Cultural language evolution: acquisition or usage?

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Introduction

- language is self-replicating system
- two modes of replication:
  1. (first) language acquisition
  2. language usage
- the modes differ in
  - selection pressure
  - source of variation
  - time scale

How do they interact?
**Acquisition dynamics**

- **replicator**: I-language in its entirety
- **interactors**: “teacher” (adult) and “student” (infant)
- **source of variation**: imperfect learning
- **time scale**: measured in decades
Usage dynamics

- **replicator**: components of I-language (lexical entries, constructions, ...)

- **interactors**: (mainly adult) language users

- **source of variation**: errors, language contact, ...

- **time scale**: detectable even within single text
The Iterated Learning Model

- formal model of acquisition dynamics
- many computational implementations (Hurford, Kirby, Briscoe, Niyogi, Berwick, ...)
- analytical mathematical formulation by Nowak (with various co-authors):
The Iterated Learning Model (cont.)

\[
\frac{dx_i}{dt} = \sum_j x_j f_j(x) Q_{ji} - x_i \sum_j x_j f_j(x)
\]

\[
f_j(x) = \sum_k x_k U_{jk}
\]

- main components:
  - fitness function \( f \)
  - learning matrix \( Q \)
Fitness

- **Biology**: fitness $\equiv$ expected number of fertile offspring
- **Linguistics**: communicative functionality, efficiency, social prestige, ...
first approximation

- finite number of languages $L_1, \cdots, L_n$
- $\sigma_{ij}$ ... average probability that a speaker using $L_i$ is understood by a listener using $L_j$
- $c_i$ ... average complexity of utterances of $L_i$ (length, entropy, whatever)
- utility of communication between users of $L_i$ and $L_j$:

$$U_{ij} = \frac{1}{2}(\sigma_{ij} + \sigma_{ji} - r(c_i + c_j))$$
Fitness (cont.)

- $x_i$ ... relative frequency of users of $L_i$ in proportion to total population

\[ \sum_{i} x_i = 1 \]

- $x$ ... vector of relative frequencies $x_1, x_2, \cdots, x_n$

- fitness = average utility:

\[ f_j(x) \doteq \sum_k x_k U_{jk} \]
not every language is perfectly learnable

\[ Q_{ij} \ldots \text{probability that an infant growing up in an } L_i\text{-environment acquires } L_j \]

\[ \sum_j Q_{ij} = 1 \]
The learning matrix (cont.)

**simplest case:**
- identity matrix
- infant always acquires language of environment

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Acquisition dynamics

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Acquisition dynamics

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probability to learn \( L_i \) from an \( L_j \)-environment
Acquistion dynamics

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- probability to learn \( L_i \) from an \( L_j \)-environment
- fitness (= abundance of offspring of users) of \( L_j \)
Acquisition dynamics

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- death rate
Acquistion dynamics

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- velocity of change of abundance of \( L_i \)-speakers
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Selection for learnability and fitness
Iterated language usage

- dynamics of E-language (= population of utterances)
- each utterance is produced and perceived by language users by means of underlying grammars (= I-languages)
- replication via imitation
- dynamics describes development of I-grammar frequencies within population of utterances
Iterated language usage (cont.)

Simplest implementation:

\[
\frac{d x_i}{dt} = x_i f_i(x) - x_i X_j x_j f_j(x)
\]

Fitness of \(L_i\) (expected number of imitations of an utterance from \(L_i\))

Abundance of utterances from \(L_i\) in next generation

Abundance of utterances from \(L_i\) in current generation

Velocity of change of abundance of \(L_i\) - utterances
Iterated language usage (cont.)

- simplest implementation: replicator dynamics

\[
\frac{dx_i}{dt} = x_i f_i(x) - x_i \sum_j x_j f_j(x)
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Iterated language usage (cont.)

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Iterated language usage (cont.)

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Iterated language usage (cont.)

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Iterated language usage (cont.)

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- abundance of utterances from \( L_i \) in current generation
- velocity of change of abundance of \( L_i \)-utterances
Iterated language usage (cont.)

- selection only for fitness — ignores learnability
- only homogeneous populations can be attractors
- natural languages display high amount of optionality and non-determinism
Hybrid dynamics

- both modes of replication play a role in (cultural) language evolution
- adequate dynamics should capture both
- fitness of language is arguably negligible as factor for biological reproduction rate (at least on historical time scale)
- acquisition dynamics thus simplifies to

\[
\frac{dx_i}{dt} = \sum_j x_j Q_{ji} - x_i
\]
some fraction $b$ ($0 \leq b \leq 1$) of all utterances are uttered by language acquiring infants

rest of utterances is uttered by adults and underlies the utterance dynamics

leads to hybrid utterance dynamics:

$$\frac{dx_i}{dt} = (1 - b)(x_i f_i - x_i \sum_j x_j f_j) + b(\sum_j x_j Q_{ji} - x_i)$$

*selection for functionality and learnability*
An example: Binding Theory

Modern English: restrictions on coreference

(1)  
   a. Peter<sub>i</sub> sees him<sub>j</sub>  
   b. *Peter<sub>i</sub> sees him<sub>i</sub>

in Old English, (1b) is okay

until a certain age, Modern English learning infants accept/produce structures like (1b)

unlikely that OE infants underwent a stage corresponding to ME

ME has less ambiguity and thus higher utility though
Binding Theory (cont.)

let us assume... acquisition probs.

Q-matrix

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<tr>
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<th>ME</th>
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<tr>
<td>OE</td>
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<td>0.0</td>
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<tr>
<td>ME</td>
<td>0.2</td>
<td>0.8</td>
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Binding Theory (cont.)

- U-matrix

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- \( b = 0.05 \)
two attractors (i.e. stable states)
1. pure OE
2. predominant ME (with a low probability of OE)
Binding Theory (cont.)

- acquisition dynamics also selects for high utility and high learnability
- learnability overrides utility though — only one attractor

![Graph showing time against different variables]
two kinds of accusative marking languages
1. accusative is obligatory for all direct objects

*like Hungarian*

(2) a. Szeretem a könyvet.  
*I-LIKE THE BOOK-ACC*  
“I like the book.”

b. Egy házat akarok.  
*A HOUSE-ACC I-WANT*  
“I want a house.”
2. accusative only on prominent object NPs

like Hebrew: only definites have accusative

(3) a. Ha-seret her?a ?et-ha-milxama
    THE-MOVIE SHOWED ACC-THE-WAR
b. Ha-seret her?a (*?et-)milxama
    THE-MOVIE SHOWED (*ACC-)WAR
(from Aissen 2003)
utility matrix for competition between Hebrew and Hungarian type
(based on corpus studies; see Jäger (2004))

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complicating factor: Hungarian styly production grammar + Hebrew style comprehension grammar is also a possible language

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Typology of case marking (cont.)

Usage dynamics predicts only Hebrew to be stable.
Typology of case marking (cont.)

- Hungarian system (“All objects have accusative!”) is arguably simpler than Hebrew system (“All definite objects have accusative!”)

- Acquisition matrix something like

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- $b = 0.1$
Typology of case marking (cont.)

under hybrid dynamics (as under acquisition dynamics) both Hungarian and Hebrew style case systems are evolutionarily stable

\[ \text{time} \]
natural languages are shaped both by selection for learnability and selection for usability

corresponds to replication via acquisition and replication via usage

combined dynamics leads to refined typological predictions
Conclusion (cont.)

Question for future research

- How can the parameters of these equations (fitness, learnability matrix) be determined in a non-circular way?

- Can we observe micro-evolution directly (psycholinguistics, corpus linguistics, ...) to validate formal models?
References


