The typology of lexical classes in emergent languages

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

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Introduction

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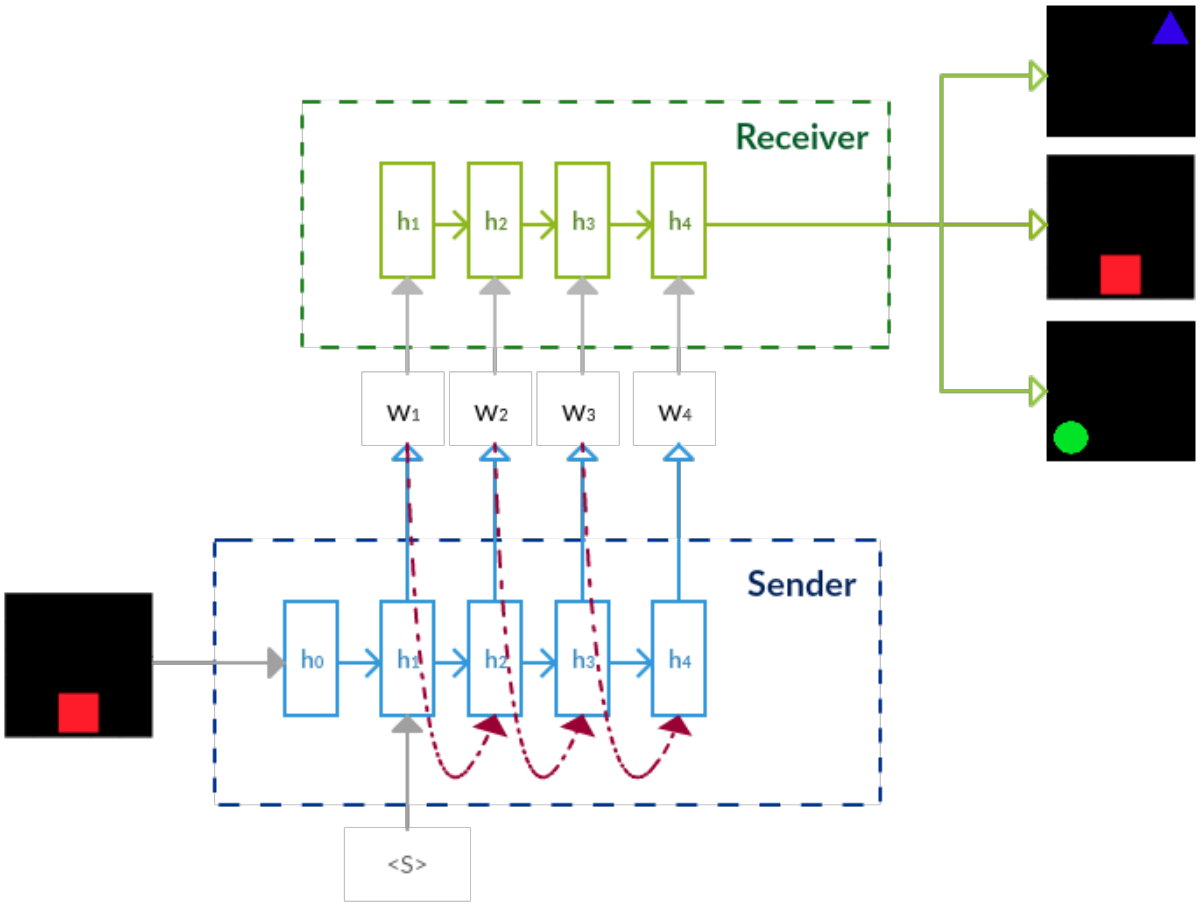
L. Steels, 2015

Referential games



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

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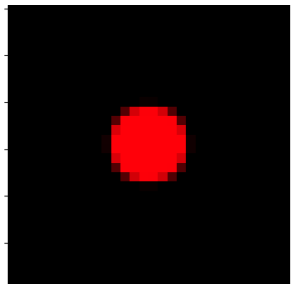
What do they say?



bo bo di la la

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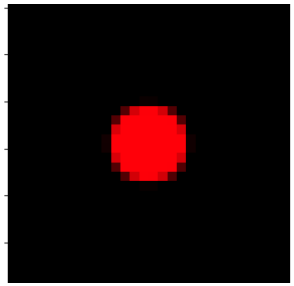
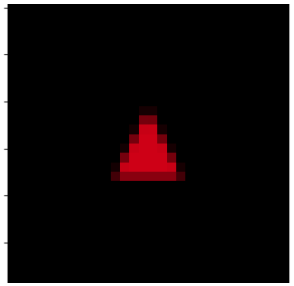


bo bo di la la



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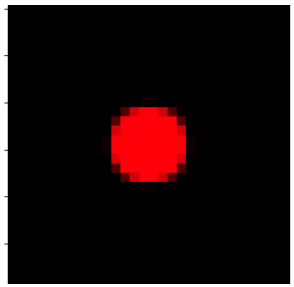

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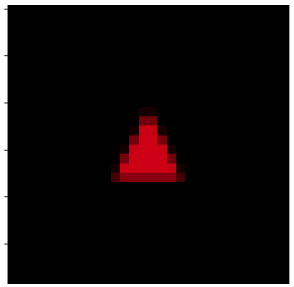

di la bo ke la

What can we do with these languages?

Research questions

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

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- Does this depend on the hyperparameters L and $|V|$?

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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

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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

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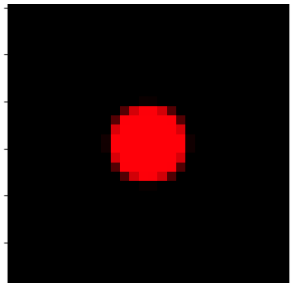

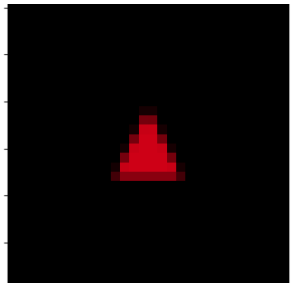

$|V| = 7$, L=5 bo bo di la la di la bo ke la

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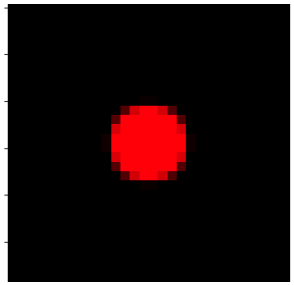

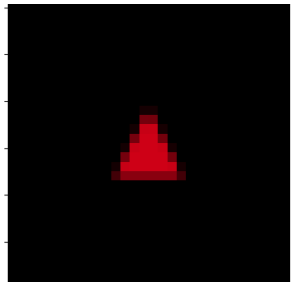

$\|V\| = 7$, L=3	la di di	la mu di
$\|V\| = 7$, L=5	bo bo di la la	di la bo ke la
$\|V\| = 28$, L=5	ti fa do ke ti	ti ti ke do la

What is their language like?

- Topographic similarity (Brighton and Kirby, 2006)
- Causal influence (Lowe et al., 2019)
- Representational similarity (Kriegeskorte et al., 2008)
- Message distinctness (Choi et al., 2018)
- Perplexity per word (Havrylov and Titov, 2017)

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What is their language like?

Two types of information:

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

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Semantic analysis

Local Mutual Information

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

(Evert, 2005)

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Semantic Analysis

Purity of words and features

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		$\lvert V \rvert$		
		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.

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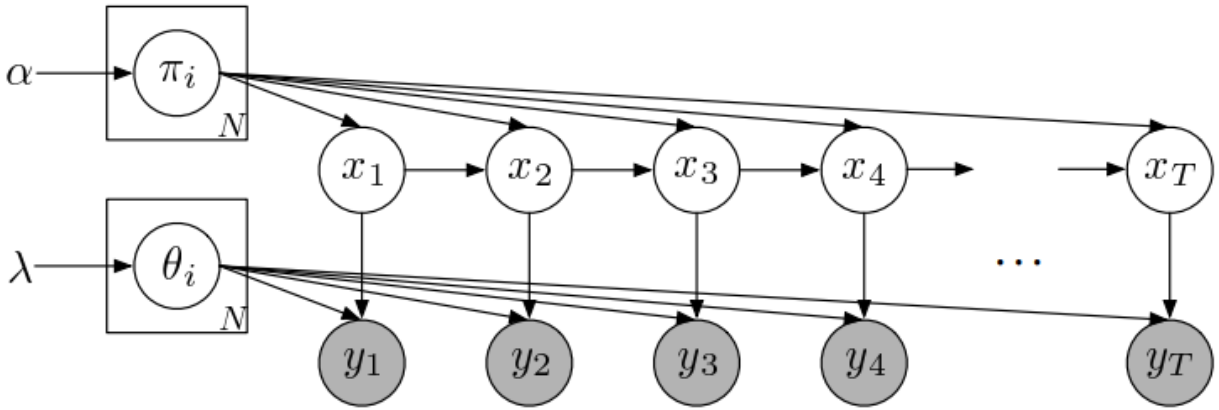
Syntax

Hidden Markov Model with Hierarchical Dirichlet Process



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

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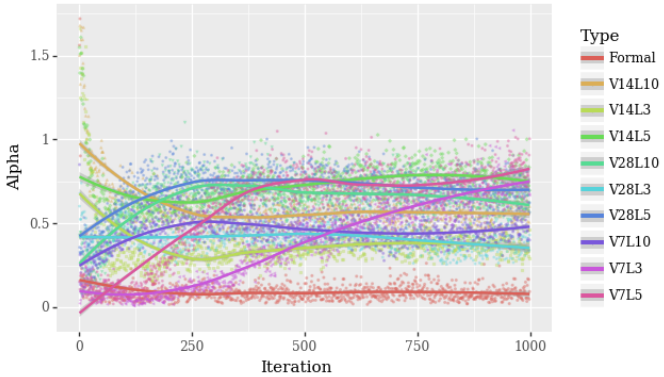
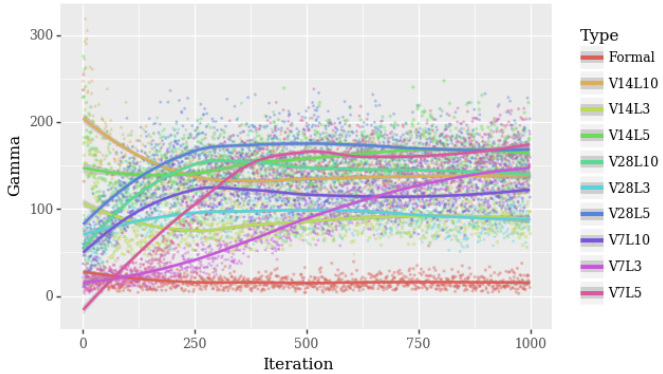
Hyperpriors



α hyper-prior.



γ hyper-prior.

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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

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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

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Some intermediate conclusions

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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

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

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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

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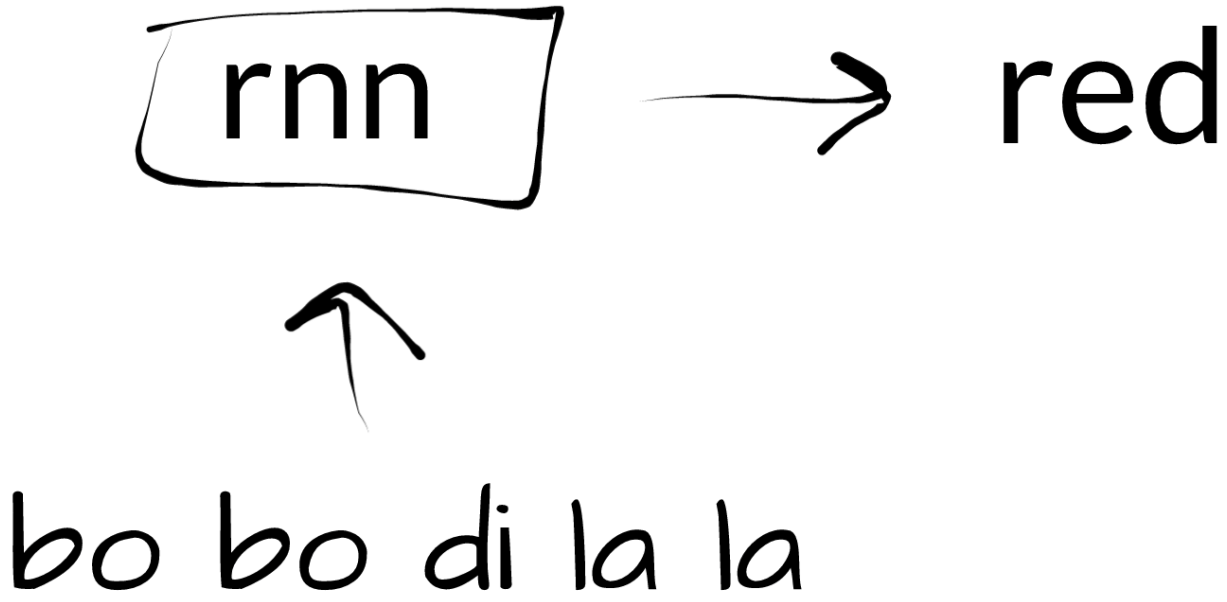
Diagnostic Classifier Accuracy



(Diagnostic Classifiers, Hupkes et al., 2018)

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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

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Colour constancy	0.36	0.67	0.60	0.99	1.00
World distibution	0.68	0.73	0.88	0.97	0.97

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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

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