Bayesian Language Games

Unifying and evaluating agent-based models of horizontal and vertical language evolution

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The (Little) Tower of Babel by Pieter Bruegel the Elder (c. 1563) oil on panel; 60 cm × 74.5 cm; Museum Boijmans Van Beuningen, Rotterdam
THE CENTRAL PROBLEM

Sound does not fossilise.
The origins of language?

unifying and evaluating agent-based models of cultural language evolution
Iterated learning
Every generation learns the language spoken by the previous generation.
*Vertical* transmission across generations
1. Train subject to learn the names of a subset

2. Test the subject on the full set of objects

Emerging compositionality

Used objects of different colors, including errors, to train the next subject.
Compositional language

Meaning of a signal determined by meaning of parts

Cultural processes (transmission & communication) pressure for compositional languages
**Naming game**

Population negotiates a shared convention via local interactions:
1. Select random speaker & hearer
2. The hearer utters a word.
3. Both agents ‘align’ languages
Minimal NG
Every agent can invent, add and remove words to its vocabulary
Success

Lateral inhibition
After success, decrease the scores of competing words
Dynamics of the minimal NG
Three stages lead to the convergence to a single word:
1. Invention of words
2. Spread through population
3. Elimination of words

Cultural process of social negotiation leads to shared emergence of a convention
unifying and evaluating agent-based models of cultural language evolution
1. shared formalism  
2. population model
1. shared formalism
2. population model
1. Shared (Bayesian) formalism

2. Population model

production algorithm

\[ p(data \mid lang) \]

learning algorithm

\[ p(lang \mid data) \]

\[ p(lang \mid data) \propto p(data \mid lang) \cdot p(lang) \]

probability of adopting a language

biases of the learners
1. Shared (Bayesian) formalism

production algorithm
\[ p(\text{data} \mid \text{lang}) \]

learning algorithm
\[ p(\text{lang} \mid \text{data}) \]

\[ p(\text{lang} \mid \text{data}) \propto p(\text{data} \mid \text{lang}) \cdot p(\text{lang}) \]

probability of language after previous interaction
1. Shared (Bayesian) formalism

**VERTICAL**
transmission chain

**HORIZONTAL**
homogeneous mixing

**BOTH**
random walk

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**LIFE EXPECTANCY $\gamma$**
The age at which a speaker dies
The Bayesian Naming Game

production algorithm

\[ p(\text{data} \mid \text{lang}) \]

learning algorithm

\[ p(\text{lang} \mid \text{data}) \]

A language is a distribution over words (or e.g. linguistic features)
• Lineage specificity
• Reflection of the bias
  (rather than convergence to the prior)
• Language stability
The Bayesian Naming Game
The Bayesian Naming Game

On average, the Bayesian Naming Game reproduces the innate biases.

Reminiscent of “wide but constrained variation” (e.g. colour terms)

Regier et al. (2015). doi 10.1002/9781118346136.ch11
Different strategies

But why this?

production algorithm $p(\text{data} \mid \text{lang})$

Shouldn’t we expect this?

Strategies
One can vary the ‘production strategy’ and ‘language strategy’ sample or maximise
Different strategies

Life expectancy $\gamma$

Production strategy $\zeta$

Language strategy $\eta$

IL NG

ITERATED LEARNING

NAMING GAME
Different strategies

A. Iterated learning ($\gamma = 1$)

B. Naming Game ($\gamma = \infty$)

C. Quick turnover ($\gamma = 10$)

D. Medium turnover ($\gamma = 100$)

- **Aggregate language $\bar{\pi}$**
- **Expected language $\pi$**
- **External language $\psi$**
unifying and **evaluating**

agent-based models of cultural language evolution

**The origins of language?**

- biology
- archeology
- cognitive science
- anthropology
- linguistics
- computational modelling
Take home messages

Iterated learning and the naming game closely related:

- Language evolution through frequency tracking and innate biases.

Realistic?

Lineage-specific languages reflecting innate biases in the Bayesian naming game.

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