

Intelligence artificielle et modèles théoriques de l'origine du langage

Luc Steels

ICREA

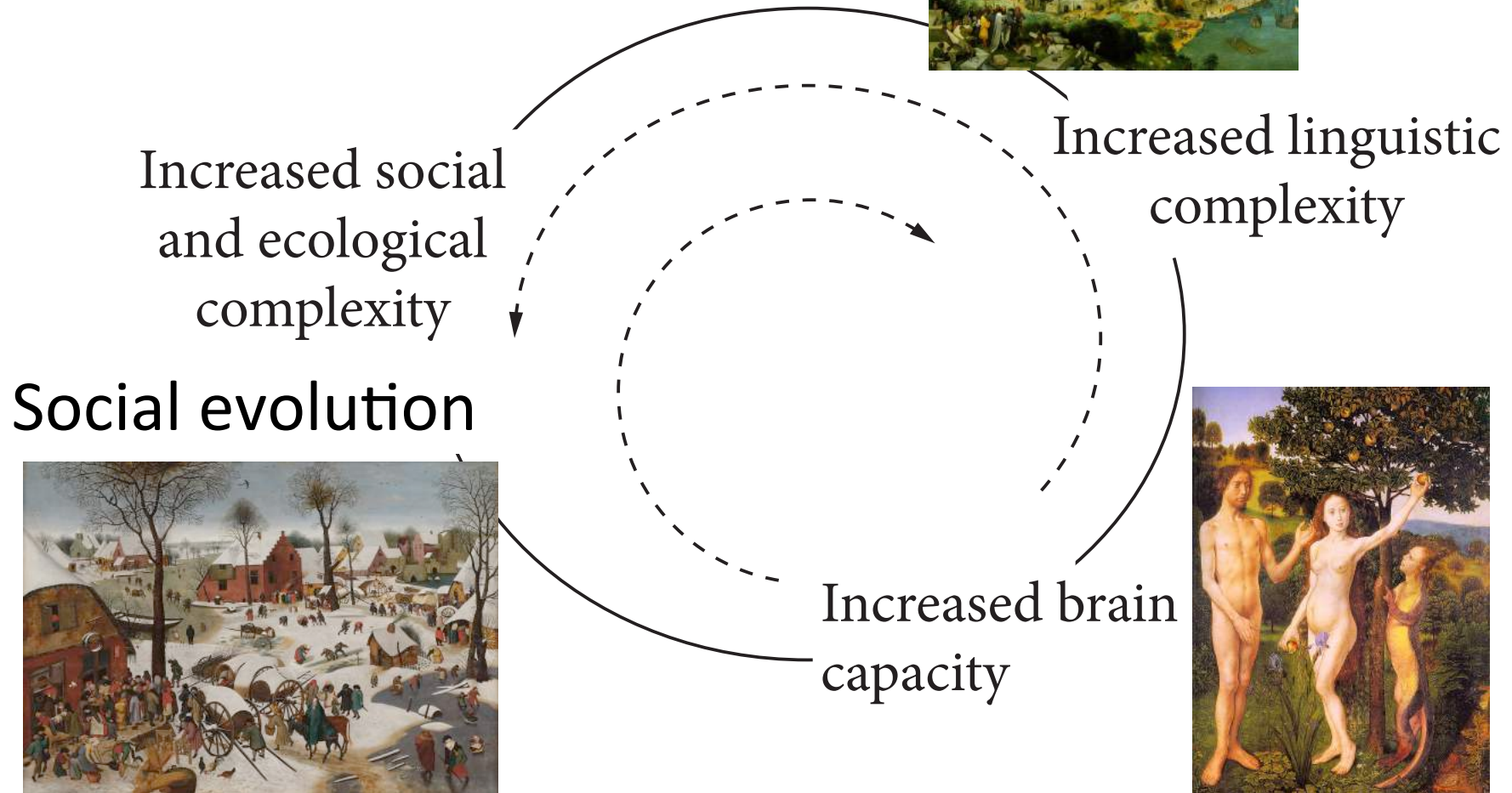
Institut de Biologia Evolutiva (UPF-CSIC)

Barcelona

EVOLUTIONARY LINGUISTICS (linguistique évolutive)



Linguistic
evolution



Steels L. (2016) Agent-based models for the emergence and evolution of grammar. *Phil. Trans. R. Soc. B* 371: 20150447.

‘‘Languages change, but they do not evolve. It is unhelpful to suggest that languages have evolved by biological and nonbiological evolution (...) . The latter is not evolution at all.’

Berwick, R.C. and N. Chomsky. 2016.
Why Only Us: Language and evolution.
Cambridge, MA: MIT Press. p. 52

A language is a culturally evolving complex adaptive system recruiting available cognitive capacities

Steels, L. (2016) Language evolution or language change? *Journal of Neurolinguistics*. Vol 52.

1. Quantum Deus scire et posse mihi dat, servabo hunc meum fratrem Carolum, et ope mea et in quacumque re, si come on par dreit son fredre salver deit. (Classic Latin, I century),
2. Quan que Dieus saveir et podeir me donct, si salverai jo cest mien fredre Charlon, et en aiude, et en chascune chose, si come on par dreit son fredre salver deit. (Ancien Français, XIe siècle)
3. Quan que Dieu savoir et pouvoir me done, si sauverai je cest mien frere Charle, et par mon aide et en chascune chose, si comme on doit par droit son frere sauver. (Moyen Français, XVe siècle)
4. Autant que Dieu m'en donne le savoir et le pouvoir, je soutiendrai mon frère Charles de mon aide et en toute chose, comme on doit justement soutenir son frère (Français contemporain, XXe siècle)

If God gives me the knowledge and the power

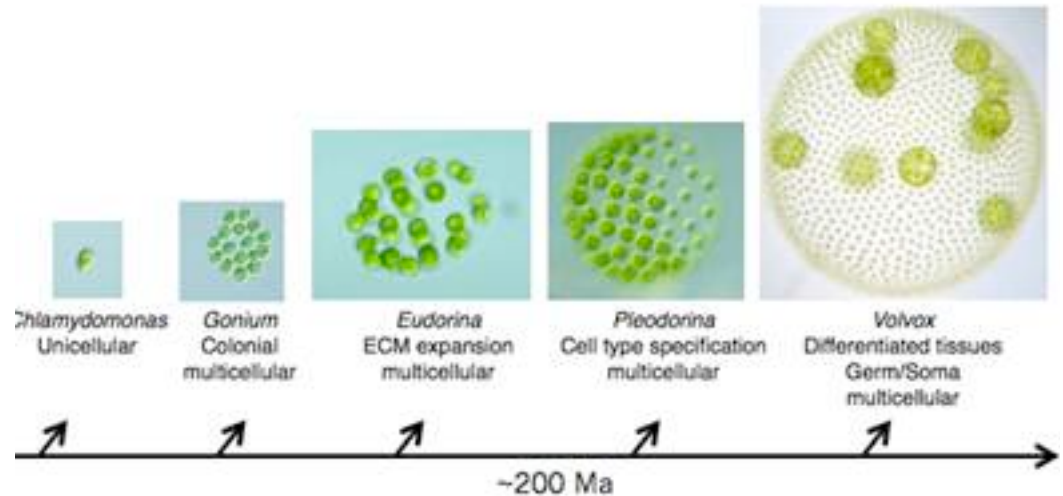
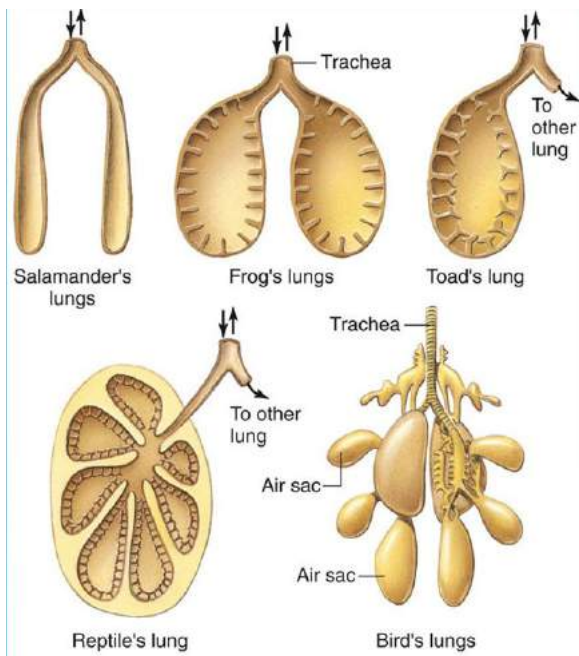
Languages are organisms of nature; they have never been directed by the will of man; they rose, and developed themselves according to definite laws; they grew old and they died out. They, too, are subject to that series of phenomena which we embrace under the title of “life”. The science of language is generally altogether the same as that of any other natural science.

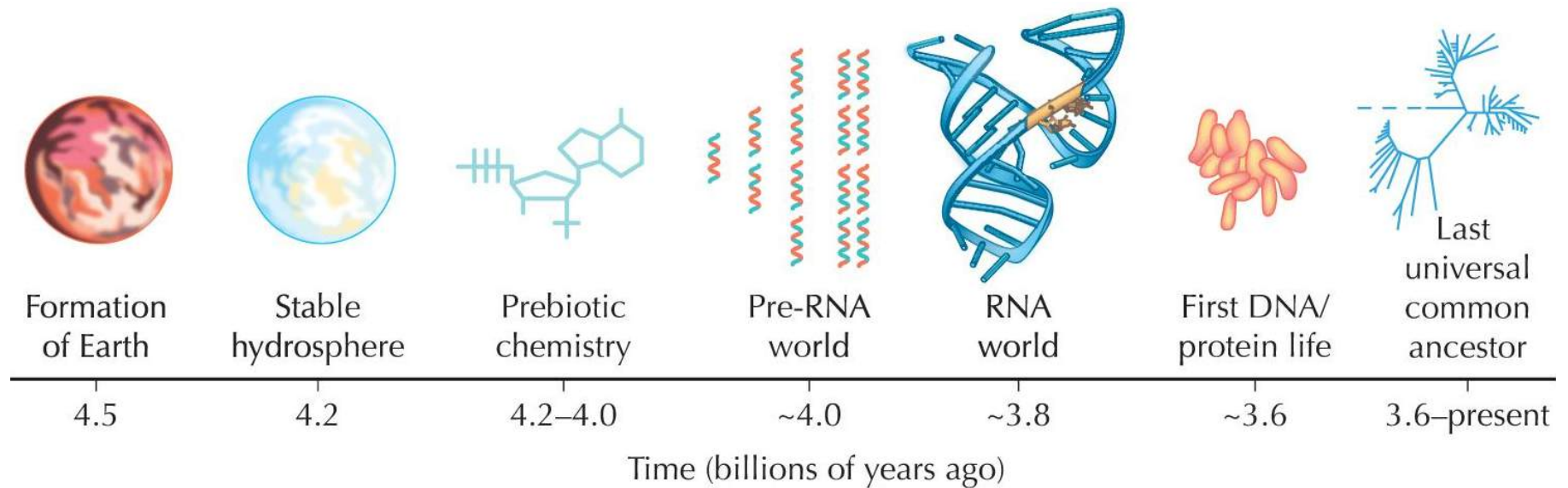
August
Schleicher
(1821-1868)



Schleicher, A. (1869) Darwinism tested by the science of language. Hotten, London.
<https://archive.org/stream/darwinismtestedb69schl#page/4/mode/2up0>

Transitions in (evolutionary) biology (How to go from A => B?)





Origins of life

+ Search for general principles

J. Maynard Smith and E. Szathmáry (1995) *The Major Transitions in evolution*.
Oxford University Press, Oxford.

	Masc	Neut	Fem
	Singular		
NOM	<i>dër</i>	<i>daz</i>	<i>diu</i>
ACC	<i>dën</i>	<i>daz</i>	<i>die</i>
DAT	<i>dëmu</i>	<i>dëmu</i>	<i>dëru</i>
GEN	<i>dës</i>	<i>dës</i>	<i>dëru</i>
	Plural		
NOM	<i>die</i>	<i>diu</i>	<i>deo</i>
ACC	<i>die</i>	<i>diu</i>	<i>deo</i>
DAT	<i>dën</i>	<i>dën</i>	<i>dën</i>
GEN	<i>dëro</i>	<i>dëro</i>	<i>dëro</i>

	Masc	Neut	Fem
	Singular		
NOM	<i>dër</i>	<i>daz</i>	<i>diu</i>
ACC	<i>dën</i>	<i>daz</i>	<i>die</i>
DAT	<i>dëm</i>	<i>dëm</i>	<i>dër</i>
GEN	<i>dës</i>	<i>dës</i>	<i>dër</i>
	Plural		
NOM	<i>die</i>	<i>diu</i>	<i>die</i>
ACC	<i>die</i>	<i>diu</i>	<i>die</i>
DAT	<i>dën</i>	<i>dën</i>	<i>dën</i>
GEN	<i>dër</i>	<i>dër</i>	<i>dër</i>

	Masc	Neut	Fem
	Singular		
NOM	<i>der</i>	<i>das</i>	<i>die</i>
ACC	<i>den</i>	<i>das</i>	<i>die</i>
DAT	<i>dem</i>	<i>dem</i>	<i>der</i>
GEN	<i>des</i>	<i>des</i>	<i>der</i>
	Plural		
NOM	<i>die</i>	<i>die</i>	<i>die</i>
ACC	<i>die</i>	<i>die</i>	<i>die</i>
DAT	<i>den</i>	<i>den</i>	<i>den</i>
GEN	<i>der</i>	<i>der</i>	<i>der</i>

900	1100	1500	1900
Old High German		Middle High German	
New High German			

van Trijp, Remi (2013). Linguistic selection criteria for explaining language change: a case study on syncretism in German definite articles. *Language Dynamics and Change*, 3(1): 105-132.

Transitions in language

(How to go from A => B?)

- No *color* expression => color terms + color categories
- No expression for the *determination* of a noun => system of articles => syncretic system
- No *nasalisation* (Latin) => nasalisation (French)
- No *argument structure* expression (e.g. with cases: nom, acc., etc.) => case grammar
- No grammatical marking for *tense, aspect, mood, modality* => marking
- No Language => primitive form of language

+ Search for general principles

Focus on four puzzles

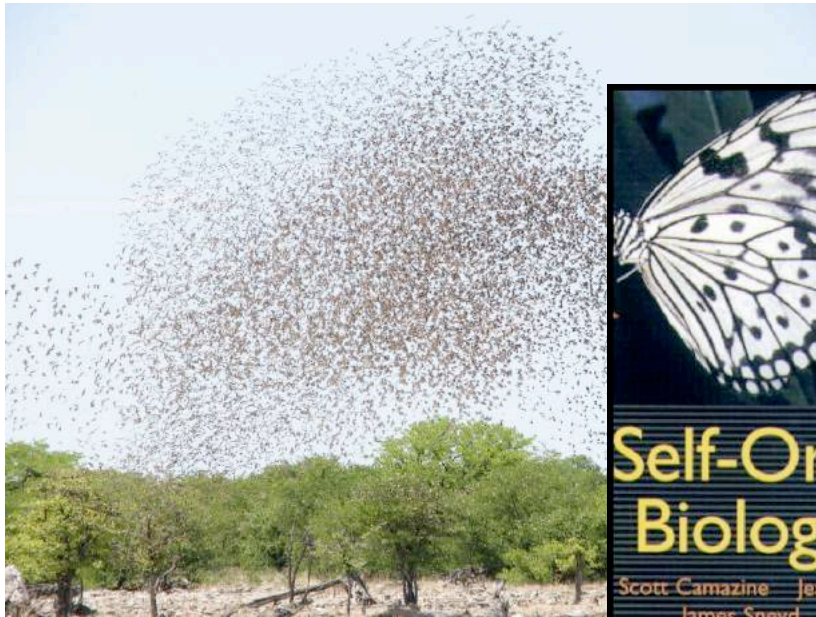
1. How do speakers reach and maintain global coherence?
2. How can language be so adapted to human embodiment, ecological needs, human cognitive capacities?
3. Where do linguistic innovations come from?
4. How do hierarchical structures emerge?

1. How do speakers reach and maintain coherence?

Self-organization

- Elements interacting with each other
- Each element has random behavior
- But influenced by environment and behavior of others
- Coherent structure may emerge due to positive feedback loop between emergent structure and subsequent behavior

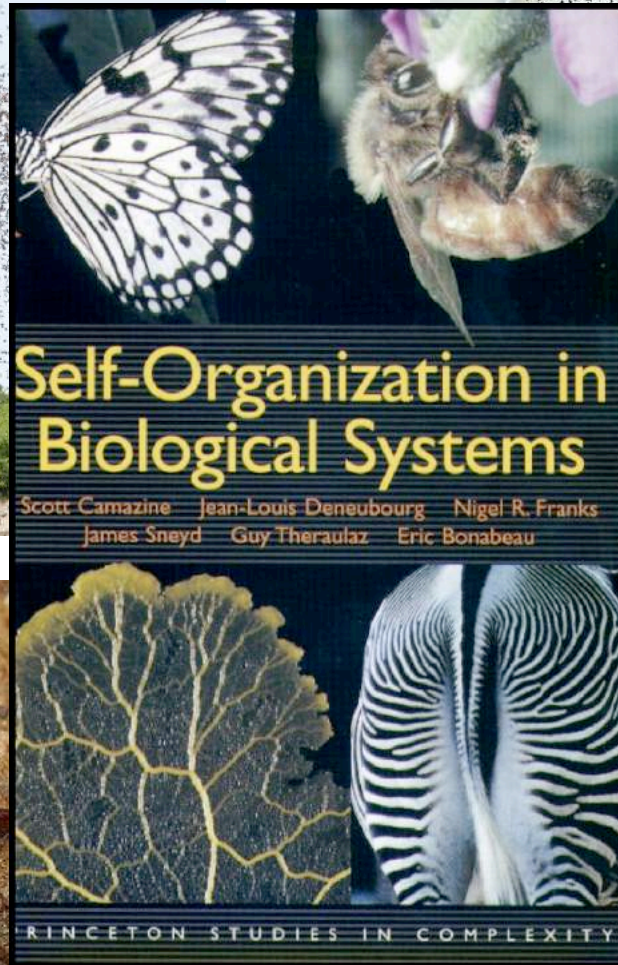
Self-organisation in biology



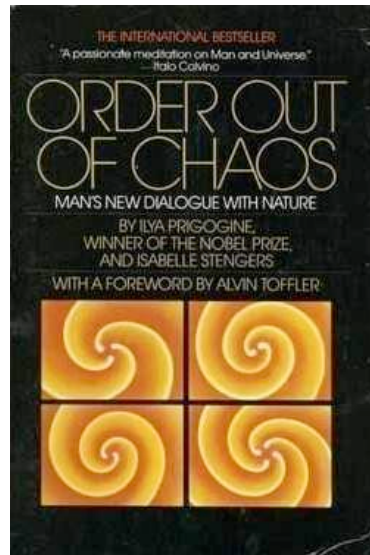
birds



ants



Self-organisation in chemistry

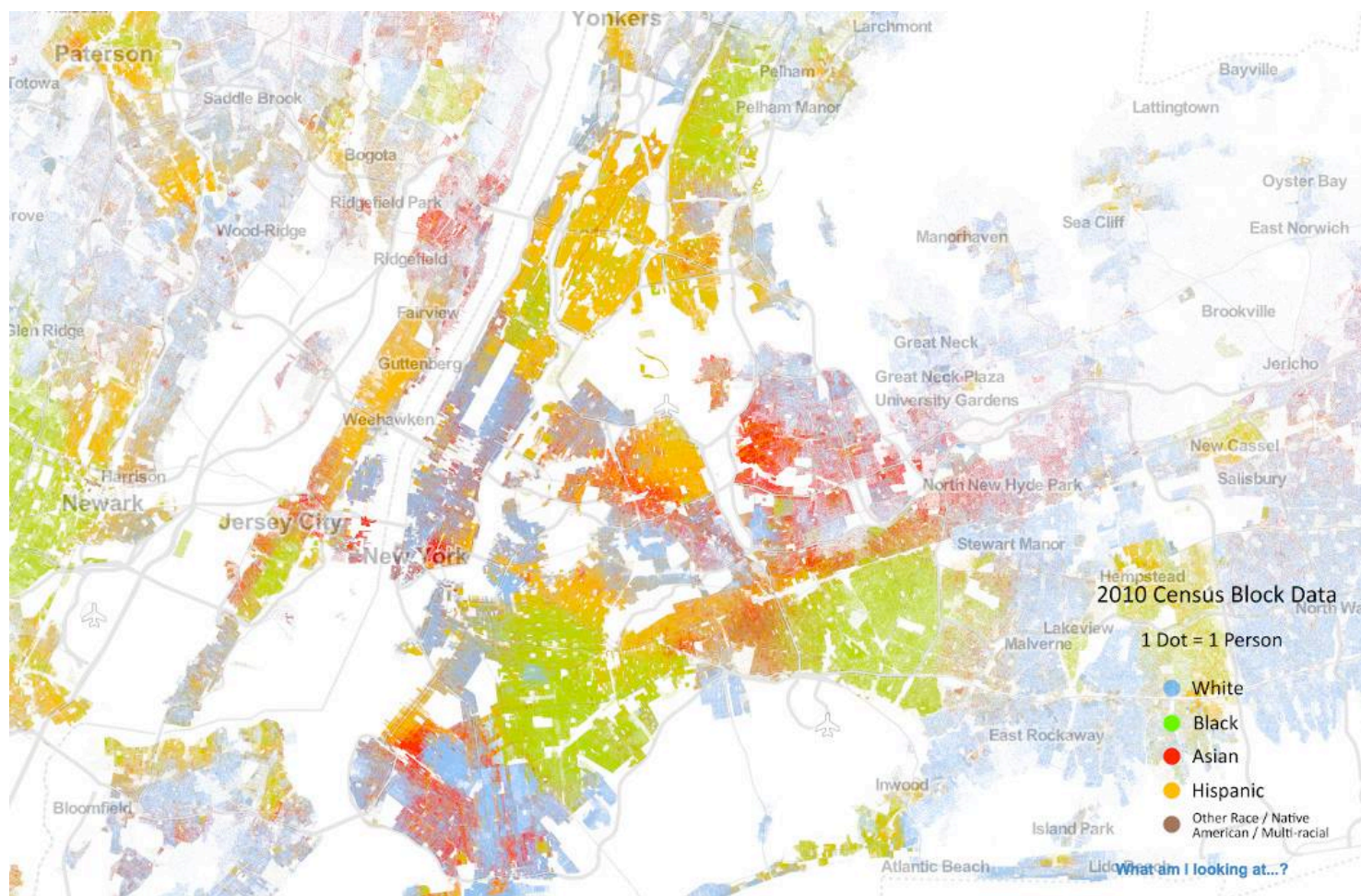


I. Prigogine and
I. Stengers
(1985) Order out
of Chaos.
Flamingo
Paperbacks.
London



Belousov-Zhabotinsky
reaction

Self-organisation in social science



2010 US Census New York City map – color coded by race

Micromotives
and Macrobehavior

with a New Preface
and the Nobel Lecture

THOMAS C. SCHELLING

1978

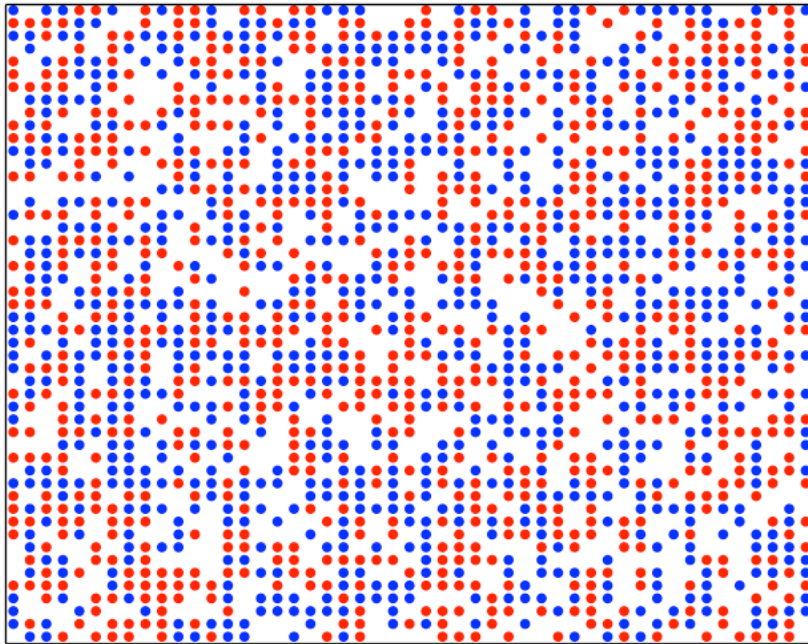


Thomas Schelling

w·w relation between the behavior characteristics of the *individuals* who comprise some social aggregate, and the characteristics of the *aggregate*.

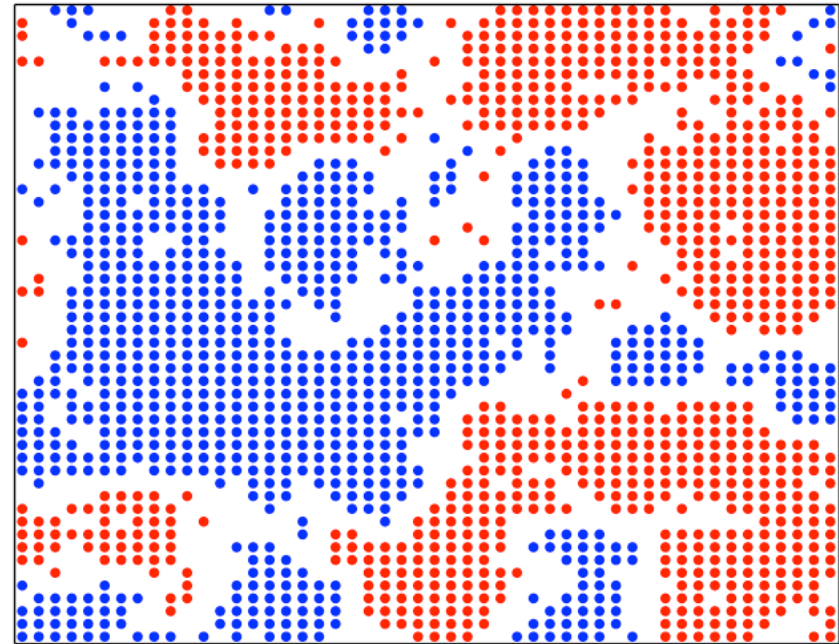
Schelling agent-based segregation model

Schelling Model with 2 colors: Initial State



Initial state

Schelling Model with 2 colors: Final State with Happiness Threshold 80%

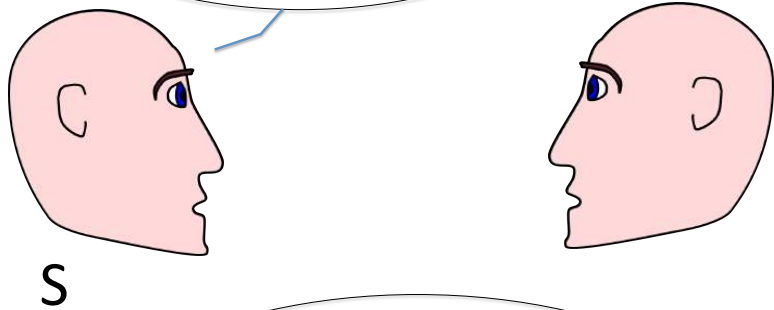
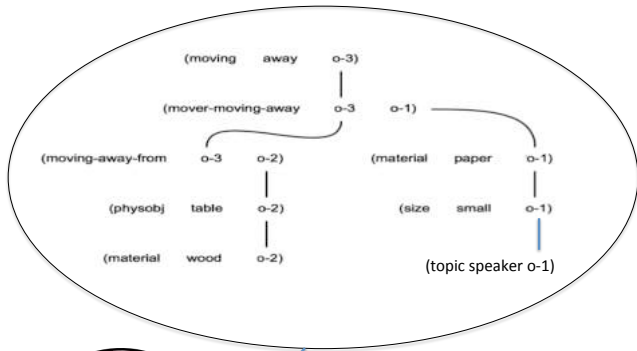


Final state

Schelling agent-based segregation model

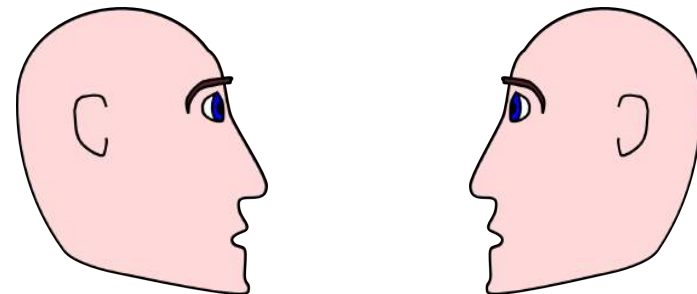
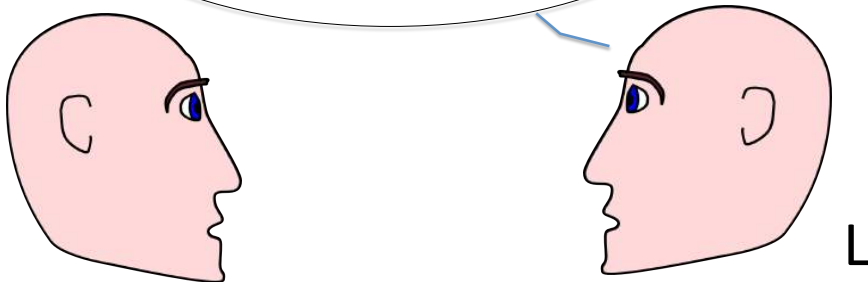
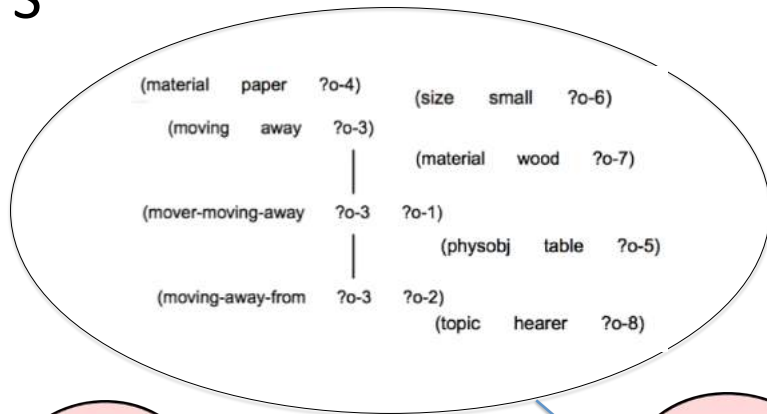
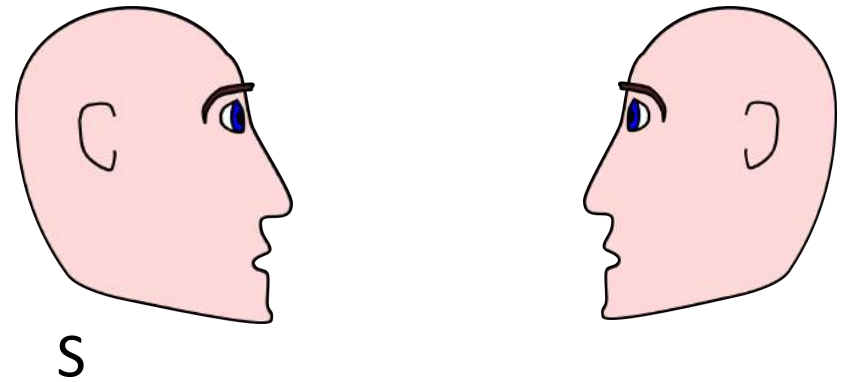
- Population of agents and a world consisting of houses (= grid with cells)
- Agents 'live' in a house (cell)
- Agents have internal state of satisfaction based on percentage of neighbors of same preference
- Select random agent
 - If satisfaction is below threshold, agent moves to another random empty cell
 - Otherwise agent stays
- Track global properties (i.e. degree of segregation)

Language Games in population of agents



on paper small
table wood

?



L: Points to
paper

Agent-based models in evolutionary linguistics

- Population of agents and a world
- Agents have minimal capacities for participating in using, acquiring, expanding language (language-ready brain)
- Select two random agents (speaker, listener) and let them play a language game
- Agents adapt their language systems based on the outcome of the game
- Iterate and monitor individual and collective behavior

Steels, L. (1995) A self-organizing spatial vocabulary *Artificial Life Journal*, 2(3),1995.

Case study: Origins of lexicons

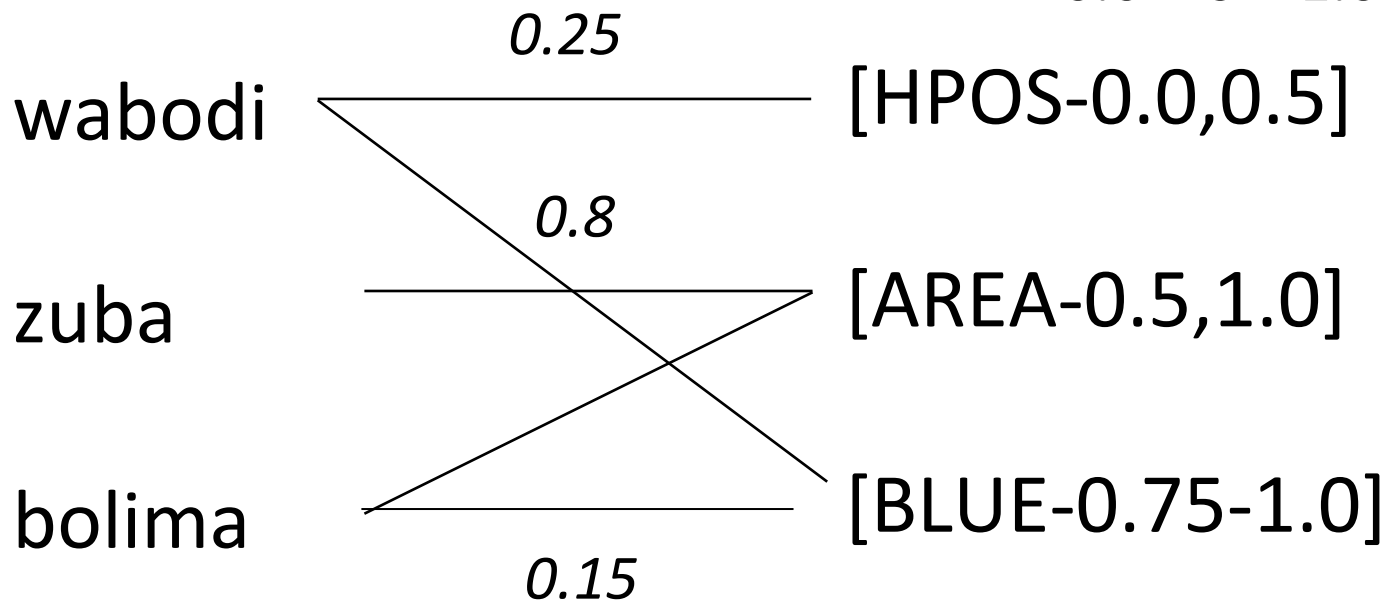
2-way associative
memory with scores

$$L = P \times W \times S$$

P is set of predicates

W is set of words

$0.0 < \sigma < 1.0$ is a score



Steels, L. (1998) The Origins of Ontologies and Communication Conventions in Multi-Agent Systems. Journal of Agents and Multi-Agent Systems. pp. 169-194

$$\sigma_{f_i, m_i} \leftarrow \sigma_{f_i, m_i} (1 - \gamma) + \gamma$$

$$\sigma_{f_j, m_i} \leftarrow \sigma_{f_j, m_i} (1 - \gamma) \quad j \neq i$$

$$\sigma_{f_i, m_k} \leftarrow \sigma_{f_i, m_k} (1 - \gamma) \quad k \neq i$$

Naming Game strategy (lateral inhibition)

- Speaker:

- If no word yet, invent one

$$\sigma_{f_i, m_i} \leftarrow \sigma_{f_i, m_i} (1 - \gamma) + \gamma$$

- If several words, pick the one with the highest score

$$\sigma_{f_j, m_i} \leftarrow \sigma_{f_j, m_i} (1 - \gamma) \quad j \neq i$$

$$\sigma_{f_i, m_k} \leftarrow \sigma_{f_i, m_k} (1 - \gamma) \quad k \neq i$$

- Hearer:

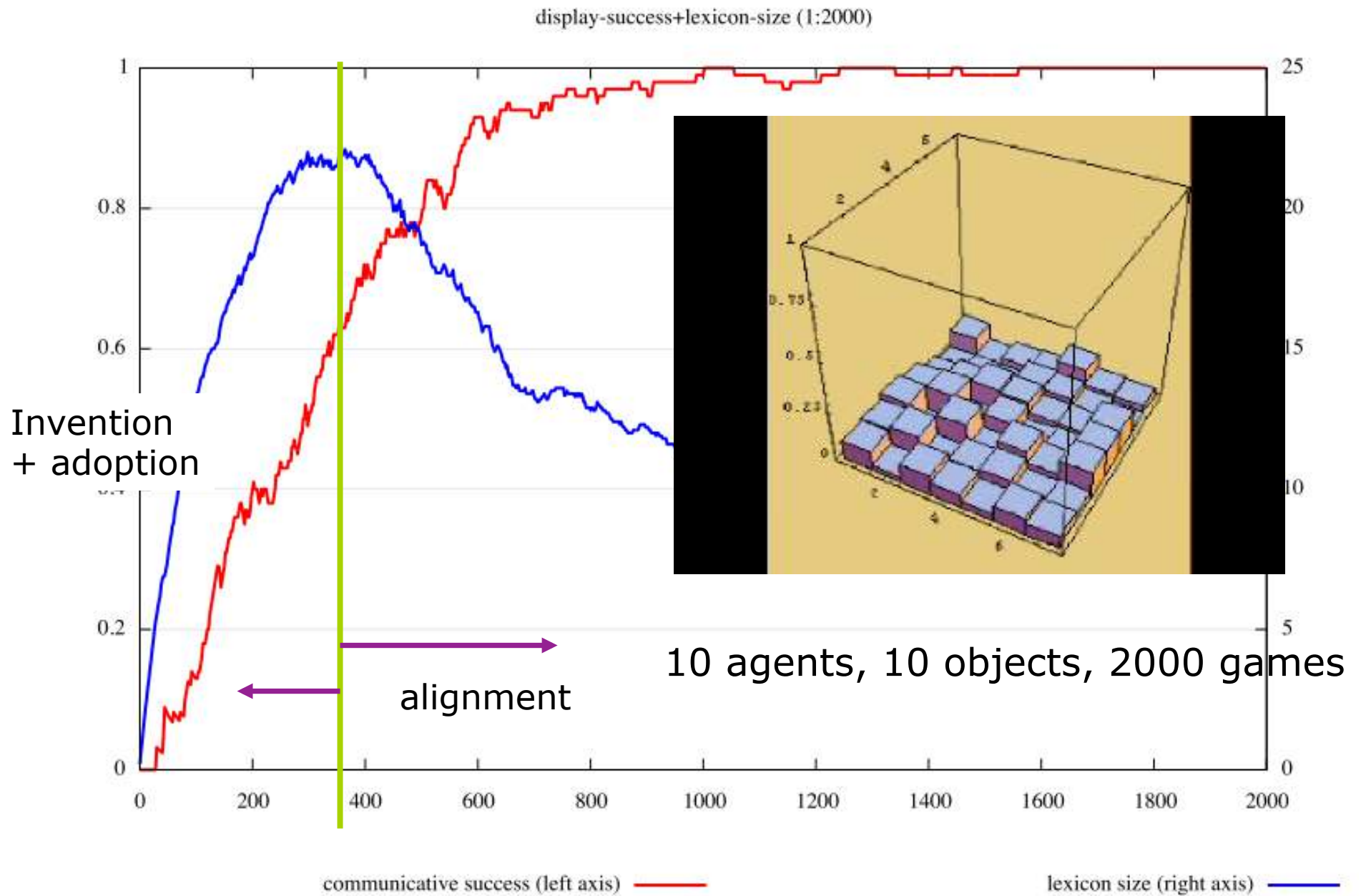
- If unknown word, store it after guessing its meaning based on context and feedback

- If wrong choice, store new hypothesis

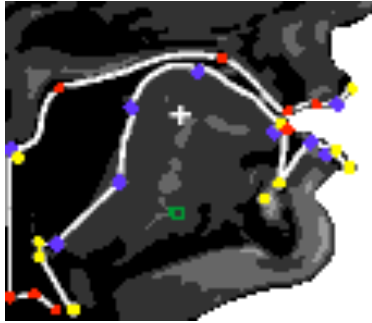
- Speaker + Hearer (alignment):

- If success, increase score of word used and decrease competitors

- If failure, decrease score of word used

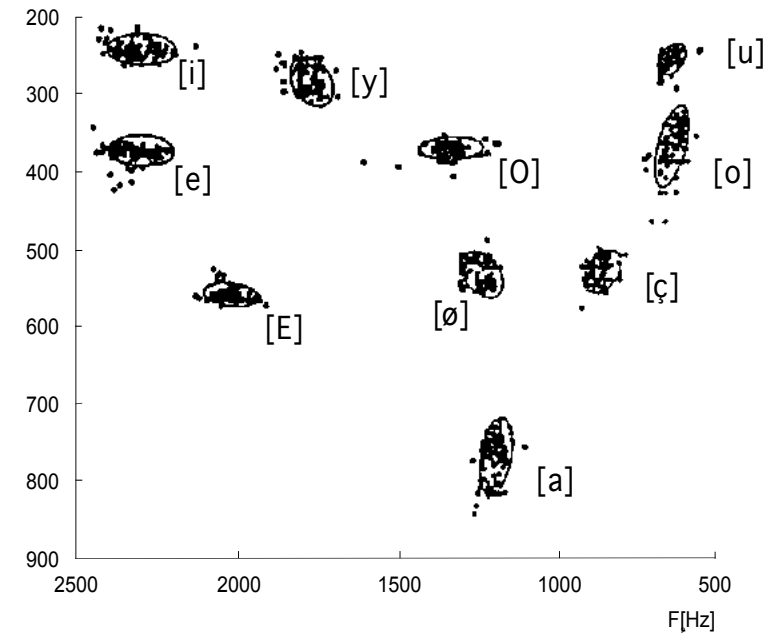


Steels, L. (1995) A self-organizing spatial vocabulary *Artificial Life Journal*, 2(3),1995.



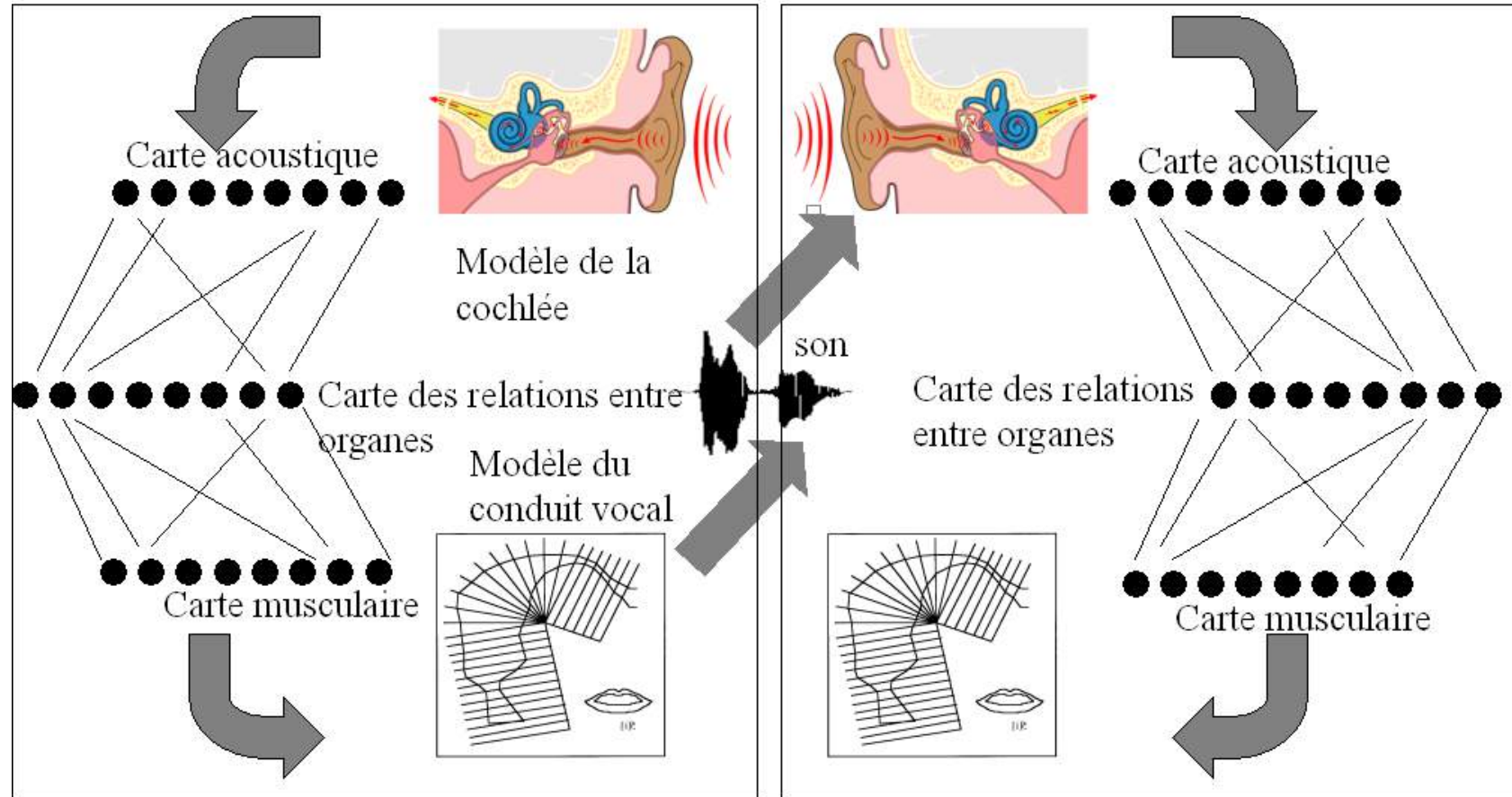
Case study: Origins of vowels

	tract variable	articulators involved
LP	lip protrusion	upper & lower lips, jaw
LA	lip aperture	upper & lower lips, jaw
TTCL	tongue tip constrict location	tongue tip, tongue body, jaw
TTCD	tongue tip constrict degree	tongue tip, tongue body, jaw
TBCL	tongue body constrict location	tongue body, jaw
TBCD	tongue body constrict degree	tongue body, jaw
VEL	velic aperture	velum
GLO	glottal aperture	glottis

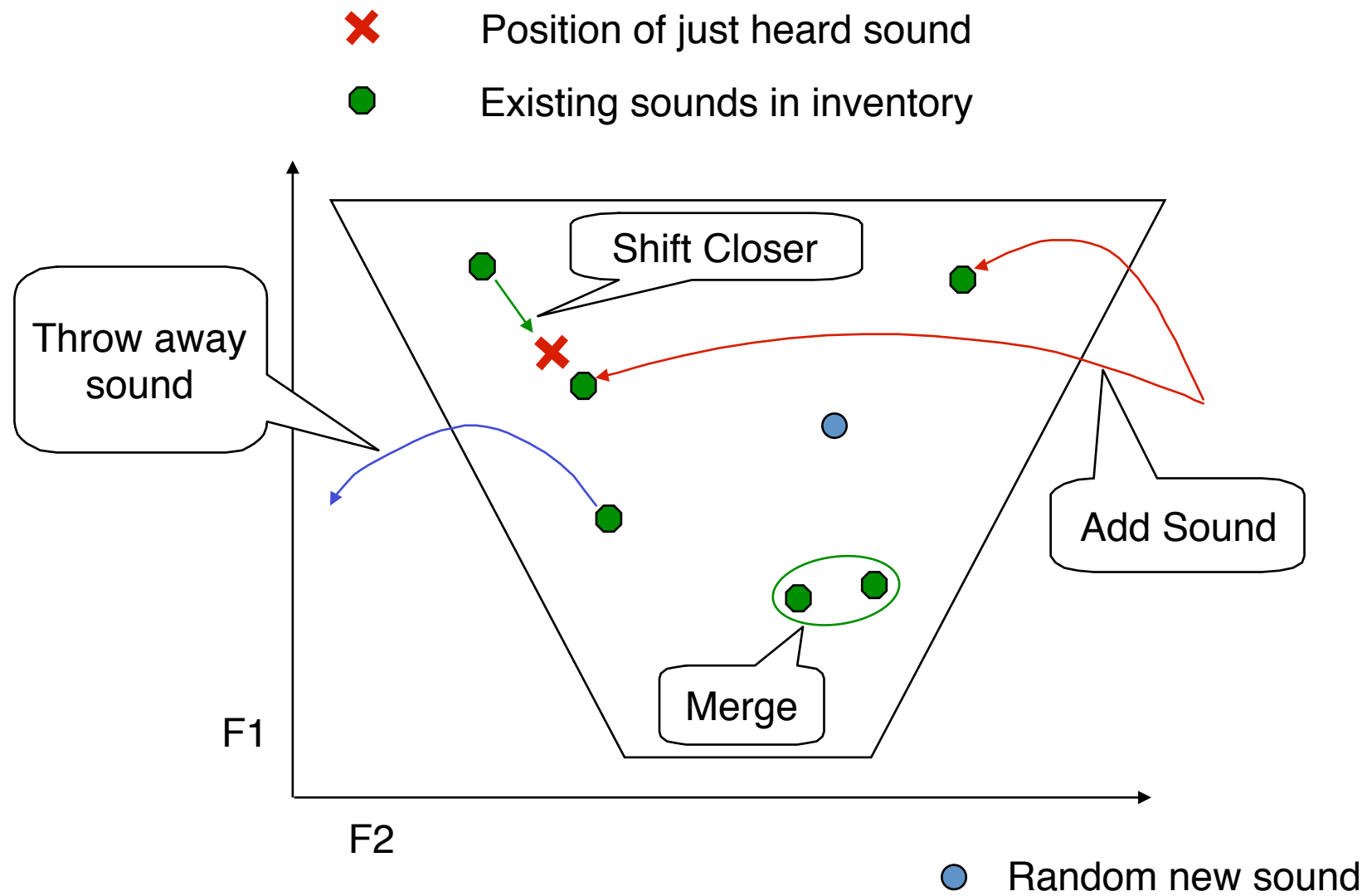


L'agent 1 produit une vocalisation

L'agent 2 perçoit cette vocalisation

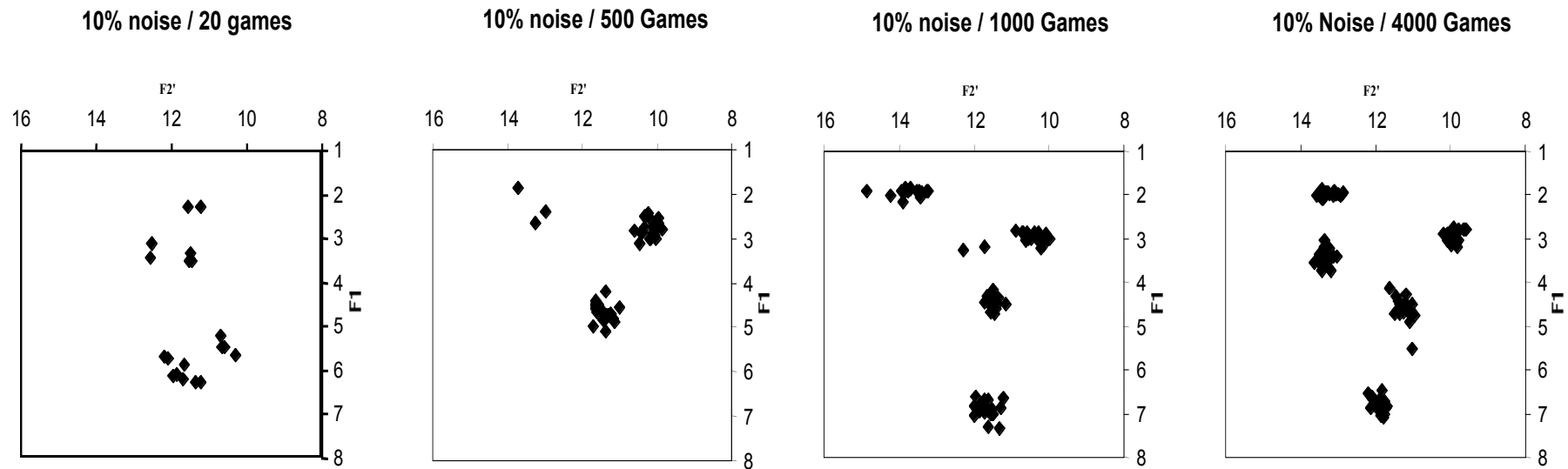


Bart De Boer (2000) The origins of vowel systems. Oxford University Press, Oxford.
Pierre-Yves Oudeyer (2003) Self-Organization in the Evolution of Speech.
Oxford University Press. Oxford



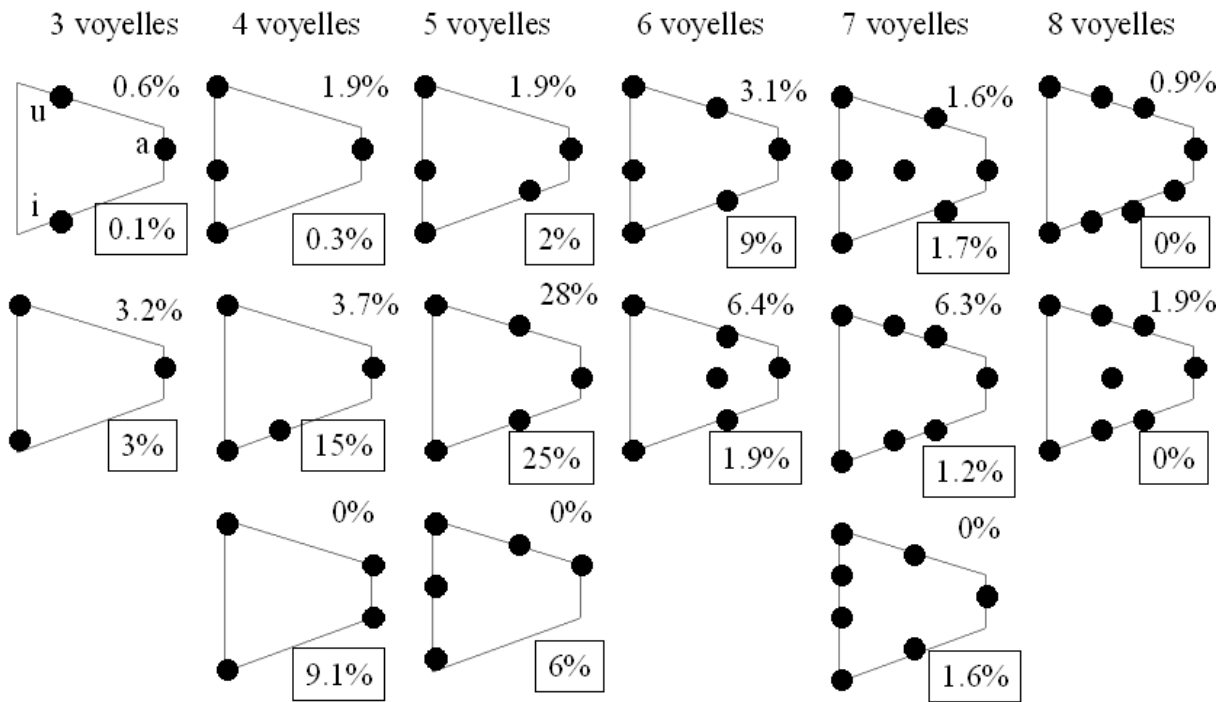
Bart De Boer (2000), Pierre-Yves Oudeyer (2003)

Alignment + emergence of a Vowel System

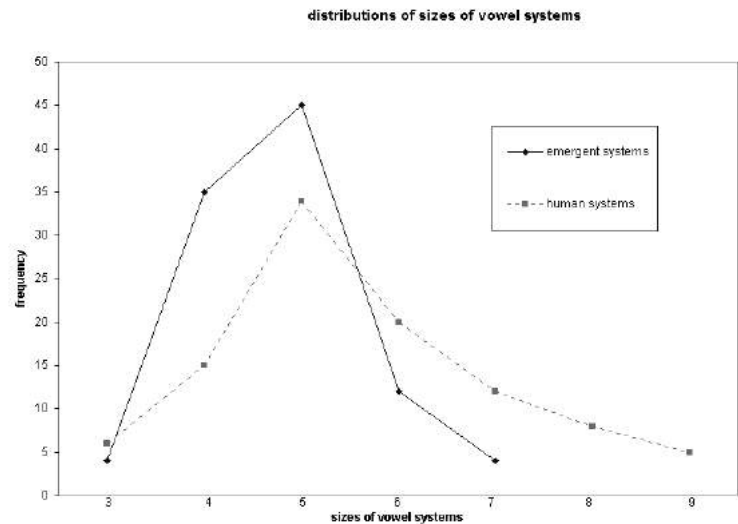


Population of 20 agents

Systèmes de voyelles les plus fréquents dans les langues humaines et dans le système artificiel



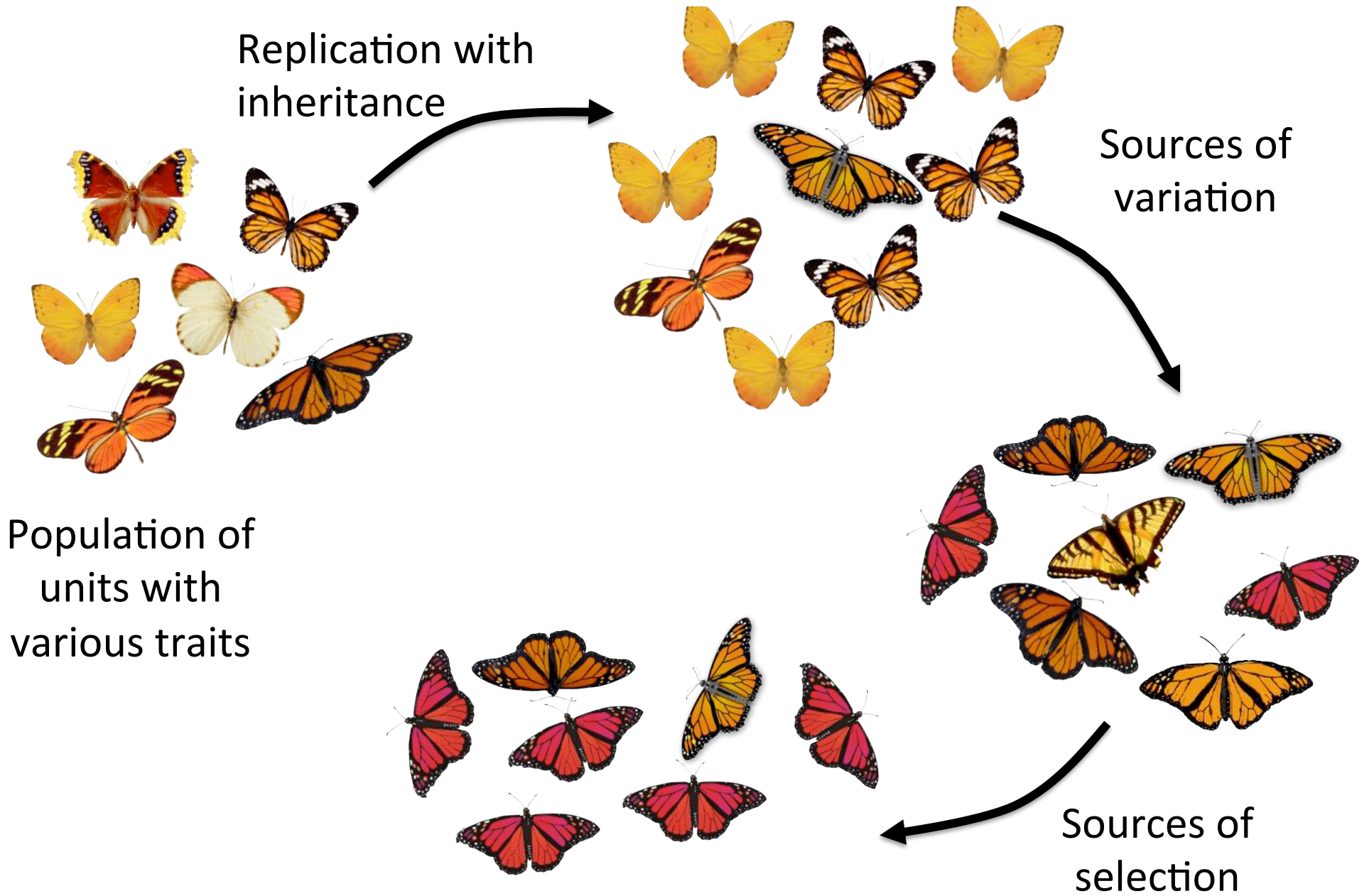
12% : fréquence dans les langues humaines
 19% : fréquence dans le système artificiel



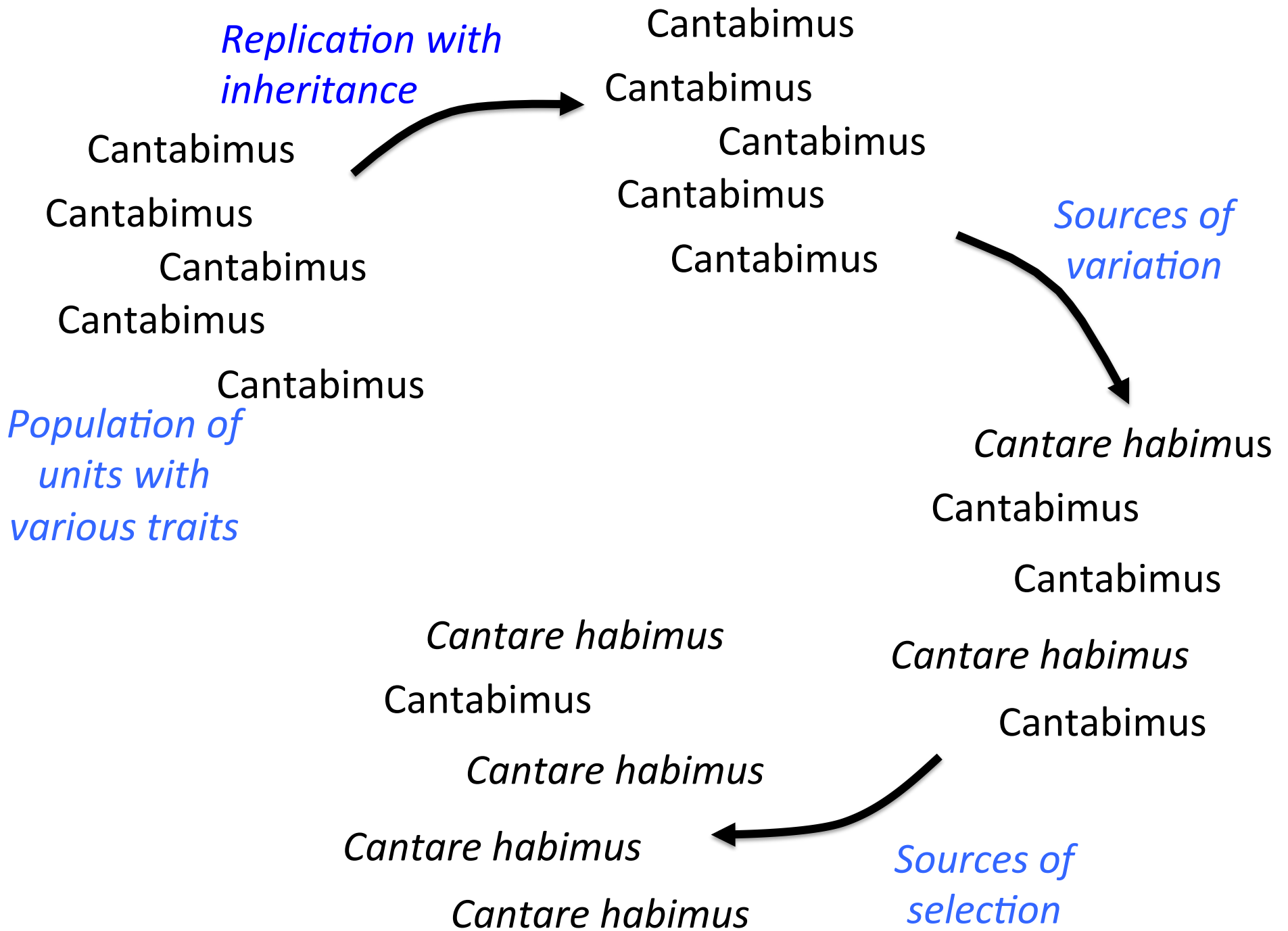
2. How can language be so adapted to human embodiment, ecological needs, human cognitive capacities?

Selectionism

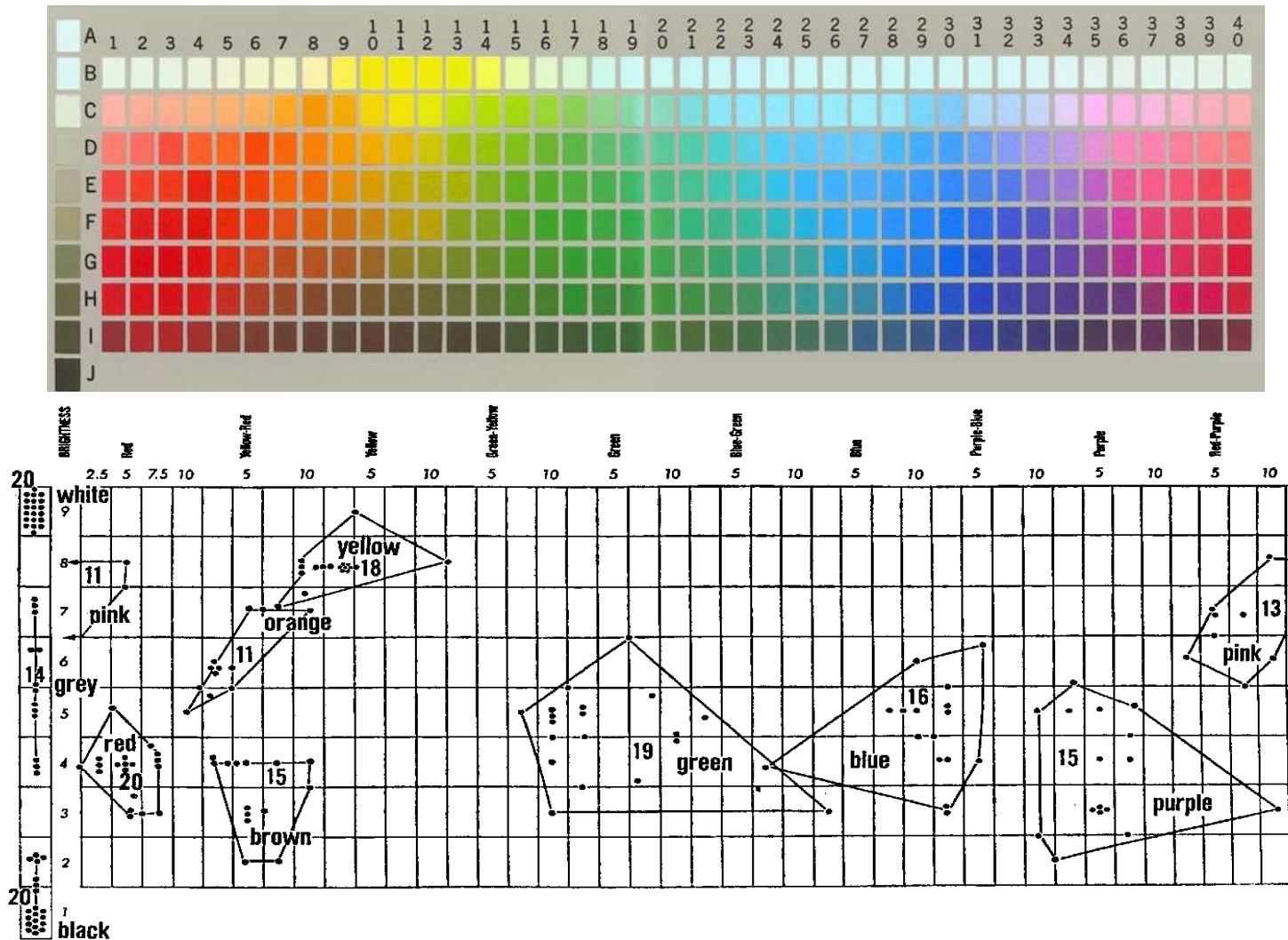
- Elements are able to replicate with inheritance of features
- Replication involves random variation (Darwinian) or acquisition (Lamarckian) of features
- Some elements are more adapted than others and therefore have a higher chance of replicating



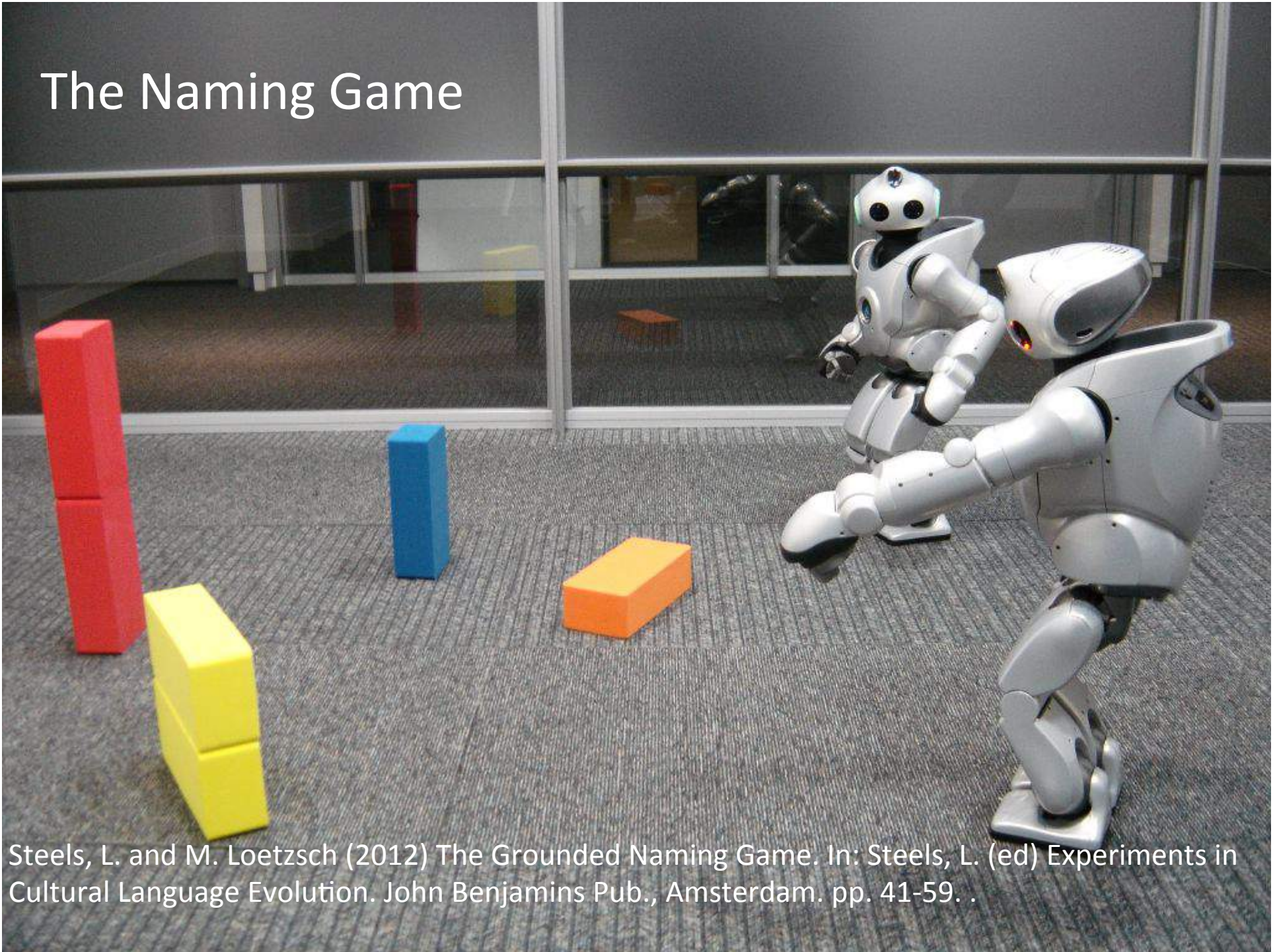
Selectionism



Case study: Origins of color words + color categories

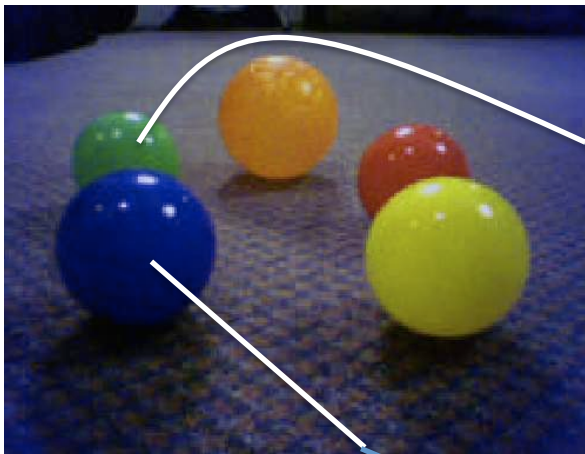
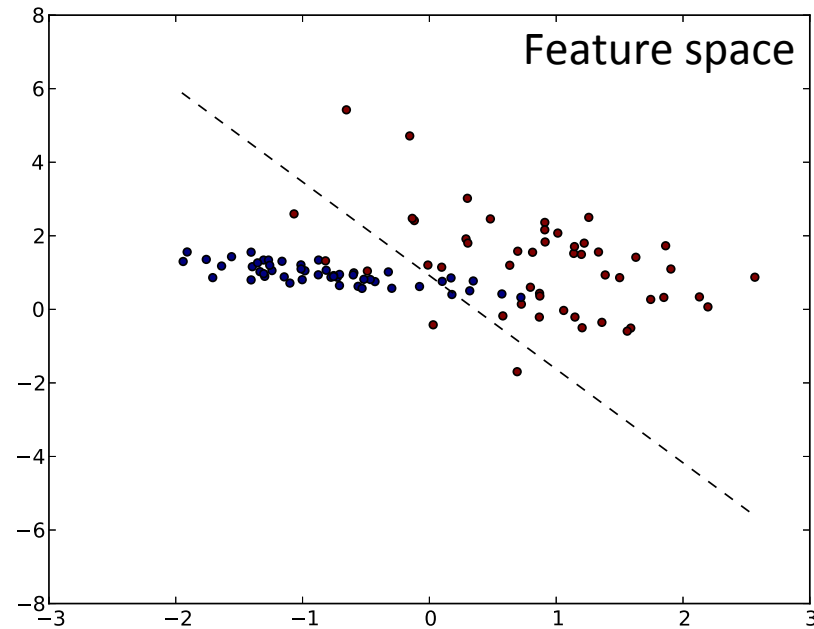


The Naming Game

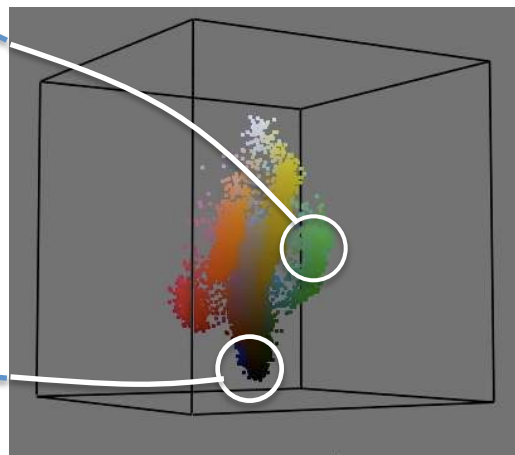


Steels, L. and M. Loetzsch (2012) The Grounded Naming Game. In: Steels, L. (ed) Experiments in Cultural Language Evolution. John Benjamins Pub., Amsterdam. pp. 41-59. .

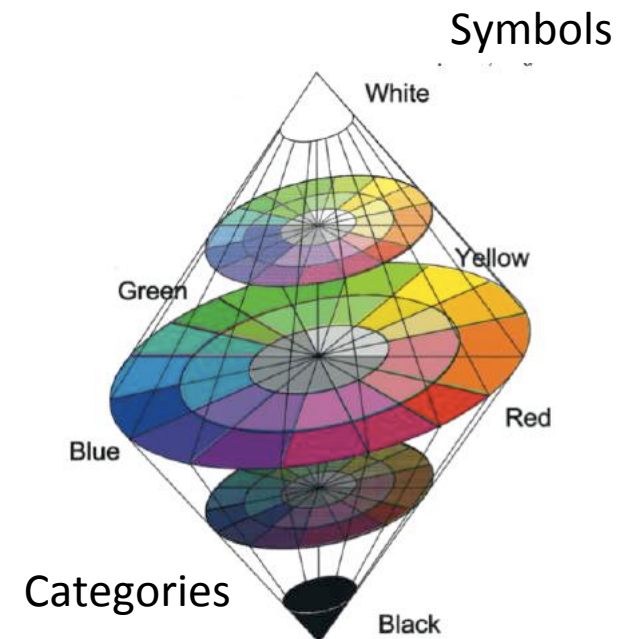
Dealing with the grounding problem



perception



Feature space





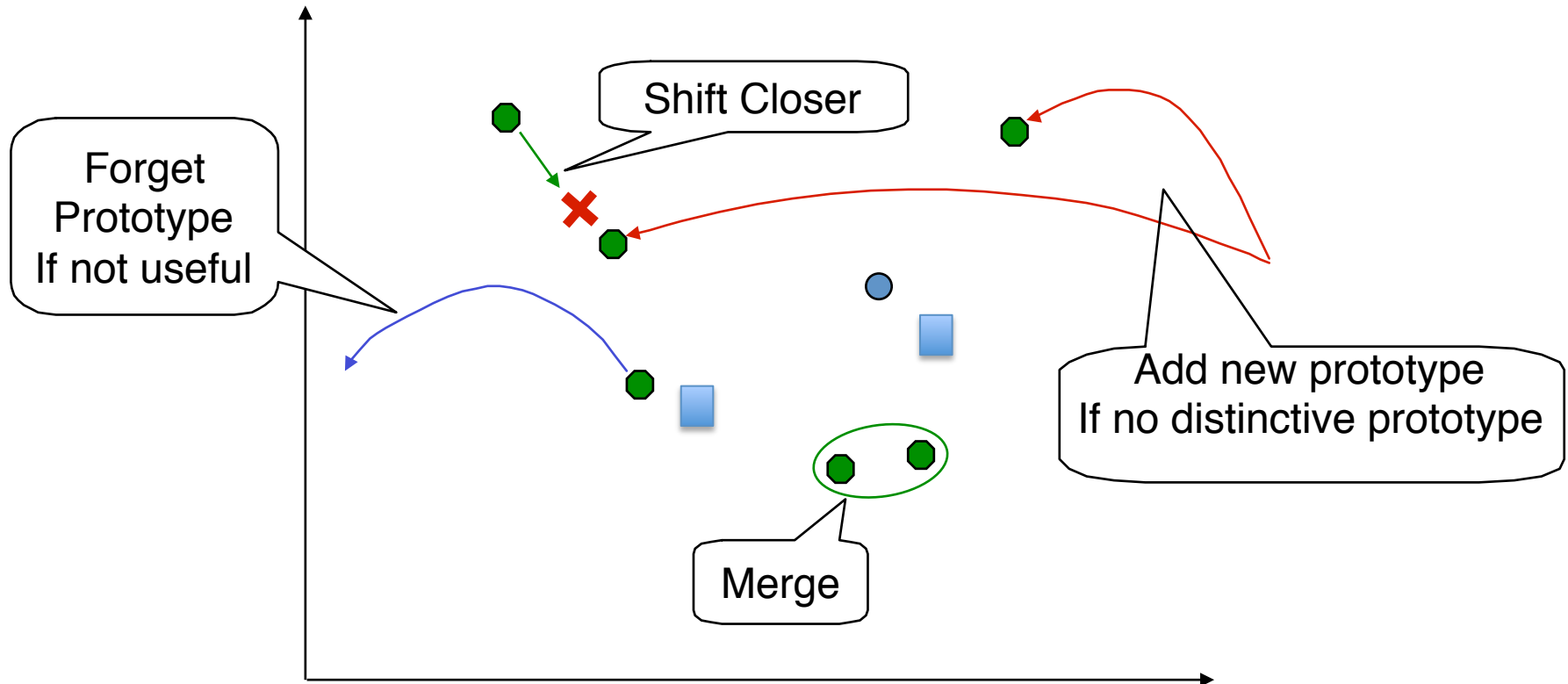
Position of topic



Existing color prototypes



Other objects in the context



Example emergence of color concepts and lexicon for 5 agents



After 1000 games

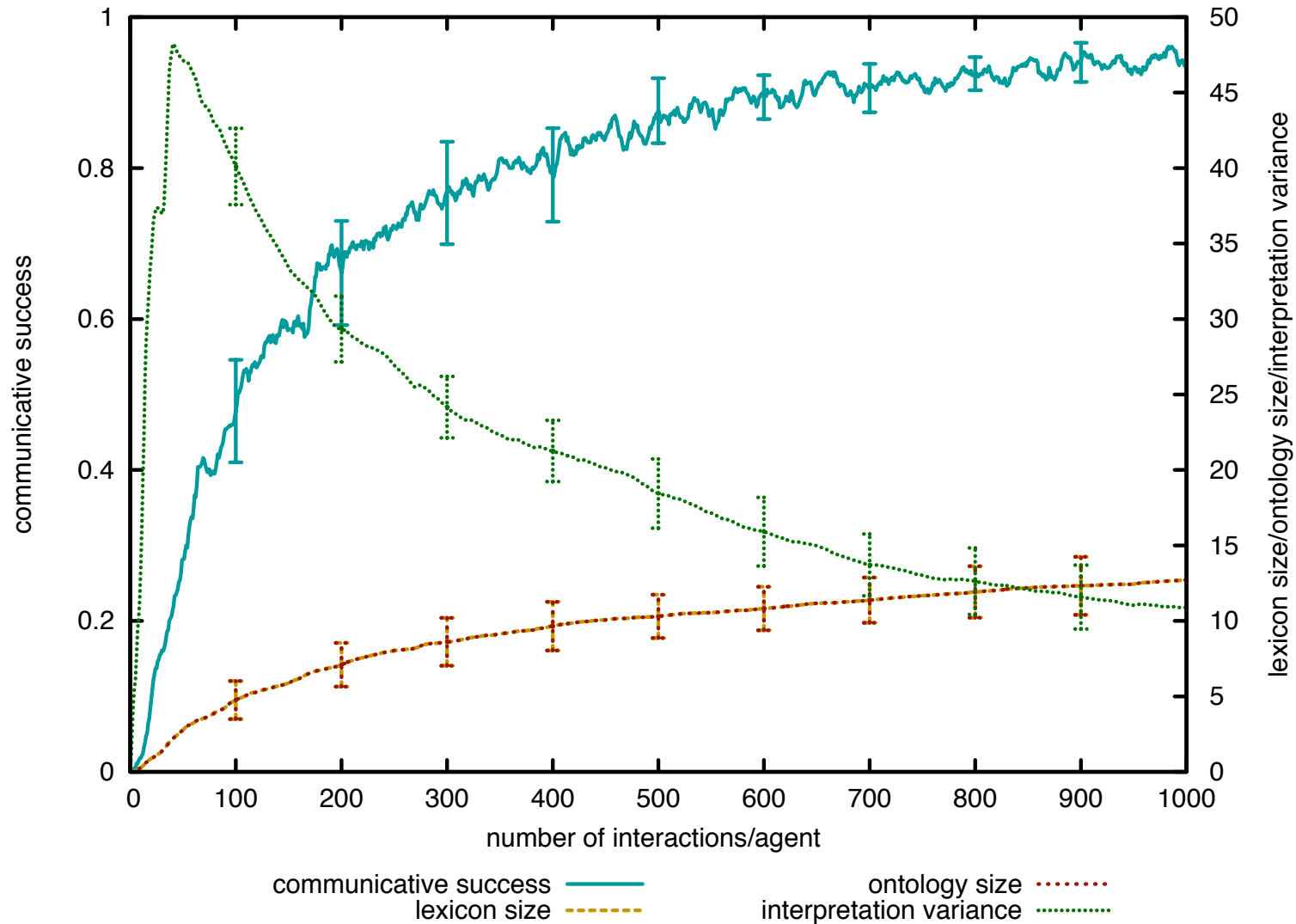


After 2500 games

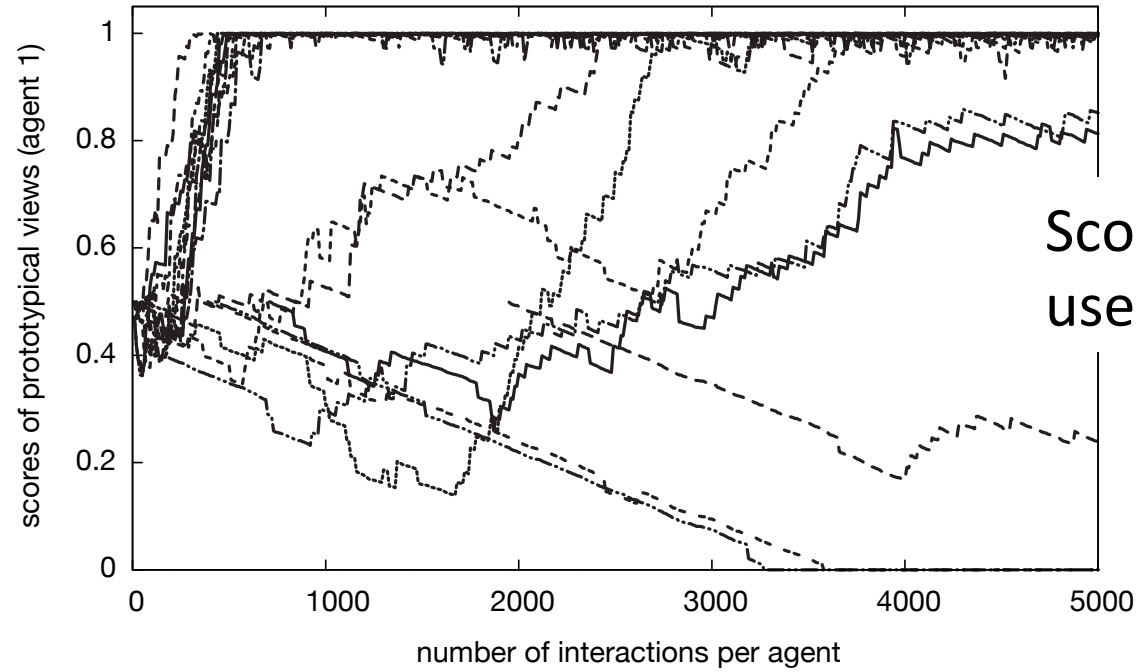
'final' lexicon

wuvana	papalo	newadi	gezabe	duderu	madovo	subumu	ravebe	rufaxi	tezeke	wulepe	mugige	visozu	wasoli	terira	ragoza	tutuze
wuvana	papalo	newadi	gezabe	duderu	madovo	subumu	ravebe	rufaxi	tezeke	wulepe	mugige	visozu	wasoli	terira	ragoza	tutuze
wuvana	papalo	newadi	gezabe	duderu	madovo	subumu	ravebe	rufaxi	tezeke	wulepe	mugige	visozu	wasoli	terira	ragoza	tutuze
wuvana	papalo	newadi	gezabe	duderu	madovo	subumu	ravebe	rufaxi	tezeke	wulepe	mugige	visozu	wasoli	terira	ragoza	tutuze
wuvana	papalo	newadi	gezabe	duderu	madovo	subumu	ravebe	rufaxi	tezeke	wulepe	mugige	visozu	wasoli	terira	ragoza	tutuze
wuvana	papalo	newadi	gezabe	duderu	madovo	subumu	ravebe	rufaxi	tezeke	wulepe	mugige	visozu	wasoli	terira	ragoza	tutuze
wuvana	papalo	newadi	gezabe	duderu	madovo	subumu	ravebe	rufaxi	tezeke	wulepe	mugige	visozu	wasoli	terira	ragoza	tutuze
wuvana	papalo	newadi	gezabe	duderu	madovo	subumu	ravebe	rufaxi	tezeke	wulepe	mugige	visozu	wasoli	terira	ragoza	tutuze
wuvana	papalo	newadi	gezabe	duderu	madovo	subumu	ravebe	rufaxi	tezeke	wulepe	mugige	visozu	wasoli	terira	ragoza	tutuze
wuvana	papalo	newadi	gezabe	duderu	madovo	subumu	ravebe	rufaxi	tezeke	wulepe	mugige	visozu	wasoli	terira	ragoza	tutuze

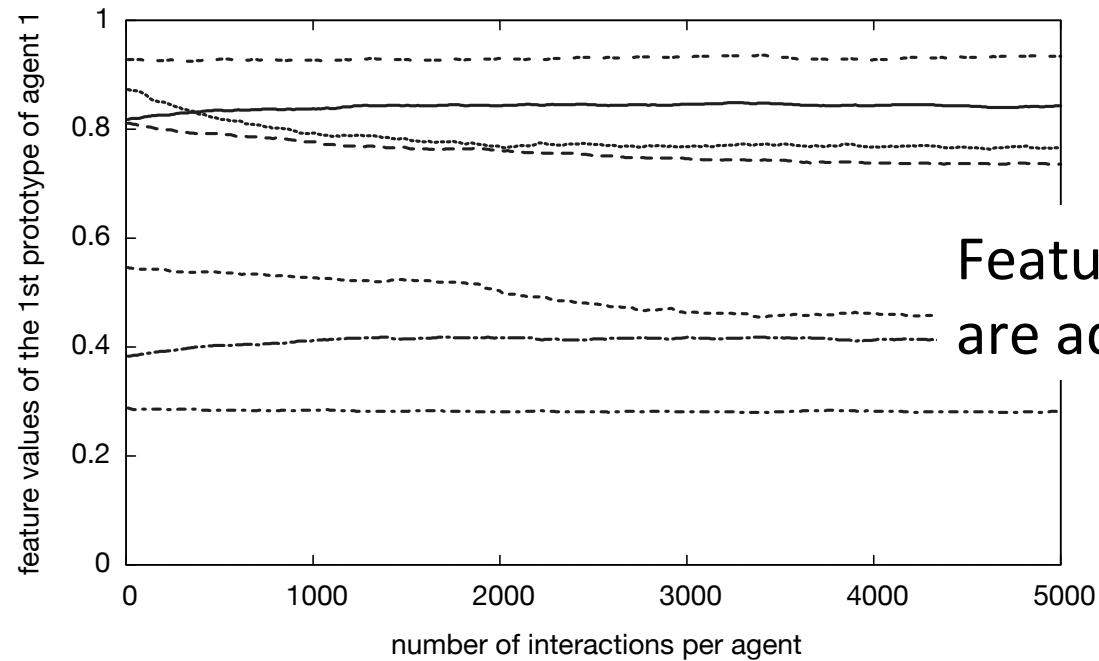
Evolving a vocabulary and concept inventory from scratch



5 agents



Score reflects successful use of a prototype



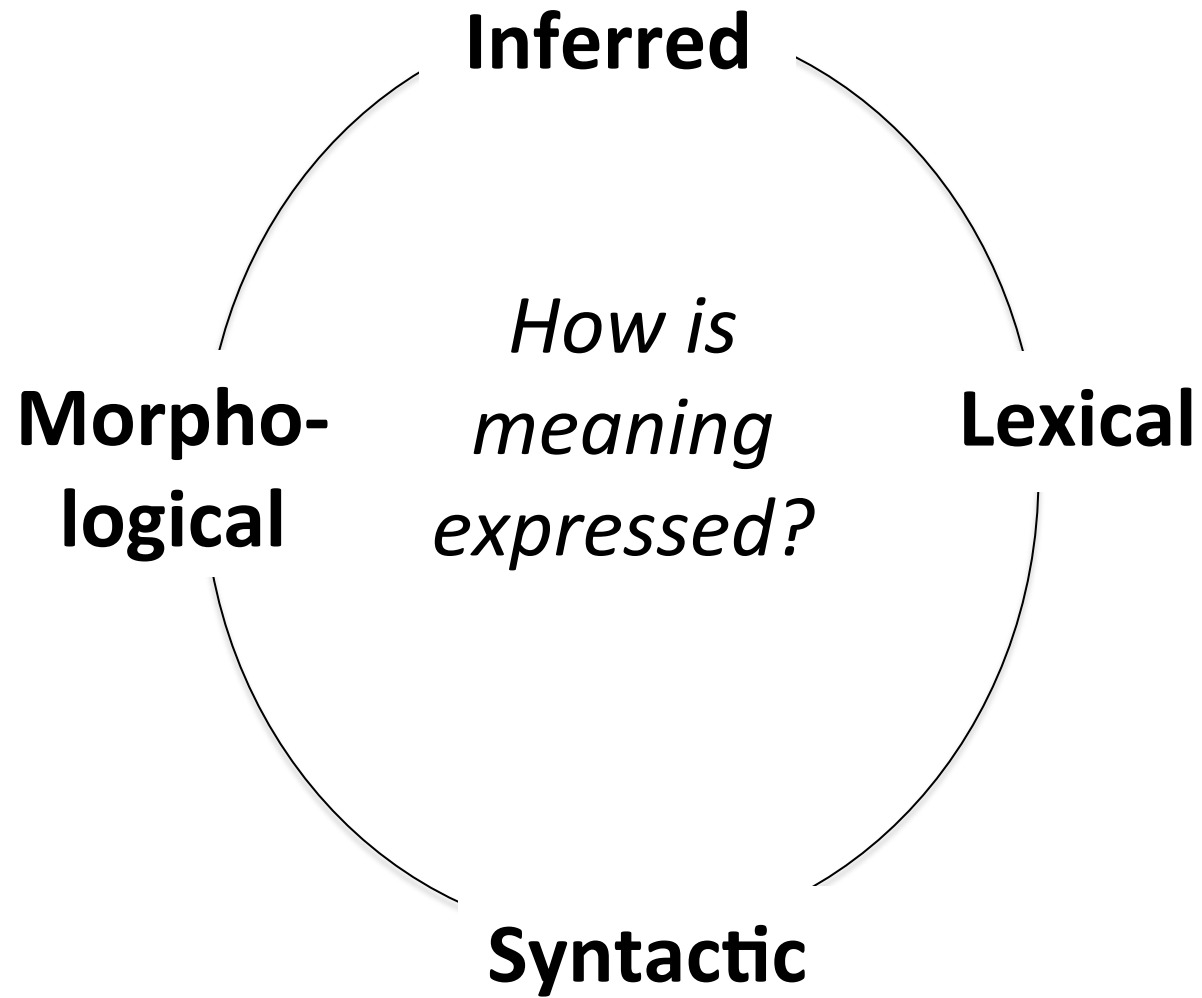
Feature values of a prototype are adjusted continuously

3. Where do linguistic innovations come from?

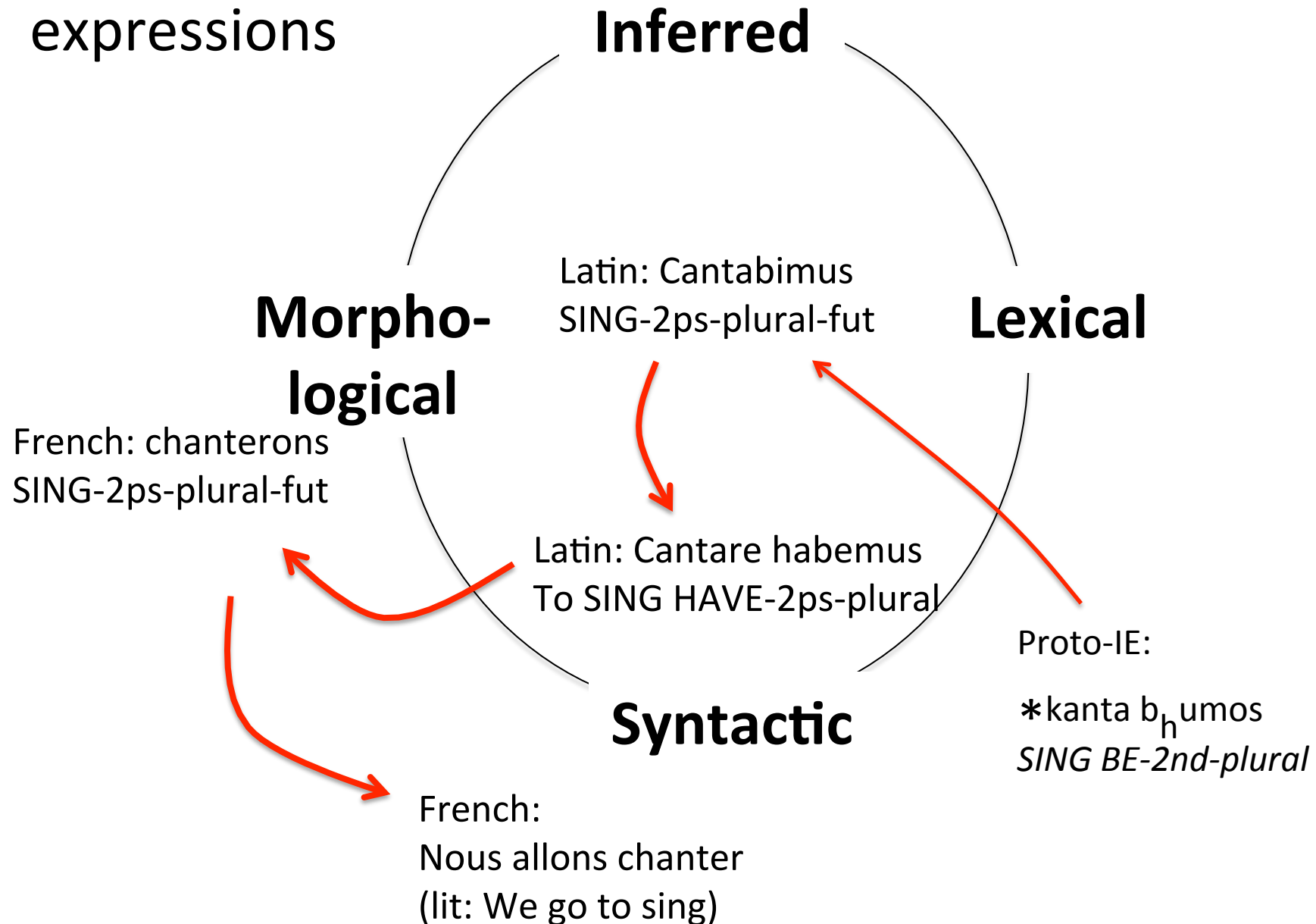
Emergent functionality

- Functioning of components + environment leads to certain (positive) side effects (recruitment)
- Side effect gets preserved and reused with new function

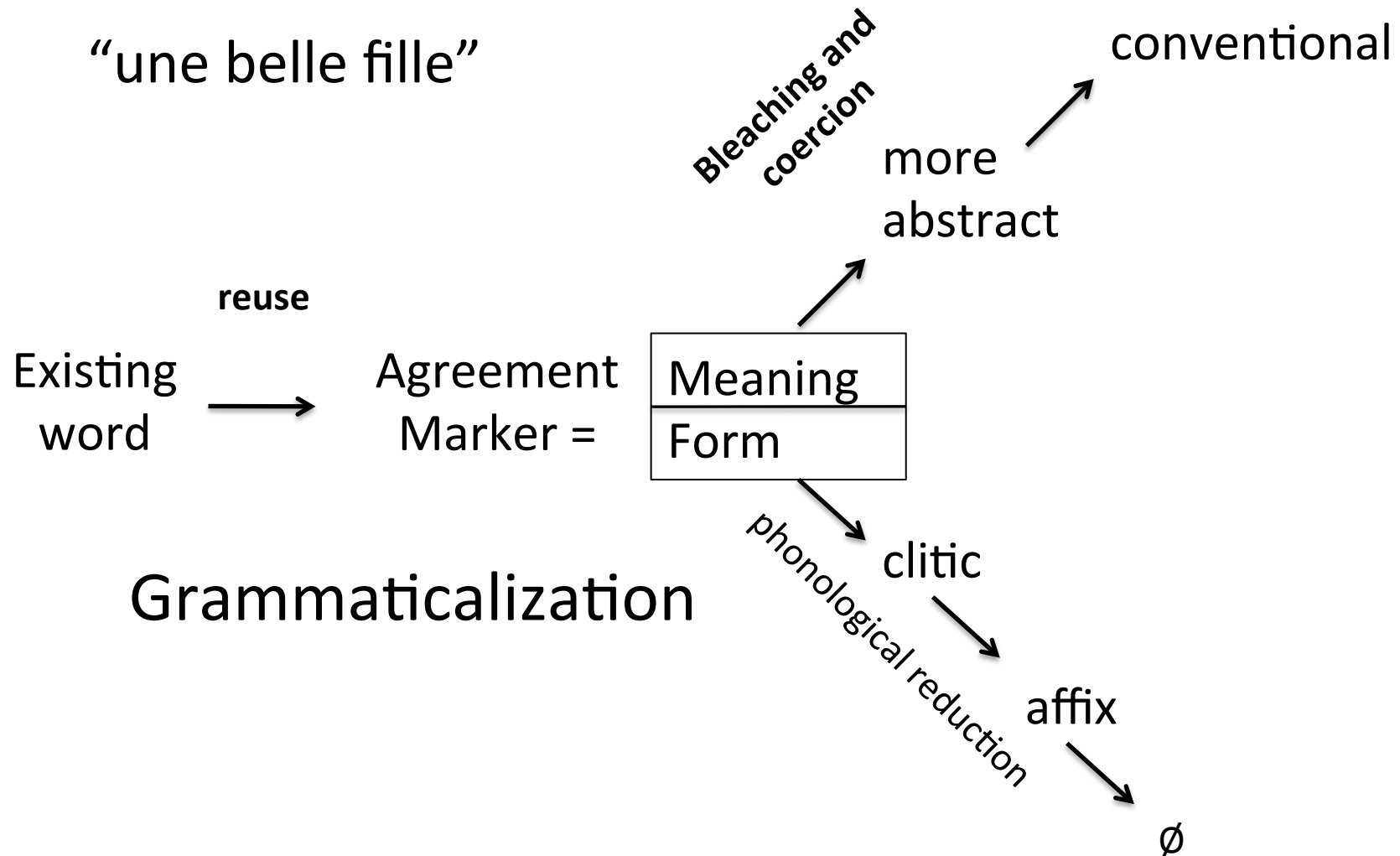
Steels, Luc (1990), "Towards a Theory of Emergent Functionality", in J-A Meyer; S. Wilson, *From Animals to Animats* Cambridge, MA & London, England: Bradford Books (MIT Press), pp. 451-461



Evolution of future expressions

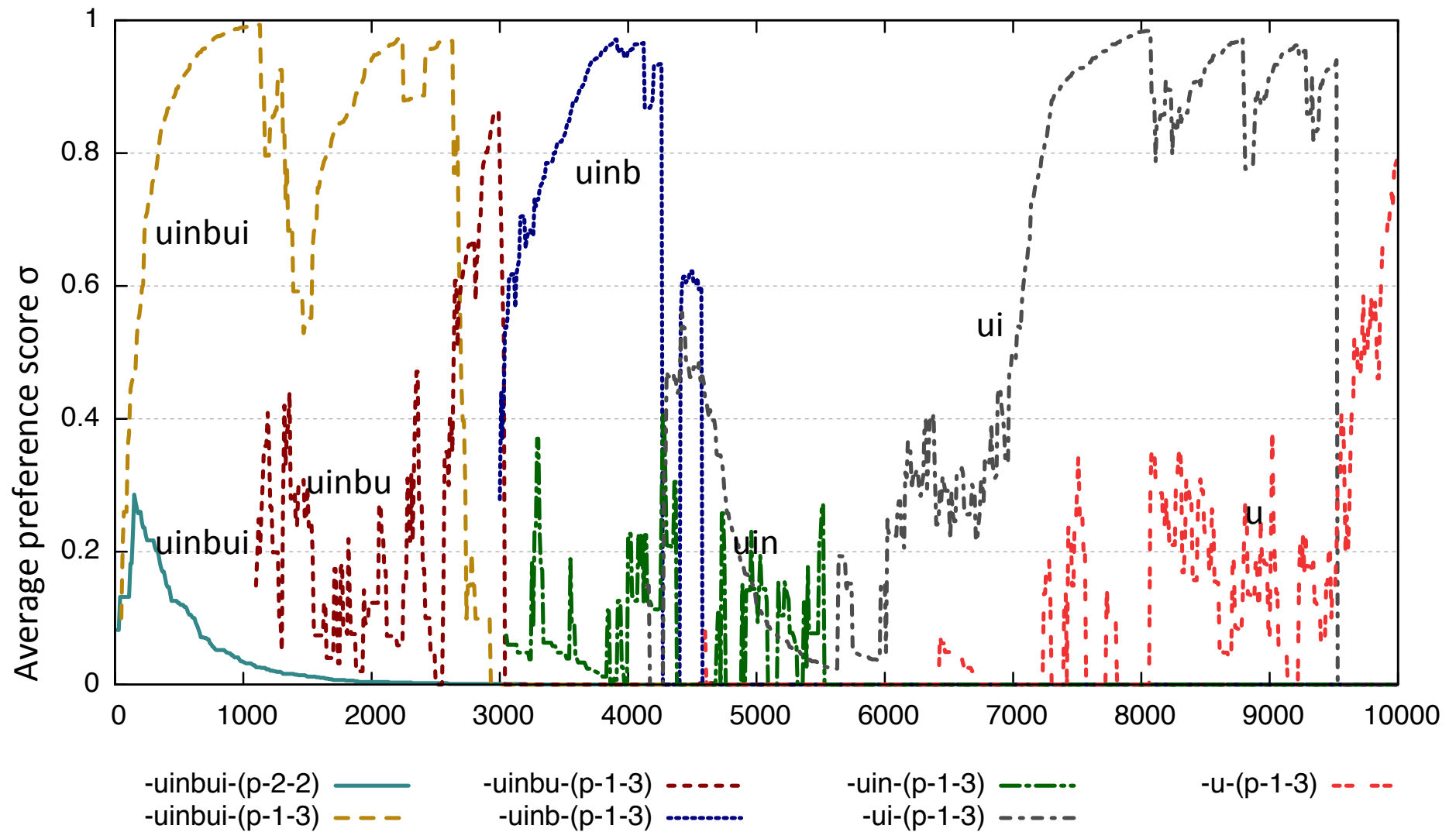


Emergence of agreement systems



Beuls, K., & Steels, L. (2013). Agent-Based Models of Strategies for the Emergence and Evolution of Grammatical Agreement. PLOS ONE, 8(3)

Shift in wordform



Phonological reduction

vita > vida

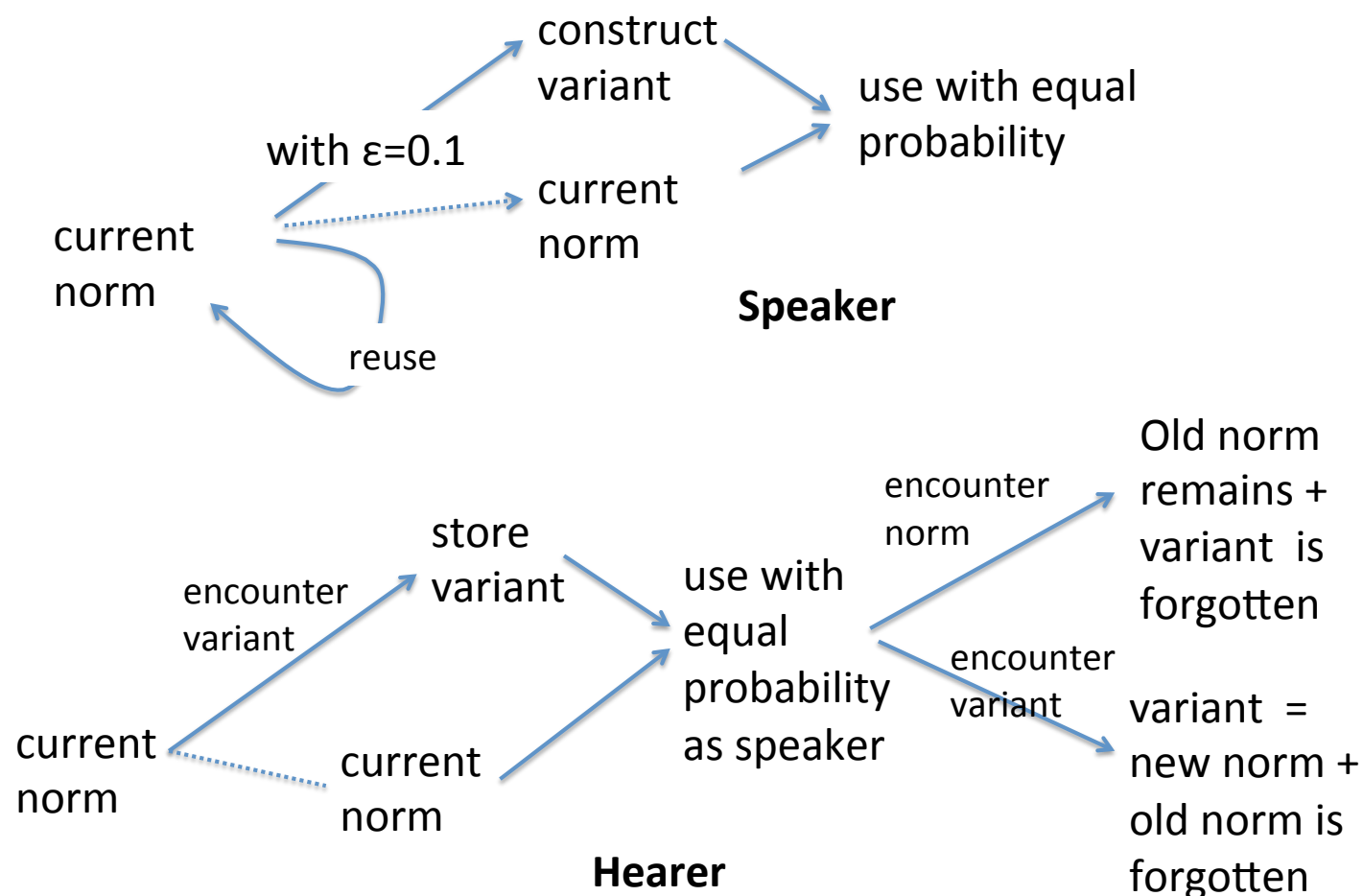
vida > vitha

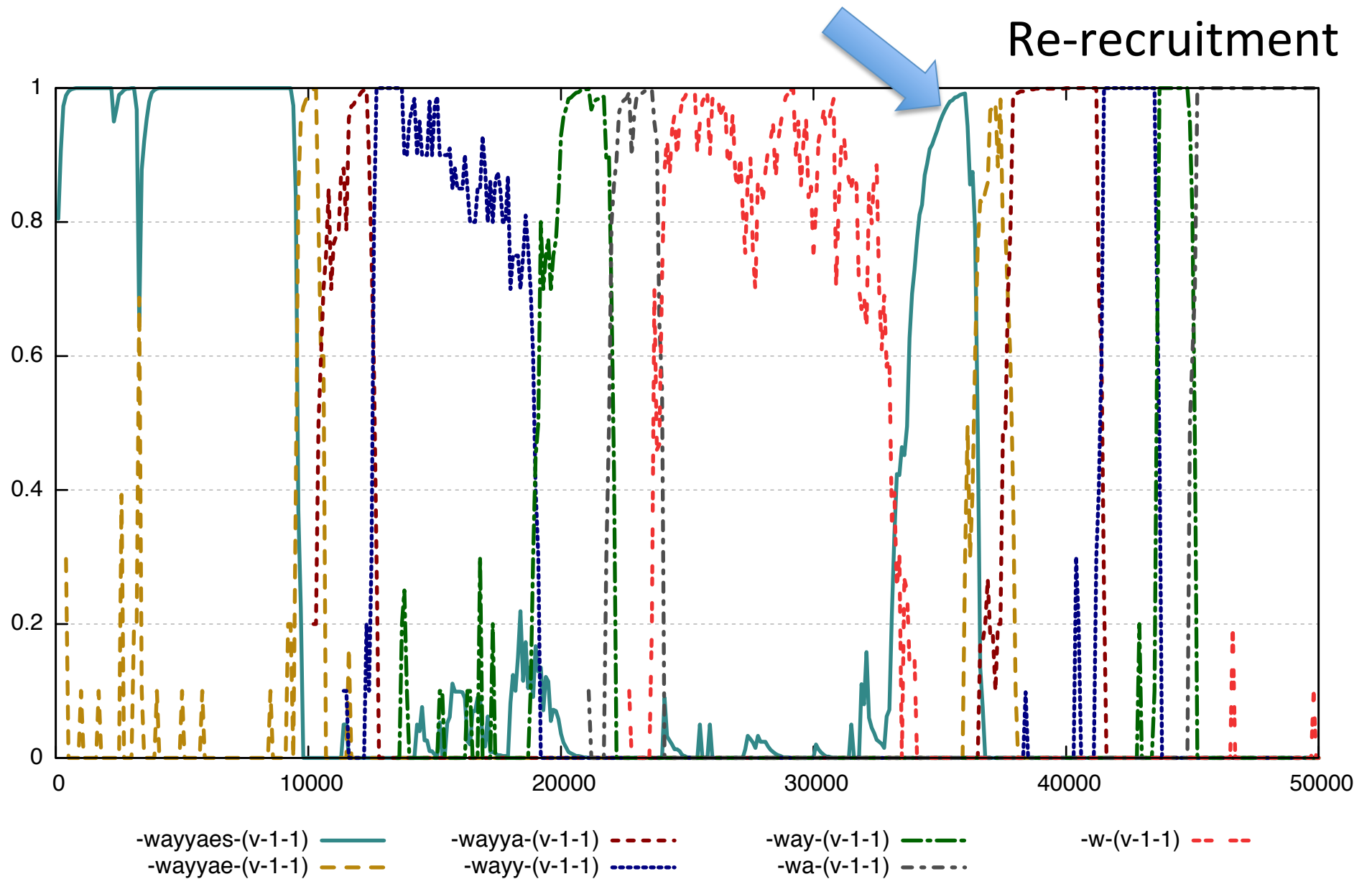
vitha > via

via > vie

vie > /vi/

Perret, M. (2009)
Introduction à
l'histoire de la
langue française
Armand Colin,
Paris.





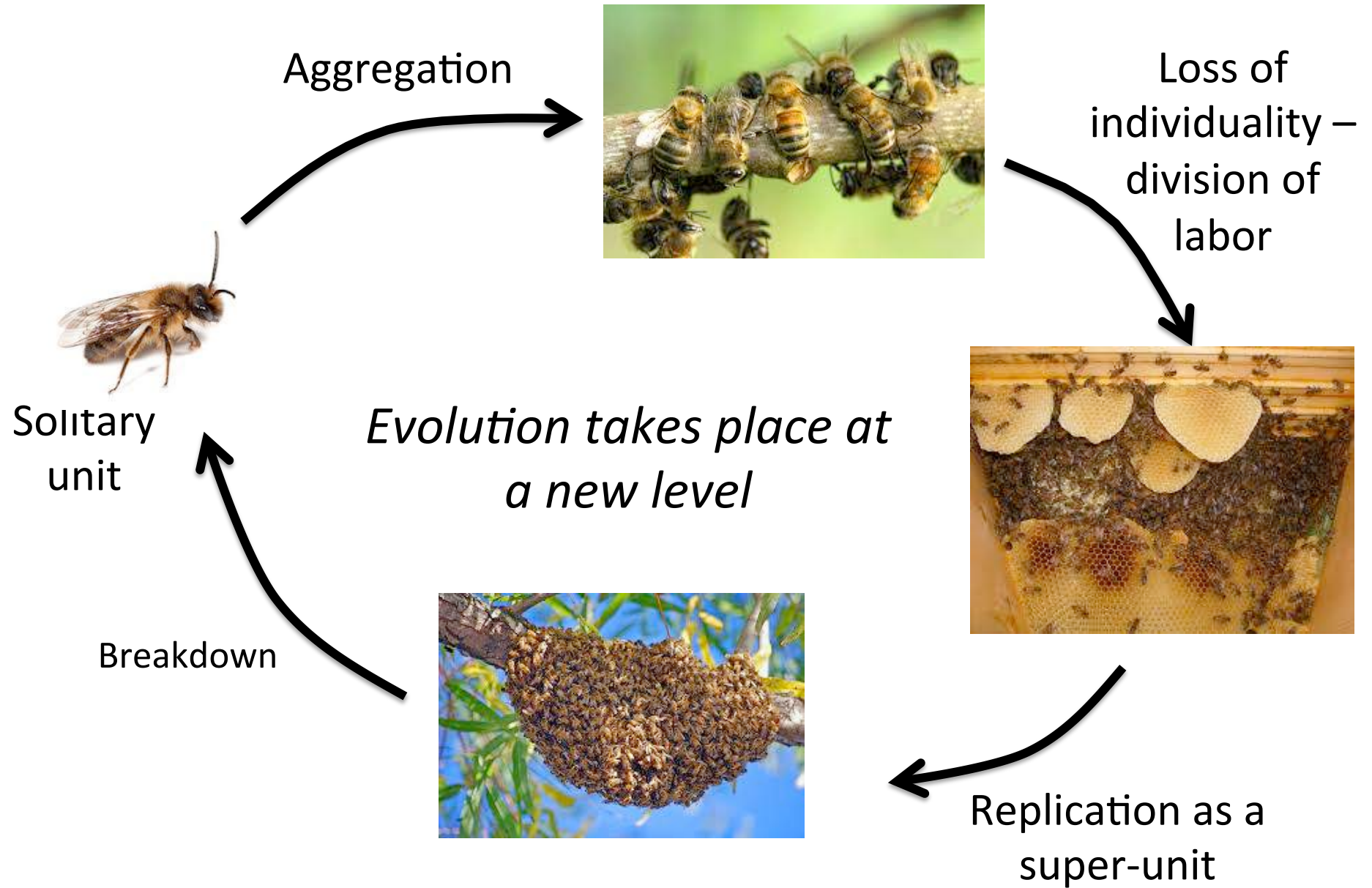
Beuls, K. (2014) Spirals in language evolution. *Proceedings of the Tenth International Conference on the Evolution of Language*, Vienna, 389-390.

3. Where do hierarchical structures come from?

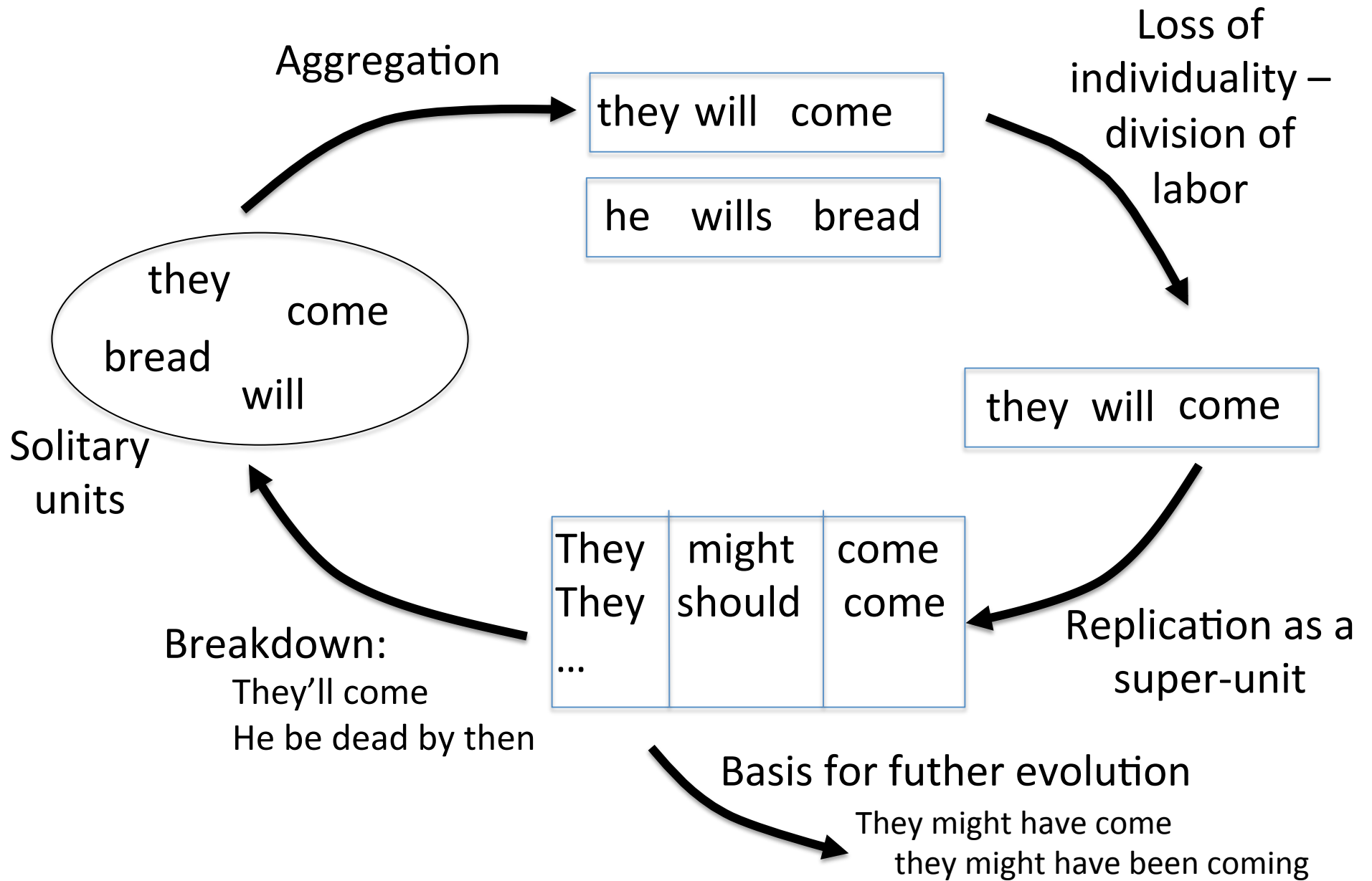
Level Formation

- Solitary units aggregate
- Loss of individuality and specialization of function
- Aggregates replicate as superunits.

Bourke, A. (2011) Principles of social evolution. Oxford: Oxford University Press.



Level formation

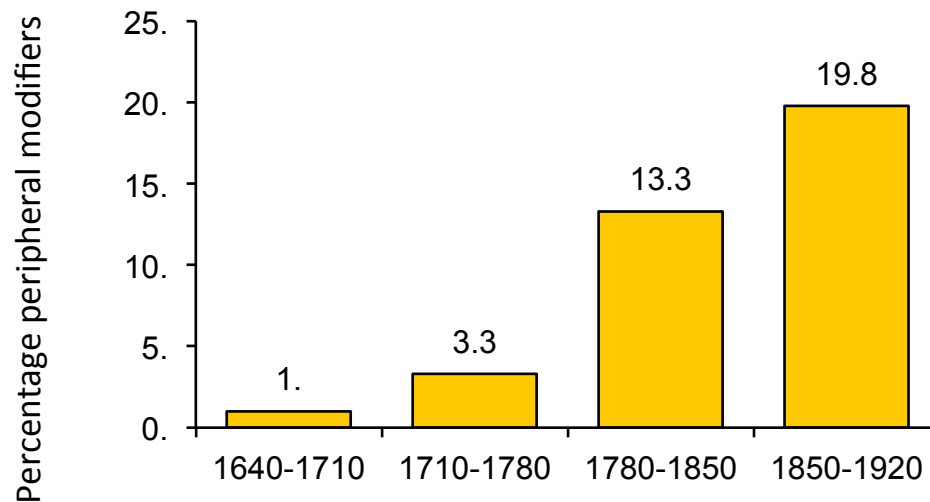


Level formation

Case study: growth of noun phrase

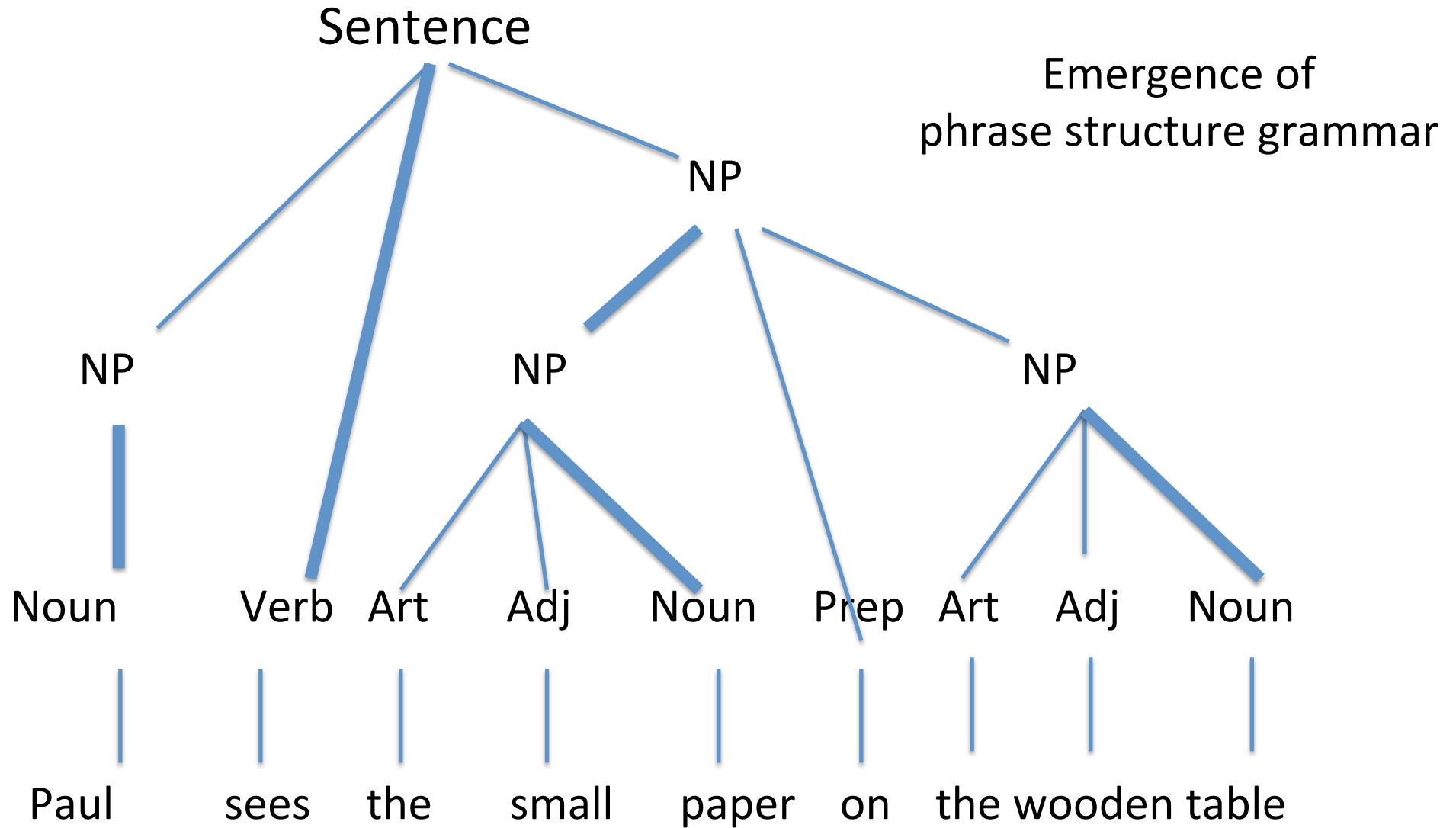
Period	Structure	New slot	example
PIE	N	Noun	<i>sheep</i>
PGm	[_{NP} A [N]]	Slot for adjectives	<i>black sheep</i>
OE	[_{NP} D [A [N]]]	Slot for determiners	<i>the black sheep</i>
MdE	[_{NP} M [D [A [N]]]]	Slot for peripheral modifiers	<i>only the black sheep</i>

ContEng “I mean the "What's the point of voting? What's the point of caring? What's the point of getting out of bed?" lot.” (Guardian 17feb2015)

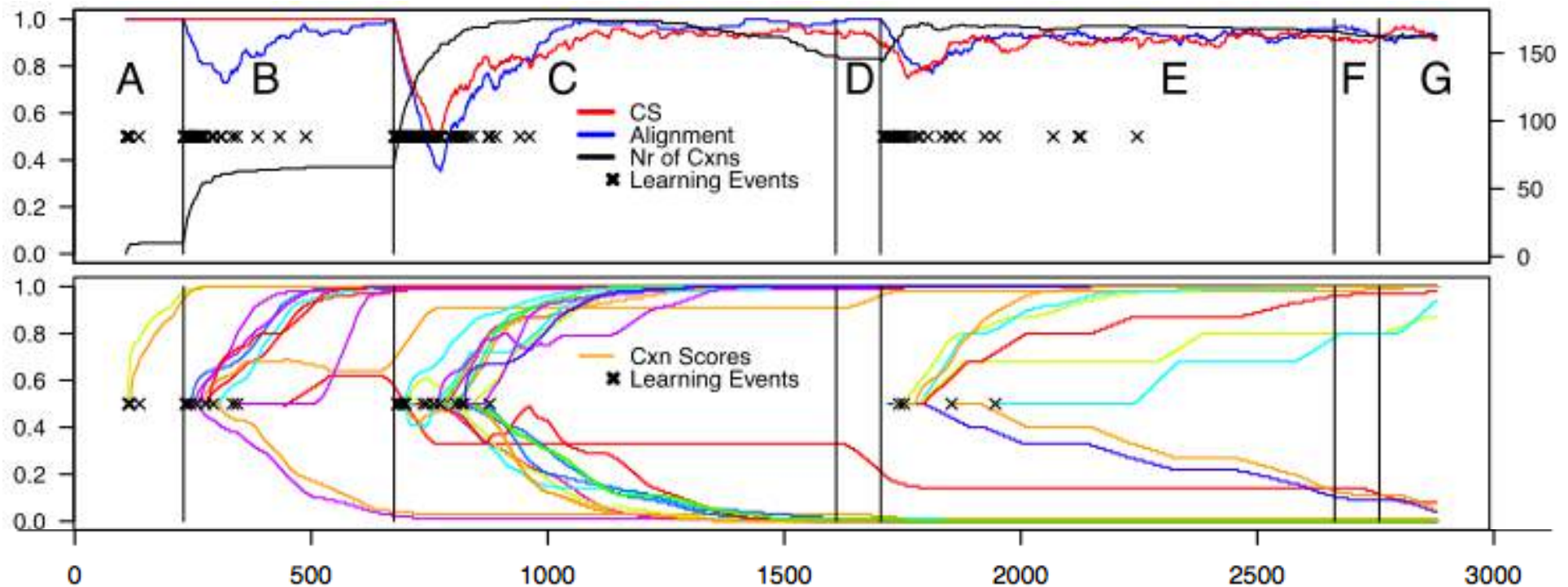


Elements ‘floating’ at the sentence level are progressively incorporated as part of the noun phrase.

Van de Velde, F. (2011). Left-peripheral expansion of the English NP. *English Language and Linguistics* 15: 387-415.



Steels, L. and E. Garcia-Casademont (2015) How to play the Syntax Game. In: Andrews, P. et al. (2015) Proceedings of the European Conference on Artificial Life 2015. The MIT Press, Cambridge Ma. pp. 479-486.



A: single words, unary predicates - e.g. 'block', 'ball'

B: two words, unary predicates – e.g. 'red block'

C: three words, one binary relation – e.g. 'block in box'

D: four words, one binary relation – e.g. 'red block in box'

E: five words, two binary relations- e.g. 'Hassan wants (that) Michael eats cheese'

F: six words, two binary relations – e.g. 'Jane suggests (that) Michael asks (that) Pia goes for a walk'

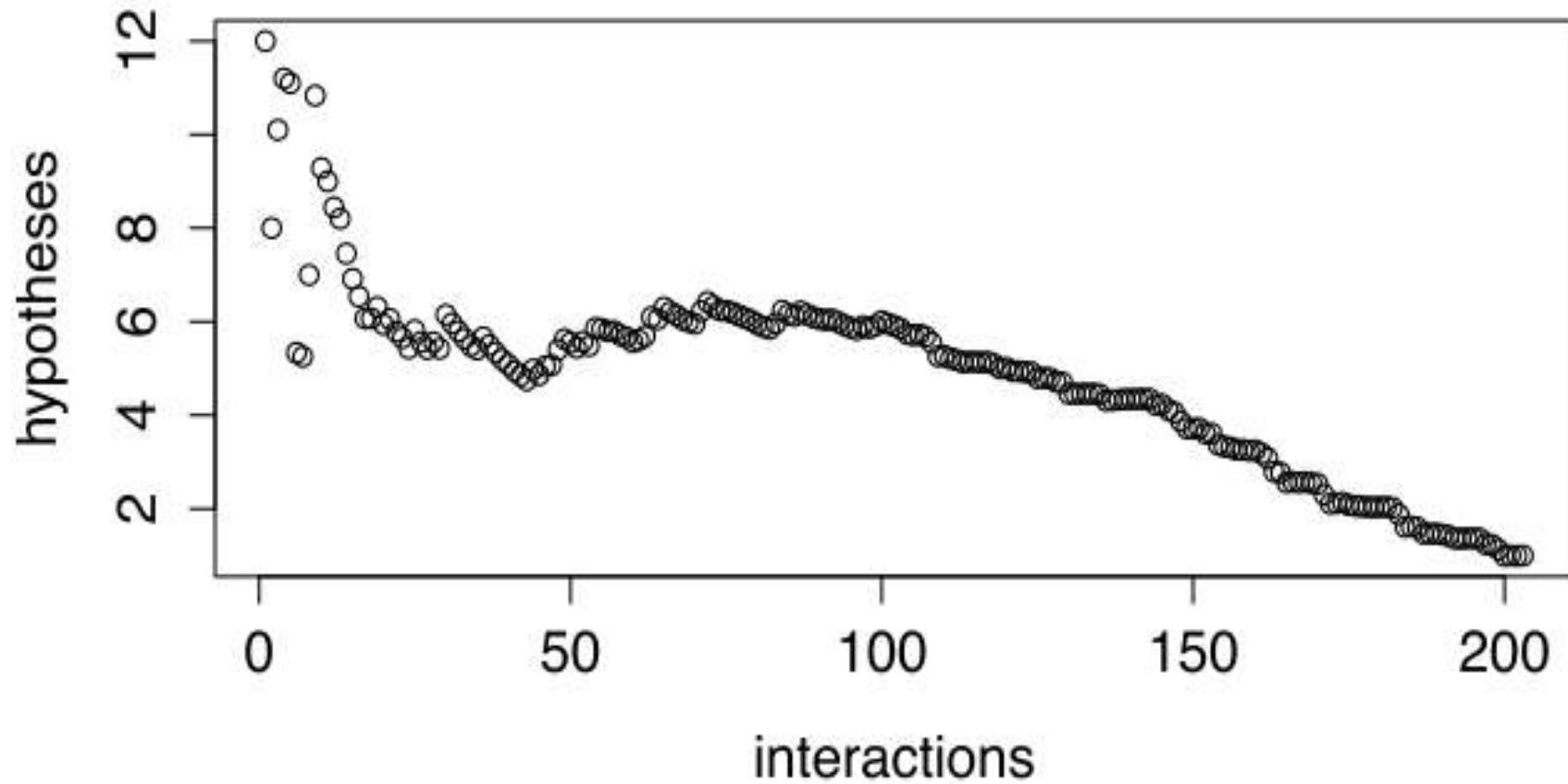
- 'the box on the table in the kitchen of Villa Jaffé'

G: seven words, three binary relations

(Recursive) hierarchy formation

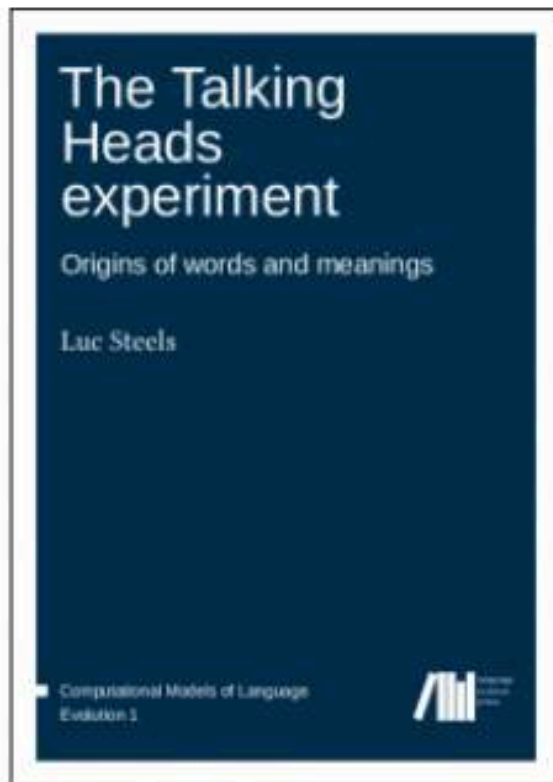
Steels, L. and E. Garcia-Casademont (2015) How to play the Syntax Game. In: Andrews, P. et al. (2015) Proceedings of the European Conference on Artificial Life 2015. The MIT Press, Cambridge Ma. pp. 479-486.

Reduction of cognitive effort



Focus on four puzzles

1. How do speakers reach and maintain global coherence?
 - Self-organization
2. How can language be so adapted to human embodiment, ecological needs, human cognitive capacities?
 - Selectionism
3. Where do linguistic innovations come from?
 - Emergent functionality
4. How do hierarchical structures emerge?
 - Level formation



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The Talking Heads experiment: Origins of words and meanings

Luc L Steels (Author)

SYNOPSIS

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The Talking Heads Experiment, conducted in the years 1999-2001, was the first large-scale experiment in which open populations of situated embodied agents created for the first time ever a new shared vocabulary by playing language games about real world scenes in front of them. The agents could teleport to different physical sites in the world through the Internet. Sites, in Antwerp, Brussels, Paris, Tokyo, London, Cambridge and several other locations were linked into the network. Humans could interact with the robotic agents either on site or remotely through the Internet and thus influence the evolving ontologies and languages of the artificial agents.

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