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?

Acqusition 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 acqusition dynamics
- many computational implementations (Hurford, Kirby, Briscoe, Niyogi, Berwick, ...)
- analytical mathematical formulation by Nowak (with various co-authors):

The Iterated Learning Model (cont.)

(1) $$\frac{dx_i}{dt} = \sum_j x_j f_j(\mathbf{x}) Q_{ji} - x_i \sum_j x_j f_j(\mathbf{x})$$

(2) $$f_j(\mathbf{x}) \doteq \sum_k x_k U_{jk}$$

- main components:
  - fitness function f
  - learning matrix Q

Fitness

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

Fitness (cont.)

- first approximation
  - finite number of languages $L_1, \cdots, L_n$
  - σ_{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

$$\sum_i x_i = 1$$

- $\mathbf{x}$ ... vector of relative frequencies $x_1, x_2, \cdots, x_n$
- fitness = average utility:

$$f_j(\mathbf{x}) \doteq \sum_k x_k U_{jk}$$

The learning matrix

- not every language is perfectly learnable
- Q_{ij} ... probability that an infant growing up in an L_i-environment acquires L_j

$$\sum_j Q_{ij} = 1$$

The learning matrix (cont.)

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

	L_1	L_2	L_3	$\cdots$
L_1	1	0	0	$\cdots$
L_2	0	1	0	$\cdots$
L_3	0	0	1	$\cdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	

Acquistion dynamics

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- death rate

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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.)

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- simplest implementaton: **replicator dynamics**

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Iterated language usage (cont.)

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- 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.)

- selection only for fitness — ignores learnability
- only homogeneous populations can be attractors

$\rightsquigarrow$ 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)
- acqusition dynamics thus simplifies to

$$\frac{dx_i}{dt} = \sum_j x_j Q_{ji} - x_i$$

Hybrid dynamics (cont.)

- 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

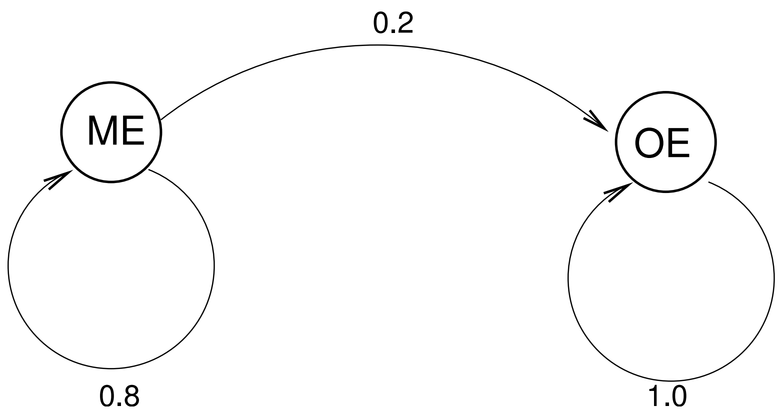
(1) a. Peter$_i$ sees him$_j$
    b. *Peter$_i$ sees him$_i$

- 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

	OE	ME
OE	1.0	0.0
ME	0.2	0.8

Binding Theory (cont.)

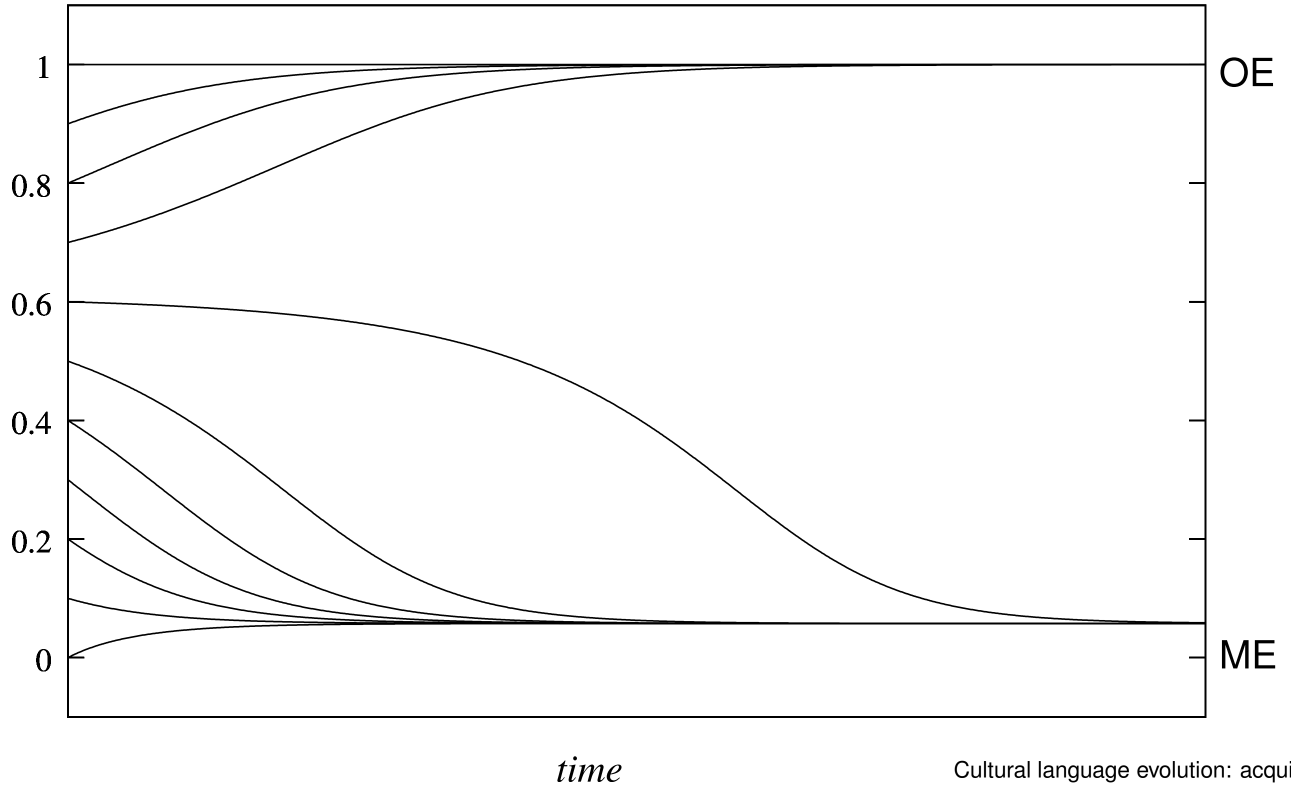
- U-matrix

	OE	ME
OE	0.9	0.8
ME	0.8	1

- $b = 0.05$

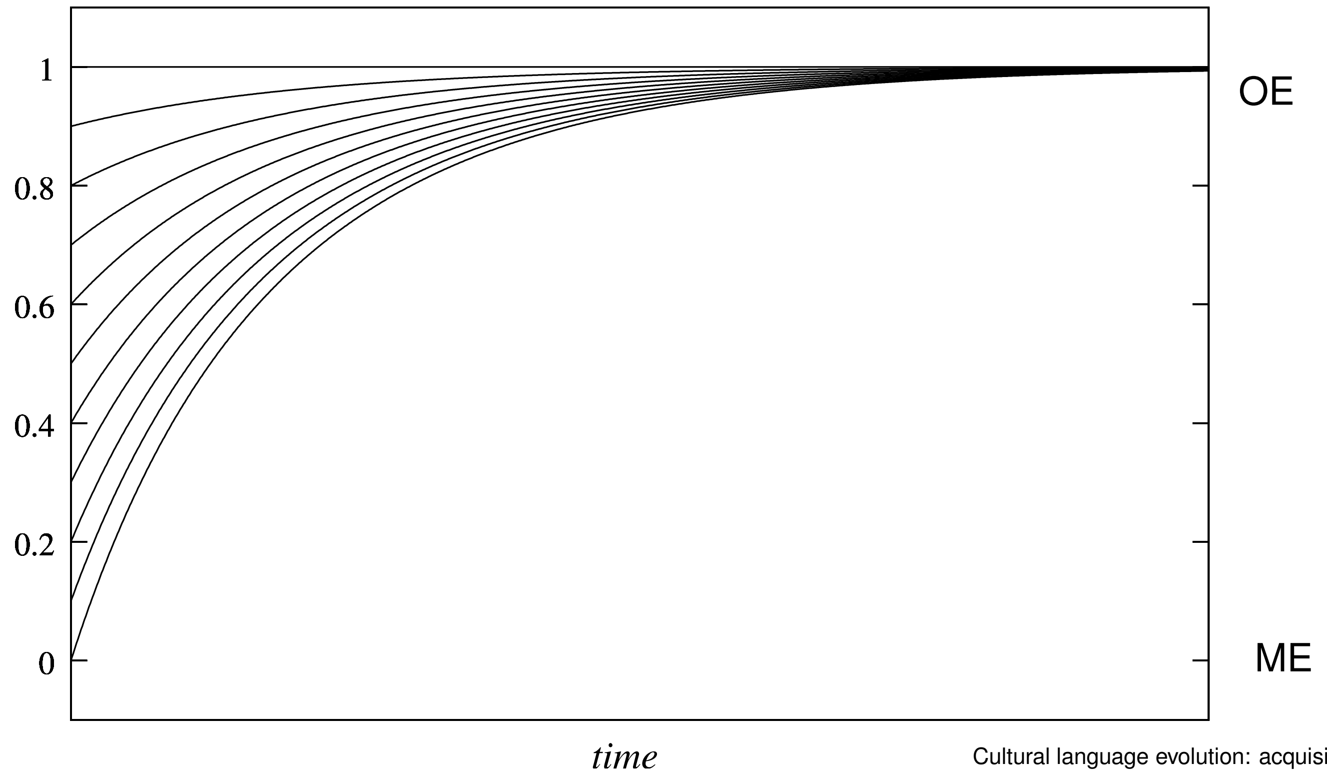
Binding Theory (cont.)

- 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



Typology of case marking

- two kinds of accusative marking languages
  1. accusative is obligatory for all direct objects

     like Hungarian

(2) a. Szeretem a könyv**et**.
I-LIKE THE BOOK-ACC
"I like the book."

b. Egy ház**at** akarok.
A HOUSE-ACC I-WANT
"I want a house."

Typology of case marking (cont.)

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)

Typology of case marking (cont.)

- utility matrix for competition between Hebrew and Hungarian type
  (based on corpus studies; see Jäger (2004))

	Hun	Heb
Hun	$.1100$	$.1060$
Heb	$.1060$	$.1734$

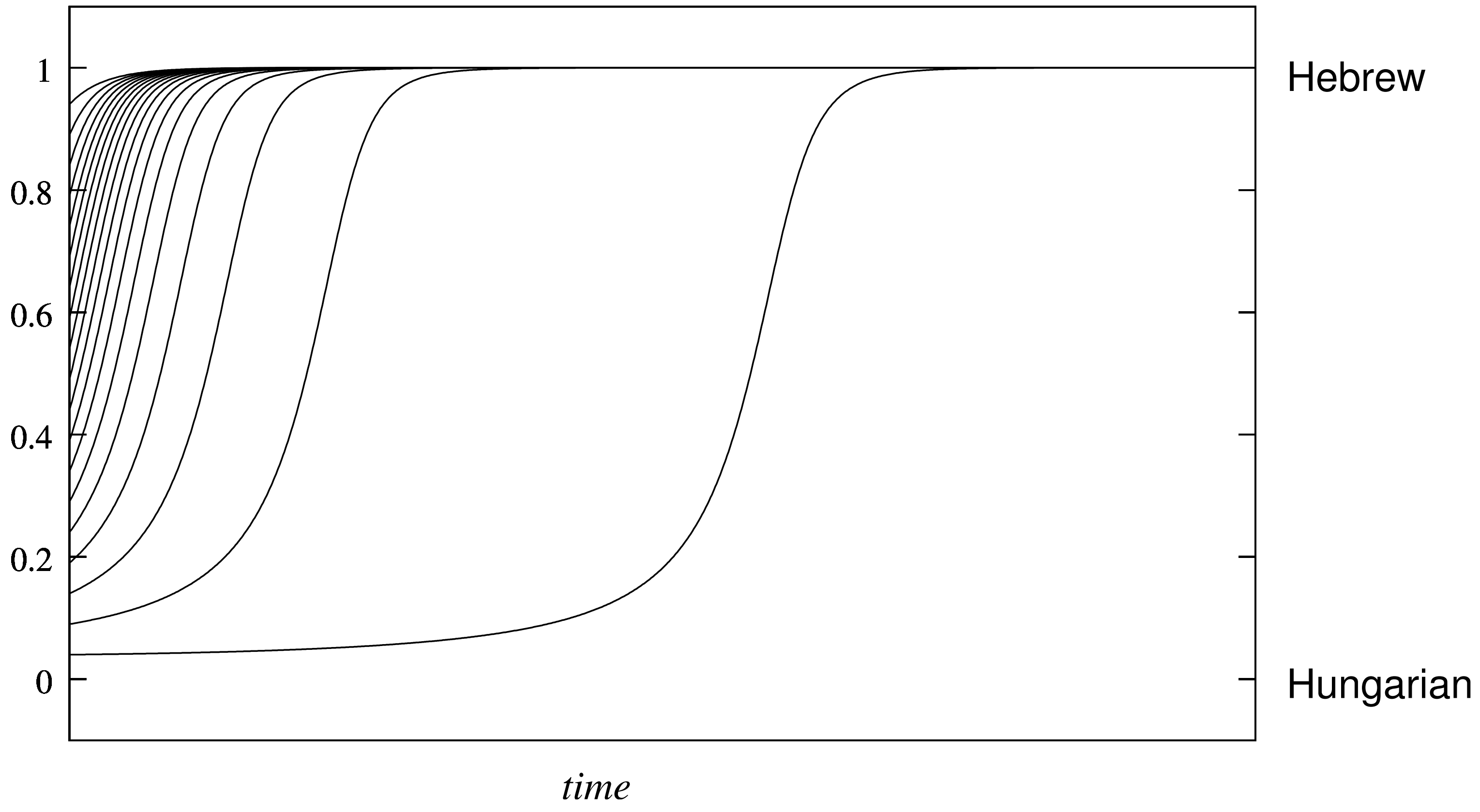
Typology of case marking (cont.)

- complicating factor: Hungarian styly production grammar + Hebrew style comprehension grammar is also a possible language
- utility matrix for competition between Hebrew and Hungarian type
  (based on corpus studies; see Jäger (2004))

	Hun	Hun/Heb	Heb
Hun	$.1100$	$.1100$	$.1060$
Hun/Heb	$.1100$	$.1100$	$.1417$
Heb	$.1060$	$.1417$	$.1734$

Typology of case marking (cont.)

- usage dynamics predicts only Hebrew to be stable



Typology of case marking (cont.)

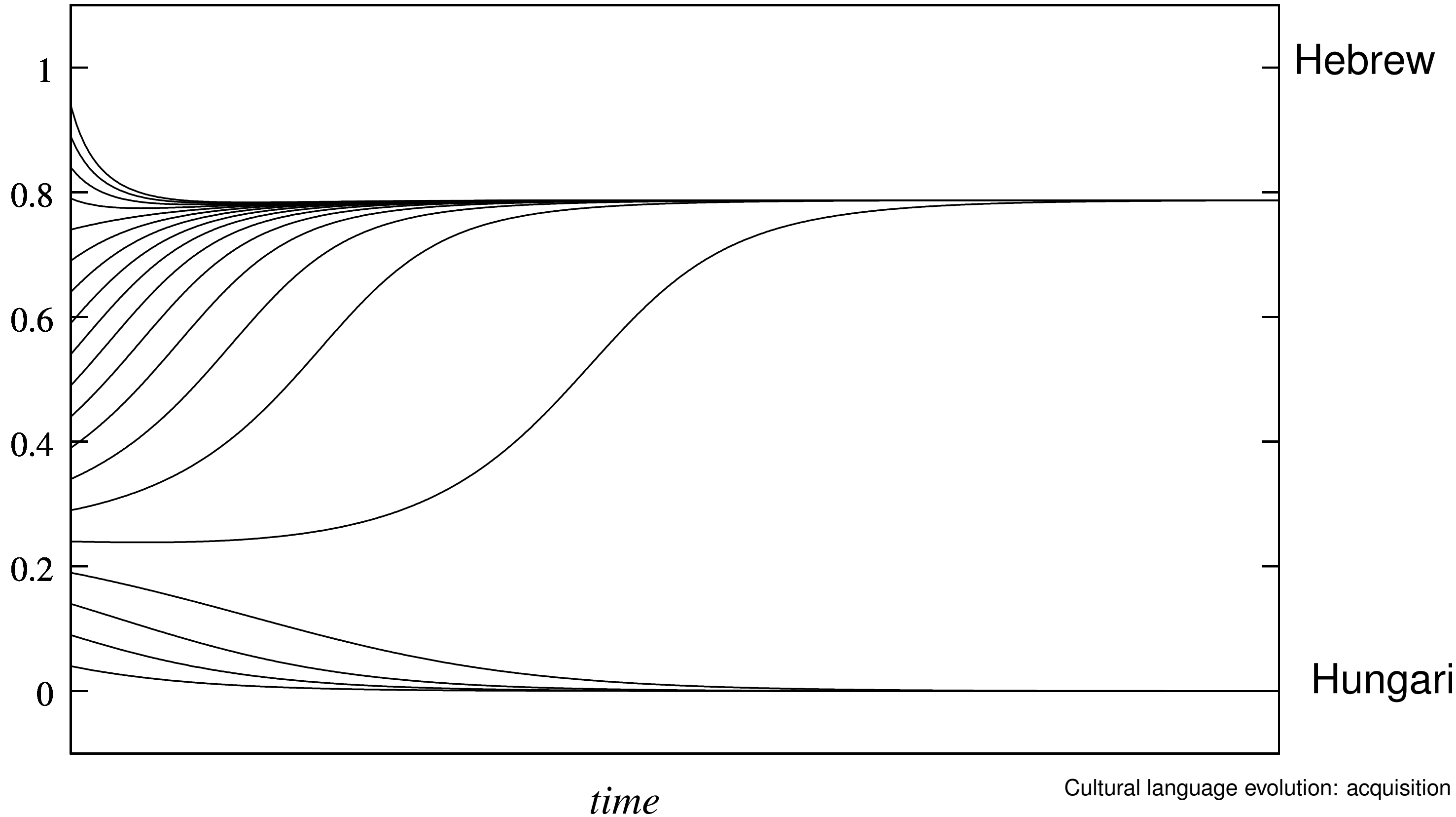
- Hungarian system (“All objects have accusative!”) is arguably simpler than Hebrew system (“All **definite** objects have accusative!”)
- acquistion matrix something like

	Hun	Hun/Heb	Heb
Hun	1.0	0.0	0.0
Hun/Heb	0.0	1.0	0.0
Heb	0.1	0.0	0.9

- $b = 0.1$

Typology of case marking (cont.)

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



Conclusion

- natural languages are shaped both by selection for learnability and selection for usability
- corresponds to replication via acqusition 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?*

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