

Iterated Learning, Attention and the Origins of Language

My research plans at LEC, University of Edinburgh

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Outline

Introduction

Language evolution research

Overview

Evolutionary dynamics

Research proposal

Curiosity

Computer model

Postface

Motivation

Fundamental questions:

- ▶ What is language?
- ▶ What is the role of language in cognition?
- ▶ What is it that makes us human?



Multidisciplinarity:

- ▶ Linguistics
- ▶ Neuroscience
- ▶ Computer modeling

LEC, University of Edinburgh



- ▶ Language Evolution and Computation research unit
- ▶ Department of Linguistics
- ▶ “Postgraduate Worker” for six months (starting February)

If you are bright, fascinated by what it is that makes us human, willing to work very hard, and keen to explore new areas of study, then we want to hear from you.

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A short history

- ▶ 1850s: viewing languages as evolving species (Schleiger)
- ▶ 1900: scientific death (no fossils!)
- ▶ 1980s: revival due to
 - ▶ computer modeling
 - ▶ advances in neuroscience

The problem of reverse engineering

Given:

- ▶ The current languages of the world
- ▶ Virtually no fossil records

Find out:

- ▶ Why our languages are as they are (structure)
- ▶ Why only humans have language (uniqueness)
- ▶ How language could evolve (function)
- ▶ When language evolved (history)

Recent 'theories' on language evolution

Language originates from

- ▶ Social relationships!
- ▶ Planning!
- ▶ Proto-gestures!
- ▶ Tool use!
- ▶ Bipedalism!
- ▶ Grooming!
- ▶ Spatial attention!
- ▶ ...



Computer models to the rescue

Typical ingredients:

- ▶ Population of agents
- ▶ Set of meanings
- ▶ Set of forms
- ▶ Meaning-form interface
- ▶ Meaning-selection mechanism
- ▶ Learning or reproduction mechanism

So, where should we begin?



Language Universals

Great variety:

- ▶ Absolute (“all languages have X” - Chomsky)
- ▶ Implicational (“if a language has X, it will have Y”)
- ▶ Tendencies (frequency distributions)
- ▶ Preference hierarchies
- ▶ Abstract (e.g. about hidden structure)
- ▶ ...

Examples

- ▶ No language has the vowel system $/i/ - /e/ - /u/$.
- ▶ Gricean maxims (quantity, quality, relevance, manner)
- ▶ Zipf's law
- ▶ Every language has words for 'black' and 'white'
- ▶ Concepts are convex regions in meaning space (Gärdenfors 2000)
- ▶ All (and only) human languages have recursion (Hauser, Chomsky & Fitch 2002)
- ▶ NPs always have case, even though it may not be realized phonologically.
- ▶ In declarative sentences with nominal subject and object, the dominant order is almost always one in which the subject precedes the object (Greenberg 1966)

Evolutionary dynamics

Three dynamic systems:

- ▶ Biological evolution (phylogeny)
- ▶ Cultural evolution (glossogeny)
- ▶ Individual learning and use (ontogeny)

Biological evolution (phylogeny)

How did language emerge on a phylogenetic timescale? E.g.

- ▶ Chomsky's Universal Grammar:
 - ▶ The sudden mutation of a recursion 'gene', or
 - ▶ The gradient transition of some capacity into a language faculty
- ▶ The descended larynx



Cultural evolution (glossogeny)

How do languages change on a cultural timescale? E.g.

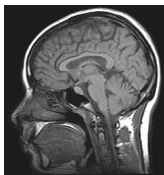
- ▶ Do all languages have a common mother tongue?
- ▶ When and why did the great vowel-shift in English occur?



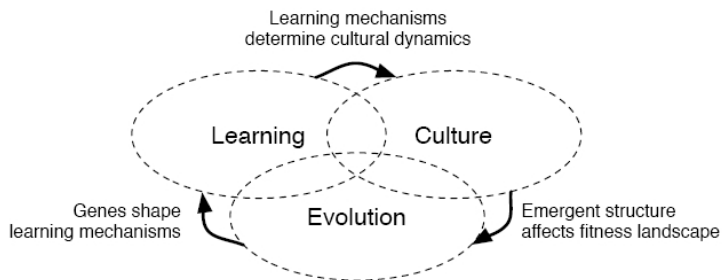
Individual learning and use (ontogeny)

How does language work within an individual? E.g.

- ▶ How are languages learned?
(learning bottleneck)
- ▶ What happens in our brain
when we learn or use language?



Interplay

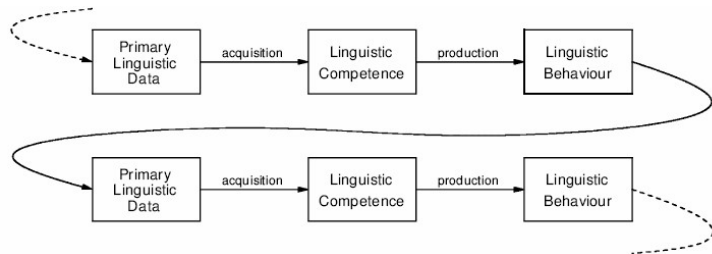


(from Kirby 2007)

Iterated learning (IL)

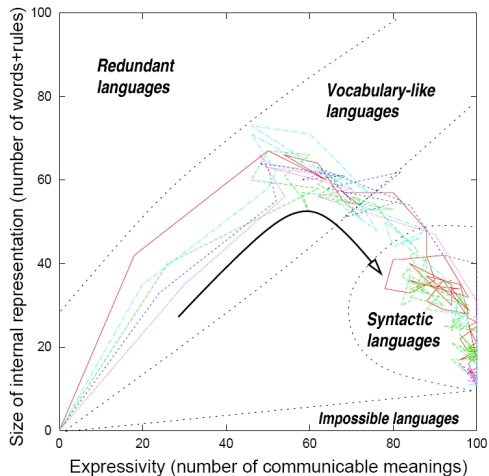
Modeling the interplay between ontogeny and glossogeny:

- ▶ Learners become teachers
- ▶ Acquisition mechanism changes culture



(from Smith, Kirby & Brighton 2003)

IL and the emergence of syntax (from Kirby & Hurford)



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Question

What is the influence of the world's structure on languages?

- ▶ Current IL models tend to isolate syntax
- ▶ The simultaneous evolution of syntax and semantics is rarely investigated (exception: Kirby 2005)
- ▶ The link between meanings and the world is ignored

Meanings and the world

What is the link between mental ‘meaning space’ and the world?

- ▶ Symbol grounding problem
- ▶ Simplifying assumption:
 - ▶ meaning space = the visible environment
 - ▶ no *Sinn*, only *Bedeutung*
- ▶ Perception drives meaning selection

Perception



?



What mediates perception?

1. Color vision, stereopsis, edge detection
2. Object recognition, perceptual binding
3. Attention

Which level is relevant?

Attention

Interesting links between attention and language have been suggested earlier:

- ▶ Language and spatial cognition (Arsenijevic 2008)
- ▶ Acoustic headedness of syllables (Brown & Golston to appear)
- ▶ Functional roles and word-order (Tomlin 1986)

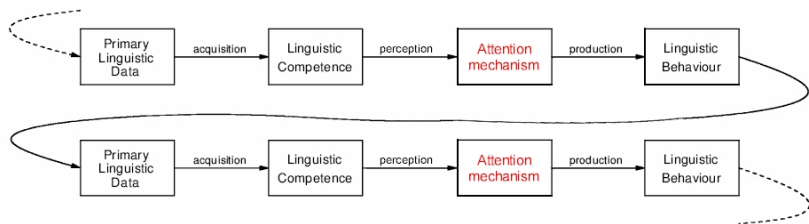
And on a meta-level:

- ▶ Attention and human uniqueness (Tomasello 2000)

Generic research question

So we end up with:

- ▶ *Could the human attention mechanism influence the language evolved?*

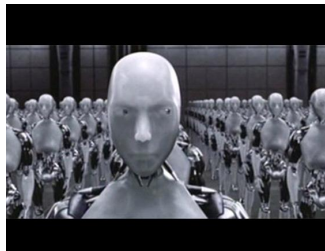


(adapted from Smith, Kirby & Brighton 2003)

Computer model

Ingredients:

- ▶ A : a population of agents
- ▶ F : a set of forms
- ▶ M : a set of meanings
- ▶ E : a set of environments
(generally $E = \wp M$)



Agent architecture

Grammar:

- ▶ Probabilistic (e.g. NN, PCFG)
- ▶ Learnable (e.g. backpropagation, grammar induction)

- ▶ Produce a form corresponding to a meaning:

$$P : M \rightarrow (F \rightarrow [0, 1]) \text{ (abbrev. } P(m)(f) = P_f(m))$$

- ▶ Interpret a form as having a certain meaning:

$$I : F \rightarrow (M \rightarrow [0, 1]) \text{ (abbrev. } I(f)(m) = I_m(f))$$

Attention mechanism:

- ▶ Meaning probability distribution (“noticability”)

$$N : E \rightarrow (M \rightarrow [0, 1]) \text{ (abbrev. } I(e)(m) = S_m(e))$$

- ▶ Dynamic, depending on discourse

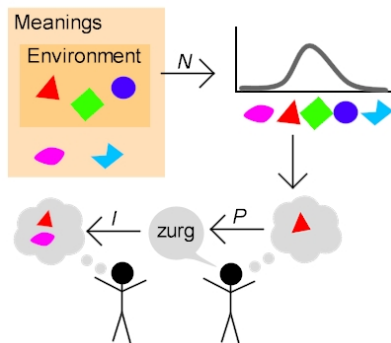
Agent architecture

Probabilistic grammar:

- ▶ $P : M \rightarrow (F \rightarrow [0, 1])$
- ▶ $I : F \rightarrow (M \rightarrow [0, 1])$

Attention mechanism:

- ▶ $N : E \rightarrow (M \rightarrow [0, 1])$



Actions and effects

Agent actions:

- ▶ **Pronounce** form f in an environment e with probability:

$$p(f|e) = \sum_{m \in M} P_f(m) * N_m(e)$$

- ▶ **Consider** meaning m after hearing form f in an environment e with probability:

$$p(m|e, f) = I_m(f) * N_m(e)$$

Action effects:

- ▶ **Pronounce**: conversational partners **consider** m with probability $p(m|e, f)$.
- ▶ **Consider**: meaning noticability increased ('psycholinguistic priming')

Evolution

Fitness function:

- ▶ Number of times joint attention is achieved
- ▶ Survival-relevance of meanings considered
- ▶ Language expressivity
- ▶ ...

Reproduction

- ▶ Of languages, through iterated learning
- ▶ (Possibly) of agents, through recombination
 - ▶ Change in acquisition mechanism
 - ▶ Change in attention mechanism

Possibilities

- ▶ Word-order universals, through
 - ▶ Associations ('co-priming')?
 - ▶ Functionally different meanings?
- ▶ Headedness (e.g. through acoustic attentional effects)?
- ▶ Sapir-Whorfian patterns?
- ▶ Zipf's law?

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Summary

- ▶ Computer models as an essential tool for language evolution research
- ▶ Language universals as a starting point
- ▶ Phylogeny, glossogeny, ontogeny
- ▶ The iterated learning framework
- ▶ What happens if IL is mediated by a perceptual (attention) mechanism?

Questions? Suggestions?