

# NLP2 Project: *Language Emergence in Referential Games*

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## 1 Introduction

**Background** Natural Language Processing (NLP) has seen great success in areas such as Machine Translation, Information Extraction, and Image Captioning, with the combination of deep learning and the distributional hypothesis, where large corpora are used for learning general statistical relations. However, this approach misses the functional aspect of language, namely that language is used by the speaker to reach a certain goal. In recent years, there has been an increased interest in having deep neural agents develop their own languages through cooperative games. Not only does this allow us to test theories for the evolution of human language *in silico*, but this could also improve on current NLP techniques, such as Machine Translation or Conversational AI.

A cooperative game that has been used extensively to simulate language emergence, is the *referential game*, also known as the *Lewis Signalling Game*. In this game two agents, the Sender and Receiver, have to cooperate to reach a shared goal. In a common setup, the Sender gets to see a *target image* and sends a description—a string of a priori meaningless symbols—to the Receiver. The Receiver then has to choose the *target image* from a set of objects also containing other images, the *distractors*. The agents get a reward if the Receiver correctly identifies the *target image*. Through playing this game, the agents will develop a common language which they can use to cooperate successfully.

There are three important challenges in studying language emergence through these referential games. First of all, there is the technical challenge of updating the model parameters, as it is not possible to back-propagate through the sampling of *discrete* messages (see the symbols  $w_1$  to  $w_4$  in Figure 1). Conventional back-propagation with Stochastic Gradient Descent can be used on the Receiver, but we need another way to estimate the gradient for the Sender. Two common methods for dealing with this problem are using *REINFORCE* or *Gumbel-Softmax (GS) relaxation* instead<sup>1</sup>.

Other research focuses on the evaluation of the emergent languages and tries to come up with different measures to find out to what extent these emergent languages are similar to natural languages. Despite the challenging task because of the lack of dictionaries and gold annotations, researchers have come up with different metrics and qualitative methods to analyse the *semantic* and *structural properties* of these languages.

Last of all, there is the challenge of finding *pressures* that can steer the language evolution in an interesting direction. Different choices can be made in the game design, architecture

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<sup>1</sup>See Havrylov and Titov (2017) or Kharitonov et al. (2019) in the suggested reading if you are interested in learning more about this.

of the agents, or the data set, that can lead to the emergence of certain properties. One example of a pressure is the use of a penalty proportional to the message length to achieve a more natural power-law distribution of the word frequencies (Zipf’s law). Finding other such pressures can help us not only in creating more eloquent AI, but also in better understanding the evolution of natural languages in humans and animals.

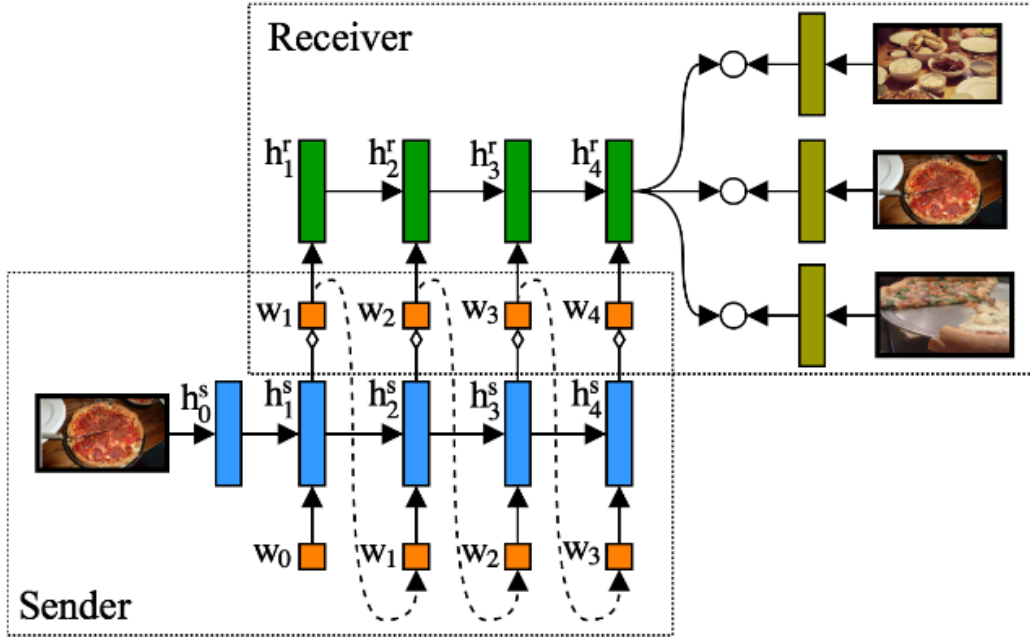


Figure 1: Example of a Sender and Receiver architecture in a referential game (Havrylov and Titov, 2017). Notice how the gradient of the loss needs to back-propagate through the discrete message sampling ( $w_1$  to  $w_4$ ) in order to update the Sender’s parameters.

**Assignment** In this project, you will come up with your own referential game experiment that could lead to a more natural language. Specifically, you will devise a hypothesis for what could be an interesting *pressure* and test whether you can indeed find natural language properties.

For implementing the experiment, you will make use of the Python library EGG: **E**mergence of lanGuage in Games<sup>2</sup>. I’ll provide you with a template you could use for implementing a variable length signalling game during the first lab session.

1. [Jupyter notebook, due Febuary 26, 2021](#). The notebook should contain the entire pipeline from data generation to model training to the analysis conducted. Functions or classes are allowed to be defined in Python files externally, as long as the main functionality is listed in the notebook. We recommend training your models on GPUs through the Google Colab service.<sup>3</sup>

<sup>2</sup>Visit the library: <https://github.com/facebookresearch/EGG>

<sup>3</sup>Visit Google Colab: <https://colab.research.google.com/>.

2. [Short paper, due February 26, 2021](#). The short paper should use the ACL conference’s template<sup>4</sup> and contain four pages (references excluded). A suggested page distribution is as follows:
  - (a) **Abstract:** summarise the research in a short piece of text that emphasises your contributions and findings (0.1 pages);
  - (b) **Introduction:** introduce the reader to your research area, summarise your contributions and highlight the relevance of your research, provide a clear and explicit problem statement as well as your research questions (0.5 pages);
  - (c) **Related Work:** summarise research papers relevant for your work. Be brief, since this is a short paper (0.4 pages);
  - (d) **Approach:** dependent on the particular project, this section should detail the tasks or models designed (1 page);
  - (e) **Experiments and Results:** detail the precise experimental setup used and the results of your evaluation measures (1 page);
  - (f) **Discussion:** interpret the results of analysing the emergent language. Do the findings support your hypothesis? Can you explain which *pressures* are likely to have contributed to the language property (or not)? Any suggestions for future work? (1 page).
3. [Poster presentation, due February 24, 2021](#). Compress the paper’s content into a single-page poster that could be presented at a conference. Support the textual content through visual aids, such as tables and graphs that facilitate fast understanding of the paper’s contributions and main results. You will present this poster via a Zoom session in a presentation of about 5 minutes; details about the poster session will be made available in due time.

## 2 Suggested Schedule

To stay on track, we recommend adhering to the following schedule.

### 2.1 Week 1

**Reading** Go through the Suggested Reading list at the end of this document to get a feel for the field of language emergence through referential games. Follow your curiosity and see which language properties you find interesting.

**Coding** Try out the EGG library<sup>2</sup> in a Google Colab notebook. You should get a simple implementation of a *signalling game* running where the task success is close to 100%, by making use of the provided template—this will serve as your baseline. For inspiration, see the EGG tutorial on a simple autoencoder implementation and have a peak at their implementation of the signalling game.

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<sup>4</sup>Visit the template: <https://acl2020.org/calls/papers/#paper-submission-and-templates>.

**Writing** It is a good habit to write about the research along the way. At this point, the ‘Introduction’ and ‘Related Work’ sections could already be drafted after the literature review. You could also write about the language emergence through referential games in the ‘Approach’ section.

## 2.2 Week 2

**Reading** This week you should come up with a hypothesis of which pressures you would like to try and how you think it will affect the language. Make sure you have also found ways to test for the resulting language properties, both qualitatively and with metrics.

**Coding** Setup your Referential Game in line with your hypothesis. Can you still get a task success of close to 100% if you implement your pressures? If not, could you make the set-up simpler again? It is also a good idea to start implementing the methods for analysing the emergent languages.

**Writing** This week, the ‘Experiments and Results’ section is to be filled out. Extend the paper with an experimental setup detailing the models used for the agents, the data-set, the loss function, and specifically the *pressures* experimented with. Also write about the measures used for analysing the emergent languages.

## 2.3 Week 3

**Reading** It is time to identify gaps in your knowledge and try to find papers that can help deepen your understanding.

**Coding** Analyse the emergent languages using the metrics you have implemented and other measures you have found.

**Writing** Write the ‘Discussion’ section of the paper. Summarise the conclusions of your analyses in text and ensure that these are supported by evidence presented in tables or graphs. Create an outline for the poster to be presented.

## 2.4 Week 4

**Reading** Given your analysis of the languages, are your findings in line with the literature?

**Coding** Ensure that the notebook is understandable for the reviewers and that it details the entire pipeline from data generation to the analysis of results.

**Writing** Finish the paper and edit its content to fit into four pages. Additional analyses can be put in the appendices, but the grade is primarily based on these first four pages. Include the paper’s main points in the poster, supported by visual aids, such as tables and graphs that facilitate fast understanding of the setup, the most interesting results, and the analyses conducted.

### 3 Suggested Reading

- Angeliki Lazaridou, Alexander Peysakhovich, Marco Baroni: Multi-Agent Cooperation and the Emergence of (Natural) Language. ICLR 2017
- Serhii Havrylov, Ivan Titov: Emergence of Language with Multi-agent Games: Learning to Communicate with Sequences of Symbols. NIPS 2017: 2149-2159
- Satwik Kottur, José M. F. Moura, Stefan Lee, Dhruv Batra: Natural Language Does Not Emerge 'Naturally' in Multi-Agent Dialog. EMNLP 2017: 2962-2967
- Eugene Kharitonov, Rahma Chaabouni, Diane Bouchacourt, Marco Baroni: EGG: a toolkit for research on Emergence of lanGuage in Games. EMNLP/IJCNLP (3) 2019: 55-60
- Diane Bouchacourt, Marco Baroni: How agents see things: On visual representations in an emergent language game. EMNLP 2018: 981-985
- Diana Rodríguez Luna, Edoardo Maria Ponti, Dieuwke Hupkes, Elia Bruni: Internal and External Pressures on Language Emergence: Least Effort, Object Constancy and Frequency. EMNLP (Findings) 2020: 4428-4437
- Kris Cao, Angeliki Lazaridou, Marc Lanctot, Joel Z. Leibo, Karl Tuyls, Stephen Clark: Emergent Communication through Negotiation. ICLR (Poster) 2018
- Diane Bouchacourt, Marco Baroni: Miss Tools and Mr Fruit: Emergent Communication in Agents Learning about Object Affordances. ACL (1) 2019: 3909-3918
- Angeliki Lazaridou, Karl Moritz Hermann, Karl Tuyls, Stephen Clark: Emergence of Linguistic Communication from Referential Games with Symbolic and Pixel Input. ICLR 2018
- Oskar van der Wal, Silvan de Boer, Elia Bruni, Dieuwke Hupkes: The Grammar of Emergent Languages. EMNLP (1) 2020: 3339-3359
- Angeliki Lazaridou, Marco Baroni: Emergent Multi-Agent Communication in the Deep Learning Era. CoRR abs/2006.02419 (2020)