

# Expressivity of Emergent Languages is a Trade-off between Contextual Complexity and Unpredictability

Shangmin Guo, Yi Ren, Kory Wallace Mathewson,  
Simon Kirby, Stefano V Albrecht, Kenny Smith

March 15, 2022



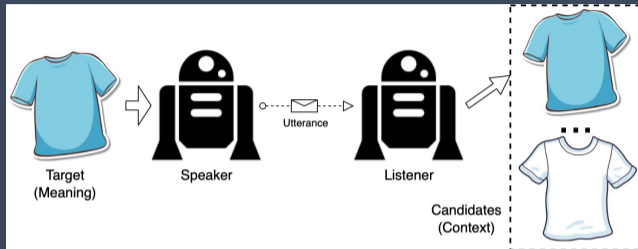
THE UNIVERSITY of EDINBURGH  
**informatics**



**NLP**

UKRI CENTRE  
FOR DOCTORAL  
TRAINING

# Referential Game



- Language: mappings from meanings to utterances
- “Emergent”: no supervision on utterances
- Previous works:<sup>12</sup>

<sup>1</sup>Serhii Havrylov, Ivan Titov, Emergence of language with multi-agent games: Learning to communicate with sequences of symbols, NeurIPS, 2017.

<sup>2</sup>Angeliki Lazaridou, Karl Moritz Hermann, Karl Tuyls, Stephen Clark, Emergence of linguistic communication from referential games with symbolic and pixel input, ICLR, 2018.

# Why Referential Games?

- Language is functionally used to communicate
- Understand the origin and evolution of natural languages
- Understand how multiple agents can complete tasks through communication
- Shape emergent languages to provide better human computer interaction
- ...

# Utterances in Different Expressive Degree



- t-shirt
- striped t-shirt
- blue striped t-shirt
- white blue striped t-shirt
- white blue horizontally striped t-shirt
- ...

# Expressivity of Emergent Languages

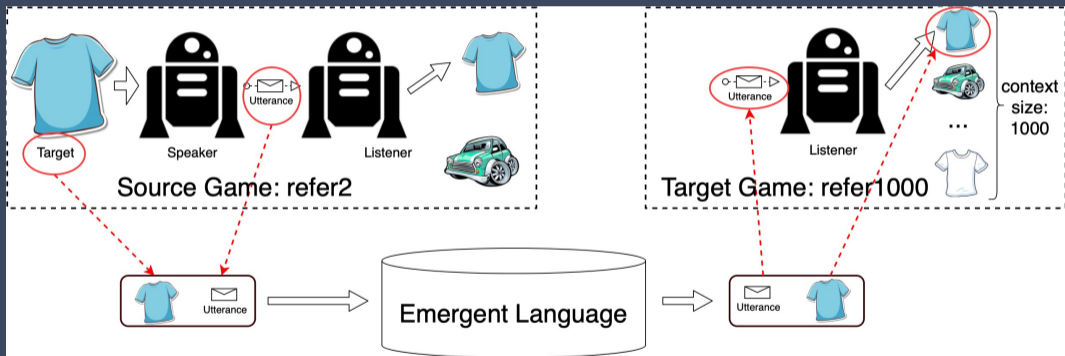
Intuition: less dependency on context

→ ability to work on more diverse tasks (Transfer Learning)

## Partial Ordering between Expressivity

Given a set of games and two emergent languages, if emergent language  $A$  performs **better** than the other  $B$  on some games while they perform approximately the **same** on the remaining games, then expressivity of  $A > B$ .

# Language Transfer Experiment



# Expressivity: Trade-off Complexity and Unpredictability

## Hypothesis

The expressivity of emergent languages is a trade-off between the **complexity** and **unpredictability** of context in language games.

## Predictions:

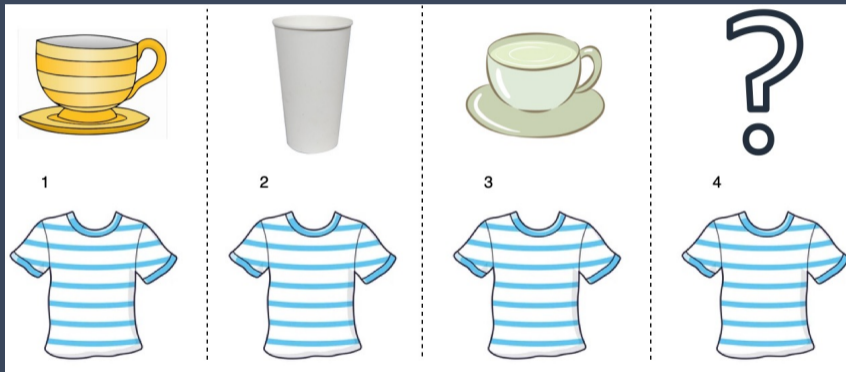
- ① unilateral increment of contextual complexity can increase the expressivity
- ② unilateral increment of contextual unpredictability can increase the expressivity
- ③ if the size of meaning space is fixed, moderate complexity and unpredictability should lead to the highest expressivity

# Factor 1: Complexity of Context

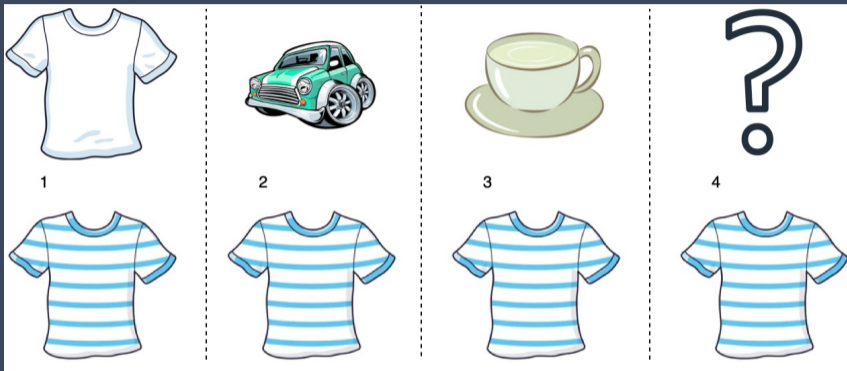


Definition: expectation of the probability that a context contains an object whose similarity degree to the target is  $\leq$  certain value.

## Factor 2: Unpredictability of Context (1)



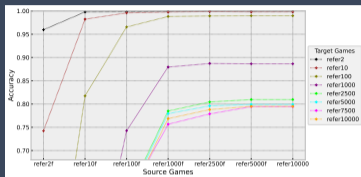
## Factor 2: Unpredictability of Context (2)



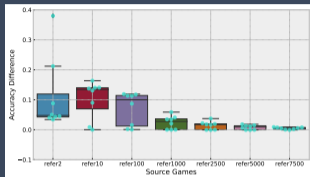
Definition: expectation of the ratio of candidates in the current context that are not from the context of previous round.<sup>3</sup>

<sup>3</sup>James Winters, Simon Kirby, Kenny Smith, Contextual predictability shapes signal autonomy, Cognition, 2018.

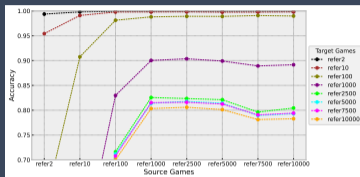
# Experiments



(a) fixed unpredictability, higher complexity  $\rightarrow$  more expressive language



(b) fixed complexity, higher unpredictability  $\rightarrow$  more expressive language



(c) moderate complexity and unpredictability  $\rightarrow$  highest expressivity

Various game setups:

- larger *channel* capacity
- larger *agent* capacity
- larger *channel&agent* capacity

Thank You!