

Learning biases may prevent the lexicalization of pragmatic inferences

A case study combining iterated learning and replicator dynamics

Thomas Brochhagen
ILLC, University of Amsterdam

Joint work with Michael Franke (Tübingen) & Robert van Rooij (Amsterdam)

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The semantics-pragmatics distinction

Semantics

Literal meaning (truth-conditional)

Pragmatics

Information beyond literal meaning (e.g. defeasible inferences)

Scalar inferences

(1) $\langle \text{few}, \text{some}, \text{many}, \text{most}, \text{all} \rangle$

a. All students came to class

→ **Some** students came to class

b. Some students came to class

\rightsquigarrow **Not all** students came to class

(2) $\langle \text{may}, \text{should}, \text{must} \rangle$

(3) $\langle \text{one}, \text{two}, \text{three}, \dots \rangle$

(4) $\langle \text{or}, \text{and} \rangle$

(5) ...

The use of a less informative expression when a more informative one could have been used* can license a defeasible inference that the stronger alternatives do not hold

*The hearer assumes the addressee to be knowledgeable and cooperative

· Laurence R. Horn. *On the Semantic Properties of Logical Operators in English*.

Indiana University Linguistics Club, Bloomington, IN, 1972

· Gerald Gazdar. *Pragmatics, Implicature, Presupposition and Logical Form*.

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· Paul Grice. *Logic and conversation*.

In *Studies in the Ways of Words*, chapter 2, pages 22–40. Harvard University Press, Cambridge, MA, 1975

Explanations for a lack of semantic upper-bounds I

(1) Signal no commitment to stronger alternatives when knowledge/cooperativity are not given

Cf. lexicalizing 'some' and 'sbna'

Conditions that may pressure for English-like semantics:

- Contextual cues are very reliable
- Morphosyntactic disambiguation is not frequently necessary
- Morphosyntactic disambiguation is not very costly
- Cost of larger lexica higher than morphosyntactic disambiguation

Explanations for a lack of semantic upper-bounds II

(2) Lack of upper-bounds provides learnability advantage

1. Why are (pragmatically inferred) upper-bounds of weak(er) alternatives not part of semantics?
2. What justifies semantic structure in light of pragmatic enrichment?

Today's talk:

- Propose a model to address (2) and analyze dynamics of linguistic pressures more broadly
- Use (1) as a case study for (2)

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Model

Components I: Cultural transmission

Two competing pressures:

1. Communicative efficiency

... as replicator dynamics

2. Learnability

... iterated Bayesian learning
as mutator dynamics

} Replicator-mutator dynamics

· Thomas L. Griffiths and Michael L. Kalish. *Language evolution by iterated learning with bayesian agents.* *Cognitive Science*, 31(3):441–480, 2007

· Josef Hofbauer and Karl Sigmund. *Evolutionary game dynamics.* *Bulletin of the American Mathematical Society*, 40(04):479–520, 2003

· M. A. Nowak and D. C. Krakauer. *The evolution of language.* *Proceedings of the National Academy of Sciences*, 96(14):8028–8033, 1999

Components II: Probabilistic (pragmatic) language users

- Varied lexica
- Varied production and comprehension behavior
(here: parametrized *literal* or *pragmatic*)

} A player's type

· Anton Benz, Gerhard Jäger, Robert Van Rooij, and Robert Van Rooij, editors. *Game theory and pragmatics*. Springer, 2005

· Leon Bergen, Roger Levy, and Noah D Goodman. *Pragmatic reasoning through semantic inference*. *Semantics and Pragmatics*, 2016

· M. C. Frank and N. D. Goodman. *Predicting pragmatic reasoning in language games*. *Science*, 336(6084):998–998, 2012

· Michael Franke and Gerhard Jäger. *Pragmatic back-and-forth reasoning*. *Semantics, Pragmatics and the Case of Scalar Implicatures.*, pages 170–200, 2014

- s_1 : Bill read some but not all books
- s_2 : Bill read all books

$$L_a = \begin{matrix} & m_{\text{all}} & m_{\text{some}} \\ \begin{matrix} s_1 \\ s_2 \end{matrix} & \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \end{matrix}$$

$$L_b = \begin{matrix} & m_{\text{all}} & m_{\text{some}} \\ \begin{matrix} s_1 \\ s_2 \end{matrix} & \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \end{matrix}$$

Literal behavior

$$R_0(s|m; L) \propto P^*(s)L_{sm} \quad (1)$$

$$S_0(m|s; L) \propto \exp(\lambda L_{sm}) \quad (2)$$

Pragmatic behavior

$$R_1(s|m; L) \propto P^*(s)S_0(m|s; L) \quad (3)$$

$$S_1(m|s; L) \propto \exp(\lambda R_0(s|m; L)^\alpha) \quad (4)$$

A **player type** t_i is a combination of signaling behavior and a lexicon

Functional pressure (replicator dynamics)

- Population of types x

x_i is the proportion of t_i in x

- Fitness of type i

$$f_i = \sum_j x_j U(x_i, x_j)$$

- Average fitness in the population

$$\Phi = \sum_i x_i f_i$$

Iterated learning (mutator dynamics)

- $Q_{ji} \propto \sum_d P(d|t_j)P(t_i|d)$
 - $d = \langle \langle s_h, m_n \rangle, \dots, \langle s_l, m_o \rangle \rangle$ of length k
 - $P(d|t_j)$ corresponds to t_j 's production probabilities of
 - $P(t_i|d) \propto [P(t_i)P(d|t_i)]^l, l \geq 1$
 - Prior encodes learning biases of players prior to data exposure
- $P(t_i) \propto n - c \cdot r$, where $n = |S|$ and r a count of semantically upper-bounded weak alternatives in L_i

Parametrized posterior $P(d|t_i)^l$

- $l = 1$ corresponds to posterior sampling
- $l \rightarrow \infty$ approaches MAP

Analysis

Lexica, signaling behavior & types

Lexica

$$L_1 = \begin{pmatrix} 0 & 0 \\ 1 & 1 \end{pmatrix} \quad L_2 = \begin{pmatrix} 1 & 1 \\ 0 & 0 \end{pmatrix} \quad L_3 = \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix}$$

$$L_4 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad L_5 = \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \quad L_6 = \begin{pmatrix} 1 & 1 \\ 1 & 0 \end{pmatrix}$$

Signaling behavior

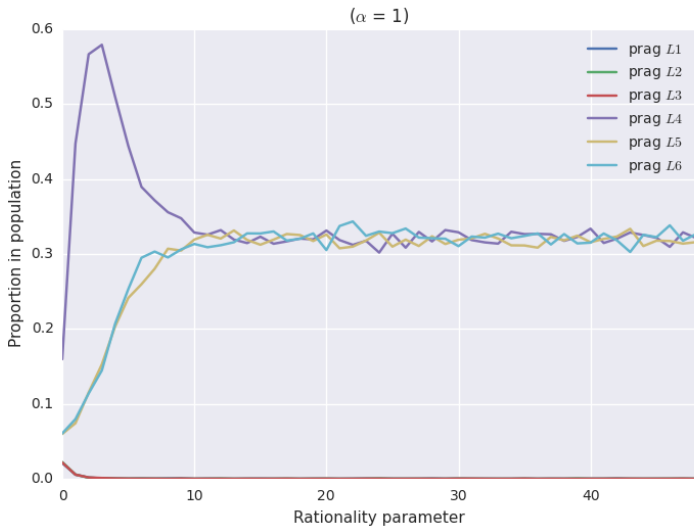
Literal or pragmatic

Types

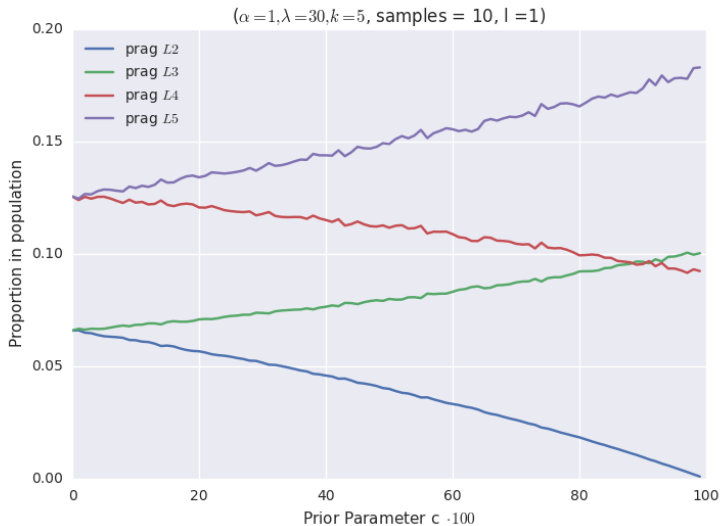
12 types (2 behaviors \times 6 lexica)

What factors lead to the selection of L_5 -like semantics?

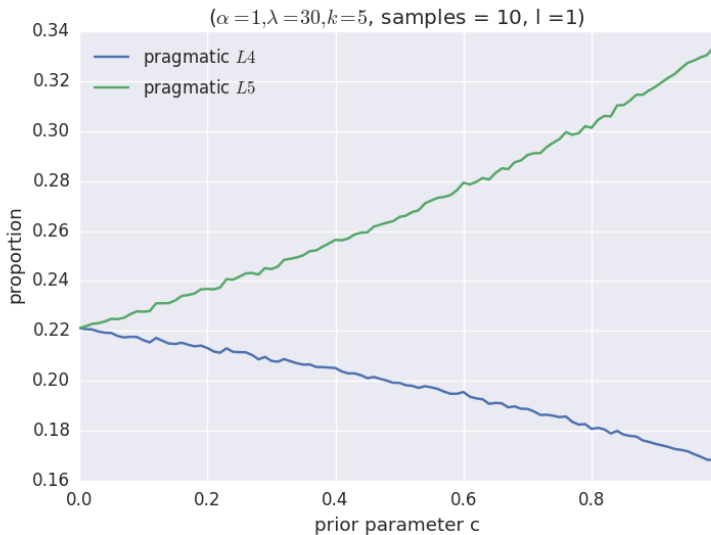
Fitness only



Learning only



Fitness and learning



- Lack of semantic-upper bounds can overcome pressures and stabilize in a population provided...
 - Bias for simpler representations
 - Pragmatics to compensate lack of upper-bounds in use

But

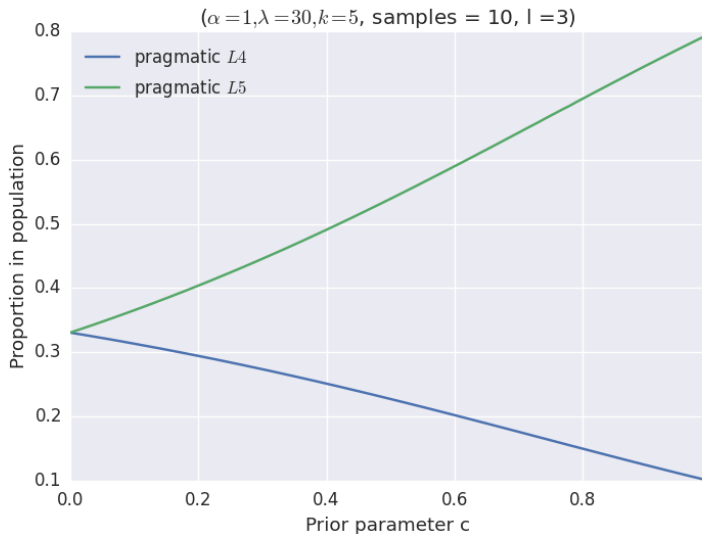
- Highly polymorphic populations even for high c
- Role of learning mechanisms, rationality, and learning observations unexplored

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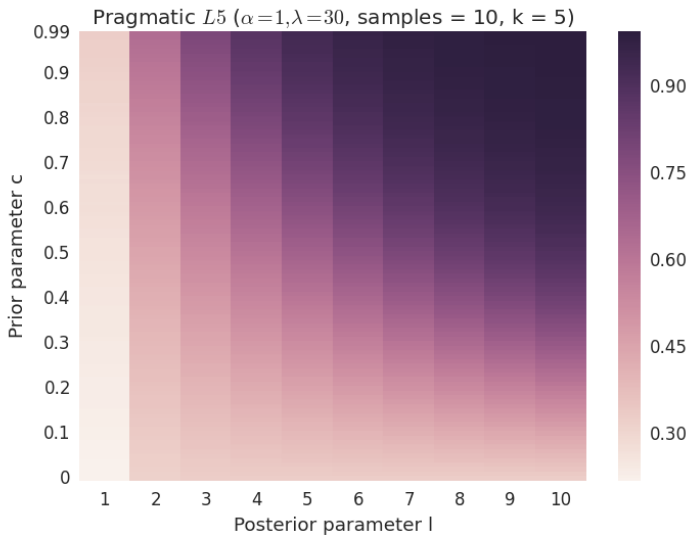
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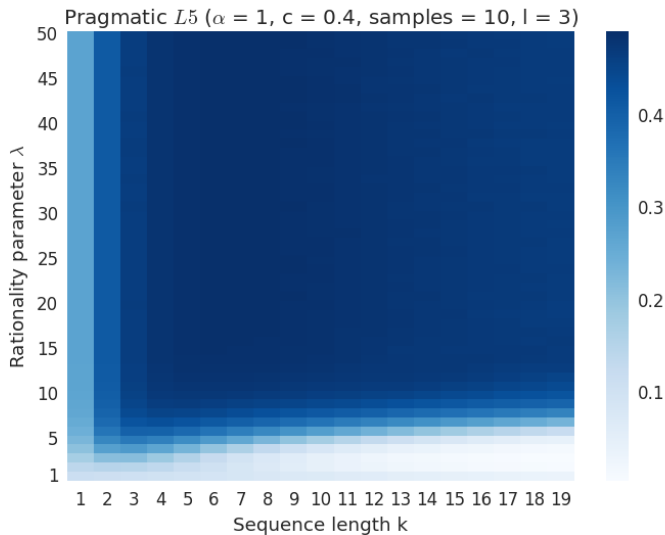
Effect of prior with more posterior maximization



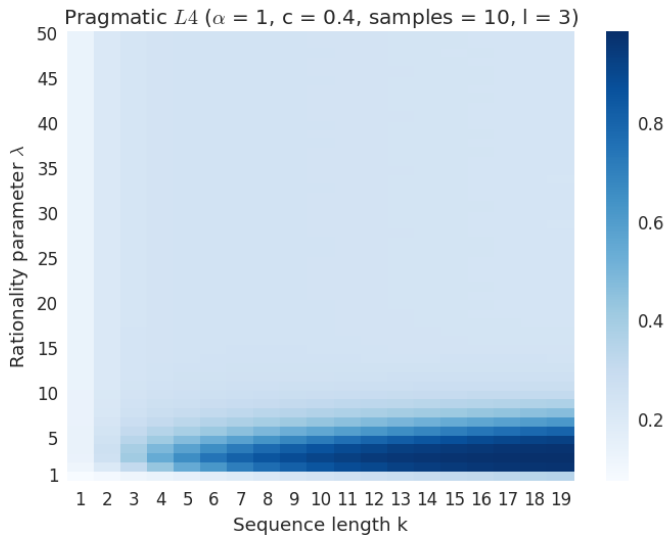
Prior and posterior



Rationality and sequence length I



Rationality and sequence length II



Conclusion & Outlook

Concluding remarks: Application

- Learnability steers language towards simpler semantics
 - Pragmatics compensates for potential loss in expressivity
 - Functional advantages
 - Reliability of contextual cues to cancel implicatures
 - Lexicon size
 - ...
- } Lack of semantic upper-bounds

Provided

- Some degree of rationality in learning & choice
- Relation between bounds and simplicity

Concluding remarks: Model

- Combines
 - Functional pressure
 - Learning pressure
 - (Probabilistic) hearer & speaker models
 - Distinct languages

Future directions

- Generalization
- Frequency effects
- Larger lexica & uncertainty
- Further applications

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