The typology of lexical classes in emergent languages

Edoardo Ponti[1], **Dieuwke Hupkes**[2], Diana Rodriguez[2] and Elia Bruni[3]

[1]University of Cambridge, [2]University of Amsterdam, [3]Universitat Pompeu Fabra

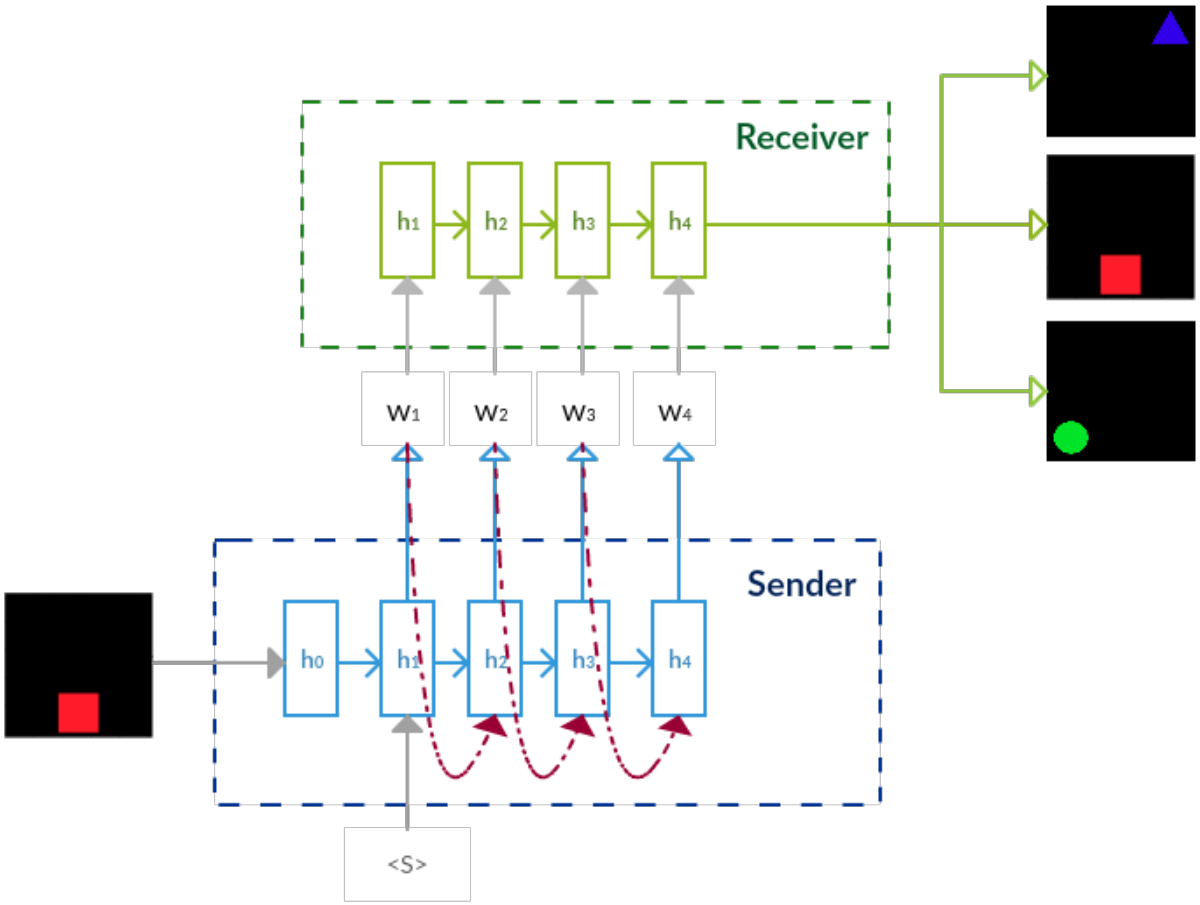
Interaction and the Evolution of Linguistic Complexity
University of Edinburgh, June 18, 2019

Introduction

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

L. Steels, 2015

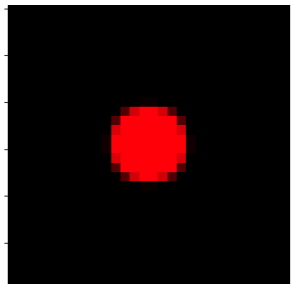
Referential games



Setup: Havrylov et al (2017)
Data: Shapes, Andreas et al (2016)

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

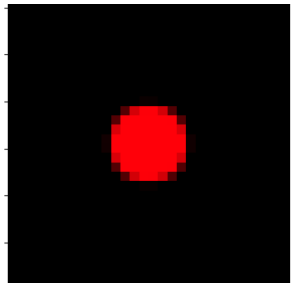
What do they say?



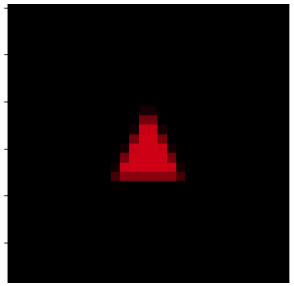
bo bo di la la

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

What do they say?



bo bo di la la



di la bo ke la

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

What do they say?

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

bo bo di la la di la bo ke la

What can we do with these languages?

Research questions

- Do *lexical classes* emerge in the agents' languages?

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Research questions

- Do *lexical classes* emerge in the agents' languages?
- Does this depend on the hyperparameters L and $|V|$?

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Setup

- Do *lexical classes* emerge in the agents' languages?
- Does this depend on the hyperparameters L and $|V|$?

- 9 different setups:
  - Initial vocabulary sizes $|V|$: 7, 14 or 28
  - Maximum lengths L: 3, 5 or 10

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

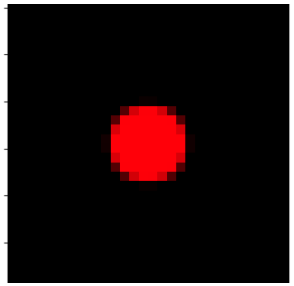
Some statistics

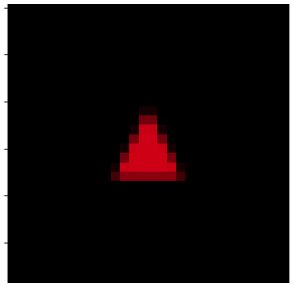
Settings		*Language Properties*			
L	$\|V\|$	Average L	Min L	Max L	N tokens used
3	7	3	3	3	7
3	14	3	3	3	14
3	28	3	3	3	23.3
5	7	5	5	5	7
5	14	5	5	5	13.7
5	28	5	5	5	3.7
10	7	10	10	10	7
10	14	10	10	10	14
10	28	10	10	10	22

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

What do they say?

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

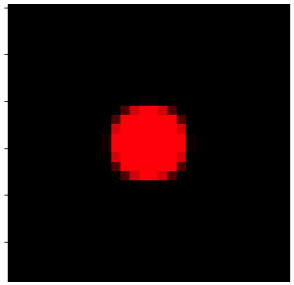


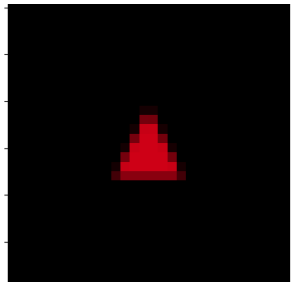


$|V| = 7$, L=5 bo bo di la la di la bo ke la

What do they say?

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni





$\|V\| = 7$, L=3	la di di	la mu di
$\|V\| = 7$, L=5	bo bo di la la	di la bo ke la
$\|V\| = 28$, L=5	ti fa do ke ti	ti ti ke do la

What is their language like?

- Topographic similarity (Lazaridou et al, 2018)
- Causal influence (Lowe et al., 2019)
- Representational similarity (Bouchacourt et al, 2018)
- Message distinctness (Choi et al., 2018)
- Perplexity per word (Havrylov and Titov, 2017)

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

What is their language like?

Two types of information:

- What images do the messages refer to (*Semantic*)
- What do the messages look like ('*Syntactic*')

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Semantic analysis

Local Mutual Information

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

$$\mathrm{LMI}(symb; feat) = p(symb, feat) \cdot log \frac{p(symb|feat)}{p(symb)}$$

(Evert, 2005)

Semantic Analysis

Purity of words and features

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

		$\lvert V \rvert$		
		7	**14**	**28**
L	**3**	0.37	0.35	0.24
	5	0.29	0.31	0.31
	10	0.29	0.36	0.28

Word purity

$\lvert V \rvert$		
7	**14**	**28**
0.28	0.22	0.15
0.25	0.21	0.17
0.22	0.21	0.12

Feature purity

Semantic Analysis

Highest scoring features

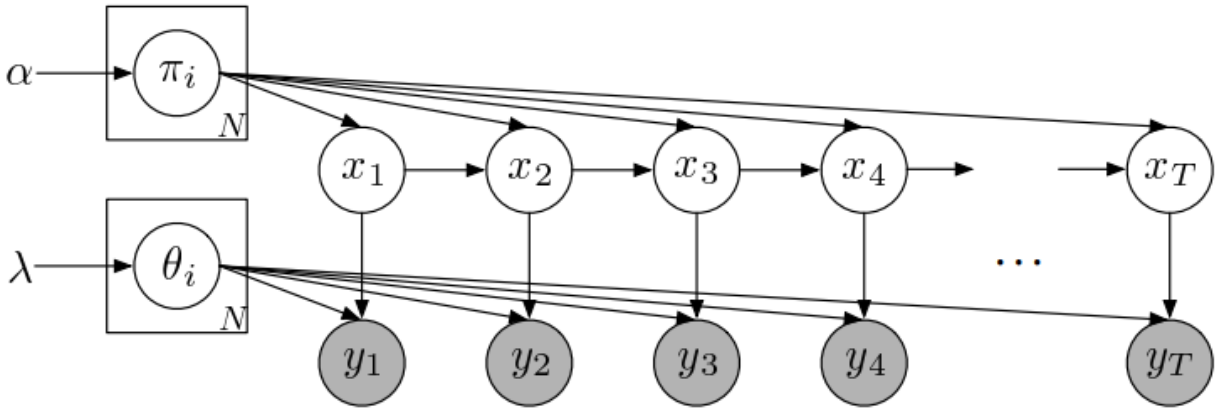
$\|V\|$	L	**Feature**	**Purity**
7	3	triangle	0.74
7	5	right	0.82
7	10	lower	0.52
14	3	middle	0.44
14	5	right	0.46
14	10	right	0.60
28	3	triangle	0.39
28	5	left	0.38
28	10	lower	0.29

Table: Highest scoring feature per setup.

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Syntax

Hidden Markov Model with Hierarchical Dirichlet Process

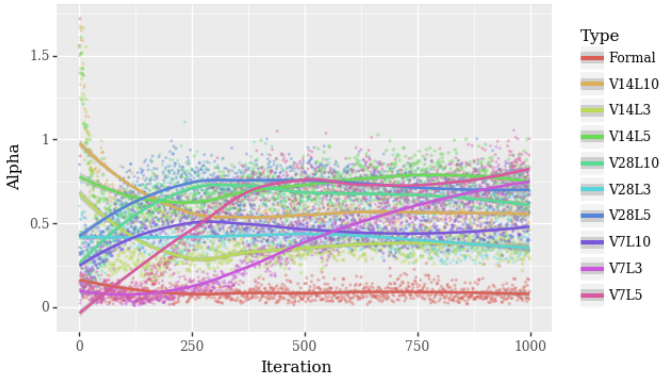


(Johnson and Willsky, 2013; Teh et al., 2005)

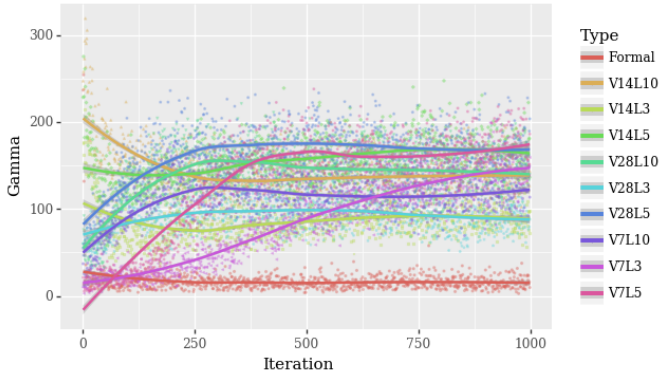
Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Syntax

Hyperpriors



α hyper-prior.



γ hyper-prior.

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Overlap between semantic and syntactic clusters

$\lvert V \rvert$	**L**	**B-cubed**	**NMI**
7	3	**0.426**	0.464
7	5	0.244	**0.466**
7	10	0.346	0.378
14	3	0.371	0.284
14	5	0.395	0.234
14	10	0.266	0.267
28	3	0.320	0.189
28	5	0.224	0.076
28	10	0.167	0.096

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Some intermediate conclusions

- Large variation for both syntactic and semantic analysis, depending on the initial vocabulary size and maximum message length
- Agents talk primarily about position, and not about shapes and colors

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Some intermediate conclusions

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

- Large variation for both syntactic and semantic analysis, depending on the initial vocabulary size and maximum message length
- Agents talk primarily about position, and not about shapes and colors

There is a framework that addresses the *functional* aspect of language, but we should also take care of the ecosystem that the agents live in.

Preview of a parallel project

Internal and External Pressures

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Internal

- **Least effort:** Speaking has a cost

External

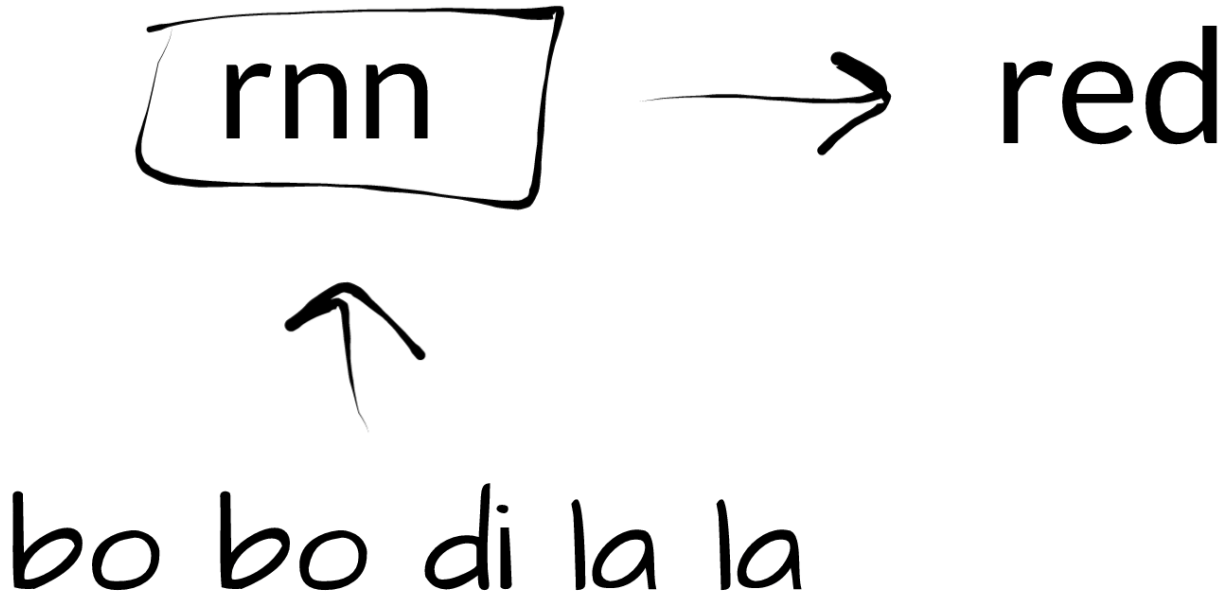
- **Subjective Constancy:** Objects can be recognised under different circumstances
  - *Illumination*
  - *Position*
- **Object Frequency**: objects and features are non-uniformly occurring in the real world

Internal pressure for least-effort

	Acc	Avg Length	Std Length	N tokens
baseline	0.99	11.0	0.0	20.67
penalty	0.98	6.10	0.87	13.0

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Diagnostic Classifier Accuracy



(Diagnostic Classifiers, Hupkes et al., 2018)

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Diagnostic Classifier Accuracy

Game	Shape	Colour	Size	Hor	Vert
Chance	0.33	0.33	0.50	0.33	0.33
Baseline	0.53	0.45	0.60	0.93	0.96

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Diagnostic Classifier Accuracy

Game	Shape	Colour	Size	Hor	Vert
Chance	0.33	0.33	0.50	0.33	0.33
Baseline	0.53	0.45	0.60	0.93	0.96
Location invariance	0.65	0.99	0.91	0.33	0.34

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Diagnostic Classifier Accuracy

Game	Shape	Colour	Size	Hor	Vert
Chance	0.33	0.33	0.50	0.33	0.33
Baseline	0.53	0.45	0.60	0.93	0.96
Location invariance	0.65	0.99	0.91	0.33	0.34
Colour constancy	0.36	0.67	0.60	0.99	1.00

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Diagnostic Classifier Accuracy

Game	Shape	Colour	Size	Hor	Vert
Chance	0.33	0.33	0.50	0.33	0.33
Baseline	0.53	0.45	0.60	0.93	0.96
Location invariance	0.65	0.99	0.91	0.33	0.34
Colour constancy	0.36	0.67	0.60	0.99	1.00
World distibution	0.68	0.73	0.88	0.97	0.97

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni

Recap

- Do lexical classes emerge in the agents' languages?
  - Semantic analysis (LMI and Purity)
  - Syntactic analysis (HMM)
  - Cluster overlapping
- Answer: a little bit
- Internal and External Pressures
  - Least effort
  - Subjective Constancy
  - Object Frequency
- Diagnostic classification
- Conclusion: the ecosystem matters

Edoardo Ponti
Dieuwke Hupkes
Diana Rodriguez
Elia Bruni