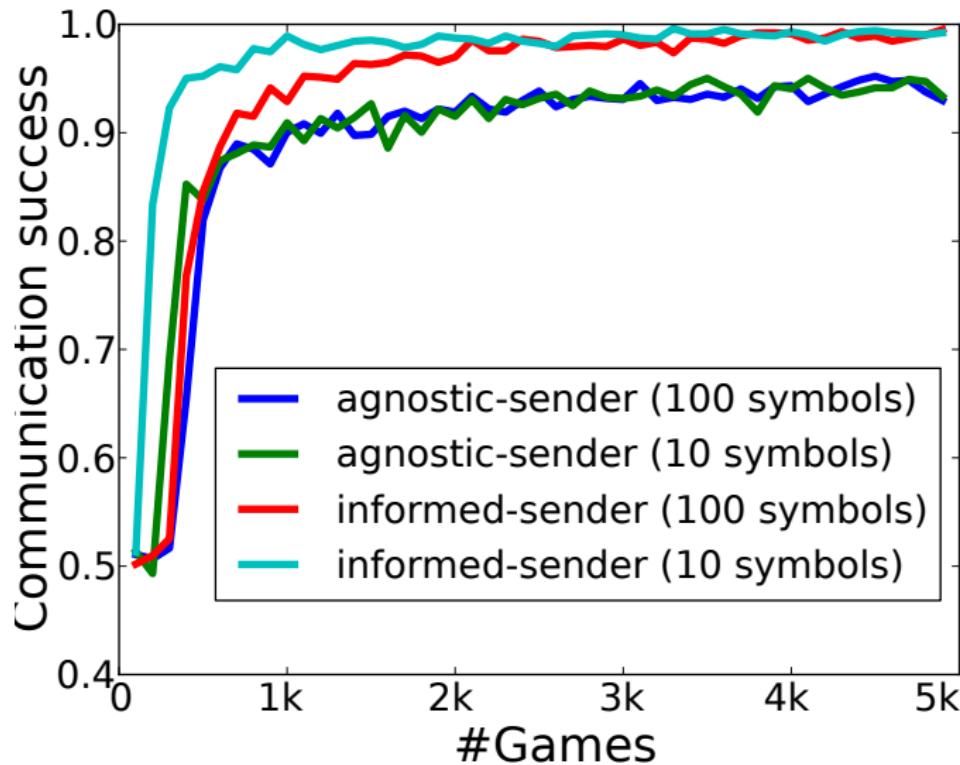
$$-\mathbf{E}_{\tilde{i} \sim p(i|i_1, i_2, s)}[R(\tilde{i})] \quad (1)$$

- ▶ parameters updated with REINFORCE rule (Williams, 1992)
- ▶ *Contextual Bandits* (Sutton and Barto, 2015, Chapter 2)

Research Questions

- ▶ Do agents learn to coordinate?
- ▶ Are the agents learning “natural language”?

Learning to communicate

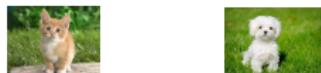


Communicate about high-level semantics

Removing “common knowledge”



sender

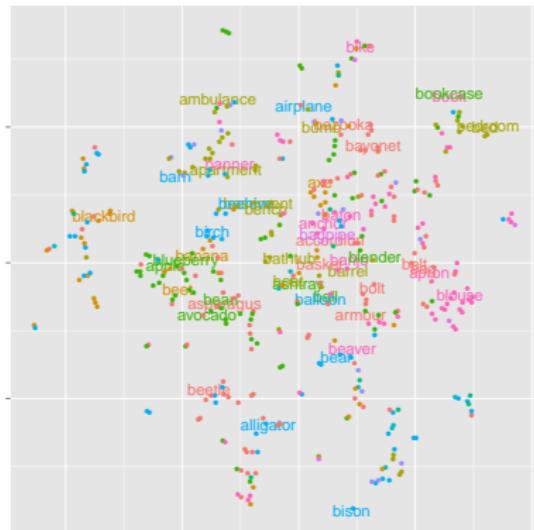


receiver

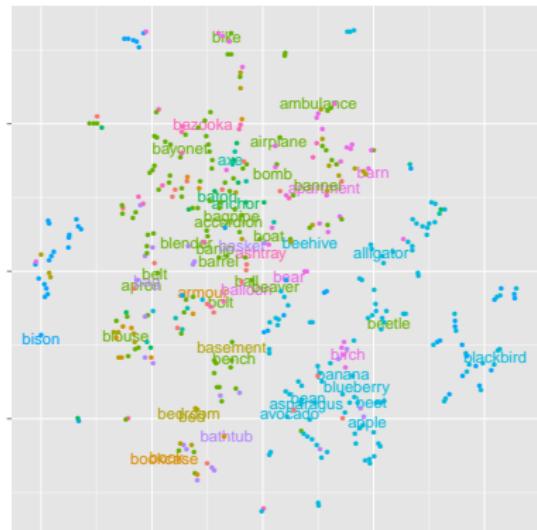
- ▶ “Common knowledge”: facts that everyone knows, everyone knows that everyone knows, etc...
(Brandenburger et al., 2014)
- ▶ forcing agents to communicate about *abstract* and not *low-level* properties

Communicate about high-level semantics

Visual vectors of targets colorcoded by the most frequent **symbol**



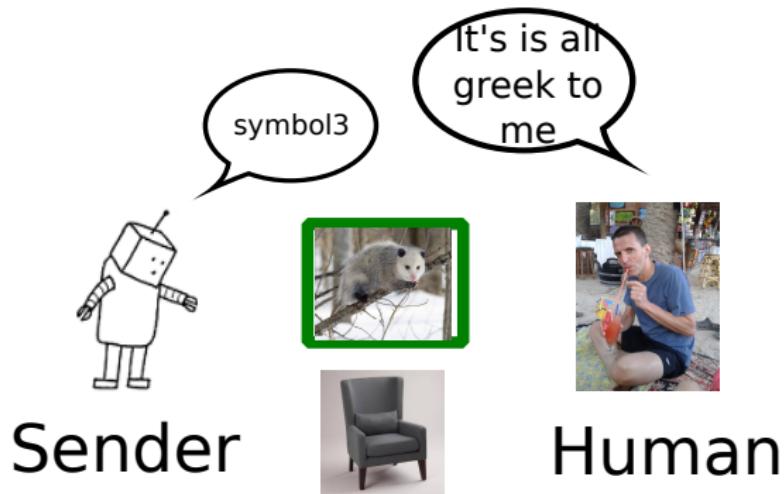
+ visual features



- visual features

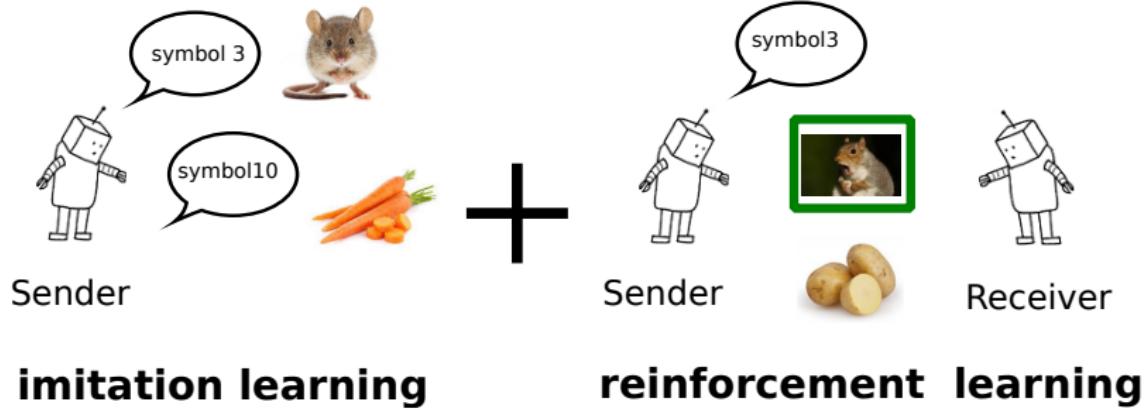
Grounding communication in natural language

Problem: Symbols not understandable by humans



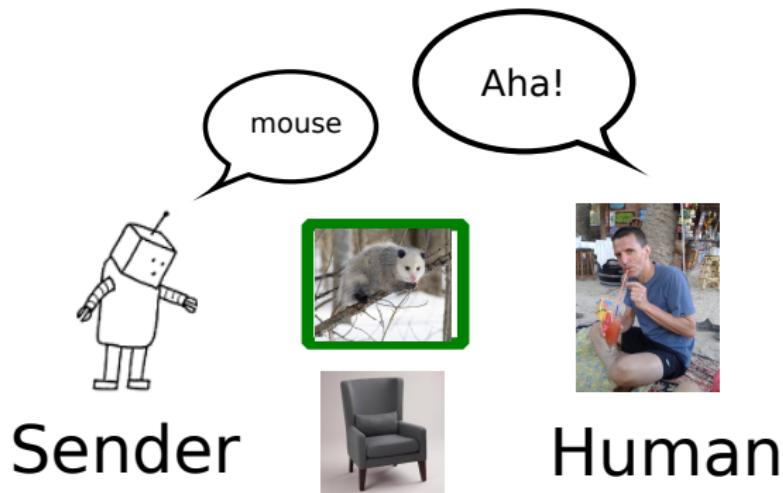
Grounding communication in natural language

structure + function



Grounding communication in natural language

Interpretable symbols



Grounding communication in natural language

Humans playing with the sender, 68% on communication success

dolphin



fence



Discussion

- ▶ **goal-oriented** language learning through **grounded** co-operation games
 - ▶ complementary to human-in-the-loop and “Wizard-of-Oz”
 - ▶ human-interpretable protocol through explicit supervision
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- ▶ closer fit to human **language** →
 - ▶ closer fit to human **dialogue** →

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- ▶ closer fit to human **language** → sequence of symbols
 - ▶ closer fit to human **dialogue** → multi-step interaction, modeling common ground, theory of mind

Bigger picture

Collective intelligence through communication

