# Emergent Communication in a Multi-modal, Multi-step Referential Game



Katrina Evtimova<sup>1</sup> Andrew Drozdov<sup>2</sup> Douwe Kiela<sup>3</sup>

Kyunghyun Cho<sup>1,2,3,4</sup>

Artificial Intelligence Research

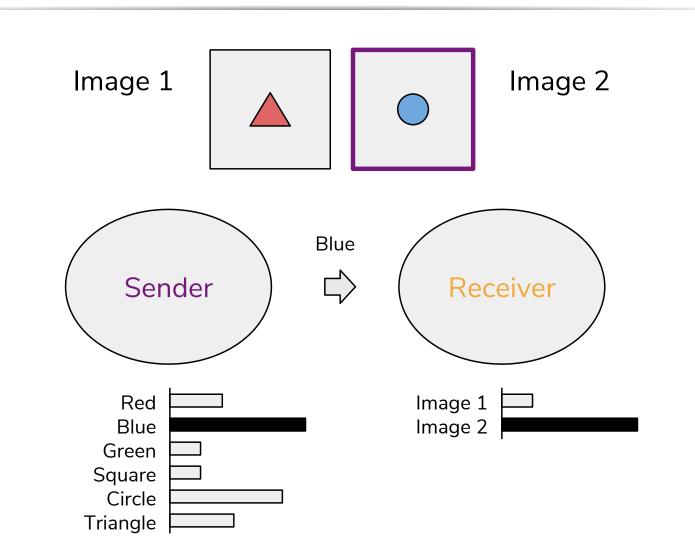
<sup>1</sup>Center for Data Science, New York University <sup>2</sup>Department of Computer Science, New York University <sup>3</sup>Facebook Al Research <sup>4</sup>CIFAR Azrieli Global Scholar

#### Overview

This works presents a novel referential game where the sender and receiver are grounded in two separate modalities, have an adaptive conversation length, and learn a communication protocol.

We find that the agents vary conversation length according to the difficulty of the task and gradual information exchange informs better predictions.

## Referential Games



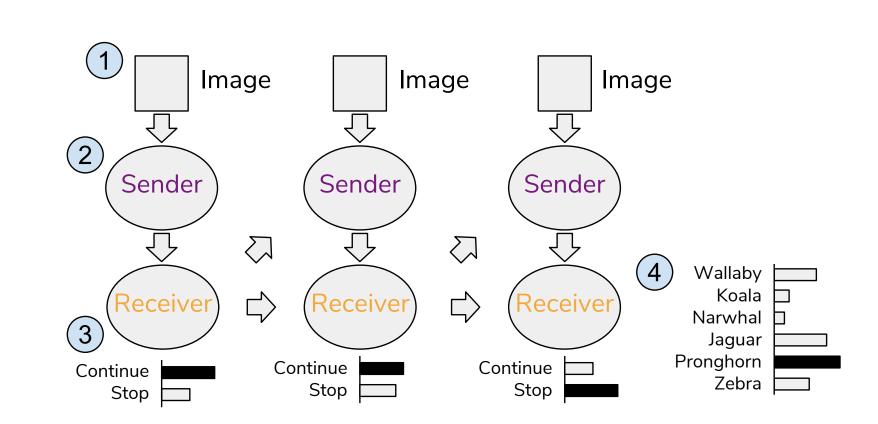
An example Referential Game where both agents see the images, the Sender knows the target image, and it may send one message to the Receiver [Lazaridou et al., 2017].

Other setups have been studied such as one where the Sender and Receiver have a conversation of fixed length, the Receiver may send a single discrete token from a small vocabulary, and the Sender may only answer yes or no [Jorge et al., 2016].



Paper (arXiv) 1705.10369

#### This Work



- 1. The image features are extracted using a pre-trained network.
- 2. The Sender incorporates the image and the Receiver's message (if it's available) to generate a message for the Receiver.
- 3. The Receiver incorporates the class descriptors, the Sender's message, and its own hidden state to generate a message for the Sender.
- 4. When the conversation terminates, the Receiver predicts the image's most likely class.

#### Per-Instance Loss:

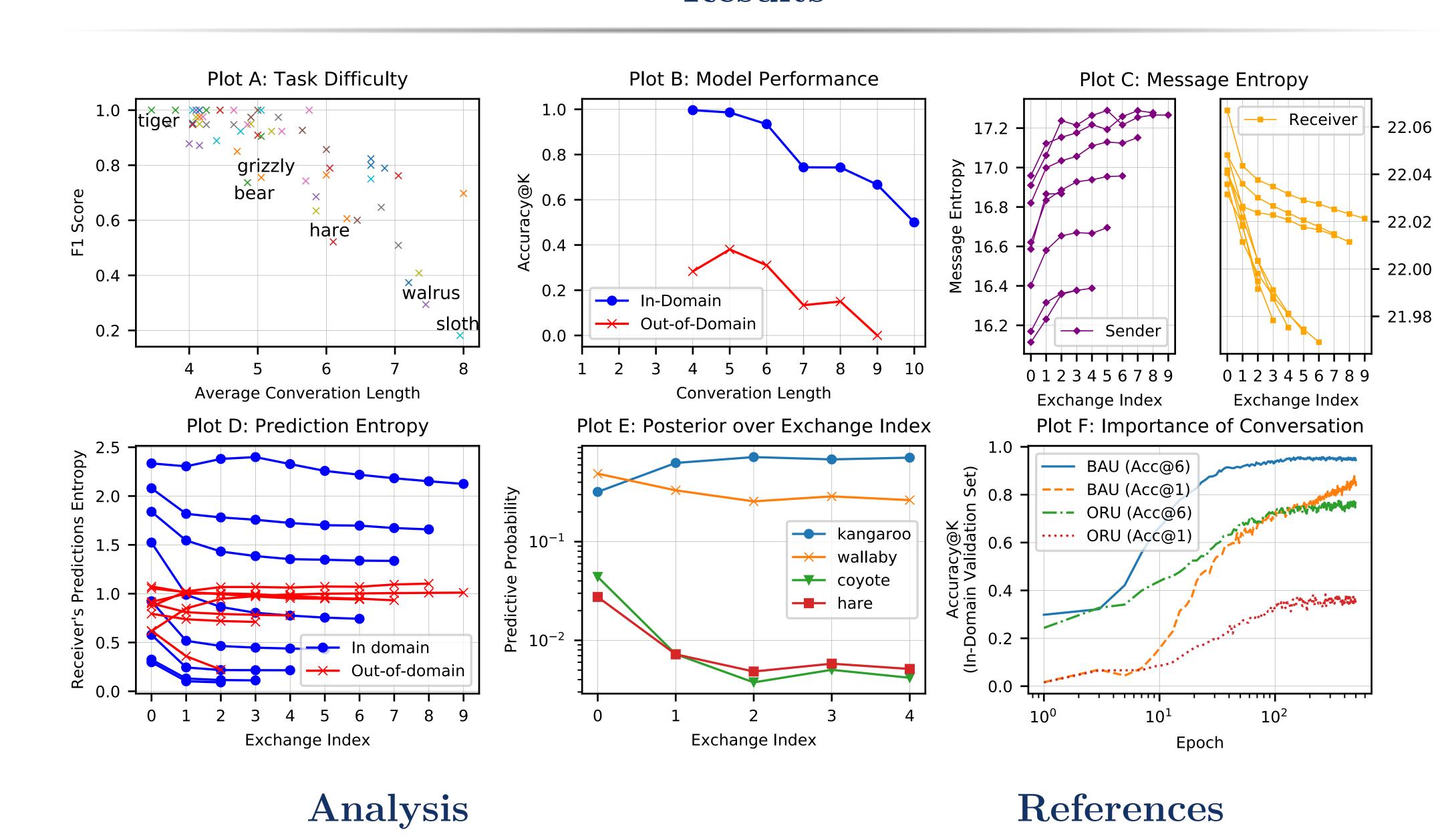
$$L^{i} = L_{c}^{i} + L_{r}^{i} - H_{stop,sen,rec}^{i}$$

- $L_c^i$  is the classification loss.
- $L_r^i$  is the reinforcement learning loss.
- $H^{i}_{stop,sen,rec}$  is the entropy regularization on the Sender's messages, the Receiver's messages, and the Receiver's stop-bit.

# Experimental Setup

In-Domain: 60 mammals with 550 images per mammal for training, 50 validation, and 20 test. Out-of-Domain: 10 mammals with 20 images. **Transfer:** 10 insects with 100 images.

### Results



- There's a significant negative relationship between class difficulty and the average conversation length [Plot A].
- Examples for which conversations are shorter are better classified [Plot B].
- As the conversation progress, the Receiver's messages become more specific [Plot C right] and the Sender's messages become less certain [Plot C left].
- The conversation length correlates well with the Receiver's prediction confidence [Plot D].
- As the Receiver gathers more information, similar but incorrect categories receive smaller probabilities than the correct one [Plot E].
- The learned protocol was more effective when communication was bidirectional [Plot F].

[Jorge et al., 2016] Jorge, E., Kågebäck, M., and Gustavsson, E. (2016). Learning to play guess who? and inventing a grounded language as a consequence.

In Deep Reinforcement Learning Workshop at NIPS.

[Lazaridou et al., 2017] Lazaridou, A., Peysakhovich, A., and Baroni, M. (2017).

Multi-agent cooperation and the emergence of (natural) language. In Proceedings of ICLR.



Code (Github) nyu-dl/MultimodalGame