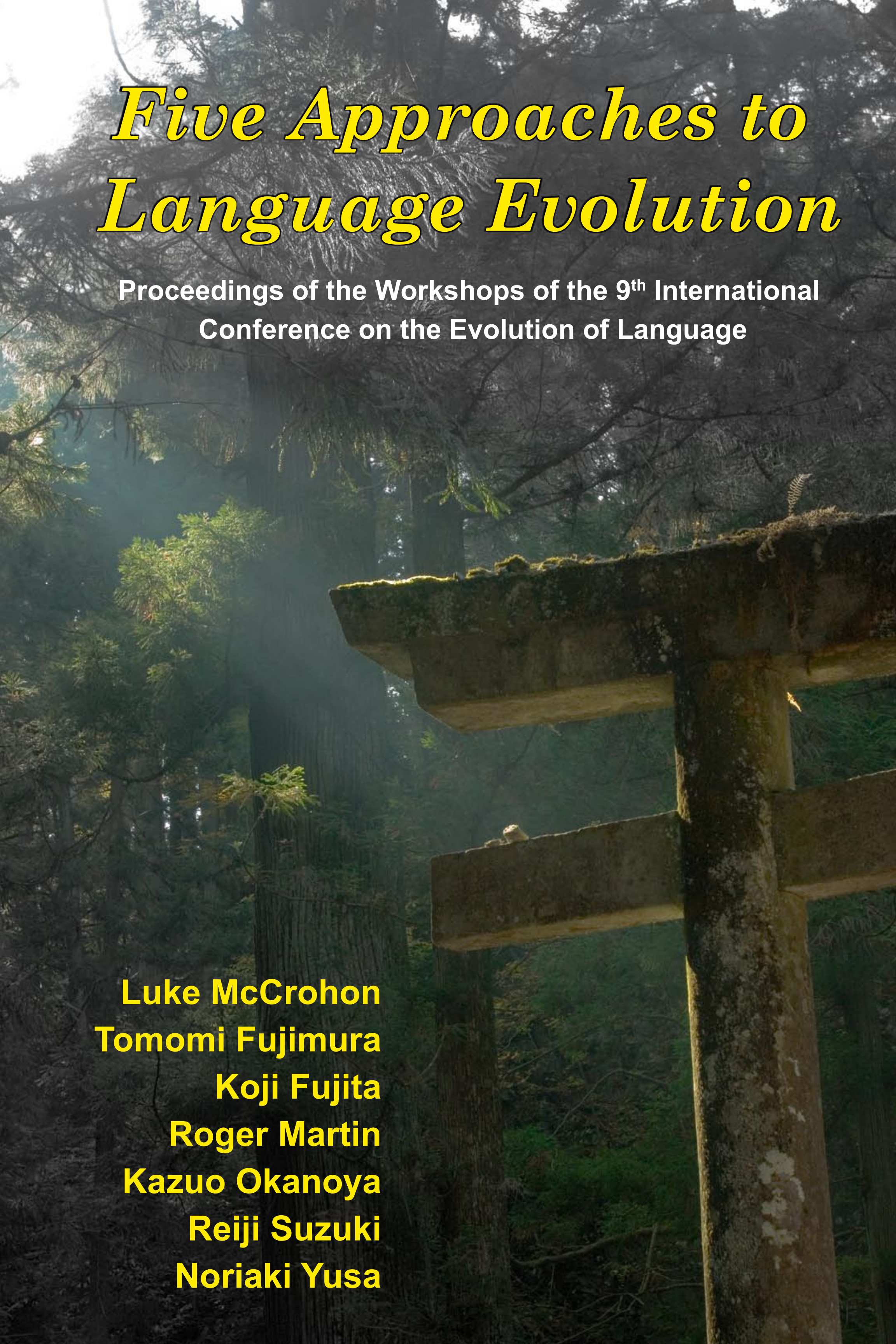

Five Approaches to Language Evolution

Proceedings of the Workshops of the 9th International Conference on the Evolution of Language

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Proceedings of the Workshops of the 9th International Conference on the Evolution of Language (Evolang*IX*)

13 March 2012, Kyoto, Japan

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Preface

The 9th International Conference on the Evolution of Language was held in Kyoto, Japan, between the 13th and 16th of March 2012. The first day of the conference consisted of five independent workshops, each focusing on a different approach to the study of language evolution. This volume collects together the abstracts of papers presented at those workshops.

The preparation of this volume was financially supported by the *JST-ERATO Okanoya Emotional Information Project* and indirectly through the contributions of other Evolang sponsors. In addition to these organizations, thanks are due to the following individuals for their assistance:

- **Workshop Organizers:** Johan Bolhuis (Utrecht University), Tomomi Fujimura (ERATO, JST), Koji Fujita (Kyoto University), Takashi Hashimoto (JAIST), Roger Martin (Yokohama National University), Kazuo Okanoya (University of Tokyo), Hajime Ono (Kinki University), Reiji Suzuki (Nagoya University) and Noriaki Yusa (Miyagi Gakuin Women's University)

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- And most importantly, thanks are due to the authors whose papers are collected here.

Contents

Workshop 1

Theoretical Linguistics/ Biolinguistics

Organized by:

Roger Martin (Yokohama National University)

&

Koji Fujita (Kyoto University)

Lecture Room 1, 5th floor, Campus Plaza, Kyoto, Japan

13th of March, 2012 9.15 – 15.45

Workshop Description

Biolinguistics is a highly interdisciplinary study (including, at least, linguistics, biology, neuroscience, psychology, computer science, mathematics, and physics) that focuses on the biological and evolutionary aspects of language. At the center of this research stage have been the two so-called logical problems: of language acquisition, often referred to as Plato's problem (how could something like knowledge of language emerge in the mind of an individual, during early stages of childhood, and given what little relevant experience the child is exposed to?) and of language evolution, or what some might like to call Darwin's problem (namely, how could an object such as the human language faculty have evolved?). These issues of course line themselves up with a wide range of additional biolinguistic questions, concerning where and how language is represented in the brain, how language interacts with other human mental faculties, components of the mind/brain, and so on.

Needless to say, to address any of these concerns presupposes some understanding of what sort of natural object language is. That is, we need some theory of language - and for this obvious reason theoretical linguistics has always gone hand in hand with biolinguistic pursuits, often playing a guiding role. Recent developments in theoretical linguistics, particularly within the minimalist program (Chomsky 1995, et. seq.) with its focus on so-called third factors, have served to (re)fuel the biolinguistic enterprise, and have led to a wide range of new perspectives on the design of the human language faculty and its evolution.

The purpose of this workshop is to bring together researchers working on the sorts of general concerns briefly described. The six invited speakers (there will be a total of five talks including one joint presentation) are leading scholars of theoretical linguistics whose work is highly related to the biolinguistic enterprise. Topics addressed include, very generally, the form of language, problems of language acquisition, the nature of parameters, the interplay of linguistic theories and evolutionary theories, the relation between the language faculty and other human cognitive faculties, and so on. Some talks will deal more directly with biolinguistic issues, whereas others will focus more on the form/properties of language itself, laying some of the groundwork for studies of the former type. One of our main goals with this workshop is for it to serve as a meeting ground for scholars pursuing what is ultimately a biolinguistic approach to the study of language, although perhaps from different perspectives. All speakers were asked to submit abstracts of their talks, either short (up to 2 pages) or long (up to 10 pages), which are included in the following section.

Acknowledgements

This workshop is supported by the following JSPS Grants-in-Aid for Scientific Research: #23520458 [PI: Roger Martin] and #23242025 [PI: Koji Fujita].

Workshop Timetable

9.15 – 9.30	Opening Remarks *Koji Fujita (Kyoto University)*
9.30 – 10.00	Invited talk: Subject-auxiliary inversion in child English revisited *Koji Sugisaki (Mie University)*
10.00 – 10.50	Invited talk: Structuring the parametric space without assuming an overspecified UG *Cedric Boeckx (ICREA/Universitat de Barcelona), Youngmi Jeong (Universitat Autònoma de Barcelona)*
	Coffee Break
11.10 – 12.00	Invited talk: The design features from which signs and recursion emerged in language *Denis Bouchard (Université du Québec à Montréal)*
12.00 – 13.30	Lunch Break
13.30 – 14.20	Invited talk: Copies as inert elements *Ángel Gallego (Universitat Autònoma de Barcelona)*
	Coffee Break
14.40 – 15.30	Invited talk: Biolinguistics, minimalist grammars, and the emergence of complex numerals *Anna Maria Di Sciullo (Université du Québec à Montréal)*
15.30 – 15.45	Closing Remarks *Roger Martin (Yokohama National University)*

SUBJECT-AUXILIARY INVERSION IN CHILD ENGLISH REVISITED

KOJI SUGISAKI
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1. Introduction

Within the principles-and-parameters framework, investigations into children's acquisition of "subject-auxiliary inversion" phenomena in English (as in *Can smart eagles swim?*; Chomsky 1968) have played a prominent role in providing evidence that a biologically predetermined "Universal Grammar" constrains the course of acquisition from the earliest observable stages. For example, Crain & Nakayama (1987) demonstrated that the grammar of English-speaking preschool children is structure-dependent by showing experimentally that these children rely on structural closeness (rather than linear closeness) when locating the auxiliary that moves to the sentence-initial position.

Pursuing this line of acquisition research further, within the current Minimalist framework, this study investigates whether children acquiring English produce any incorrect *yes/no*-questions in which the most prominent element in the subject noun phrase undergoes inversion (as in (1b)). The results of this study show that children are adult-like from the very beginning in excluding sentences like (1b), which in turn suggests that the subject originates within a *v*P-internal position even in the grammar of very young children.

(1) a. Can smart eagles swim?
b. * Eagles smart can swim?

2. New Puzzle in the Subject-Aux Inversion and the Simplest Answer

Addressing the "subject-auxiliary inversion" in English within the Minimalist framework, Chomsky (2010a,b) argues that there is an issue which "we should be puzzled about but nobody has been puzzled about" in the formation of *yes/no*-questions: Why is the Tense element raised to the C(omplementizer) position (as in (1a)), not the nominal element in the subject noun phrase (as in (1b))? Given the structure shown in (2a), this question can be reformulated as follows: Why is the T element *can* regarded as structurally closer to the C position than the nominal element *eagles* contained in the specifier position of T?

(2) a. [C [$_{DP}$ smart eagles] [$_{T'}$ can$_{T}$ swim]]
    b. [C [$_{TP}$ can$_{T}$ [$_{vP}$ [$_{DP}$ smart eagles] swim]]

Chomsky (2010a,b) proposes arguably the simplest answer: The subject noun phrase is not there when the relation between C and T is established. This analysis builds on the so-called predicate-internal subject hypothesis (e.g. Kitagawa 1986, Kuroda 1988, Koopman & Sportiche 1991), in which the subject originates inside the verb phrase (as in (2b)) and subsequently moves to the specifier position of T. Thus, according to Chomsky (2010a,b), the ungrammaticality of (1b) constitutes a strong argument for the assumption that thematic subjects are base-generated within the verb phrase (see also Kitahara 2011).

3. Transcript Analysis

In order to determine whether English-learning children produce incorrect *yes/no*-questions of the sort illustrated in (1b), I examined longitudinal corpora for English from the CHILDES database (MacWhinney 2000). The spontaneous speech data from three children (Adam Eve, and Sarah; Brown 1973) have been analyzed so far, which provided a total sample of more than 94,000 lines of child speech. The CLAN program KWAL was used to identify all the potential questions (the sentences that end with "?"), which were then searched by hand and checked against the original transcripts to locate the errors that correspond to the example in (1b).

The results are summarized in Table 1. Even though children produced both (i) inverted *yes/no*-questions with a "simple" subject (the subject which consists of a single word, like "Can I eat an apple?"), and (ii) inverted *yes/no*-questions with a "complex" subject (a subject which consists of more than a single word, like "Can this pig eat an apple?"), no question with an incorrect inversion was found in which a part of the "complex" subject noun phrase was moved. Furthermore, an account in terms of the frequency of questions as in (1a) in the adult input turned out to be quite difficult to maintain, because almost all the *yes/no*-questions produced by adults were those with a "simple" subject, and hence are superficially consistent with a rule like "Move the second element of the sentence to the front", which would yield questions as in (1b). Thus, if Chomsky's (2010a,b) analysis is on the right track, these results suggest that the original position of the subject is within the verb phrase even in children's grammar, and that children's *yes/no*-questions are formed through the interaction between the simplest Merge and the structural closeness (which should result from the third-factor principle of computational efficiency).

Table 1: The Number of Children's *Yes/No*-questions

Child	Correct questions with a "simple" subject	Correct questions with a "complex" subject	Incorrect questions with a "complex" subject
Adam (2;03 - 4;10)	1345	50	0
Eve (1;06 - 2;03)	34	0	0
Sarah (2;03 - 5;01)	570	17	0

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STRUCTURING THE PARAMETRIC SPACE WITHOUT ASSUMING AN OVERSPECIFIED UG

CEDRIC BOECKX & YOUNGMI JEONG
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The notion of 'parameter' (in the classical sense) goes hand in hand with the vision of an overspecified Universal Grammar that has dominated the field of generative grammar since its inception.

The recent minimalist, and more broadly biolinguistic, attempt to reconstruct linguistic theory around a much reduced, highly underspecified core seems to us to demand that parameters be abandoned.

Once this is done, though, certain properties of parametric systems must be recaptured in another fashion. The present talk seeks to open up several avenues of inquiry to do precisely this. In so doing, our attempt aligns itself with recent calls in favor of a more developmental/emergentist approach to language acquisition, and marks a certain return to the Constructivist view advocated by Piaget.

We structure our attempt around the following aspects:

(i) attention to Plato's problem (the logical problem of language acquisition) should not be confused with what a concern for typology.

(ii) local, micro-parameters are notational variants of finite-state morpho-phonological rules.

(iii) macro-parametric effects can be recaptured by resorting to learning biases.

If correct, our approach suggests that much of the concern about variation found in the generative literature has been misguided as soon as it moved away from learnability considerations and focused on typological generalizations. The latter, we think, is not a concern of biolinguistics proper, but rather reflects the continued influence of philology in theoretical linguistics.

THE DESIGN FEATURES FROM WHICH SIGNS AND RECURSION EMERGED IN LANGUAGE

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Language is a uniquely human cognitive faculty: no other animal has this capacity to productively create signs that link a form and a meaning, and to combine these signs into sentences. This cognitive capacity is due to some set of properties in the human brain. The question therefore arises how the human brain got that capacity, how it evolved.

The evolutionary scenario must address the question of design: it must provide a plausible account of how and why language evolved with the properties that we observe rather than some other set. One's theory of the origins of language is therefore intimately linked with one's particular theory of language: the evolutionary scenario depends on what the properties of language are according to that linguistic theory.

Conversely, language as presented by the linguistic theory must have a high degree of evolvability: it must be highly plausible according to the known laws and principles of biological evolution that the traits that the linguistic theory attributes to the human brain are evolvable. The richer the set of language-specific brain features, the harder it will be to account for its evolution. We are looking for a small change that made a big difference in its interaction with a complex set of pre-existing traits, while remaining careful not to postulate a magic bullet that somehow generated the desired phenotype. The question of the origin of language is difficult to answer since language is involved in a complex way in all human activities. Yet it can be answered if we concentrate on the design properties of the linguistic sign and how they relate to recently discovered properties that are unique to the human brain.

There are numerous structural properties that have been attributed to language. Many have been proposed recently, and some are not widely accepted because they depend on narrow theoretical assumptions. It would be a formidable task to look at hundreds of properties in exploring the origin of language. Instead, I will investigate two properties of language from which many others derive and for which there is a very broad consensus among scholars: Saussurean signs and type-recursion. If we can explain why language evolved with these two basic properties, we will be heading in the right direction.

The crucial questions are as follows:

(1) How did elements from domains of such different natures—concepts and perceptual forms—come to meet in the brains of humans to form linguistic signs?
(2) Why can't these elements meet in this way in the brains of other animals?
(3) What are the biological foundations of these signs?
(4) How and why did language evolve with type-recursion?

The human brain underwent minute neurological changes that enabled a new “representational” capacity in some human neuronal systems, resulting in a cascade of new functional capabilities, one of which is the human capacity for language. These Offline Brain Systems emerged due to an increase in synaptic interactions that was triggered by several compounding factors. These uniquely human systems of neurons have the capacity to operate offline for input as well as output: they can be triggered not only by external events stimulating our perceptual systems but also by brain-internal events; they can also be activated while inhibiting output to any external (motoric) system. These Offline Brain Systems are not specifically designed for language but they provide the crucial property that made it possible for further innovations to occur that led to language: they coincidentally allowed mental states corresponding to elements of the perceptual substance and elements of the conceptual substance to link in our brains to form Saussurean signs. The conceptual and perceptual substances of signs allow for the creation of an infinite number of signs, but this process faces material constraints. These constraints canalize the system toward particular clusterings of elements in phonology, semantics, the lexicon, and syntax. Moreover, the cognitive property of perceptual segmentation of the physical reality inherently contains combinatorial processes. I therefore hypothesize that the sign is the key innovation for language, and that linguistic combinatorial operations are exapted from the primitive combinatorial elements present in the substances of signs. Type-recursion turns out to be a side effect of these design properties of the canalizing materials, and the endocentricity it depends on results from a deep cognitive process of object identification and property attribution.

COPIES AS INERT ELEMENTS

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The notion of *chain* has played a central role in contemporary syntactic theory (cf. Chomsky 1995, Lasnik & Saito 1992, Rizzi 1986, and references therein). Although much research has been devoted to its study in recent years (cf. Abels 2003, Boeckx 2003, 2008, Hornstein 2001, Nunes 2004, Martin & Uriagereka 2008, Rizzi 2006), it is fair to say that different aspects remain to be understood from a minimalist point of view. Largely, these aspects concern *non-trivial chains* (chains formed by more than one occurrence of the same lexical token). In a Merge-based system, a non-trivial chain is obtained through Internal Merge of a syntactic object (say, α) to the edge of a given domain (say, Σ). This can be seen in (1), where the lower occurrence of α is between angle brackets (we omit intermediate occurrences for ease of representation):

(1) $\Sigma = \{\alpha, \{ \ldots <\alpha>\}\}$

As is well-known, there are certain intriguing asymmetries between the copies α and $<\alpha>$. Most significantly, all lower (and intermediate) copies seem to be ignored for computational purposes—although they can feed both the PF and LF components (for reconstruction and pronunciation) (Chomsky 2000, 2001). Such 'inert' status of *lower copies* (LCs) can be seen in the following circumstances:

(2) a. LCs fail to create intervention effects (i.e., they are invisible to Agree)
b. LCs cannot be moved (i.e., they are invisible to Merge)
c. LCs cannot label (i.e., they are invisible to the labeling algorithm)

We would like to relate these properties to the approach to chains hinted at in Chomsky (2000, 2001), whose origins go back to Chomsky's (1955[1975]) reliance on Quine's (1965) approach to chains. Chomsky (2000) defines occurrences in contextual terms: An occurrence (OCC) of α is the sister of the raised element (plus the projection, in an X-bar-theoretic sense). From this perspective, the chain that the DP *Mourinho* gives rise to in an example like (3), though informally described as in (4a) (with two occurrences occupying SPEC-T and SPEC-v* respectively), should be regarded as in (4b):

(3) Mourinho likes the Premier League

(4) a. {Mourinho, Mourinho} b. {T, v*}

The idea that (4b) tries to capture is that an occurrence of an element is a set formed by the element itself and its complement (the complement being a set that contains other objects). It must be noticed that this system automatically yields an asymmetry between a high copy and all lower ones—the latter are contained in the former. We submit that this can account for the invisible status of LCs and, at the same time, provide us with a better understanding of different narrow syntactic phenomena (agreement, intervention effects, labeling, etc.) and interface effects (types of interpretations, the A/A-bar distinction, linearization, etc.). This talk develops (actually, revamps) this conception of chains in order to address the observations listed in (2).

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BIOLINGUISTICS, MINIMALIST GRAMMARS, AND THE EMERGENCE OF COMPLEX NUMERALS

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The ability to develop complex numerals is human-specific. Thinking beyond experience is a by-product of a uniquely human, non-adaptive, cognitive capacity. Comparative studies of mathematical capabilities in nonhuman animals indicate that many animals can handle numbers up to 6-7 (perhaps directly, or perhaps via subitizing), but they cannot deal with greater numbers. Investigating the properties of complex numerals from a biolinguistic perspective may offer new insights on the specificity of human language, on the emergence of complex numerals, as well as on the connection between language and mathematics. By doing so, we aim to contribute to the Biolinguistics program. On more specific grounds, we aim to formulate a Biolinguistic model of language where the notions of (a)symmetry and symmetry-breaking are pivotal (Di Sciullo & al. 2010).

In this perspective, we explore the properties of complex numerals and consider the relation between language and arithmetic from a biolinguistic perspective (Hauser, Chomsky & Fitch 2002, Chomsky 2001, 2005, 2011, Larson & al. 2010, Di Sciullo & Boeckx 2011, a.o.). We raise the following questions: What is the computational procedure that derives complex numerals? How is this procedure biologically implemented? Given minimalist assumptions, we take the computational procedure of the language faculty to be the conjunction of a composition operation and a recursive procedure. The biological implementation of this computational procedure is the activation of specific neuronal networks.

First, we consider recursion in complex numerals. We point out to the fact that unbounded infinity of number-names is attested in at least one language. We further show that indirect recursion is part of the computational procedure deriving complex numerals, as it is more generally in the language faculty in the narrow sense (FLN, Chomsky 2004, 2011; Hauser, Chomsky & Fitch 2002). Second, we posit that complex numerals are derived by Merge, the dyadic operator of FLN. We provide a minimalist derivation for these expressions and contrast it with non-minimalist derivations. Third, we discuss recent brain imaging results on the processing of sentences and mathematical expressions and raise the question of how complex numerals are processed by the brain. We hypothesize that arithmetic is grounded in FLN, but goes beyond it.

1. Recursion

We consider recursion in complex numerals in English, e.g., *twenty one, one hundred and one, one thousand one hundred and twenty one*, … as well as in the Romance languages *vingt et un* (Fr), *venti e um* (Port), *douăzeci şi unu* (Ro) (twenty and one), *treinta y siete* (Sp) (thirty and seven) *cento e uno* (It) (one hundred and one) and provide evidence that complex numerals exhibit indirect recursion on the basis of the occurrence of functional elements, coordinating conjunctions, that may be pronounced in some cases or remain silent.

Conjunctions are assumed to be asymmetric structures (Kayne 1994), under an X-bar analysis (Kayne 1994; Munn 1987; Johannessen 1998) and under an adjunction analysis (Munn 1993). According to the adjunction approach, XP is a projection of the first conjunct XP and XP dominates XP. Adopting the adjunction analysis for coordination, we analyze complex numerals as adjunction structures contra Ionin & Matushansky (2006), where complex numerals are also head-complement structures in some cases.

XP	XP	NumP
/ \	/ \	/ \
YP X’	XP_1 ConjJP	Num_1 FP
/ \	/ \	/ \
X ZP	Conj XP_2	F Num_2

Recursion is a property of the operations of FLN (Hauser, Chomsky & Fitch 2002) that gives rise to the discrete infinity of linguistic expressions. Chinese complex numerals provide empirical evidence of unbounded recursion; complex numerals in English and in the Romance languages provide evidence of indirect recursion. We conclude that the recursive procedure operative in the derivation of complex numerals shares properties with the recursive procedure of FLN.

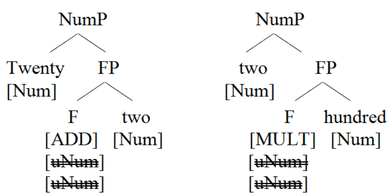
It has been argued that numerals do not present the same recursive properties as language, and that English number-names are finite (Merrifield 1968, Greenberg 1978, a.o.). However, there is at least one human language where number names show unbounded recursion (e.g. *wu zhao zhao wu zhao* (five trillion trillion five trillion), *wu zhao zhao zhao zhao wu zhao zhao* (Ch) (five trillion trillion trillion trillion five trillion trillion, …) (Brainerd 1971, Radzinski 1991). This provides empirical evidence for the discrete infinity of number-names, hypothesized for very large numbers in English (e.g. *million* : *thousand thousand,* (Amer.), *billion* : *thousand thousand thousand,* (Amer.), (Zwicky 1963). It has been shown that TAG or MCTAG could not derive

Chinese number-names (Radzinski 1991). This fact, along with the constraint on the order of the terms in complex numerals, as well as legibility phenomena discussed in section 3, could be attributed to language-mathematic interface properties.

2. Merge

Chomsky's (1988) discussion of counting as an abstraction of the Faculty of Language offers two reasons for which it should be the case, i) the development of the mathematical ability in different people, and ii) the improbability of a system exhibiting discrete infinity. Merge is crucial for counting as well as for thinking about the unobservable. Assuming the simplest possible lexicon, with only one LI 'one', the successor function can be derived by recursive applications of External Merge (Chomsky 2008) selecting 'one' from the lexicon, or by Internal Merge, if a single term numeration would permit only one selection (Bolender 2011).

We argue that Merge (External and Internal) is also uniquely human because the computational procedure is based on feature asymmetry. This property of Merge has not been found in the form on non-human expressions to our knowledge (Di Sciullo 2005, Di Sciullo & Isac, 2008). We show that Asymmetric Merge derives complex numerals. Numerals (NUM) are related by functional projections F with valued features (ADD, MULT) and unvalued features (uNUM).



The uninterpretable features are eliminated, and the interpretable features are legible by the neuronal system that processes arithmetic expressions, even when the valued features are not pronounced. MULT is never pronounced e.g., *three hundred, trecento* (*It.)* 'three hundred', quatre mille (Fr.) 'four thousand', while ADD is pronounced by *and* /*e* (It) /*et* (Fr.) in restricted contexts, e.g., *one hundred and one*, *cento e uno* (It.), *vingt et un* (Fr.) 'twenty one'.

Complex numerals are derived by asymmetric merge. (Un)pronounced functional heads merge within numerals in the derivation of complex numerals, which then presents a particular case of indirect recursion. Indirect recursion introduces configurational asymmetry in a set of otherwise unstructured numeric terms.

3. Brain, language and mathematics

Brain-imaging results reported in Friedrich & Friederici (2009) and Friederici & al. (2011) indicate that the brain interprets mathematic and syntactic expressions differently, as evidenced by differences in the strength of fronto-parietal activations. These imaging results bring support to our claim that complex numerals and syntactic expressions are derived by Merge and the recursive procedure of FLN, while their interpretation differs. This difference might be due to the way in which the neuronal network is activated.

We show that the interpretation of the (un)pronounced heads in complex numerals differs from their interpretation in phrasal syntax. First, numeral ADD conjunctions are distinct from phrasal AND conjunctions, notwithstanding the fact that their functional heads can be pronounced by *and/e/et*. Second, some phrasal AND conjunctions are symmetrical, numeral ADD conjunctions are asymmetrical only. Third, phrasal AND conjunctions cannot be interpreted as the sum of their parts, numeral ADD conjunctions must be. Fourth, phrasal conjunctions with an unpronounced head cannot be interpreted as the product of their parts; whereas this is the case for complex numerals with an unpronounced MULT head, e.g., *les nombres deux, cent et mille* (Fr.) 'the numbers two, one hundred, and one thousand' (2, 100, 1,000), vs. *deux cent mille* (Fr.) 'two hundred thousand' ((2 x 100) x 1,000).

These facts indicate that complex numerals interface with the neuronal network sub-serving mathematics. It supports the view that complex numerals emerged with Merge and the recursive procedure of FLN, while their locus of interpretation is the interface with the neuronal network sub-serving mathematics.

Acknowledgements

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Workshop 2

Language and the Brain

Organized by:

Noriaki Yusa (Miyagi Gakuin Women's University)
&
Hajime Ono (Kinki University)

Lecture Room 2, 4th floor, Campus Plaza, Kyoto, Japan
13th of March, 2012 9.15 – 15.40

Workshop Description

Language makes us what we are. In this respect, the first decade of the 21st century saw an exponential increase in empirical and theoretical studies that are leading to a watershed in our understanding of the differences between human and non-human communication systems. This workshop is intended as an interdisciplinary platform for discussing the recent results that research into the brain and language have provided, bringing together linguists, neuroscientists, philosophers, cognitive scientists, as well as other researchers interested in the neurobiology of language. Given the fact that the evolution of language remains shrouded in mystery, the question of how languages are encoded or processed in the brain will be raised as a central topic. The scope of the workshop includes, but is not limited to, the following areas: aphasics, imaging language in the brain, language acquisition and development, language disorder, language processing, language and cognition, mirror neurons, social cognition. Brain scientists, psychologists, linguists, neuroscientists, computer scientists, philosophers, and other researchers interested in interdisciplinary research on neurobiological mechanisms underlying human language are invited to participate in the workshop.

Acknowledgements

This workshop has been supported by JSPS Grants-in-Aid for Scientific Research #21320078 [PI: Noriaki Yusa] and #23242025 [PI:Koji Fujita].

Workshop Timetable

9.15 – 9.20	Welcome *Noriaki Yusa (Miyagi Gakuin Women's University)*
	Chair: *Hajime Ono (Kinki University)*
9.20 – 9.50	A Cohort Study on Child Language Acquisition and Brain Development *Hiroko Hagiwara (Tokyo Metropolitan University)*
9.50 – 10.20	Structure Dependence in the Brain *Noriaki Yusa (Miyagi Gakuin Women's University)*
	Coffee Break
	Chair: *Noriaki Yusa (Miyagi Gakuin Women's University)*
10.30 – 11.30	Invited talk: Imaging Syntax and Semantics in the Brain *Stefano F. Cappa (Vita-Salute University and San Raffaele Scientific Institute)*
11.30 – 12.50	Lunch Break
	Chair: *Hisao Tokizaki (Sapporo University)*
12.50 – 13.20	Recursion in Intra-Morphemic Phonology *Kuniya Nasukawa (Tohoku Gakuin University)*
13.20 – 13.50	Implications of Tonogenesis on Tone Processing *Suki Suet Yee Yiu (University of Hong Kong)*
	Chair: *Hirohisa Kiguchi (Miyagi Gakuin Women's University)*
13.50 – 14.20	Against Protolanguage *Ermenegildo Bidese (University of Trento), Andrea Padovan (University of Verona) and Alessandra Tomaselli (University of Verona)*
	Coffee Break
	Chair: *Toshio Inui (Kyoto University)*
14.35 – 15.35	Invited talk: Evolving the Direct Path in Praxis as a Bridge to Duality of Patterning in Language *Michael A. Arbib (University of Southern California)*
15.35 – 15.40	Concluding Remarks *Hajime Ono (Kinki University)*

A COHORT STUDY ON CHILD LANGUAGE ACQUISITION AND BRAIN DEVELOPMENT

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1. Language Acquisition and Brain development in Primary School Years

While first language (L1) is acquired without much effort and seems to develop as the brain matures, learning a second (L2) or foreign language (FL) is not always as easy as acquiring the L1. The neural mechanisms underlie L1 and L2/FL acquisition in primary school years are yet to know and the overall picture still remains as mystery. Therefore, we conducted a large-scale longitudinal study to see when and how these processes occur in the children's brain of 6 to 11 years of age.

2. Spoken-Word Processing in L1 and L2: an ERP Cohort Study

We first investigated how adult-level speed of spoken-word processing emerges during L1 acquisition. In a picture–word mismatch paradigm, we recorded event-related potential (ERP) responses to the words, focusing on the onsets of semantic congruency effects. One group of children (N =40) who had initially been around 7 years of age demonstrated a shortening of the response onset by about 70 milliseconds two years later (when they were around 9). Another group of children (N = 40) who had initially been around 9 did not show such changes two year later (when they were around 11). The responses of both groups of children at age 9 or older were equivalent to those of adults. These data challenge the previous hypothesis that word-processing is well established at age 7. Instead they support the view that the acceleration of spoken-word processing continues beyond age 7 (Ojima, et al., 2011a).

We also asked whether or not the process of FL learning is similar to that of L1 acquisition. ERP responses to FL words of 322 children with diverse FL proficiency were analyzed, in a picture-word mismatch paradigm. It was shown that as FL proficiency increased, various ERP components previously reported in L1 acquisition (such as a broad negativity, an N400, and a late positive component) appeared sequentially, critically in an identical order to L1 acquisition. Our data suggest strong biological constraints on language learning (Ojima, et al., 2011b).

3. Cortical Processing of Words in L1 and L2: a fNIRS study

Neural mechanisms of children's word repetition were investigated using functional near-infrared spectroscopy (fNIRS). Based on the analyses of 484 children, we found hemispheric asymmetry in that low frequency words elicited more right-hemispheric activation (BA40), while high frequency words elicited more left-hemispheric activation (BA39). Our results exemplify the strong involvement of a bilateral-language-network in children's brains at the early stages of language acquisition/learning. Left-hemispheric segmental and right-hemispheric supra-segmental information processing are presumed to be executed in parallel, and children might depend more on supra-segmental processing while acquiring unfamiliar words (Sugiura, et al., 2011).

Cortical representation of gender differences was also examined and it was found that boys made full use of the language network as language proficiency increased, whereas girls distinctively used the right frontal region tending to engage in supra-segmental processing irrespective of proficiency. Moreover, as L2 proficiency increases and/or acquisition of L2 words progresses, a right-to-left shift in laterality proceeds in the language-related cortical region for both genders. Our results suggest that boys and girls employ different strategies for language learning, and that language proficiency is achieved through common mechanism.

Acknowledgements

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STRUCTURE DEPENDENCE IN THE BRAIN

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1. Syntactic Hierarchical Structures in Human Language

Hierarchical structures are a crucial property of human language, creating a "watershed" between human and nonhuman communication systems (Anderson 2008; Moro 2011). It is claimed that human languages resort to structure-dependent rules that require an analysis of a sentence into an abstract hierarchical structure and operate on abstract grammatical constructs such as phrases or clauses, instead of structure-independent rules that just operate on the rigid-order of words (Chomsky 1980). The principle of structure dependence rules out impossible rules that are blind to hierarchical structures. Hierarchical structures are found in other modules than syntax and in non-linguistic domains (Tettamanti et al. 2009). Syntactic hierarchies are, however, of special interest in that they are generated by recursive Merge, manifesting endocentricity (headedness). I will first illustrate structure dependence in language acquisition and then review the results of Yusa et al. (2011), which show a crucial role of Broca's Area in processing syntactic hierarchical structures. I will further (rather boldly) suggest that domain-general Merge might be implemented in the pars opercularis (BA 44) of Broca's Area rather than the pars triangularis (BA 45). An amodal role for BA 44 might have implications for the function of BA 45 and the evolution of language (Yusa 2012).

2. Neural Correlates of the Acquisition of a New Syntactic Rule

Neural correlates of acquiring new second language knowledge were examined using functional magnetic resonance imaging (fMRI). Postpuberty Japanese participants learned a new English rule with simplex sentences during one-month of instruction, and then they were tested on "uninstructed complex sentences" as well as "instructed simplex sentences". The behavioral data show that they can acquire more knowledge than is instructed, suggesting the interweaving of nature (universal principles of grammar, UG) and nurture (instruction) in second language (L2) acquisition. The comparison in the "uninstructed complex sentences" between post-instruction and pre-instruction using fMRI reveals a significant activation in the pars triangularis of Broca's Area (Yusa et al. 2011). This study thus provides the first neuroimaging evidence to clearly demonstrate that L2 learners know more than they could have learned from the data they have encountered, suggesting that there is much more to L2 acquisition than merely learning what is instructed, and pointing to the interweaving of nature (UG) and nurture (instruction) in L2 acquisition. Our result fits well with recent imaging studies in that BA 45 subserves the acquisition of a real syntactic rule (Musso et al. 2003; Sakai et al. 2004; Tatsuno and Sakai. 2005), and that Broca's area (BA 44/45) supports hierarchical dependencies and long-distance dependencies (Tettamanti et al. 2003; Ben-Shachar et al. 2004; Friederici et al. 2006). On the basis of recent neuroimaging evidence on the neural correlates of syntactic processing, I will attempt to speculate the implications of our results for the evolution of language.

Structure dependence is an abstract principle without any overt realization in any language, making it difficult to receive enough information of structure dependence. It is possible for a person to go through life without encountering any relevant examples that would choose between the structure dependent rules and structure independent rules (Berwick et al. 2011). This fact makes it difficult to explain syntactic processing in terms of the mirror neuron system.

Acknowledgements

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IMAGING SYNTAX AND SEMANTICS IN THE BRAIN

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Functional imaging, in particular functional magnetic resonance, has been extensively applied in the last decades to the investigation of the neural substrates of language processing. In my talk I consider the study of semantic and syntactic processing in the human brain. The main emphasis is historical, with a special consideration of the mutual relationship between the traditional, lesion-based approach to the neurology of language and the contributions of the tremendous development of imaging techniques of the last decades.

1. Semantic processing

In psycholinguistics, word meaning is generally considered to be closely connected to conceptual representations. In his inaugural paper on the neurology of language, Wernicke felt the need to provide a theory of conceptual representations, which is in many ways similar to some contemporary models, assuming distributed representations in modality specific and heteromodal cortical areas. It is thus impossible to separate functional imaging studies of semantics from those investigating conceptual knowledge. Several reviews are available, providing an exhaustive coverage of what is now an impressive body of research (Binder, Desai, Graves, & Conant, 2009; Cappa, 2008). Overall, functional imaging has confirmed the concept that the neural system underlying semantic knowledge is distributed in the brain. Dynamic maps of conceptual and lexical-semantic representations appear to be modulated by at least three factors: modality of stimulus presentation (typically, words vs. pictures), category membership (for example, objects, actions, abstract concepts) and task requirements (naming, categorizing, monitoring, etc.).

2. Syntactic processing

While the assumption of a distributed semantic system was already present in the classical anatomo-clinical aphasia literature, the idea that syntax is localized in the brain, specifically in Broca's area, was a direct consequence of the relatively strong correlation between the clinical syndrome of agrammatism and damage to Broca's area (see Cappa, 2012 for a review). Many of the early imaging studies dealt with single word processing. At this level, the only insight into the possible correlates of syntactic processing could be derived from studies contrasting nouns and verbs (for a review, see Vigliocco, Vinson, Druks, Barber, & Cappa, 2011). The complex pattern of results of these studies indicates that, once we take into account the confounding in most studies between semantic distinctions (objects vs. actions) and grammatical distinction (nouns vs. verbs), and the conflation between studies concerned with mechanisms of single word processing and those studies concerned with sentence integration, clear neural separability is observed between the processing of object words (nouns) and action words (typically verbs), while grammatical class effects emerge only for tasks and languages imposing greater processing demands. Sentence level processing has also been extensively investigated. As in the case of semantic processing, there are multiple aspects related to task requirements, which should be taken into proper consideration when interpreting the results of imaging studies. A complementary, productive line of investigation is based on the study of the brain correlates of the acquisition rules in artificial grammars, and specifically on the contrast between grammars at different ranking of Chomsky's hierarchy (Chomsky, 1956). Some imaging studies investigated this subject extracting the rules of an artificial language (Tettamanti et al., 2002), or learning possible (hierarchical, non-rigid) or impossible (linear, rigid) rules of real languages they did not know (Musso et al., 2003). The comparison of the neuroanatomical correlates underlying the acquisition indicated that only hierarchical rules result in specific activation of Broca's area. The processing of hierarchical dependency rules was specifically associated with activation of Broca's area and neighboring ventral premotor cortex. This finding does not seem to be limited to the language domain. (Tettamanti et al., 2009) contrasted the acquisition by normal subjects of rigid (linear) and non-rigid (hierarchical) syntax in a visuo-spatial task consisting of linear sequences, confirming the crucial role of Broca's area.

Acknowledgements

Andrea Moro (IUSS, Pavia, Italy) and Gabriella Vigliocco (UCL, London, UK) have been crucial collaborators in most of the studies mentioned in my talk.

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RECURSION IN INTRA-MORPHEMIC PHONOLOGY

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Hauser, Chomsky & Fitch (2002) claim that the abstract linguistic computational system (FLN: the faculty of language in the narrow sense) solely comprises a recursion module that prescribes the nature of (morpho-)syntax. This places phonology within FLB (the faculty of languages in the broad sense) rather than FLN, since phonology is generally not thought to involve recursion (Neeleman & van de Koot 2006, Samuels 2009, Scheer 2010). What have been analysed as recursive procedures in phonology (Ladd 1986) are limited to higher prosodic levels such as prosodic phrases and intonational phrases, which are not strictly phonological as they are entirely dependent on syntactic computation. In the case of phonological structures within morphemes, recursion does not apply: e.g. one syllable is never embedded in another syllable (Pinker & Jakendoff 2005). It may be concluded, then, that phonology does not concatenate structural units. Rather, it merely interprets fully concatenated strings of morphemes/words.

Contrary to this view, and based on the working hypothesis called Structural Analogy, van der Hulst (2010) assumes that recursion exists at intra-morphemic levels of phonological organization such as syllable and foot in the framework of Dependency/Government Phonology. He interprets codas as ‘syllables within syllables’ and feet as ‘syllables containing syllables’. But although van der Hulst’s proposal is attractive on theoretical grounds, it lacks any pre-theoretical definition deduced from observed phenomena.

In the debate on the question of recursion in phonology, segmental structure is typically ignored, and instead, the focus is on higher levels such as syllable, foot, prosodic word, prosodic phrase and intonational phrase. This is presumably because segments, rather than features, are seen as central units for constructing phonological (higher) structures – features are considered irrelevant to recursion because they do not function as structural building blocks and their structural specifications are intrinsically determined within the segment. Yet this is at odds with arguments made in morpho-syntax, where morphemes/words (the minimal contrastive units therein) are treated as the basic units in phenomena that support the existence of recursive procedures. To bring phonology into line with morpho-syntax, features (minimal contrastive units in phonology) rather than prosodic constituents should be employed for discussing the issue of recursion.

Element Theory (Nasukawa & Backley 2008) employs a relatively small set of phonological features called elements (|U| |I| |A| |ʔ| |H| |N|). Unlike other types of features, elements (monovalent and independently interpretable) serve as the building blocks of melodic structure and can be freely concatenated to make melodic compounds. For example, the whole expression of a set which is made by concatenating |I| with |A| and is labeled as the |I| set is phonetically interpreted as mid front vowel *e* while the |A|-labeled set with the same elements is interpreted as *æ*. These sets can be dominated by another set of the same kind: the set in which |I|(|I||A|) is dominated by |I|(|I||A|) is interpreted as a long vowel *ee*. Phonetic manifestation of element compounds (phrases) is thus determined by the intrinsic nature of elements and their head-dependency relations (labeling).

In this paper, I extend this concatenation-based melodic construction to levels above the segment. This ultimately eliminates the need for constituents such as segment, onset, nucleus, rhyme, syllable, foot, all of which are generally assumed to be below intra-morphemic level. This leads to the proposal that elements, and not prosodic constituents, are the only variables of structural operations. This model reinterprets the notion of minimalism in phonology by opposing the string-based flat structure pursued by Scheer (2004), Neeleman & van de Koot (2006), Samuels (2009) and others.

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IMPLICATIONS OF TONOGENESIS ON TONE PROCESSING♠

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Tonogenesis and the processing of tone have each engrossed ample attention in literature with proposal of different models and analyses. This paper focuses on the replacement of voicing contrast with tone contrast by following the historical traces, and its relation to the processing of tones in neuroscience. The link between them suggests an intriguing change of hemispheric lateralization for tone and consonant processing in human brain through language evolution.

1. Tonogenesis and Processing of Tone

From the historical-linguistic perspective, it is common to have a tone contrast developed from a voicing contrast. For instance, the reconstructed Proto-Cham makes a distinction between voiced and voiceless stops in initial position whereas such voice contrast is neutralized as voiceless in E. Cham and replaced by a low and non-low tone contrast instead. More than mere difference in F_0, tone in E. Cham demonstrates contrastiveness in meaning, an important indicator for qualifying a language as tonal. Other languages such as Yabem, West Kammu and Utsat also developed low tones on vowels following voiced stops and non-low tones elsewhere like E. Cham. In addition to the preceding voiced consonant, the following voiced consonant in Vietnamese and Old Chinese is also found to induce a low tone. These developments suggest tone arises through exaggeration of a phonetic side effect of voicing in stops, or obstruents generally.

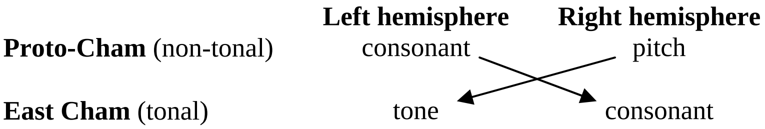
From the neuroscientific perspective, processing of tone and consonant are found to be specialized in the two hemispheres of human brain for efficient processing of diverse information with the complex neural structure. fMRI or

♠ This abstract is modified from a paper first submitted as part of the course requirement of LING6030 Language Evolution at HKU, and benefited from valuable comments by Tao Gong, Stephen Matthews and Jeremy Collins. Mistakes which remain are my own.

positron emission tomography studies find that the F_0 differences in tone languages like Mandarin Chinese which have lexical tones are preferentially processed in the left hemisphere of native speakers (Whalen & Liberman, 1987; Liberman & Whalen, 2000) because they are phonologically significant while differences in consonants are processed in the right hemisphere. In other words, processing of the more important acoustic cue is left-lateralized.

2. Alternated Hemispheric Lateralization in Human Brain

Studying the interface of the historical-linguistic perspective and neuroscience perspective ensures i) the essentiality of laryngeal contrasts in consonants to the emergence of tone, and ii) an opposite pattern of hemispheric lateralization for tone and consonant contrast. A puzzling representation now appears on a simple graph mapping the consonant and tone contrast in E. Cham with reference to processing.



Graph 1. Changes in hemispheric lateralization.

The above graph models a shift of roles between the left and right hemisphere when Proto-Cham develops from non-tonal to tonal. The left hemisphere which used to process consonant contrast is now responsible for processing tonal contrast whereas the right hemisphere has changed from processing pitch differences to consonant contrast.

In brief, the phonation contrast of consonants leading to emergence of tone could give rise to the proposed alternation in hemispheric lateralization for tone/pitch and consonant processing in human brain during the evolutionary journey. This paper urges further research to take an interdisciplinary approach to examine data across linguistic typology and possibility of the shift in neuroscience.

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AGAINST PROTOLANGUAGE

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Since Hauser-Chomsky-Fitch (2002) the operation Merge has been taken to be the discriminating boundary between language and non-language. In our talk, we propose some reflections on the simplest stage of this syntactic mechanism, namely the so-called Head-head Merge (Primary Merge in Rizzi's 2010 Complexity Scale), showing that silent functional categories must be necessarily assumed in order to explain the realization of the most basic hierarchical structure. In this perspective the notion of "protolanguage" turns out to be as contradictory as the notion of "protogrammar".

The notion of protolanguage (henceforth PL) has characterized the debate on language origin and evolution in the last decade. In particular, two different views about the design of PL have prevailed (cf. Arbib & Bickerton 2010): 1) the "Holophrastic View", according to which PL emerged as grammarless 'protowords' which refer to recurrent but nevertheless complex events; 2) The "Compositional View" that assumes that PL had grammatical units like nouns and verbs but it was devoid of syntax and syntactic operations.

Within the Compositional View, Rizzi (2010) has proposed to widen the range of the syntactic operation Merge which was first introduced as core device of the faculty of language (Chomsky 1995, Hauser-Chomsky-Fitch 2002) proposing a finer-grained articulation of it in a three-stage complexity scale:

1. Primary Merge (head-head Merge) = two words stage

2. Recursive Merge (head-phrase Merge) = head-complement stage
3. Phrasal Merge (phrase-phrase Merge) = specifier-head stage + movement

Conceiving Merge in terms of a complexity scale allows us to identify the first two stages as precursors of the human language faculty in a proper sense, making the notion of protolanguage theoretically compatible with the theory of grammar.

In our contribution we try to get into the finer-grained details of merge, not surprisingly ending up with the original question as to how the first step of this scale might look like. In our point of view it is the rise of Functional Categories that reveals as the pivotal point for the distinction between non-language and language revising and relativizing the concept of PL itself. In other words, if on the one hand Merge is taken to be the discriminating difference between what language is and what it is not, on the other hand – even within a Merge-based complexity scale – the simplest version of Merge must already imply grammar i.e. language. In doing so, we put forward a radically compositional view of the first stage in Rizzi's system.

In fact, as regards Rizzi's Primary Merge, we emphasize the fact that it basically "conceals" all core properties of Merge (hierarchical relations, feature-characterization, i.e. asymmetry between the two elements which combine). Crucially, even the two-word combination cannot be taken as a linear combination, i.e. a mere sum of two elements (as the Holophrastic view seems to suggest) since primary merge intrinsically involves hierarchical combination.

Therefore, even at this "early" stage, we are forced to assume a syntactic configuration that prevents merged heads from being symmetrical – hence mutually c-commanding – in the first place (see Moro 2000; Barrie 2005).

We propose that this configuration (i.e. Primary Merge) be thought of as a hierarchical structure with elements already containing a bunch of abstract/grammatical features. In turn, this entails that there be "more invisible structure" which guarantee an asymmetric configuration.

Even the second stage in Rizzi's system (Head-phrase Merge) is problematic. It is taken to be the level where recursion emerges by simply adding another head to the already merged units; however, this notion of recursion is highly restricted and resembles the arithmetical instantiation of recursion, such as the Fibonacci sequence where the n^{th} element of the sequence results from the sum of the preceding two and not from the sum of the whole preceding elements, in other words 5 is not just 0+1+1+1+1+1 but 2+3 instead. The different 1's – from a mathematical viewpoint – are identical, i.e. same status corresponds to same weight. On the contrary, human language operates on items having different "loads" in terms of functional categories. Simple head recursion has no actual realization: as a matter of fact, linguistic recursion is never actualized as simple head recursion yielding something like arithmetical series).

Thus, we put forward that it is the role of the third element per se that forces the two-word configuration to make its hierarchical structure explicit with the rise of functional categories (and crucially movement) conflating the stage of Recursive Merge with Phrasal Merge.

To sum up, the notion of protolanguage is a mere speculative concept lacking any possibility of actualization. In our reconstruction of Language Origin there is no 'in-between' i.e. no PL but just a 'before' and an 'after' i.e. non-language and language.

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EVOLVING THE DIRECT PATH IN PRAXIS AS A BRIDGE TO DUALITY OF PATTERNING IN LANGUAGE

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We advance the Mirror System Hypothesis (Arbib, 2012) by offering a new neurologically grounded theory of duality of patterning in praxis and show how it serves complex imitation and provides an evolutionary basis for duality of patterning in language.

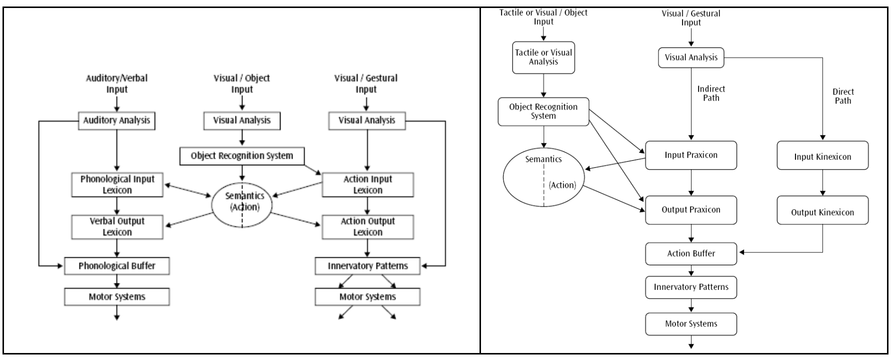

Figure 1. (Left) A model of praxis processing (Rothi, Ochipa, & Heilman, 1991). (Right) Figure 2. "Duality of patterning" in praxis, explaining the direct path as providing a kinexicon of "tweaks" which gain their meaning through their utility to bridge the gap between known actions and novel actions.

DeRenzi (1989) reports that some apraxics have difficulty in classifying gestures and in performing familiar gestures on command yet may be able to copy the movement pattern of a gesture without "getting the meaning." To address such data, Rothi, et al. (1991) proposed a dual route imitation model inspired by a model for the recognition, comprehension and production of words and non-words (Patterson & Shewell, 1987): one may recognize a word as an entry in the "auditory input lexicon" and use this to retrieve the motor plan for speaking the word (the *indirect* route) or simply repeat the sequence of phonemes heard (the *direct route*). This is *duality of patterning*.

Rothi et al. (1991) transformed this into a dual route imitation model for praxis in which the *direct route* for imitation of meaningless and intransitive gestures converts a visual representation of limb motion into a set of intermediate limb postures or motions for subsequent execution. For Rothi et al., the language system at the left simply serves as a model for their conceptual model of the praxis system at right, with semantics playing a bridging role. To develop the Mirror System Hypothesis of the evolution of the language-ready brain, we add an "action buffer" in which various actions are combined and explain the direct path as having evolved uniquely to provide tweaks to aid complex imitation in the rapid acquisition of new elements for the praxicon of meaningful actions. This replaces the implausible view of the evolution of a system for capturing meaningless gestures within the praxis system. In this way, we provide an account of "duality of patterning" within the praxis system.

The full paper will explore the neural correlates of the modules of the diagram shown in Figure 1 (right), using the results to update the ascription of roles to the ventral and dorsal systems for action and language offered elsewhere (Arbib, 2010).

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Workshop 3

Emotion and Language

Organized by:

Tomomi Fujimura
(JST-ERATO Okanoya Emotional Information Project)

Seminar Rooms 2–4, 5th floor, Campus Plaza, Kyoto, Japan
13th of March, 2012 9.40 – 14.40

Workshop Description

Emotion is conveyed by language (i.e. during emotional episodes), but at the same time language is modified by emotion (i.e. through prosody). So while both emotion and language are essential aspects of communication, the importance of their interactions should also not be overlooked. Currently however, details of this interaction remains somewhat unclear, and it is this issue which this workshop seeks to address. Taking a multi-disciplinary perspective, the workshop presents recent work in linguistics, acoustic engineering, psychology, and developmental studies.

Human language explicitly conveys intentions and thoughts, whereas emotion implicitly conveys information about subjective states. The first direction of interaction is thus exemplified by an utterances such as I agree, to understand it you must infer the speaker's authentic attitude from an analysis of his/her prosody, facial expression, and gestures, all of which are expressing emotional information. In such situations we are using both linguistic and emotional information to understand others' internal states. An understanding of the integration of emotion and language in perceptual processing is thus essential to understanding the process of communication more generally. This issue will be discussed during the workshop based on the data from perception experiments and developmental studies.

In the opposite direction, external emotion representations are also partly defined by language. Humans use words to express emotional states, i.e., anger, happiness, and sadness. Language can help to separate, and understand, certain complex emotions expressed during communication. However, recent work has reported that perception of emotional facial expressions is not driven by lexical categories, which indicates that while emotion representation is influenced by language, it is not totally dependent on it. Several talks will address the various ways in which linguistic information defines emotional concepts.

It is hoped that the approaches presented in this workshop will provide a framework for future work on emotion and language.

Acknowledgements

This workshop is supported by Japan Science and Technology Agency (JST), Exploratory Research for Advanced Technology (ERATO), Okanoya Emotional Information Project.

Workshop Timetable

9.40 – 9.50	Welcome *Tomomi Fujimura (JST-ERATO Okanoya Emotional Information Project)*
9.50 – 10.35	Invited talk: Competition in the acoustic encoding of emotional speech *Frank Eisner (Max Planck Institute for Psycholinguistics)*
10.35 – 11.00	Dimensional modeling of perceptual difference of multimodal emotion perception *Yoshiko Arimoto (JST-ERATO Okanoya Emotional Information Project), Kazuo Okanoya (The University of Tokyo)*
11.00 – 11.25	Cerebral responses to emotional and prosodic modifications of speech in human full-term neonates and preterm infants *Nozomi Naoi (JST-ERATO Okanoya Emotional Information Project), Yutaka Fuchino, Minoru Shibata, Masahiko Kawai, Yukuo Konishi, Kazuo Okanoya, Masako Myowa-Yamakoshi*
	Lunch Break
12.30 – 13.15	Invited talk: Concepts and perception of emotions in the absence of a lexical emotion category *Disa Sauter (University of Amsterdam)*
13.15 –	Mixed feelings and emotion clusters in the dynamics of verbal interaction *Barbara Lewandowska-Tomaszczyk (University of Łódź)*
– 13.50	The influence of emotion and approach-avoidance motivation on the production and understanding of metaphor *Paul Wilson (University of Łódź) – presented by Barbara Lewandowska-Tomaszczyk (University of Łódź)*
	Coffee Break
14.00 – 14.25	Language in music: The emotional valence in low arousal music are susceptible to language *Kazuma Mori (Hiroshima University), Makoto Iwanaga (Hiroshima University)*
14.25 – 14.40	Question & Answer *All presenters*

COMPETITION IN THE ACOUSTIC ENCODING OF EMOTIONAL SPEECH

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1. Introduction

Speech conveys not only linguistic meaning but also paralinguistic information, such as features of the speaker's social background, physiology, and emotional state. Linguistic and paralinguistic information is encoded in speech by using largely the same vocal apparatus and both are transmitted simultaneously in the acoustic signal, drawing on a limited set of acoustic cues. How this simultaneous encoding is achieved, how the different types of information are disentangled by the listener, and how much they interfere with one another is presently not well understood. Previous research has highlighted the importance of acoustic source and filter cues for emotion and linguistic encoding respectively, which may suggest that the two types of information are encoded independently of each other. However, those lines of investigation have been almost completely disconnected (Murray & Arnott, 1993).

2. Acoustic source vs filter cues

Source and filter components of the speech signal reflect distinct underlying articulatory mechanisms (Fant, 1960). The acoustic source originates at the level of the larynx through the quasi-periodic opening and closing of the vocal folds. Perceptual correlates of changing parameters in this vocal fold vibration such as jitter, shimmer, and especially its frequency (f0) are important for emotional inflection in speech (Patel, Scherer, Björkner, & Sundberg, 2011). This source excitation is shaped by the resonances of the supralaryngeal vocal tract, acting as a dynamic filter by changing the constellation of the articulators. The identity of speech segments is largely determined by the filter (Nearey, 1989), but the importance of filter cues for emotion recognition has been considered to a much lesser extent in the literature.

3. Factorial approach

We investigated the relative contributions of these cues directly by using a vocoder technique to manipulate acoustic source and filter information independently (Eisner, Sauter, Hunt, Rosen, & Scott, n.d.). The results of a perception experiment showed that the two types of acoustic information have asymmetrical contributions to the recognition of emotional and linguistic content. An impairment of emotion recognition was found when either source or filter information was reduced. Source and filter channels were furthermore found to interact in emotion recognition such that the information carried by the filter was more beneficial in combination with original source information than without it. Comprehension of linguistic content, in contrast, was unaffected by altered source cues and relied only on filter cues.

4. Conclusions

Unlike nonverbal emotional vocalizations such as laughter or crying, paralinguistic expression of emotion competes with linguistic content in the acoustic filter channel, and this competition can be expected to further extend into the source channel in tonal languages. Independent manipulation of source and filter cues enables systematic investigations into how different types of information are encoded in speech and how they interact with each other.

Acknowledgements

This work was supported by Netherlands Organisation for Scientific Research and the Wellcome Trust.

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DIMENSIONAL MODELING OF PERCEPTUAL DIFFERENCE OF MULTIMODAL EMOTION PERCEPTION

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Emotion is one of the information conveyed by verbal and nonverbal cues in human communication. Emotional information from multiple cues, such as facial and vocal expressions, is simultaneously perceived from different modalities, e.g., auditory and visual. However, each verbal or non-verbal cue does not always express a congruent emotion. Speakers sometimes give incongruent emotions via each verbal or non-verbal cue, such as an angry speech with a smile, and observers perceive such incongruent emotions as a single emotion, or even as a third emotion that the speakers do not actually express. This raises questions about what combinations of incongruent emotional expressions are perceived as a third emotion, and what emotions are perceived from incongruent emotional expressions. Previous studies on multimodal emotion perception indicated that vision is dominant in multisensory perception, and that emotion perception is strongly biased by audio information (Massaro & Egan, 1996; de Gelder & Vroomen, 2000; Hietanen, Leppänen, Illi, & Surakka, 2004; Collignon et al., 2008). However, these studies did not deal with which combination of emotional expressions emerges a third emotion and how to measure a third emotion perception.

This study proposes three-dimensional model of multimodal perception of emotion to visualize and quantify perceptual differences of unimodal emotion perception and bimodal emotion perception of congruent/incongruent combinations of emotional expressions, and to examine whether the model describes a third emotion perception. Our approach, named “emotional geometry”, is simple in that unimodal and bimodal perceptual information was mapped on an emotional space, and that spatial gaps between the unimodal and bimodal perceptual information were calculated as perceptual differences which imply a third emotion perception. The emotional space was obtained with principal component analysis on scores of perception tests for unimodal and bimodal dynamic stimuli. The unimodal stimuli portrayed five emotional states and the bimodal stimuli consist of the unimodal stimuli to create congruent/incongruent combination of emotion. Each stimulus was rated on intensities of six emotions from 0 (not emotional) to 5 (strong) in the test. The result showed that the spatial gaps formed by the incongruent stimuli were significantly larger than those of the congruent stimuli ($t(178.69) = 8.53$, $p < 0.001$). Moreover, some combinations of the incongruent stimuli show significantly larger spatial gaps than those of the control combination of neutral voice and neutral face ($p < 0.05$).

This study focused on multimodal emotion perception from non-verbal cues. We concluded that "emotional geometry" can visualize and quantify a third emotion perception from combinations of vocal and facial emotional expressions. Cues to convey emotional information are not only vocal and facial expressions. As speech conveys verbal information and nonverbal information simultaneously, emotional information should be perceived from multiple cues of speech. The emotional geometry is expected to enhance its function to model a third emotion perception from many types of verbal and non-verbal cues.

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CEREBRAL RESPONSES TO EMOTIONAL AND PROSODIC MODIFICATIONS OF SPEECH IN HUMAN FULL-TERM NEONATES AND PRETERM INFANTS

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Previous behavioral studies have indicated that human infants display a remarkable sensitivity to infant-directed speech (IDS) and to speech with happy prosody before acquisition of language (e.g., Cooper & Aslin, 1990). However, few studies have examined the neural substrates underlying the processing of emotional and prosodic modifications of speech at a very early developmental stage.

We examined cerebral responses to IDS in full-term neonates and preterm infants at term-equivalent age using multichannel Near Infrared Spectroscopy (NIRS). Twenty-five healthy full-term newborn infants (mean gestational age at birth was 39.6 weeks; mean postnatal age was 4.1 days) and 25 preterm infants (mean gestational age at birth was 32.0 weeks) of equal postconceptional age were participated. In NIRS measurement, two sets of 3 x 10 probes (94 recording channels) were used to record activations in the frontal, temporal, parietal, and occipital regions (Figure 1A). A blocked design was used, and IDS and adult-directed speech (ADS) conditions were alternated 8 times with intervening control condition (pink noise).

The results showed that IDS increased broader brain areas compared to ADS both in full-term and preterm infants. In addition, preterm infants showed decreased activity to speech in the right temporal area when compared to full-term infants (Figure 1B).

This group differences might suggest that preterm infants and full-term neonates follow different developmental trajectories during the postnatal period owing to the differences in auditory experiences during perinatal period. In the uterus, exogenous high-frequency sounds are attenuated by maternal tissues and fluids, and preserved prosodic properties of speech are accessible to the full-term fetus (e.g., Benzaquen et al., 1990), whereas preterm infants are exposed to various frequencies from the extrauterine environment. It is possible that auditory experiences during the prenatal and postnatal periods may have effects on neurodevelopment of emotional prosodic processing in infants.

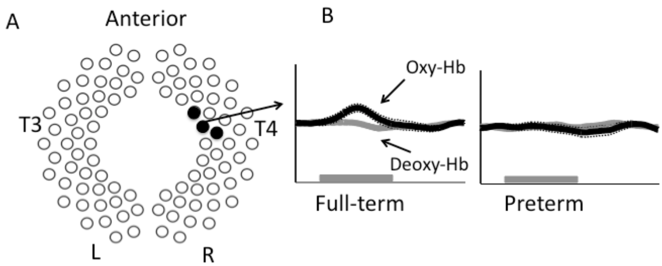

Figure 1. A. Measurement channels showing statistically significant main effect of group (the black-filled circles, $p < 0.01$, uncorrected). B. Grand averaged time courses of oxygenated- (Oxy-Hb) and deoxygenated-hemoglobin (Deoxy-Hb) changes to IDS in full-term and preterm infants.

Acknowledgements

This work was supported by Japan Agency of Science and Technology, ERATO, "Okanoya Emotional Information Project".

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CONCEPTS AND PERCEPTION OF EMOTIONS IN THE ABSENCE OF A LEXICAL EMOTION CATEGORY

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1. Introduction

Is the relationship between emotional expressions and their meaning learned via language, or do we perceive signals in the same way regardless of the lexical labels we use to describe them? Previous studies have examined the relationship between language and emotion in pre-linguistic infants, aphasic patients, or using interference tasks (see Roberson, Damjanovic, & Kikutani, 2010). Yucatec Maya speakers lack of word for disgust, allowing for the direct investigation of emotion perception and concepts in a healthy, adult population with no lexical category for one of the 'basic' emotions.

2. The absence of a lexical emotion category

Fifteen native Yucatec Maya speakers took part in a pilot task where they were asked what they thought a person in a brief story was feeling (Levinson, Senft, & Majid, 2007) and were asked to name emotional facial expressions taken from the Ekman and Friesen set (Ekman & Friesen, 1976). Responses to disgust stories and expressions were indistinguishable from those of anger, primarily utilizing terms meaning angry and fierce. Although most of the participants spoke some Spanish, they were unfamiliar with the meaning of Spanish terms for disgust (see Sauter, LeGuen, & Haun, 2011).

3. Categorical perception of disgusted facial expressions

Twenty-three native Yucatec Maya speakers performed a delayed XAB task with emotional facial expressions of disgust, anger, and sadness (Ekman & Friesen, 1976). Participants perceived emotional expressions on the disgust – anger continuum categorically (see Figure 1), and the magnitude of the effect was equivalent to that seen for the two other emotion continua (sadness – anger and disgust – sadness). This demonstrates that the categorical perception of emotional signals is not driven by lexical categories (see Sauter et al., 2011).

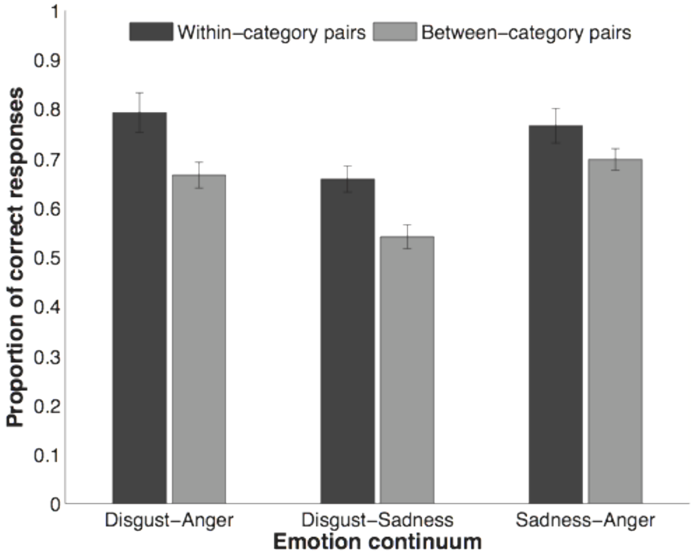

Figure 1. Proportions of correct responses for between-category and within-category stimulus pairs on each continuum. Note: Chance is 0.5.

4. Q-sorting and free naming of emotional facial expressions

Twenty native Yucatec Maya speakers carried out a q-sort task and a free naming task with 32 stimuli from the Radboud Faces Database (Langner et al., 2010), including disgust, anger, contempt, fear, sadness, surprise, joy, and neutral expressions. Hierarchical cluster analysis of the sorting data revealed eight conceptual categories, mapping onto the eight emotion categories. The naming data showed that participants named disgust and anger expressions using the same terms, but they also described the disgusted faces using more complex linguistic constructions. Hierarchical cluster analysis of the naming data including these additional responses showed a similar pattern to that of the sorting data, whereas considerable differences were found when including only emotion terms.

5. Conclusions

This set of studies demonstrates that the lexical categories available in different languages to classify emotions differ, but the perception of emotion signals is nevertheless consistent. The conceptual structure of emotions maps onto perceptual, rather than linguistic structure, and appears largely independent of emotion terms.

Acknowledgements

This research was funded by the Max Planck Society and the Netherlands Organisation for Scientific Research.

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MIXED FEELINGS AND EMOTION CLUSTERS IN THE DYNAMICS OF VERBAL INTERACTION

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1. Research questions

The focus of the paper is an elucidation of the concepts of *mixed feelings* and *emotion clusters* (Lewandowska-Tomaszczyk and Wilson, in press) in the context of ongoing language exchanges and their dynamics. Language can facilitate, construct and regulate the occurrence of an emotion (Baumeister et al., 2004) and out of a number of communicative functions it has an important function which covers two areas. Firstly, language is used to talk *about* emotions, descriptively or in narration. This kind of *emotion talk* can be complemented by *emotional talk* (see Bednarek 2008), in which a speaker uses diverse prosodic clues (stress, pitch, intonation) and paralinguistic markers (facial expression, body movements) together with a specific verbal repertoire (interjections, swear-words, marked expressions such as intensifiers, evaluative expressions, etc.) to *express* feelings and emotions.

2. Materials and methods

In the first part of the paper, an analysis of emotion and emotional words will be presented, as they are used in authentic language materials (spoken and written) in two languages: English and Polish, in large collections of language data (British National corpus and the National Corpus of Polish www.nkjp.pl) and an attempt will be made to infer their regular patterns of use in terms of canonical or elaborate *Emotion Events (EEs)* (Wilson and Lewandowska-Tomaszczyk, 2012). Canonical Emotion Events will be shown to be patterned in terms of *prototypical scenarios* which cover states and activities and involve participants interconnected by relations in a given spatio-temporal context.

More elaborate EEs extend the scenarios towards *less transparent cases*, which include, inter alia, mixed feelings and emotion clusters.

3. Analysis

The analysis involves a presentation and discussion of the concept of mixed feelings and their verbal expression, in which the Experiencer is not able to identify separate emotion instances and in consequence a blended type of emotion is observed. Another type of complex emotion, i.e., *conceptual clusters*, includes cases which imply the co-occurrence of more than one emotion at the same time, which are more readily identified and labelled by language users. In each of the cases speakers negotiate their emotions, arriving eventually either at more pure types or remaining at a lower level of linguistic specification. The paper looks at similarities and contrasts in emotion or emotional language between Polish and English to see what is more universally shared in terms of cognitive image schemas and/or (whenever possible) body language on the one hand, and which semantic properties and discourse strategies remain language and culture-specific on the other (cf. Dziwirek and Lewandowska-Tomaszczyk, 2010; Wilson (ed.), 2012).

4. Interaction and evolutionary implications

The function of these two types of linguistic *exbodiment* (Mittelberg 2008) of the structures will be exemplified and discussed in terms of the dynamics of ongoing verbal interaction and their different roles proposed with respect to possible scenarios of language evolution.

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THE INFLUENCE OF EMOTION AND APPROACH-AVOIDANCE MOTIVATION ON THE PRODUCTION AND UNDERSTANDING OF METAPHOR

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This paper reviews evidence pertaining to possible underlying causes of the relative influences of approach vs. avoidance motivation and emotion on metaphor production and understanding.

To explain the effect of approach vs. avoidance and emotion on metaphor one needs to first understand that in the early stages of metaphor construction and understanding it is necessary to notice an association between distant concepts. Whereas evidence consistently shows that approach motivation relative to avoidance motivation is associated with the broadening of such conceptual scope, it remains unresolved whether this broadening is restricted to positive emotions (e.g., Isen and Daubman, 1984) or negative emotions (e.g., Kaufmann and Vosburg, 1997).

The approach and avoidance motor actions that are typically employed in experimental procedures are referred to as *implicit affective cues* as they cue safety or danger in the absence of any conscious feelings of positive or negative emotional arousal. Whereas arm flexor contraction (i.e., pulling the arm towards the body) is associated with the approach motor action of acquiring or consuming desired objects, arm extensor contraction (i.e., pushing the arm away from the body) is associated with the avoidance motor action of rejecting or restraining noxious objects. Using a similar approach vs. avoidance procedure, Kuschel, Förster and Denzler (2010) showed that subtle cues of approach orientation facilitated performance in a subsequent metaphor understanding task. Evidence suggests that the increased dopamine activity associated with *implicit affective cues* provides an explanation for this manifestation of broadened conceptual scope.

A main difference between the effects of *implicit affective cues* induced by motivational orientation and emotion is that emotion is associated with extensive conceptual knowledge. From an embodied simulation perspective (Barsalou 1999), simulators for specific emotions such as anger develop as instances of anger accumulate, and sensory, motor and somatovisceral features are blended across instances and settings where anger is experienced. The complex, relational structure of emotional states such as anger (Wiemer-Hastings and Xu, 2005) could be a key underlying factor in the effect of emotion on the breadth of conceptual scope, and metaphor production and understanding. An embodied simulation account of the possible effect of emotion on the breadth of the scope of conceptual attention does not predict valence effects; however, the influence of rumination offers a potential explanation for the inconsistent effects of valence described above (e.g., Altamirano, Miyake and Whitmer, 2010).

The conceptual links that underlie metaphor are also at the heart of the theory of conceptual integration, which, as Fauconnier and Turner (2008) argue, is a fundamental precursor to language evolution.

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LANGUAGE IN MUSIC: THE EMOTIONAL VALENCE IN LOW AROUSAL MUSIC ARE SUSCEPTIBLE TO LANGUAGE

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1. Introduction

People can perceived emotions in music (Juslin & Sloboda, 2010) and the majority of music that people listen to in their daily lives includes lyric, that is, language. To examine the effect of language without changing the acoustic properties of the songs, we use "foreign songs" as stimuli without language while maintaining the acoustic properties of the song. We also used as the stimuli foreign songs with the text of the "lyric translations" into the language of the listener. We predict that the influence of language could appear more clearly in low arousal music than in high arousal music. People find it easier to judge the emotional valence of high arousal instrumental music than the emotional valence of low arousal one (Gabrielsson & Juslin, 2003). Language may be a useful cue to judge the emotional valence in low arousal music.

2. Experiment 1

2.1. *Method*

53 students participated S condition which presented foreign songs and SL condition which presented foreign songs with lyric translations, and rated the overall emotional valences (positive and negative) by questionnaire. We selected the high or low arousal positive song and lyrics based on a pilot study.

2.2. *Results*

Two-way ANOVAs were computed with conditions and arousal level, separately positive or negative. The results showed that the emotions in SL condition did not differ from S condition in high arousal level but, in low arousal level, SL condition was rated more positive and less negative than S condition (Figure 1).

3. Experiment 2

3.1. *Method*

Another 40 students participated S condition (n=20) or SL condition (n=20), and rated the time series emotional valence (happy[n=10] or sad[n=10]) every 4Hz by computer. The stimulus is a high arousal foreign song and lyric translations the same as experiment 1. The foreign song include low arousal segment.

3.2. *Results*

Two-way fANOVAs were computed with conditions and time, separately happy or sad. The fANOVAs revealed that the emotions in SL condition was generally not differed from S condition. However, happy emotion in SL condition was higher than S condition only in low arousal segment (Figure2).

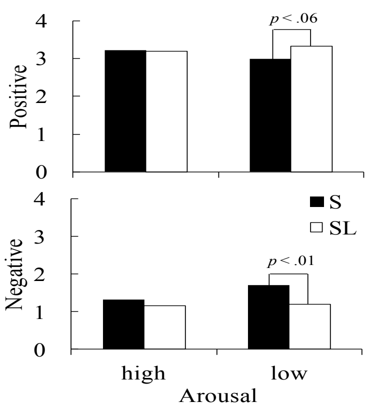

Figure1. Overall rating for high or low arousal foreign song

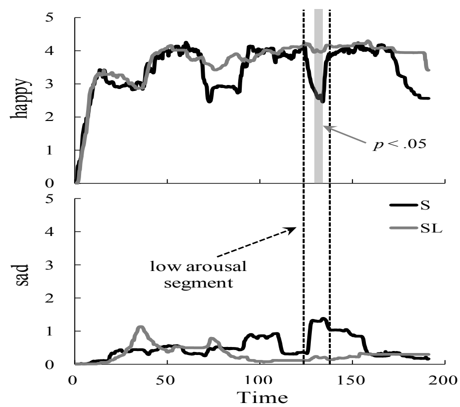

Figure2. Time series rating for high arousal foreign song including low arousal segment

4. Discussion

The results of experiment 1 and 2 supported our prediction that the emotional valences in low arousal music is more influenced by language than the emotional valences in high arousal music. In primitive age, music boosted the morale of the hunt (Okanoya, 2010), and human have been developed high arousal music through long time as vital for survival. However, low arousal music may evolve after settle down for ordinary life. Therefore, high arousal music has been confirmed as emotional communication, on the other hand, low arousal music has less developed as emotional communication. This may why language affect the emotional valences in low arousal music and complement the emotional communication of music.

Workshop 4

Animal Communication and Language Evolution

Organized by:

Johan Bolhuis (Utrecht University)
&
Kazuo Okanoya (University of Tokyo)

Lecture Room 3, 4th floor, Campus Plaza, Kyoto, Japan
13th of March, 2012 9.45 – 15.30

Workshop Description

It has often been suggested that language is a uniquely human cognitive trait. But this uniqueness does not preclude that there may be evolutionary homologies or analogies between human speech and certain aspects of animal communication systems, at either the neural or behavioral level. Therefore through the comparative study of animal vocalizations and human speech, we may gain insights into the origin and evolution of language.

Neural control and evolution of song sequences and vocal learning in birds will be one of the main topics in this workshop. Language and birdsong are obviously different in that language has lexical syntax, while birdsong does not. However, the basic neural architecture for auditory-vocal learning may be shared in both birds and humans. We will discuss common and unique features of birdsong and human speech.

Apart from birdsong learning, this workshops is open to research on other animal taxa and in other modalities, as long as a comparative perspective with human speech or language is provided. We particularly welcome presentations on gestural/vocal communication, social behavior. Topics on theory of mind, counting, and tool-using, thought not directly related with communication, are also considered as a comparative biological basis for language.

Acknowledgements

This workshop is supported, in part, by Grant-in-Aid Basic Research A #2324033, Grant-in-Aid on innovative areas #4301 (Adolescent mind and self-regulation) from MEXT, Japan to Kazuo Okanoya, and also by ERATO Okanoya Emotional Information Project, JST, Japan.

Workshop Timetable

9.45 – 10.00	Welcome *Johan Bolhuis (Utrecht University) & Kazuo Okanoya (University of Tokyo)*
	Part I. Theoretical Studies
10.00 – 10.25	Language and animal communication: The evolutionary and cognitive divide *Charles N. Li (University of California)*
10.25 – 10.50	Can evidence of a discontinuity in the evolution of language be found in a comparative study of animal signalling? *Dominic Mitchell (University of Bath)*
10.50 – 11.15	Statistical patterns of human language in other species: Facts, origins and controversies *Ramon Ferrer-i-Cancho (Universitat Politècnica de Catalunya)*
	Part II. Experimental studies
11.15 – 12.00	Invited talk: Birdsong and spoken language: Similarities and differences *Johan J. Bolhuis (Utrecht University)*
12.00 – 13.20	Lunch Break
13.20 – 13.45	Abstract rule learning in human and non-human animals *Reiko Hoshi-Shiba (University of Tokyo), Fang Sun, Kenta Suzuki, Dilshat Abla, Kazuo Okanoya*
13.45 – 14.10	Combinational vocal usage for emotional expression in common marmoset (Callithrix jacchus) *Yoko Kato (National institute of radiological sciences), Hayato Gokan, Arata Oh-Nishi, Takafumi Minamimoto*
14.10 – 14.55	Invited talk: Vocal deviance detection in auditory cortex of a social songbird *Gabriël Beckers, Manfred Gahr*
	Break
15.00 – 15.30	General Discussion *All participants*

LANGUAGE AND ANIMAL COMMUNICATION: THE EVOLUTIONARY AND COGNITIVE DIVIDE

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A communicative signal carries information and serves a function. Information and function, however, are not equivalent to meaning. Whereas the concept of meaning can be convoluted and philosophical (See, for instance, *The meaning of meaning* by C.K. Ogden and I.A. Richards, 1989), it is uncontroversial that referring to something constitutes entry-level meaning. In case of a communicative signal, it will carry meaning as long as it has a reference that is not dependent on its use or function. Many animal communicative signals, e.g. the warning calls of vervet monkey and Campbell monkey, refer to something. But their references are inextricably associated with their function, i.e. the reference is not independent of the signal's function. If a linguistic unit refers to some entity, however, the reference is free-standing, and independent of the signal's communicative function. It is this free-standing and independent referential property of linguistic units that animal communicative signals lack. This distinction between linguistic units and animal communicative signals underlies and explains such frequently-cited differences between language and animal communication as: (1) linguistic units can be concatenated to form larger units whereas animal communicative signals cannot be concatenated although a putative counterexample has been proposed by Ouattara, Lemasson & Zuberbuhler (2009), (2) metaphors are omnipresent in language (Lakoff & Johnson, 1980) whereas animal communicative signals do not have metaphors.

The distinction between a communicative signal having a free-standing and independent reference, on the one hand, and a communicative signal having only an associated/dependent reference, on the other hand, may seem, at first sight, hair-splitting or trivial. But the evolutionary significance of this distinction is anything but trivial. For eons of time, many animals have signals that refer to some entities in the context of the function of a signal and or the entity's relationship with the signaler. None of those signals has evolved into one that refers to an entity independent of its functional and relational context. The emergence of the first communicative signal which, as a symbol, refers to an entity independent of the signal's function/relation with the signaler, occurred only in hominid evolution, and it marks the dawn of the emergence of language. This capability, as Deacon (1989) observed, requires a totally different neurological system. Extrapolating from Deacon, I propose that the explanation underlying the afore-mentioned critical distinction between linguistic unit and animal communicative signal is that animals, including non-human primates, are incapable of conceptualizing an object independent of the relational and functional context in which that object exists. Such conceptualization involves a level of abstraction that is beyond the reach of animal cognitive capability. According to my proposal, a vervet monkey, for instance, is incapable of conceptualizing a boa constrictor as a free-standing entity independent of its prey-predator relationship to the boa constrictor. My proposal explains why a vervet monkey is likely to utter a specific call warning against reptiles even if other members of its troop are not present. My proposal also explains Tamasello's insight (2000) that non-human primates do not point or gesture to an object in order to bring it to the attention of troop-mates. Pointing or gesturing to an object in order to bring it to the attention of troop-mates require the actor to have the cognitive capability of conceptualizing an entity as a free-standing object independent of its relationship to the actor. Finally, my proposal explains what Hockett (1960) observed: displacement is a feature of language that does not occur in animal communication. In order to communicate about something that is not in the temporal and spatial context of communication, which constitutes the displacement feature, the signaler has to have the cognitive capability of conceptualizing that 'something' as a free-standing entity, free from its functional and relational context.

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CAN EVIDENCE OF A DISCONTINUITY IN THE EVOLUTION OF LANGUAGE BE FOUND IN A COMPARATIVE STUDY OF ANIMAL SIGNALLING?

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A common account of language evolution is that evolution of cognitive abilities enables the cooperation and culture necessary for language, but (Wilson, 2011) prefers an alternative in which a major evolutionary transition (Maynard-Smith & Szathmary, 1977) results in this cooperation and culture without a prior advance in cognitive ability (and in fact is a pre-requisite for such cognitive advances). But is there any evidence to support his preference? In this talk I ask if any trace of such a discontinuity be found in a comparative study of animal signalling. I argue that it can but only if we look in the right place and that using a computer science framework can be of use in this.

Animal signals involve information that is of some value, and where there is value in the use of a signal there is by definition the possibility of advantage in abuse. Therefore the continued use of a signal depends on a guarantee of correct use in some form which can underwrite the signal, without this the signal will be subject to abuse its value decline accordingly and so it will fall out of use. This has been described by (Krebs, Dawkins, & Davies, 1984) as the principle of exploitation, not to be confused with terms such as selfishness as used in descriptions of cooperation. Another perhaps less emotive term for this process has been widely used in computer modelling: ‘feedback’.

Examples of feedback mechanisms include: signals incidental to behaviour, costly signalling, signalling of shared interests and cooperative signalling.To take an example of a signal, the directed scratch in Chimpanzees (Pika & Mitani, 2009) in which males seem to indicate a precise spot on the body to be groomed it is most likely that what is underwriting this signal is shared interests or possibly cooperative signalling and that delicate signals of this nature requiring cortical control are not used by this species in the other ways listed above for instance as costly signalling or as incidental to behaviour such as aggression. In the same species, vocal grunts in contrast, are more likely to be signals incidental to behaviour than costly signalling or signals of a shared interest. In another species the situation may be different, in songbirds, vocalizations which are long beautiful complex calls (Okanoya, 2002) are most likely to be underwritten by costly signalling and are unlikely to be signalling of shared interest or any of the other categories.

As the introduction to this workshop suggests any attempt to find a discontinuity between human and animal signals based on the structure of the signal or on the ability, cognitive or physical required to produce it seems doomed to failure. The same pattern has been repeated many times: no sooner has a new candidate identified in human language been put forward than the same feature or ability is discovered in one or more non-human species. The above examples of referential and syntactical communication respectively are part of this trend.

However if we repeat the same investigation with respect to signal guarantees the picture is very different. In all animal signalling as in the examples above the signal is highly correlated with its guarantee, except in the case of humans where there is no correlation between signal and guarantee. Humans may occasionally borrow these techniques; for example in intimate whispers, but this is for prosodic effect only, and on the occasions when we may be motivated by such guarantees (giving to charity is arguably costly signalling) we use the same repertoire of signals as on occasions when costly signalling does not apply. Moreover when we compare species closely related to humans with those more distantly so we find further evidence of a disconnect: the pattern of correlation in chimpanzees is no closer to ours than is the pattern in songbirds or other distant species, and yet Chimpanzees are our closest relative, this is highly suggestive of the kind of discontinuity cited by DS Wilson.

But might not further research into non-human animal communication reveal as yet undiscovered signalling which is not correlated with its guarantee? While this is possible, the study of animal signalling so far consists of confirming in increasing detail the various relationships between signal and guarantee, and sometimes discovering new ones (Zahavi & Zahavi, 1997), this trend tends to support rather than deny the argument being made here. We can imagine in a thought experiment the kind of behaviour that would falsify the argument, for example if chimpanzees were found to use intricate gestures to signal information regarding sexual selection or songbirds used long demanding calls to signal information of a shared interest, then the correlation would be broken and a precedent for the human case would be evident.

I suggest that a comparison of animal signals with human language reveals clear evidence of a discontinuity in one respect: the correlation with guarantee. In all animal communication this is highly correlated, in human speech there is no correlation. This suggests that in the evolution of speech from signals a key step was this disassociation; and that as a promising candidate for the major transition required by DS Wilson, this warrants further investigation.

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STATISTICAL PATTERNS OF HUMAN LANGUAGE IN OTHER SPECIES: FACTS, ORIGINS AND CONTROVERSIES

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World languages exhibit many statistical patterns that qualify as candidates for linguistic universals: they hold in any language where they have been tested. A popular example is Zipf's law for word frequencies, namely that the probability of the r-most frequent word in a text is approximately $p(r) \sim r^{-\alpha}$, where α is the exponent of the law (Zipf, 1949). Languages show many other statistical regularities such as the law of abbreviation, i.e. the tendency of more frequent words to be shorter (Zipf, 1949, pp. 63), a law of meaning distribution indicating that more frequent words tend to have more meanings (Zipf, 1949, pp. 28-31), Menzerath-Altmann law stating that the longer a construct (e.g., a sentence), the shorter its components (e.g., the shorter the clauses) (Boroda & Altmann, 1991),...and so on. Statistical patterns of language defy the claim that linguistic universals are a myth (Evans & Levinson, 2009).

Over the last decade, many parallels between human language and the behavior of other species have been established by means of statistical 'laws' of language (Ferrer-i-Cancho, 2011). Zipf's law and a parallel of the law of meaning distribution have been found in dolphin whistles (McCowan, Hanser, & Doyle, 1999; Ferrer-i-Cancho & McCowan, 2009). Parallels of the law of abbreviation have been reported in the vocalizations of Formosan macaques (Semple, Hsu, & Agoramoorthy, 2010) and the surface behavioral patterns of dolphins (Ferrer-i-Cancho & Lusseau, 2009).

Here we will review these discoveries and present the abstract principles of organization that have been put forward to explain their universality beyond human language (Ferrer i Cancho & Díaz-Guilera, 2007; Ferrer-i-Cancho & Hernández-Fernández, 2012). Interestingly, statistical patterns of language have been surrounded by many controversies. We will discuss the weakness of arguments against the relevance of Zipf's law based upon random typing or die rolling (Suzuki, Tyack, & Buck, 2005). We will also show that the exceptions to the law of brevity in two New World primates (Bezerra, Souto, Radford, & Jones,

2011) do not qualify as true exceptions due to some limits and subtleties of the statistical analysis employed (Ferrer-i-Cancho & Hernández-Fernández, 2012). In sum, statistical patterns of language offer new prospects for comparative research among species and ground-breaking directions in the quest for true universals of communication and behavior across species.

Acknowledgements

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BIRDSONG AND SPOKEN LANGUAGE: SIMILARITIES AND DIFFERENCES

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1. Parallel Mechanisms in Birdsong and Spoken Language

1.1. *Behavioural Similarities*

Behaviorally, there are at least three ways in which song learning in songbirds and speech acquisition in human infants are similar (Bolhuis *et al*., 2010; Beckers *et al*., 2012). First, both human infants and songbirds acquire their speech and song repertoire, respectively, through a combination of predispositions and learning. Second, in both songbirds and humans there is a sensitive period early in development, during which auditory-vocal learning is optimal. Third, in both human infants and juvenile songbirds there is a transitional phase at the start of vocal production, which is called 'babbling' in human infants and 'subsong' in songbirds.

1.2. *Neural Similarities*

There is a similar dissociation between brain regions involved in auditory perception and memory on the one hand, and vocal production on the other, in birdsong and human speech. Essentially, birdsong involves two interconnected neural networks that are functionally dissociated (Bolhuis *et al*., 2010). First, secondary auditory regions, including the caudomedial nidopallium (NCM) and caudomedial mesopallium (CMM), are involved in song perception and are important for the recognition of tutor song. Second, the 'song system' – consisting of the song motor pathway (SMP) and the anterior forebrain pathway (AFP) – is involved in song production, sensorimotor learning and adult song plasticity. The NCM and CMM may be analogous with the mammalian auditory association cortex, including Wernicke's area that is associated with speech perception. The AFP is similar to the mammalian basal ganglia, while other parts of the song system have been suggested to correspond functionally to Broca's area, traditionally associated with speech production. The neural dissociation is already apparent in songbird juveniles and human infants (Bolhuis *et al*., 2010).

1.3. *Syntactic Similarities*

In human language, hierarchies can be assembled by combining words and words parts, and words can be organized into higher-order phrases and entire sentences (Berwick *et al*., 2011). The songs of songbirds also consist of discrete acoustic elements that occur in a certain temporal order, and variable song element sequences may be governed by sequential syntactic rules. Recently, Abe & Watanabe (2011) argued that songbirds may have the ability to acquire context-free syntactic rules. However, Beckers *et al*. (2012) conclude that the subjects in this study do not require the acquisition and use of such rules or a grammar of any kind, only the simpler hypothesis of acoustic similarity matching.

2. Conclusions

Taken together, an evolutionary scenario emerges where three factors are important. First, there is increasing evidence for neural homology, where similar brain regions are involved in auditory learning and vocal production, not only in songbirds and humans, but also in other mammals. Second, there is evolutionary convergence with regard to the mechanisms of auditory-vocal learning, which proceeds in essentially the same way in songbirds and human infants, but not in non-human primates. Third, as yet there is no evidence to suggest that non-human animals possess the combinatorial complexity of human language syntax. It may be that the neural mechanisms that evolved from a common ancestor, combined with the auditory-vocal learning ability that evolved in both humans and songbirds, enabled the emergence of language uniquely in the human lineage.

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ABSTRACT RULE LEARNING IN HUMAN AND NON-HUMAN ANIMALS

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1. Introduction

For the acquisition of language, the ability of abstract rule learning is important as well as statistical learning. The abstract rule learning mechanism enables recognizing structures or higher-order information embedded within word sequence. Marcus et al. (1999) reported that human infants could recognize abstract structure, for example, between ABA and ABB. Subsequently, many researches on non-human animals have also reported. Yamazaki et al. (2011) revealed the learning ability of the motor pattern of the sequence in male Bengalese finches, and Murphy et al. (2008) showed that rats could learn simplified rules and apply these rules to novel stimuli. These results suggest that the rule learning abilities also exist in some non-human animals not speaking a word. In the current study, we investigated the neural correlates of abstract rule learning in adult human by recording auditory event-related potentials (ERPs).

2. Experimental procedure

During ERP measurement, half of the participants were habituated with artificial three-syllable sequences constructed with the ABA rules and the remaining half with the ABB rules for learning. They were then tested on sequences of novel syllables following the 50 % of the ABA and 50 % of the ABB abstract rules, so half of which were inconsistent with the rule previously learned. We performed the behavioral experiment after the ERP study was completed.

3. Results and Discussion

According to the behavioral performance results, the participants were divided to high-learners and low-learners subgroups. In the high-learners, grand-averaged ERPs revealed significant increased the N400-like negativity in response to inconsistent sequences in the latter half. The current results suggest that temporal ERP changes are associated with the successful acquisition of abstract rules. From these results, we would like to make a comparative review of the abstract rule learning of human and non-human animals.

Acknowledgements

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COMBINATIONAL VOCAL USAGE FOR EMOTIONAL EXPRESSION IN COMMON MARMOSET (*Callithrix jacchus*)

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Contrary to the thorough understanding of birdsong studies, understanding of vocal communication in primate still fall behind in the experimental investigations. Wild common marmosets (*Callithrix jacchus*) have thirteen call repertoires described by using configuration of spectrogram and observation of behavioral context (*e.g.,* Egg call associated with vigilance behavior), suggesting their depending on rich vocal communications (Bezerra and Souto 2008). Studies using captive marmosets reported that Tsik calls were induced when they faced predator of fearful object (*e.g.,* Clara et al. 2008). These previous studies described vocal repertoires based on mono-categorical syllables. However, we found that multi-syllabic elements, compounds of Tsik and Egg calls (named Twiggy), were vocalized when marmosets were isolated in a novel, isolated cage without predatory context. Twiggy was commonly observed from all marmosets tested, and clearly distinguished from Tsik by spectrum analysis. These suggest the separate usage of combinational element (*i.e.,* Twiggy) and solitary element (*i.e.,* Tsik) for different contexts.

In this study, we aimed to experimentally differentiate the vocal usages by presentation of visual stimuli. We presented neutral or predatory photographs to six subjects to test they respond with different vocalizations. Tsik vocalizations significantly increased during the predatory stimuli than neutral stimuli (Generalized Linear Mixed Model, vocalizations = stimuli (neutoral or predator), cluster = subject, family = poisson, $p < 0.001$*). Twiggy was also vocalized, however the numbers of which were not significantly different between the stimulus contexts (Generalized Linear Mixed Model, vocalizations = stimuli (neutral or predator), cluster = subject, family = poisson, $p = 0.53$).

Tsik were vocalized specifically in the predatory context, whereas Twiggy was used in both of the contexts. To identify the physiological background of Twiggy, we measured vocalizations under pharmacologically induced anxiety state by injecting FG-7142, a partial inverse agonist of the benzodiazepine receptor. FG-7142 is considered as anxiogenic drug, since it increased anxiety behavior in rodents and primates (Belzung and Griebel 2001, Carey *et. al*. 1991). Through the habituation to the isolated cage, the marmosets decrease their Twiggy vocalization. However, injection of FG-7142 reincreased Twiggy calls.

Our results suggested that Twiggy is associated with anxiety rather than fear. Although the functional difference between the Tsik and Twiggy has to be tested by comparison of reactions to these calls, these experimental investigations would illuminate the understanding for semantic difference expressed by combination of multiple elements.

Acknowledgements

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VOCAL DEVIANCE DETECTION IN AUDITORY CORTEX OF A SOCIAL SONGBIRD

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The ability to distinguish between vocalizations that occur frequently and ones that are novel or unexpected is important in many animal communication systems. Common vocalizations do not require new decisions to be made every time they are perceived, and may thus often be processed without involvement of cognitive resources that are important when vocalizations are unexpected (e.g. attention). In dynamic communication scenes, the distinction between rare and common vocalizations can only be made by matching current sensory input with recent stimulus history, an ability that depends on short-term memory. Sensitivity to sounds that deviate from recent input has been investigated at the neural level in humans as well as animal model systems. Auditory neurons in cats and rodents habituate on short time scales to probabilistically recurring tones in a frequency-selective way, a process called "stimulus-specific adaptation" (SSA; Ulanovsky & Nelken, 2003). Furthermore, a large body of studies in humans has addressed a possibly related phenomenon called "mismatch negativity" (MMN). MMN is a difference wave obtained from EEG and MEG recordings that arises when a sound deviates from a regularity formed by repetitive auditory stimulation, and is thought to reflect a form of "primitive intelligence" of auditory cortex involved in a plethora of cognitive functions (Näätänen et al, 2007), including the processing of syntax (Pulvermüller, et al., 2007). Nevertheless, there remains a considerable gap between the experimental designs that have been used to directly investigate the neurophysiological underpinnings of deviance detection—usually involving fast sequences of simple artificial stimuli—and perceiving deviant, potentially relevant sounds in vocal communication.

We recorded neural activity in the auditory cortex of anesthetized zebra finches, *Taeniopygia guttata*, that were presented with short-range contact calls occurring probabilistically at a rate used in spontaneous communication. We applied a so-called "switching oddball" design, playing alternating blocks of call sequences, each consisting of two call vocalizations that recur with different probabilities, one being common (the "standard" stimulus) and the other one being rare ("deviant"). From one block to the next, the call stimuli remained identical, but their probabilities are reversed, so that response patterns can be directly compared for sensitivity to stimulus history, while excluding potentially confounding effects that depend on specific acoustic content. To explore spatiotemporal activation patterns within and across functionally different areas, we used multi-electrode probes and recorded analog multi-unit activity in auditory cortex at 32 sites simultaneously.

Neurons in the secondary auditory areas caudomedial nidopallium (NCM) and caudomedial mesopallium (CMM), but not in the primary thalamo-recipient area L2, respond preferentially to a call stimulus when it is deviant, as compared to the same call stimulus when it is standard. When two call stimuli alternate between standard and deviant roles, most sites exhibit a response bias to deviant events for both call stimuli. This shows that such biases are not simply based on a use-dependent decrease in response strength as sounds recur more frequently, but rather on a more complex mechanism that enables the detection of unexpected call vocalizations per se. Sites in secondary areas do not respond to all occurrences of a call stimulus, a phenomenon that underlies in large part response biases to deviants. Furthermore, we find that neural activity patterns of deviant-biased responses in secondary areas are tightly synchronized between many sites, including ones that are separated by relatively large distances. Because such activity is poorly locked to the timing of the call stimulus, synchronization of responses must be driven by internal neuronal interactions rather than by the timing of stimulus acoustic features. Thus, the medial part of the secondary auditory forebrain of this social songbird contains a large-scale, internally synchronized network of neurons that responds more often to a communicative signal when it is unexpected within the recent context than when it is expected.

We hypothesize that the deviance-sensitive, internally synchronized network of neurons that we have identified is involved in the involuntary capturing of attention by unexpected, potentially relevant vocalizations in natural communication scenes. Future research should provide further insight into parallels with EEG-recorded MMN, including the "automatic" processing of syntactic patterns.

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Workshop 5

Constructive Approaches to Language Evolution

Organized by:

Reiji Suzuki (Nagoya University)

&

Takashi Hashimoto (JAIST)

Lecture Room 4, 4th floor, Campus Plaza, Kyoto, Japan

13th of March, 2012 9.15 – 15.25

Workshop Description

Constructive approaches, that is modeling, simulation and analysis of emergent phenomena by synthesizing life-like behaviors using artificial media such as computers, robots, etc., have played a significant role in the development of our understanding of the origin and evolution of language over the last two decades. They have allowed us to observe the emergence of linguistic behaviors from communicative interactions between agents, on various levels and timescales, which are not easily observable experimentally.

During this period, several other methodologies have also emerged, which have allowed us to obtain empirical data with regard to language evolution. Experimental approaches to the cultural evolution of language have enabled us to directly observe the emergence of new languages or grammars in use by human participants. The recent progress of new media or information technologies has also allowed us to discover real language changes by analyzing huge linguistic resources, such as google books, etc. Comparative approaches based on data from non-human animal species, such as vocal learning of songbirds, is becoming increasingly significant. In addition, mathematical approaches have contributed to a better understanding of essential aspects of computational models, such as the iterated learning model, etc.

In the light of these recent developments, and progress of interdisciplinary approaches to understanding language evolution, we would like to reconsider the significance of constructive approaches such as computational and mathematical modeling in this workshop. We solicited the submission of papers on language evolution making use of constructive approaches, and invited two speakers to give talks on the significance of these approaches. The authors were requested to make specific mention of how constructive approach can contribute to research on language evolution.

Topics of interest to this workshop include, but are not limited to:

- Simulation and analyses of emergent properties of language evolution based on constructive approaches, including computational and mathematical models.
- How constructive approaches can develop a mutually complementary relationship with other methodologies for investigating language evolution.
- More general discussions of the roles of constructive approaches in scientific research, including language evolution.

Workshop Timetable

9.15 – 9.20	Welcome *Reiji Suzuki (Nagoya University)*
9.20 – 10.00	Invited talk: Modelling and language evolution: beyond fact-free science *Bart de Boer (Vrije Universiteit Brussel)*
	Coffee Break
10.10 – 10.35	Evolution of word frequency distribution based on prediction dynamics *Kazutoshi Sasahara (University of Tokyo)*
10.35 – 11.00	A simple model on the evolution process of herbivore-induced plant volatiles *Yasuhiro Suzuki (Nagoya University), Megumi Sakai (Nagoya University) and Kazuhiro Adachi (Nagoya University)*
11.00 – 11.25	Reconsidering language evolution from coevolution of learning and niche construction using a concept of dynamic fitness landscape *Reiji Suzuki (Nagoya University) and Takaya Arita (Nagoya University)*
11.25 – 11.45	From signs' life cycle regularities to mathematical modelling of language evolution: explaining the mechanism for the formation of words' synchronous polysemy and frequency of use distributions *Anatoly A. Polikarpov (Lomonosov Moscow State University) and Vasiliy V. Poddubny (Tomsk State University)*
	Lunch Break
13.10 – 13.40	Plenary talk: Integrative Approach to Dynamic Feature of Symbolic Communication System *Takashi Hashimoto (JAIST)*
	Coffee Break
13.50 – 14.15	Synthetic modeling of cultural language evolution *Michael Spranger (Sony CSL Paris) and Luc Steels (Sony CSL Paris)*
14.15 – 14.40	Language diversity in the naming game on adaptive weighted networks *Dorota Lipowska (Adam Mickiewicz University)*
14.40 – 15.05	Multilayered formalisms for language contact *Makoto Nakamura (Nagoya University), Shingo Hagiwara (JAIST) and Satoshi Tojo (JAIST)*
15.05 – 15.25	Constructing knowledge: nomothetic approaches to language evolution *Seán G. Roberts (The University of Edinburgh) and James Winters (Cardiff University)*

MODELLING AND LANGUAGE EVOLUTION: BEYOND FACT-FREE SCIENCE

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This paper investigates two pitfalls for computer models of language evolution: fact-free science (models looking for a question to answer) and cargo cult science (models that do not tell us anything that we didn't think already). Three successful lines of research related to computational modeling are investigated: mathematical modeling, experimental iterated learning and reconstruction of language history. It is analyzed why this research has had more impact than computer modeling. It is proposed that attention to what questions are relevant and to methodological rigor are important factors to increase impact.

1. Introduction

A year before the first EVOLANG conference, John Maynard Smith (1995) introduced the term "fact free science" in his review of Depew and Weber's (1995) book *Darwinism evolving*:

> "But first I must explain why I have a general feeling of unease when contemplating complex systems dynamics. Its devotees are practicing fact-free science. A fact for them is, at best, the output of a computer simulation: it is rarely a fact about the world."

Although Maynard Smith's unease was about the complex systems approach to the evolution of organisms, his observation is equally applicable to a complex systems approach to the evolution of language.

It must be noted that Maynard Smith was not against fact-free science per se. Certain fact-free science can be very useful, mathematics and computer science being prime examples. Maynard Smith's unease was about whether complex systems science could make a real contribution to biology:

> "My difficulty, then, is that I do not know what observations complex systems dynamics is trying to explain. It is a theory looking for a question to answer."

This is a criticism that is often (implicitly) raised against computer models of language evolution. The first of two issues this paper raises is how computer models of language evolution move beyond fact-free science.

The second issue has to do with what Richard Feynman (1974) in his commencement address at Caltech – incidentally, a year before the *Origins and Evolution of Language and Speech* conference of the New York Academy of Sciences, the proceedings of which have been published as (Harnad *et al.*, 1976) – has called *cargo cult science*:

> "I think the educational and psychological studies I mentioned are examples of what I would like to call Cargo Cult Science. In the South Seas there is a Cargo Cult of people. During the war they saw airplanes land with lots of good materials, and they want the same thing to happen now. So they've arranged to make things like runways, to put fires along the sides of the runways, to make a wooden hut for a man to sit in, with two wooden pieces on his head like headphones and bars of bamboo sticking out like antennas – he's the controller – and they wait for the airplanes to land. They're doing everything right. The form is perfect. It looks exactly the way it looked before. But it doesn't work. No airplanes land. So I call these things Cargo Cult Science, because they follow all the apparent precepts and forms of scientific investigation, but they're missing something essential, because the planes don't land."

Feynman identifies a number of issues that may cause a scientific endeavor to become a cargo cult. Most of these issues have to do with lack of methodological rigor that allows scientists to fool themselves. While early modeling of language evolution may have suffered from lack of methodological rigor (as did many other early complex systems modeling efforts) more recent work is much more methodologically rigorous. Papers illustrating models with a single run and containing sloppy descriptions are no longer considered acceptable. Moreover, highly abstract models are nowadays considered less interesting than models based on linguistic facts. Yet, recent computer modeling of language evolution may still suffer from a more subtle problem that Feynman (1974) identified:

> "There is also a more subtle problem. When you have put a lot of ideas together to make an elaborate theory, you want to make sure, when explaining what it fits, that those things it fits are not just the things that gave you the idea for the theory; but that the finished theory makes something else come out right, in addition."

This issue is again one that crops up in computer models of complex systems: if the number of parameters of the model is equal to or larger than the number of degrees of freedom of the data that the model attempts to explain, it is always possible to find a good match through parameter tuning. If furthermore there is some leeway in interpreting the results of the model (as there usually is in the relatively high-level models that tend to be used in the field) the risk of the researchers fooling themselves and purveying cargo cult science becomes even bigger. The second issue that this paper raises is therefore how to avoid cargo cult science in models of language evolution.

These issues will be addressed by analyzing the efforts that have been made in previous EVOLANG-conferences to advance the interaction between computer modeling and experiments, and by analyzing successful papers and lines of research that have combined models and the evolution of language.

2. What makes a good modeling paper?

A number of efforts have been made at different EVOLANG-conferences to address the issue of the (lack of) interaction between modeling on the one hand and experimental and observational work on the other. There has been a discussion on this topic at the 2002 conference in Harvard, a tutorial at the 2004 conference in Leipzig and a workshop at the 2010 conference in Utrecht. Although these events may have helped improve methodological quality of modeling papers[1] (as can be observed by comparing early papers on the topic with more recent ones) and increase awareness of the issues, it does not appear that they have resulted in major papers on modeling language evolution.

Another issue that appears to have had little influence on the quality and impact of papers is the sharing of software and the availability of simulation platforms such as Babel (McIntyre, 1998; Loetzsch *et al.*, 2008) and THSim (Vogt, 2003), even though this issue received ample discussion in all the abovementioned events. What does appear to have been influential however, is the online availability of large corpora of data and the availability of a set of tools that have their origins in the study of genetics. Another influential approach is a tendency for computer modelers to do their own experimental work.

It is instructive to look in some depth at three different lines of research that have resulted in high-impact publications, and to investigate how this work has avoided the problems of fact-free or cargo cult science (or not, of course). These lines are mathematical work about language dynamics, work in the area of ex-

[1] On the other hand: improvement of methodological quality appears to be a trend of the general field of computer modeling of life-like phenomena, probably related to the maturation of the field.

perimental iterated learning and work on reconstructing language history using tools from biology. Of course, other lines of work have been successful as well, but these examples have been selected for their high impact.

2.1. *Mathematical modeling of language dynamics*

Agent-based models exploded on the evolution of language scene starting from the mid 1990's (Christiansen, 1994; Steels, 1995; Oliphant, 1996; Batali, 1998; Kirby, 1998) although comparable work had been going on for some years (Hurford, 1989, 1991; Werner & Dyer, 1991). Much of this work was limited to very specialized journals and conferences. In contrast, a few years later Nowak and colleagues published a number of papers about *mathematical* modeling of language evolution in high profile general journals (Nowak & Krakauer, 1999; Nowak *et al.*, 1999; Nowak *et al.*, 2001). Why was it that the mathematical modeling work had a much higher profile than the agent-based work?

Part of the reason was of course that these papers were co-authored by Nowak, who already had a good reputation and experience with publishing in these journals. However, this begs the question somewhat, because why would a scientist with his reputation choose to focus on mathematical modeling rather than agent-based computational modeling?

Perhaps the higher profile can be understood by looking at the level of fact-free-ness and cargo-cult-ness of the research. One could argue that Nowak's research program was equally fact-free as the agent-based modeling efforts, because it used highly abstract mathematical models. In a sense, it was more fact-free than most of the early agent-based models, as these made many attempts at realistically implementing aspects of human cognition and behavior. However, Nowak's work focused on very specific research questions, whereas the agent-based models was mostly done in the spirit – common to much early artificial life work – of "Let's see if we can recreate this kind of behavior in a computer model." Thus Nowak's work avoided Maynard Smith's objection that complex systems work is a theory looking for a question to answer.

Interestingly, the higher complexity of agent-based models may have led to a more reluctant reception. Many of the design decisions made in building an agent-based model of language are relatively arbitrary; after all, even linguists and cognitive scientists do not agree about how language works and how it is implemented in the brain. As the higher complexity does result in less transparency and an increased number of parameters and design decisions, such models become vulnerable to Feynman's subtle problem of cargo cult science. Does the behavior of the model really lead to an increased understanding of the phenomenon, or would a different, possibly much simpler model give the same results? What exactly is the reason the model behaves as it does? And does the model really tell us something new, or does it only conform the biases that were (unconsciously) put in? As mathematical models are simpler, more transparent and, most importantly, can be analyzed uncontroversially with mathematical tools, they are much less vulnerable to Feynman's subtle problem.

Mathematical analysis also makes it easier to do a sensitivity study. This is a study to identify how the model's behavior changes when certain (combinations of) parameters are manipulated. Of course, different parameter values are generally investigated for agent-based models, but this is almost never done with the same rigor as is possible with mathematical models.

A final problem with agent-based models is that because of their complexity, it is often hard to identify the exact difference between models, or to compare their results directly. Even though nowadays models are usually described in a reimplementable way, there is no strong tradition of making only small variations on models and investigating their effect. This lack of systematicity results in young researchers falling into the same pitfalls again and again[2].

Of course, this is not to say that everybody should stop making agent-based models and start making mathematical models. There are certain things that are very difficult if not impossible to model and analyze with standard mathematical tools. However, we should always keep in mind the above-mentioned reasons why mathematical models avoid being either fact-free or cargo cult science. It is therefore important for agent-based modelers to have familiarity with existing mathematical models.

2.2. *Experimental Iterated Learning*

Another line of work that has sprung from agent based modeling and that has resulted in more high-profile publications is experimental iterated learning (Galantucci, 2005; Fay *et al.*, 2008; Kirby *et al.*, 2008; Smith *et al.*, 2008; Scott-Phillips & Kirby, 2010). In this experimental paradigm, cultural learning is studied in a laboratory setting using protocols that have been adapted from earlier computational models (Smith *et al.*, 2003). This experimental adaptation of a computational model has led to a rapidly expanding body of work.

Its popularity is understandable. First of all, it is a new paradigm in which many questions are still open and unexplored. In addition experimental iterated learning work is relatively easy to do. Although it requires large numbers of

[2] Thanks to Willem Zuidema for drawing my attention to these points.

participants, the participants are not from a specific population (as would be the case if in studying e. g. bilingualism, newly emerging sign languages, or specific types of aphasia) and no complex equipment is needed. Finally, experimental science is the opposite of fact-free science and therefore more acceptable than computer models to the general scientific community.

Does experimental iterated learning avoid being cargo cult science, however? Does it teach us something about real human behavior, or only about highly artificial behavior in an experimental setting? Methodologically, experimental iterated learning is in full development, and there is much to learn about how to correctly investigate cultural evolution experimentally. Nevertheless researchers do take care to avoid the methodological pitfalls identified by Feynman, often through cooperation between evolution of language researchers and cognitive scientists (e. g. Smith & Wonnacott, 2010). Therefore, experimental iterated learning is probably not more or less cargo cult science than ordinary cognitive science, and therefore acceptable to a large scientific community.

Again, this does not mean that we should all switch from modeling work to experimental work. After all, it is still very difficult if not impossible to deduce from the experimental results what the exact underlying cognitive mechanisms are. Therefore an interaction between experiment and modeling is probably the best way to achieve insight. Given that more than a few modelers have made the transition and that the cognitive science community appears to be increasingly interested in iterated learning, this may be a promising avenue for modelers.

Of course, interaction between models and experimental and observational work can be successful in other areas. An example is the evolution of anatomy, in which I have made some contributions (de Boer, 2009, 2010, 2011, 2012). However, an emerging consensus appears to be that the crucial innovations in the evolution of language were cognitive. Moreover, there is a lively debate (Evans & Levinson, 2009) about the nature of these innovation and about the roles of culture and cognition. The interaction between culture and cognition is therefore perhaps the more exciting topic.

2.3. *Biological models of language change*

The final type of high profile research that will be discussed here is the reconstruction of language history using techniques from biology (Dunn *et al.*, 2005; Lieberman *et al.*, 2007; Pagel *et al.*, 2007; Atkinson *et al.*, 2008; Atkinson, 2011; Dunn *et al.*, 2011). In this type of research it is attempted to reconstruct the history of groups of languages using large corpora of data and computer models that have been adapted from biology and genetics. Usually the reconstructions are used to draw some conclusions about the nature of the historical processes involved.

Again, an important factor in all these papers is that they have been co-authored by established researchers – often biologists – with strong reputations, but as in the case of mathematical models, agent-based computer modelers need to ask themselves why these researchers invest in this line of work, rather than in agent based modeling. One reason is that this research is definitely not fact-free science: it makes use of large corpora of data. A second reason is that they all address questions that are central to (historical) linguistics. Another reason is that the computational tools used in this research have an established record of success in biology and genetics. It is clear that these models, when used in the context of biological evolution do not lead to cargo cult science.

However, because the models are so well-established, they are often described very incompletely in the papers that use them. Therefore, it is not clear at all how applicable the assumptions made in these models are to cultural evolution of language and there is a risk that these papers are cargo cult science. Atkinson (2011) is a case in point: a more detailed look at the data on which his paper is based reveals his result may be spurious (Ian Maddieson, *personal communication*).

The weakness of these models is that they make certain assumptions about population behavior. Their strength is that given these assumptions, they result in very clear statistics about possible historical scenarios/evolutionary mechanisms. This is in contrast with most agent-based modeling, where in the best cases only a range of values for different random initializations is given. It would be ideal if the strength of agent-based models – the emergence of population behavior from individual behavior – could be combined with the strength of these biological techniques – clear statistics over the likelihood of different scenarios or mechanisms given observational data.

3. Conclusion

The twin pitfalls of fact-free science and cargo cult science are great risks for computational modeling of language evolution. It is easy to construct a model that does not answer a question and is therefore fact-free science. However, just incorporating facts about language and behavior may lead to cargo cult science because the model may have so many degrees of freedom that it is no longer clear whether it really answers the questions that it was designed to answer.

This paper has investigated three lines of research that show that modeling of language evolution can lead to high profile and high quality work. Fact-free modeling is possible, but it needs to be mathematically rigorous in order to be general – this has been called external validation at an earlier EVOLANG workshop on computer modeling (Zuidema & de Boer, 2010). It is also possible for computer modelers to test and investigate their models by reformulating them in terms of real experiments – it really is not that hard to do experiments – or to apply models to large corpora of existing data. This has been called external validation by Zuidema and de Boer (2010).

In all cases it is important to address questions that are relevant to other researchers (thus avoiding fact-free science) and to be as rigorous as possible (thus avoiding cargo cult science). Concerning rigor it may be useful to take inspiration from the biological models that have been used to reconstruct linguistic history. Finally, it is important to keep in mind that we are trying to answer questions about the world, not about our models. Although modelers are often more at home in the abstract world of models and computational abstractions, this is not the world we want to investigate. If we keep in mind these simple points (although it is far from trivial to apply them in practice) computational modeling work will continue to have impact for the field of language evolution.

Acknowledgements

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EVOLUTION OF WORD FREQUENCY DISTRIBUTION BASED ON PREDICTION DYNAMICS

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One of the well-known mathematical natures of language is Zipf's law, which describes that the frequency of any word is inversely proportional to its rank. This empirical law holds for many languages, and has been considered a reflection of economy in linguistic interactions, called 'the Principle of Least Effort' (Zipf, 1949). However, it is suggested that Zipf's law property found in empirical data is of little use to characterize language (Miller & Chomsky, 1963), and much is unknown about how the power law distributions of words arise from linguistic interactions. In this regard, constructive models that explicitly formalize a possible linguistic interaction can play an important role in exploring the evolutionary process of this law.

We assume 'prediction dynamics' as a key factor for the evolution of word frequency distributions. As previous studies showed, recurrent neural networks (RNNs) have a prediction ability, thereby learning simple syntactic structures in a self-supervised manner (Elman, 1998). Thus we take advantage of RNNs to simulate a language evolution driven by prediction dynamics. In this model, an agent is modeled by a RNN, used for both production and prediction of utterances. The dynamics of linguistic interaction, or discourse, between agents is conducted by coupling two RNNs, which are randomly chosen from a population of agents ($N = 20$); one as a speaker and the other as a hearer (Sasahara, Merker, & Okanoya, 2007). When a speaker produces an utterance, a hearer receives it and predicts the speaker's next utterance. This procedure is repeated over a certain length of time, or 'string', during which a hearer learns a speaker's utterances in a self-supervised manner. The discourse is evaluated based on string complexity in both utterance and prediction, and after 1000 discourses, agents leave offspring in accordance with their scores across all discourses (i.e., Darwinian evolution). Note that in this model, string complexity is regulated by agents themselves; complex strings are preferable for speakers; whilst simple predictable strings are preferable for hearers; these two factors compete and balance during evolution. With this specific design of linguistic interaction, we study emergent properties:

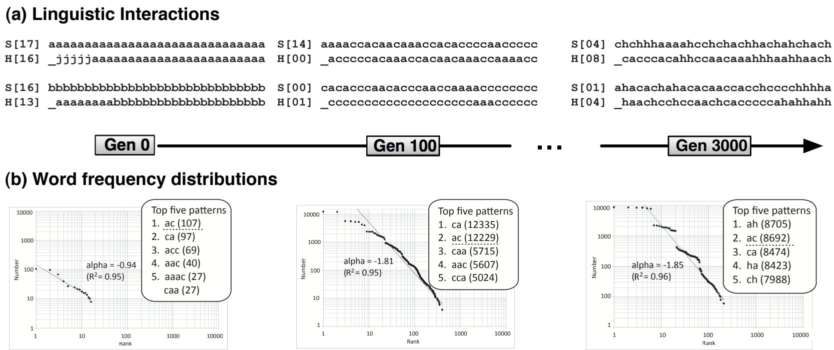

Figure 1. (a) Utterance stings of speaker (S) and prediction strings of hearer (H); (b) Word frequency distributions with the ranking of popular words

how words emerge, and how word frequency distribution evolves.

Figure 1 shows an example of language evolution in this model. This simulation demonstrates that the prediction dynamics can lead the transition from a simple repetitive language (e.g., ‘a’ and ‘b’ in Fig.1(a)) to a more structured language, during which popular words are transmitted from one generation to the next (e.g., ‘ac’ in Fig.1(b)). Further, the word frequency becomes power law distributions after 100 generations (before that, the size of common words are small). These findings suggest that the prediction dynamics can be an evolutionary driving force to diversify and constrain word frequency distributions. This result is contrasted with Ferrer i Cancho and Sole (2003), in which they demonstrated that the power law is observed in the transition from referentially useless system to indexical reference system. By introducing semantic constraint into this model, language may become more structured, providing further hints on Zipf’s law.

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A SIMPLE MODEL ON THE EVOLUTION PROCESS OF HERBIVORE-INDUCED PLANT VOLATILES

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We consider a simple model of the evolution of Hervibore Induced Plant Volatiles (HIPV), which mediate tritrophic (plants-herbivores-carnivores) interactions. We focus on cry wolf plants, which cheat carnivores by producing false HIPV. The evolution process of such HIPV has been likened to that of language, and has been traditionally modelled using evolutionary game theory. In this contribution, we devise a simpler model using the Polya's urn, a well-known stochastic model, as the base. We show that our model exhibits the evolution process of HIPV satisfactorily.

1. Background

The evolution of Herbivore-Induced Plant Volatiles (HIPV) shares common traits with the evolution of language (van Baalen et al., 2003; MI. A. Traulsen, 2007). In the evolution of language, a mutation is reflected by the change of symbols, and through natural selection, the mutated symbols become understandable and widely used. Likewise, in the evolution of HIPV, a mutation brings about a change in herbivore-induced volatile chemicals, and natural selection enables the mutated HIPV to become understandable and widely used in the ecosystem. A plant changes the response to its feeding damage through mutations. In this paper, we assume that a plant produces HIPV when it has large feeding damage, and when there are enough herbivores for predators (we will call such a plant as an 'honest plant'.) However, on account of mutations, these plants are able to change their response to produce HIPV even if there are not enough herbivores (Shiojiri et al. 2010) (we will call such a plant as a 'cry wolf plant'.)

1.1. *Basic Idea*

When the number of cry wolf plants increase, predators somehow become aware of the worthlessness of HIPV, and hence, are not attracted to it to the extent they normally would be. As a result, honest plants have to produce a different type of HIPV in order to survive. We assume that if mutated plants continue producing HIPV similar to that being produced before mutation, it can attract predators efficiently (however, this efficiency would be lower than the efficiency of HIPV produced before mutation, given that predators would take time to become accustomed to the newly produced HIPV). On the other hand, if mutated plants produce HIPV which is not similar to that produced before mutation, it cannot attract predators efficiently. However, if predators can learn to respond to this HIPV, its efficiency may exceed the original, because in such a case, there would be almost no cry wolf plants which could produce the HIPV. In the event cry wolf plants mutated and produced totally new HIPV, if no honest plants could produce the same HIPV, predators would never learn to respond to it, and such cry wolf plants would go extinct.

2. Method

For modelling the population of HIPV, we use the simple stochastic model called 'Polya's urn'. In this model, when a 'black ball' is picked, n black balls are returned the urn so the probability of selecting black balls increases. We labelled the HIPV produced by every honest plant and every cry wolf plant as a positive and negative natural number respectively. For example, the label '1' indicates HIPV produced by honest plants, while '-1' indicates the same HIPV produced by cry wolf plants. Note that predators cannot distinguish between '1' and '-1'. In order to model the memory of predators, we compose the Polya's urn using the First In, First Out (FIFO) queue. The FIFO queue has a fixed length. When the queue is full and a new item needs to be added to it, the top-most item in the queue is deleted (i.e. it leaves the FIFO queue). If the memory of the HIPV has been erased, no predators are attracted by it, and hence, the population of plants producing such HIPV would decline on account of feeding damage. On the other hand, if the memory of the HIPV has been enhanced, a greater number of predators would visit such plants, thereby increasing their numbers. Therefore, we can say that the population dynamics of HIPVs in the predator's memory also reflects the population dynamics of the plants.

3. Model

We model the population dynamics of HIPVs and predator memory using the Polya's urn composed of a FIFO queue. For example, when the capacity of the urn is 4 and predators memorize the HIPV 1, 3, 2, 1 in the given order, then the FIFO queue in the urn is 1|3|2|1. The predators are attracted by the HIPV depending on the probability of selection of a label from the urn. In this case, the probability of selecting 1 is 2/4, 2 is 1/4 and 3 is 1/4. When 1 is selected from the urn, then two 1s are returned to the urn, thereby modifying 1|3|2|1 to 1|1|1|3 (i.e. 1 and 2 are deleted). Hence, the population of plants producing 1 is increased, while those producing 2 become extinct. Also, the memory of the predators is enhanced to be attracted by 1, and does not to be attracted by 2. When cry wolf plants emerge, the selection probability changes; in such a case, the selection probability of label i is defined as N (the difference between i and -i) / total number of labels = P_i), where N( ) denotes the normalization of P_i values for satisfying ΣP_i = 1.0. For example, the P_1 of -1|1|1|3 is (2 - 1) / 4 = 1/4, P_-1 = 1/4, P_3 = 1/4, and after normalization, P_1 = P_-1 = P_3 = 1/3. Hence, as the number of cry wolf plants producing i increase, the selection probability of HIPV i may decrease. This means that predators learn that HIPV i is a cry wolf signal.

3.1. *Mutation*

- Mutation from Honest to Cry Wolf

When a positive label (HIPV of honest plants) is selected and changed to a negative label (HIPV of cry wolf plants) according to the given probability, and m flipped labels are returned to the urn, we do not assume that a cry wolf plant becomes an honest plant again. For example, when m = 2, the FIFO queue in the urn is 1|2|1|2, and 1 is selected and it flips to cry wolf, then the FIFO queue in the urn changes to -1|-1|1|2.

- Mutation in HIPV

A selected label is rewritten as another label according to the mutation probability and n labels are returned to the urn; thus a cry wolf plant can also change its HIPV. The mutation probability is proportional to the difference between the labels; for example, the probability of mutating from 1 to 2 is higher than that of mutating to 1 from 10. For example, when n = 2, the FIFO queue in the urn is 1|2|1|2, and 1 is selected and mutated to 3, then the FIFO queue in the urn changes to 3|3|1|2.

3.2. *Natural Selection*

The number of selected labels to be returned to the urn is analogous to natural selection. We assume that the number of returning labels is proportional to the scarcity of that particular label type; if the selected label is produced by honest plants and is also scarce, then there would be very few cry wolf plants producing this HIPV, and thus, the label would be of particular significance to predators. Hence the number of such labels being returned to the urn should exceed the other (abundant) labels. In this preliminary study, the number of returning labels i of an honest plant is defined as $I_i = 1 + \{(s(\text{total number of labels}) / a(\text{total number of } i))\}$, where the parameter s denotes the predator's search ability ($0.0 < s < 1.0$). Therefore, if their search ability is low, the predators would find it difficult to discover scarce HIPV. The parameter represents the degree of increments. In addition, when the selected labels depict the HIPV of cry wolf plants and are scarce (less than the given constant), no labels would be returned to the urn. While the probability exceeds the constant, the increment of label i is given by $b \times I_i$, where b denotes the benefit to the cry wolf plants compared with that to the honest plants. Furthermore, we assume that the benefit to the cry wolf plants is less than that for the honest plants ($0.0 < b < 1.0$).

4. Results

When the mutation rate of flipping from honest plants to cry wolf plants is larger than (Fig. 1) or equal to (Fig. 2) the mutation of the HIPV signal, the number of cry wolf plants overtakes the number of honest plants.

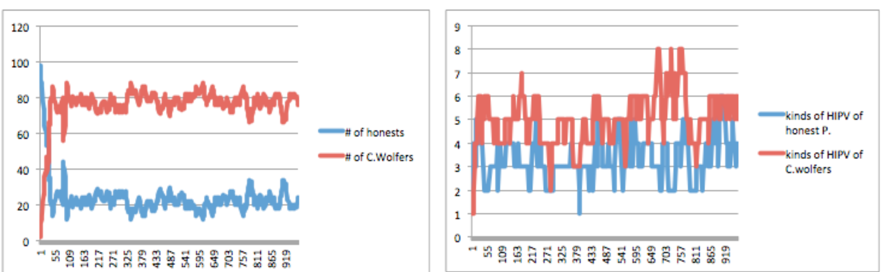


Fig. 1. The mutation rate of flipping from honest to cry wolf (0.6) exceeds the mutation of HIPV (0.3). (Left) The population dynamics of HIPV of honest plants and cry wolf plants. The vertical and horizontal axes illustrate the number of honest plants and cry wolf plants, and step time respectively. (Right) Kinds of HIPVs in honest plants and cry wolf plants. The vertical and horizontal axes illustrate the kinds of HIPV and step time respectively.

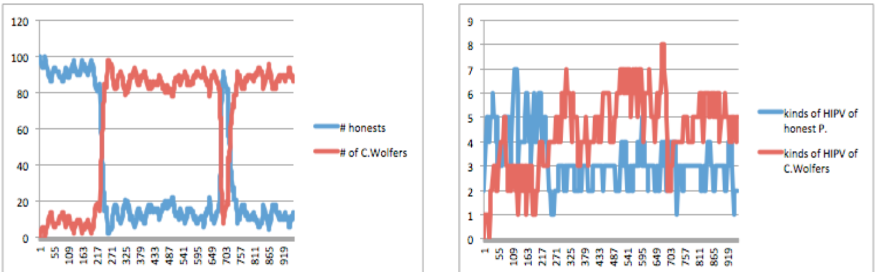


Fig. 2. The mutation rate of flipping from honest to cry wolf equals the mutation of HIPV (0.3). (Left) The population dynamics of HIPV of honest plants and cry wolf plants. The vertical and horizontal axes illustrate the number of honest plants and cry wolf plants, and step time respectively. Mostly, the number of cry wolf plants overtakes the number of honest plants. (Right) Kinds of HIPVs in honest plants and cry wolf plants. The vertical and horizontal axes illustrate the kinds of HIPV and step time respectively.

Additionally, when the mutation of HIPV is larger than mutation rate of flipping from honest plants to cry wolf plants, then the number of honest plants overtakes the number of cry wolf plants (Fig. 3).

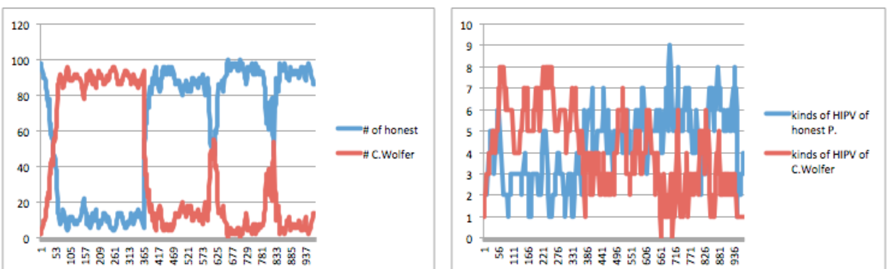


Fig. 3. The mutation rate of flipping from honest plants to cry wolf plants is 0.3, and the mutation of HIPV is 0.6. (Left) The vertical and horizontal axes illustrate the number of honest plants and cry wolf plants, and step time respectively. The number of honest plants overtakes the number of cry wolf plants. (Right) Kinds of HIPVs. The vertical and horizontal axes illustrate the kinds of HIPV and step time respectively.

These results also illustrate that plants that can generate various HIPVs are able to overtake other plants (that cannot generate as many HIPVs) in number; this is because such plants can run away from other plants that generate HIPVs.

These population dynamics change when the search ability of predators declines. Our model reveals that predators having high search ability are able to discover scarce HIPVs; in another words, such predators are sometimes attracted by unknown HIPVs, unlike predators having low search ability.

Hence, it follows that in the cases where predators have high search ability, even if the plant produces scarce HIPV on account of mutation, predators are able to detect the new HIPV.

Once it becomes commonly used (due to natural selection), previously scarce HIPV types become more frequent. On the other hand, in the event predators have low search ability, they are unable to detect plants producing scarce HIPVs. The variety of HIPVs may consequently reduce, thus making it relatively easier for cry wolf plants to catch up with the production of new HIPVs, and thereby outnumber the honest plants (Fig. 4 and Fig. 5).

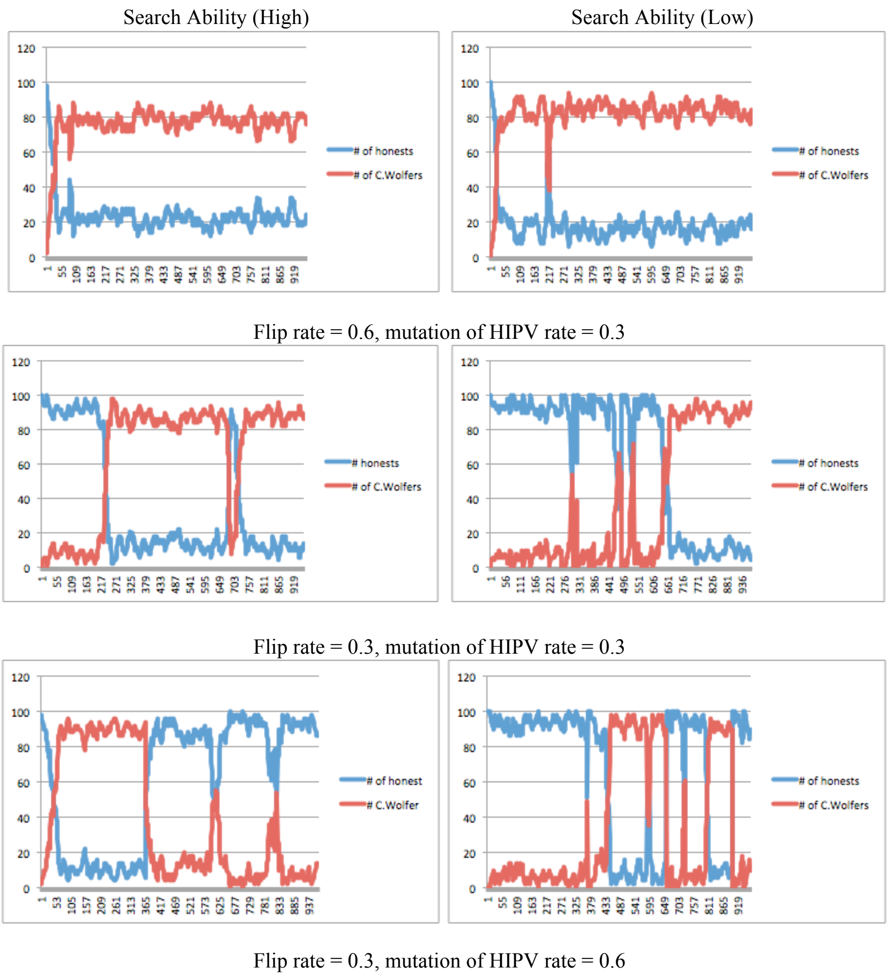
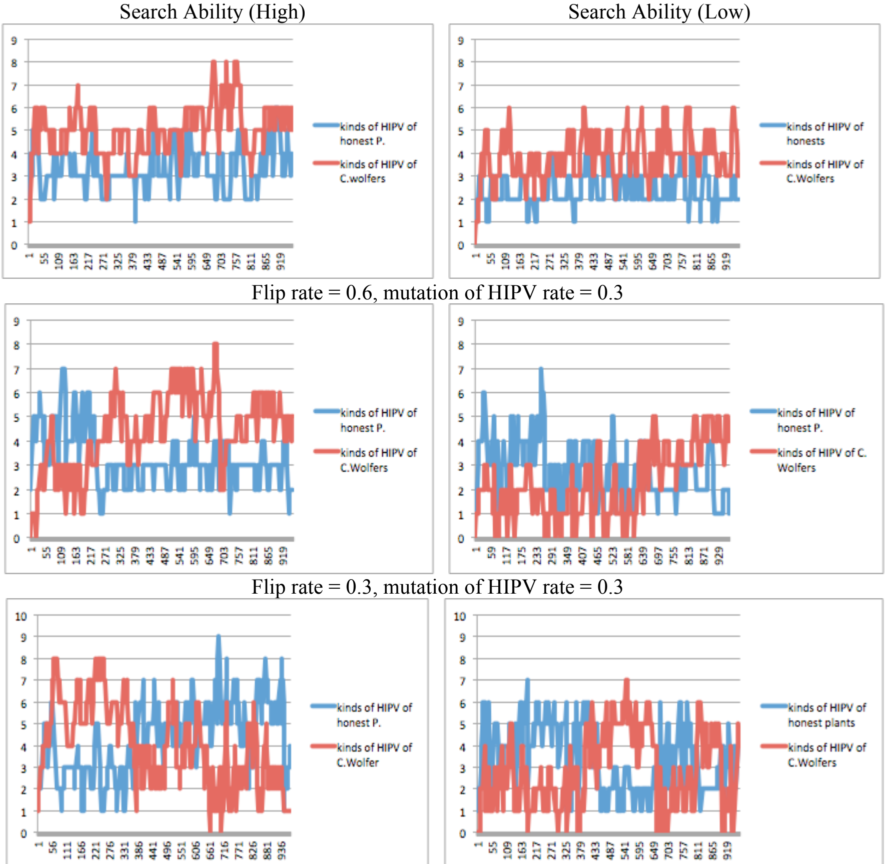


Fig. 4. The population dynamics of HIPV relative to changes in search ability of predators. The vertical and horizontal axes illustrate the number of honest plants and cry wolf plants, and step time respectively. This simulation predicts that when predators have low search ability, cry wolf plants are twice as likely to overtake and eventually outnumber the honest plants.

Search Ability (High) Search Ability (Low)



Flip rate = 0.3, mutation of HIPV rate = 0.6

Fig. 5. Kinds of HIPVs relative to changes in search ability of predators. The vertical and horizontal axes illustrate the kinds of HIPV and step time respectively. This simulation predicts that when predators have high search ability, they are able to detect scarce HIPV.

5. Summary

We devised a preliminary model investigating the evolution of HIPV signals by using the Polya's urn, a well-known stochastic model. The simulations prove that irrespective of the plant being an honest plant or a cry wolf, plants producing more kinds of HIPV would be able to gradually outnumber those that produce less. In addition, we examined the effect of the search ability of predators and confirm that when search ability is high, predators are attracted to scarce HIPVs among the various HIPV kinds in the ecosystem. On the other hand, when search ability is low, since predators are not attracted to scarce HIPVs, their variations become small, and cry wolf plants invade the territory of honest plants and eventually outnumber them.

6. Future work

In the near future, we intend to upgrade the model employed here to a Cellular Automaton. Our preliminary investigation shows that the cry wolf plants can take advantage of honest plants when HIPV cannot evolve. On the other hand, when HIPV can evolve, honest plants tend to take over the cry wolf plants (Fig.6). We aim to conduct additional simulations by changing the parameters and making suitable refinements to the model.

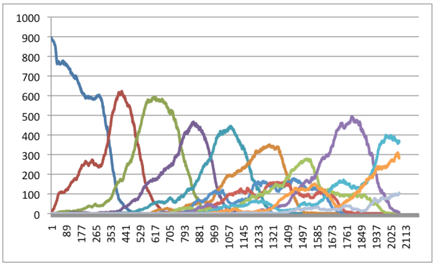


Fig. 6. Population dynamics of cry wolf plants and honest plants in the one-dimensional model. The vertical and horizontal axes illustrate the biomass of plants and step time respectively. We observe a population increase in four plants only; the rest are honest plants.

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RECONSIDERING LANGUAGE EVOLUTION FROM COEVOLUTION OF LEARNING AND NICHE CONSTRUCTION USING A CONCEPT OF DYNAMIC FITNESS LANDSCAPE

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Roles of ecological processes in evolution are attracting much attention in evolutionary studies. Learning and niche construction are regarded as ecological processes that can affect the course of evolution directly or indirectly. However, the effects of mutual interactions between them on evolution are still poorly understood, despite that both seem indispensable factors for understanding language evolution. The purpose of this paper is to provide a novel insight into language evolution from the view point of coevolution of learning and niche construction. We introduce two abstract and computational models, as example situations of direct and indirect interactions between these two ecological factors of different individuals in the context of language evolution. They show that interaction between these ecological factors can bring about complex and adaptive evolution dynamics. Another purpose is to propose a concept of dynamic fitness landscape in order to understand the emerged scenarios of complex and adaptive coevolution. We believe that the obtained findings can contribute to understanding of language evolution in that they reflect some possible scenarios of language evolution.

1. Introduction

In the standard view of the modern evolutionary synthesis, organisms are regarded as passively evolving entities based on selection and mutations. However, there are two ways, based on ecological activities, for modifying the selection pressure as conceptualized in Fig. 1 (a). One way is for individuals to change their own phenotype, called learning. A wide variety of species have abilities to modify their own traits to make themselves more adaptive in their existing environments. It has been controversial how this ecological process, called individual learning or ontogenetic adaptation based on phenotypic plasticity, can affect evolution indirectly. The other way is to change their environmental condition, called niche construction. Specifically, niche construction is an ecological process, performed by organisms that modify their own niches or the niches of others, altering selection pressures through their ecological activities by changing their external environments (Odling-Smee & Laland, 2003). The roles of these ecological processes in evolution are attracting much attention in evolutionary studies called Evo-devo (West-Eberhard, 2003) or Eco-devo (Gilbert & Epel, 2009).

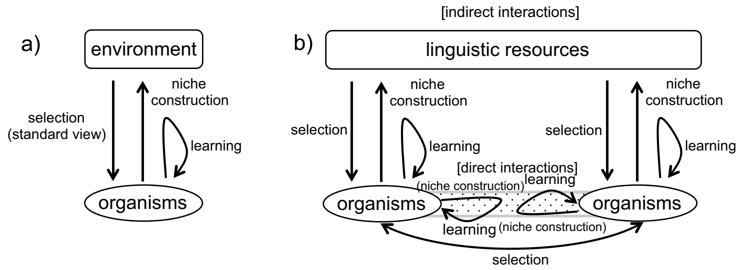

Figure 1. (a) Two processes affecting the selection. (b) Two possible ways of interactions between learning and niche construction in the context of language evolution.

So far, the effects of individual learning and niche construction on evolution have typically been analyzed separately. We can interpret them as different processes in that the former is a change in the phenotype of the learning individual itself and the latter is the change in the surrounding environment of the niche-constructing individual. However, it is clear that both processes can interact with each other through changes in the relationship between the environmental conditions and individual phenotypes, suggesting that both processes can co-evolve in complex ways.

Language evolution appears to exemplify such situations, in that their mutual interactions were implicitly incorporated. Especially, if we focus on mutual effects of these ecological factors between individuals, there are two possible ways of their interactions in the context of language evolution, as shown in Fig. 1 (b). One is indirect interactions of learning and niche constructing behaviors between individuals based on a sharing of linguistic resources. A linguistic activities of an individual can create or modify linguistic resources in the external environment. This could be interpreted as a kind of niche construction because it can affect learning process (and thus adaptive properties) of other individuals based on the shared linguistic resources. The other is direct interactions among individuals based on communicative interactions. In this case, an environment of an individual is composed of phenotypes of other individuals. Thus, learning process of an individual itself performs a niche construction for other communicating individuals, because changes in the phenotypes of an individual by learning can also affect the learning process (and thus adaptive properties) of other individuals.

The main purpose of this paper is to provide a novel insight into language evolution from the view point of coevolution of learning and niche construction. We introduce two abstract and computational models as examples of the two possible ways of interactions in Fig. 1 (b). The first one focuses on indirect interactions among individuals based on niche construction of a shared environment. The second one focuses on direct interactions among individuals in dynamically changing environments arising from communicative interactions. They show possible scenarios that a complex and adaptive coevolutionary process can emerge when we consider coevolution of these factors.

Another purpose is to propose to use a concept of dynamic fitness landscape in order to better understand the emerged scenarios of complex and adaptive coevolution. In these kinds of models, there are various factors that can modify adaptive properties of individuals. Thus, tracking such dynamic changes in adaptive properties is a key to understand the scenario of the complex evolution process, and also a key to obtain general findings from the results of specific models. By using this concept, we explain the cyclic coevolution of learning and niche construction emerged in the first model, and the adaptive evolution of communication abilities through repeated occurrences of the Baldwin effect in the second model. We also discuss the relationships of these phenomena with several hypothetical discussions on language evolution.

2. A coevolutionary model of learning and niche construction of a shared environment

2.1. *Model*

In the first model (Suzuki & Arita, 2010), we focus on indirect interactions among individuals based on niche construction of a shared environment. An environmental state shared by all N individuals is represented as a single real value e ($\in [0,1]$). Each agent has a real-valued phenotype p ($\in [0,1]$) whose initial value is determined by its genotype g_p ($\in [0,1]$). The fitness contribution of p depends on e, and is determined by the triangular shaped function (with base length $2L$) as shown in Fig. 2. The closer each agent's p is to e, the more fit it is.

Furthermore, each agent has real-valued genes for learning g_l ($\in [0,1]$) and niche construction g_n ($\in [-1,1]$). A learning process of each individual moves its phenotypic value p closer to e by (at most) g_l to increase its fitness contribution.

In addition, each individual can perform either positive or negative niche construction, which means that a niche construction can increase or decrease the fitness of the performing individual. This is due to the fact that niche construction is not always beneficial for performing individuals (i.e., there may be environmental pollution). When g_n is positive, niche construction moves e closer to its p by (at most) g_n. On the other hand, if g_n is negative, it makes e more distant from its p by $|g_n|$ within the range of the domain of $e \in [0,1]$. Fig. 2 shows example behaviors of learning and positive niche construction.

In each generation, there are T sets of ecological processes, in each of which there are N steps. In each set, the individuals randomly decide which kind of ecological process to perform. An individual who has not done its ecological process yet in the current set is randomly selected and performs an ecological process. The final fitness of each individual is defined as the average fitness contribution

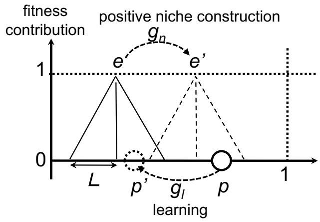

Figure 2. A learning and a niche construction in the proposed model.

evaluated in all $T \times N$ steps. The evolutionary process uses a "roulette wheel selection" (in which the probability that an individual will be chosen as an offspring is proportional to its fitness). For each gene, a mutation occurs with a small probability p_m, which randomly determines its genotypic value.

The model incorporates a mechanism called ecological inheritance, where an environmental state can be passed on to the next generation. In this model, the value of e at the last step in the previous generation is used as the initial value in each generation.

If we regard the horizontal axis as a space of possible languages and each agent having a specific language determined by its p, the value of the environmental state e can be regarded as the most adaptive language due to the accumulation of linguistic resources, which can contribute to its fitness increase, for example. In this case, a learning behavior corresponds to the process in which each agent changes its own language to a more adaptive one in its current linguistic environment, and a positive or negative niche construction corresponds to the production of linguistic resources which can make its own language more or less adaptive.

2.2. *Results and discussions*

We conducted evolutionary experiments for 2000 generations using the following parameters: N=250, T=300, L=0.1, p_m=0.05. In the initial population, the values of genotypes g_p, g_l and g_n were randomly decided within their domains, and the environmental state e was set to the intermediate value 0.5.

We focused on the evolutionary trajectory of g_l and g_n shown in Fig. 3. The horizontal axis is the average g_n and the vertical axis is the average g_l among all individuals at each generation. Although there were large fluctuations, we could see a cyclic evolutionary behavior of both indices, in which four typical states from (i) to (iv) (in Fig. 3) were traversed in a clockwise fashion. This means that the evolutionary trend of learning behaviors was strongly affected by existing niche-constructing behaviors and vice versa.

The detailed analyses (see (Suzuki & Arita, 2010)) showed that changes in the stability of the environmental state arising from positive and negative niche con-

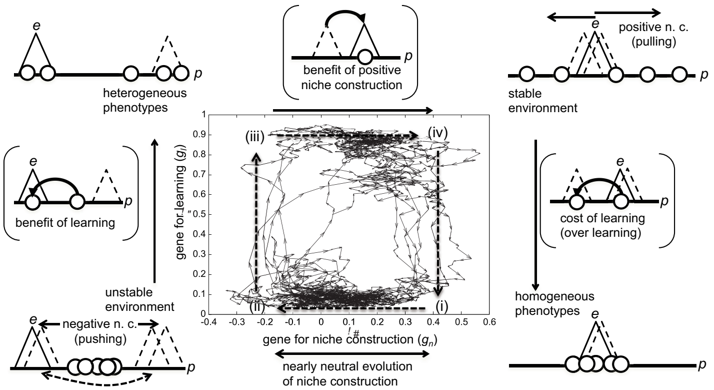

Figure 3. An example evolution of the average g_l and g_n. The subfigures around (i)-(iv) represents the state of the population, and the other subfigures between them represents the adaptive property of learning or niche-constructing behaviors that brought about adaptive evolution.

structions is a key factor that dynamically determines the benefit and cost of learning behaviors. Fig. 3 also shows a schematic image of transitions between these states using a concept of dynamic fitness landscape of phenotypes. In this model, collective behaviors with positive and negative niche construction tend to make the environment state stable and unstable, respectively. In a cycle, negatively niche-constructing individuals can occasionally dominate the population (ii), as a result of the neutral evolution of niche constructing gene (i) due to the loss of phenotypic variation in the previous cycle. In this state, the learnable individuals occupy the population (iii) because they can catch up with rapid changes in the shape of the fitness landscape. This causes the loss of selection pressure on initial phenotypes. Thus, positively niche-constructing individuals dominate the population (iii) due to the adaptive environmental modification toward individuals' own phenotypes, which makes the environment stable. Finally, the non-learnable individuals with intermediate initial phenotypes occupy the population (iv) by keeping their phenotype around the peak of the stable fitness landscape. This is because excess learning sometimes yields a kind of over learning toward exceptional fluctuations of the environment. These complex relationships among the genes for learning, niche-construction, and initial phenotype brought about the cyclic behaviors.

3. Evolution of communication levels and their learning abilities

3.1. *Model*

In the second model (Suzuki & Arita, 2008), we focus on direct interactions among individuals in dynamically changing environments arising from communicative interactions in which a learning behavior of an individual performs niche

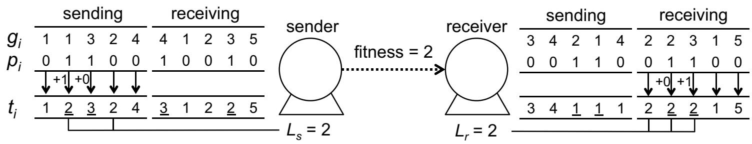

Figure 4. Example of genetic information and communication (M=5). The underlined values t_i are plastic traits (p_i=1), thus their values are slightly different from the initial (genetically determined) values g_i. The number of the traits with the value of 2 is equal or larger than 2 in the corresponding set of traits for both individuals. As a result, this communicative interaction is successful, and they obtain the fitness 2.

construction for other individuals.

There are N individuals in a population. Each individual has two different integer values for communicative interactions: the individual's levels of adaptive communication for signaling and receiving a signal L_s and L_r. Each level is derived from the corresponding set of trait values t_i ($i = 1, \cdots, M$) of each individual, respectively. The chromosomes of integer values g_i and binary values p_i of each individual determines the initial (genetically determined) values of t_i and their plasticity (plastic (1) or not (0)), as shown in Fig. 4. We assume that each individual uses the maximum value n as its communication level, satisfying the condition that the number of traits with a value of n in the trait set is equal or larger than n. This reflects that the higher the communication level, the smaller the probability that it can be acquired both genetically and ontogenetically.

In each generation, the N signaller - receiver pairs are randomly arranged under the condition that each individual becomes a signaler once and becomes a receiver once. There are $C + 1$ steps of communicative interaction for each pair, and each pair start to communicate using their initial levels. A communication is successful only when the communication level of the signaler (L_s) and the receiver (L_r) are the same, and yields a fitness contribution that is the same as their shared level. Otherwise, they obtain no fitness contribution. In subsequent steps, both individuals try to use a new level calculated from a trait set in which plastic trait values are stochastically modified by one (or not changed) from their initial value. Then, they actually adopt the most adaptive pair of levels so far.

These assumptions reflect the following two general properties of communicative interactions: more adaptive methods of communication (e.g. channels, protocols, rules, linguistic conventions, etc.) might depend on more constrained cognitive traits, and their adaptivity also might depend on the coherence of those methods with methods used by other individuals. The communicating individuals can establish more adaptive and coherent methods through trial-and-error learning processes based on their adaptive plasticity.

The *lifetime fitness* of each individual, which is used for reproductive process, is defined as the average among the fitness contributions in its all-participating

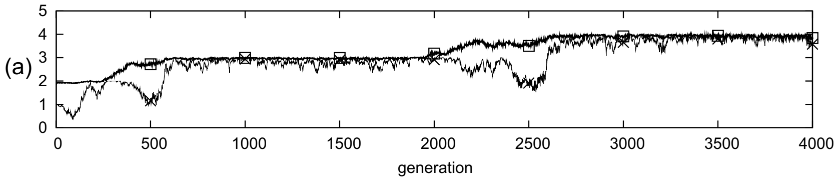

Figure 5. Evolutionary dynamics with learning (C=20). Average lifetime (upper line with box) and innate (lower line) fitness.

steps. In addition, so as to measure the innate adaptivity of each individual, we pick up the (genetically determined) fitness contributions at the initial step in its all participating communicative interactions, and define the average among them as the *innate fitness*. The offspring in the next generation are selected by "roulette wheel selection" from the current population with mutations.

3.2. *Results and discussions*

We conducted evolutionary experiments using the following parameters: N=200, M=10. The initial population was generated on the condition that the initial levels were all 1. We adopted this initial condition to observe the adaptive evolution from the state in which the individuals have established a lowest level successful communication. The control experiment with no learning (C=0) showed that the lifetime fitness remained approximately 1.0, which is expected due to strong positive frequency dependent selection on the majority of the individuals.

Fig. 5 shows the typical transitions of the lifetime and innate fitness with a learning process (C=20). It clearly shows that both the average lifetime and innate fitness gradually increased to 4.0, which means that learning guided the adaptive evolution of innate communication abilities. The detailed analyses (see (Suzuki & Arita, 2008)) showed that this adaptive evolution was due to the repeated occurrences of the Baldwin effect. In Fig. 5, we see several transitions of the average fitness through which the lifetime fitness increased while the innate fitness slightly decreased, and then the innate fitness subsequently caught up with the lifetime fitness. Each transition can be regarded as a single occurrence of the Baldwin effect composed of three steps.

This three-step evolution based on the Baldwin effect can be summarized by using a concept of a dynamically changing fitness landscape as illustrated in Fig. 6. The essential point of this scenario is that learning can move the peak of fitness landscape, and thus can move the population toward the new peak. If the population exists on a single peak of the innate level L as shown in Fig. 6 (i) by sharing the level L among all individuals, the population can not move at all if the individuals do not have any learning abilities. This is because mutant individuals with the level $L+1$ cannot succeed in communications with the existing level L.

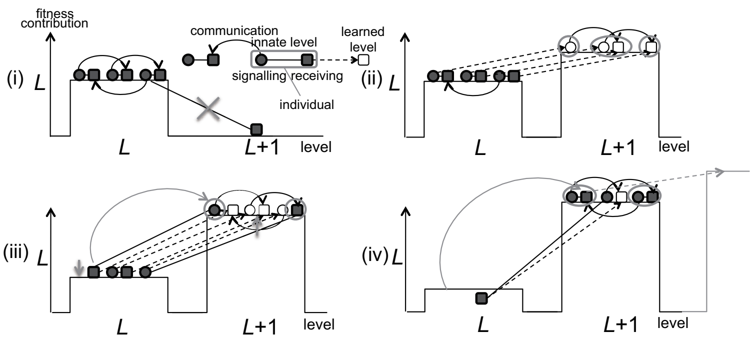

Figure 6. A conceptual image of the evolution of the population on dynamic fitness landscapes. The innate communication levels of each individual are represented as a connected set of a circle (signalling) and a square (receiving) filled in dark gray. The x-axis corresponds to the value of their levels (L or $L+1$). The learned level of the individual is also represented as an open circle or square, which is connected with the innate one. Each arrow represents the communication between two individuals.

However, if both communicating individuals have an ability to adjust their own levels depending on their counterpart's levels (Fig. 6 (ii)), they can invade into the population. This is because such individuals can improve their communication level ($L+1$) without discarding successful communications with the dominant level L, which means that the synergy of learning and its niche-constructing effect on other individuals play an important role in this scenario. This is illustrated as an appearance of another peak of the level $L+1$. These acquired phenotypes are genetically assimilated due to the implicit cost of learning (the lower fitness contribution due to unsuccessful communication based on trial-and-error learning in the initial few steps) as in Fig. 6 (iii) and (iv).This scenario can occur repeatedly because the assimilated innate levels could be used as a scaffold for learning of the more adaptive communication levels. These results clarify that if an ecological behavior plays both roles of learning and niche construction, the evolution of such behaviors can have significant effects on adaptive evolution of the population.

4. Implications for language evolution

We have shown that coevolution of learning and niche construction can bring about complex and adaptive evolution of a population of directly and indirectly interacting individuals. Several researchers have discussed the significance of mutual interactions between genetic evolution of linguistic ability and cultural evolution of language (Deacon, 2003; Godfrey-Smith, 2003; Jablonka & Lamb, 2005). Also, the Baldwin effect has been discussed in the context of language evolution, and several computational studies discussed how and what kind of linguistic abilities could be genetically acquired through the Baldwin effect (Turkel, 2002; Munroe & Cangelosi, 2002; Chater, Reali, & Christiansen, 2009; Yamauchi & Hashimoto, 2010). We discuss some implications of the findings obtained from our simple models for language evolution.

The first model showed that a cyclic coevolution of genes for learning and niche construction can occur under the assumption of indirect interactions among individuals via niche construction of a shared environment. In this model, the phenotype p of each individual might reflect its I-language, and the environmental value e might reflect the accumulation of adaptive E-languages of individuals. Our results imply that the intrinsic dynamics of coevolution of the abilities of learning a language and constructing a linguistic niche can bring about the dynamic and diverse aspects of language evolution even without any effects from external environments.

The second model showed that learning facilitates the evolution shared communication level through the repeated occurrences of the Baldwin effect if learning also performs niche construction for other individuals. Pinker and Bloom pointed out that comprehension abilities do not have to be in perfect synchrony with production abilities because comprehension can use cognitive heuristics to decode word sequences even in the absence of grammatical knowledge. Furthermore, the selection pressure on such an adaptive decoding process brings about a kind of innate grammatical module through the Baldwin effect (Pinker & Bloom, 1990). The process in which the learned level for receiving becomes innate through genetic assimilation could be regarded as an example of such a scenario, although there is no asymmetric relationship between signaling and receiving behaviors in our model. Also, the repeated occurrence of this process might correspond to the *assimilate-stretch principle* proposed by Jablonka (Jablonka & Lamb, 2005).

It also should be noticed that, as shown in Fig. 3 and Fig. 6, it is quite helpful to use the concept of a dynamic fitness landscape in order to understand the essential factors in these complex adaptive phenomena, and to obtain general findings from the specific models.

5. Conclusion

We introduced our two computational models for coevolution of learning and niche construction, showing the emergence of a complex and adaptive process of coevolution of both behaviors using the concept of dynamic fitness landscape. We also discussed some implications of these findings for language evolution.

When we interpret these models as a model of language evolution, one problem arises, that each model only focuses on either direct or indirect interactions among individuals. Thus, we are developing an integrated computational framework for investigating possible scenarios of genetic and cultural evolution of language from the viewpoint of coevolution of learning and niche construction of language (Azumagakito, Suzuki, & Arita, in press).

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FROM SIGNS' LIFE CYCLE REGULARITIES TO MATHEMATICAL MODELLING OF LANGUAGE EVOLUTION: EXPLAINING THE MECHANISM FOR THE FORMATION OF WORDS' SYNCHRONOUS POLYSEMY AND FREQUENCY OF USE DISTRIBUTIONS

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On the basis of assumptions present in the linguistic Model of Signs' Life Cycle an attempt is undertaken to build a mathematical model for revealing some mechanisms of evolutionary processes in Language. For this purpose the dissipative stochastic dynamic model of the language signs evolution is proposed, satisfying the principle of the least action - one of the fundamental variational principles of the Nature. The model assumes the Poisson nature of the language signs birth flow and the exponential distribution of signs' associative-semantic potential (ASP). The model makes it possible to deduce equations for synchronous (momentary) lexical polysemy and rank-frequency distributions. The model values parameters do not differ significantly (by Kolmogorov-Smirnov's test) from empirical values of polysemy and frequency of use distributions for lexical units, chosen from representative Russian and English explanatory and frequency dictionaries.

1. Introduction

In some of previous works of one of the authors there was developed and tested on the available material a linguistic evolutionary model based on regularities of a typical language sign life cycle – from language sign inception to its falling out of use (Polikarpov, 1988; 1993; 2004; 2006; Polikarpov, Kukushkina, Toktonov, 2008). On the basis of this approach further an attempt was undertaken of mathematical modeling of language signs life cycle by applying the splitting processes theory (Khmelev, Polikarpov, 2000). The present paper is another one in a series of studies undertaken by the authors on the creation and experimental verification of some novel language evolution mathematical model, namely, a stochastic dynamic model of evolution of language sign ensembles (Poddubny, Polikarpov, 2011) with a special accent on polysemy and frequency of use features of lexical units.

2. Linguistic preconditions for the construction of the model

Certain dissipative microprocesses invariably occurring in some degree to any sign in each communicative act constitute the core of the basic evolutionary microdynamics of any national language. Each communicative act in its basic functional nature is an act of *hinting* of the sender to the recipient at a certain sense (target image). Hinting is possible, first, by means of the sender's directional choice of a sign *meaning* which is closest to the target sense among all those meanings of the language signs in common use for both communicants. Second, hinting is possible by means of sending a sign, an object associated in communicants' memory with a chosen meaning. Third, it is possible by means of active recipients attempts to *guess* what meaning of a sign sent to him and what specific sense (from a meaning's sense area) were meant by a sender. The heuristic *hinting-guessing principle* of the use of signs' meanings determines the fact that in each communicative act there exists a principle dominating possibility of *widening, continuous expansion of the sense area for each of the meanings*.

Cumulating of such directed microchanges in a sense area of each meaning leads in time to some even more significant micro-evolutionary effects:

(1) *abstractivization of meanings* (i.e. to loss of some of components of meanings) also accompanied by gradual *despecification, subjectification and grammaticalization of remaining components of meanings*;

(2) *production of new, relatively more abstract meanings* by some (maternal) meanings.

These two processes in a combination with

(3) the process of a *gradual loss of early acquired, most concrete meanings* form a basis for various *directed changes of a sign within its life cycle* (changes in lexical, morphemic and phraseological polysemy, homonymy, synonymy, antonymy, idiomaticity of meanings, frequency of signs use, shortening of signs' lengths, etc.) which received a systematic explanation in a linguistic model called "the Model of a Sign Life Cycle" (Polikarpov, 1988; 1993; 2004; 2006).

The ability of a sign to generate new meanings is called in the model *"associative-semantic potential (ASP) of a sign"*. ASP is measured by the maximum quantity of meanings which a sign is capable to generate during its life cycle. ASP is present in the original meaning of a sign from which its history begins. Generating of new meanings redistributes to a certain extent the amount of ASP among successive meanings. Loss of previously acquired meanings leads to the diminishing of remaining amount of ASP.

The process of abstractivizing in history of each of sign's meanings gradually slows down, because the most specific, i.e. the least stable components of meanings, are lost first, and the remaining, less specific components exist longer: the less specific are the components, the longer they exist.

The process of acquisition of new meanings by a sign gradually slows down during redistribution and reduction ("waste") of its ASP. This phenomenon can be explained by the fact that meanings of each subsequent generation of them in a sign, being, on the average, relatively more abstract, possess relatively smaller associative activity, smaller ability to "jump" outside the limits of a previously established area of their sense field, which makes the further generation of new meanings less probable.

The process of losing previously acquired meanings begins with some delay as compared to the process of acquisition of new meanings, but proceeds similarly, with *gradual retardation of the process (because relatively later acquired meanings of a sign, being more abstract, live relatively longer).*

The difference between the quantity of meanings acquired by a sign and the quantity of meanings, which fell out of use at the given moment of sign's life, forms the size of an *actual sign's polysemy*. The curve of a polysemy development in time for each sign is, in general, *a unimodal curve with a maximum of polysemy achieved very fast, close to the beginning of the process, and with a very long time for polysemy gradual diminishing until disappearance of the last meaning.*

The same basis can be also used for the prediction of the general character of the development in time (for each stage of realization of its life cycle) of an *overall semantic (sense) volume of a sign* (measured by the sum of semantic volumes of all meanings of a sign), as well as, of the general character of the development in time of an *overall frequency of sign's use*, of *its length*, etc.

Language signs in the *overall ensemble of sign units* of the given linguistic level (for example, of a lexical one) differ in sizes of their ASP, activity and stability and therefore – differ in parameters of curves of their *evolutionary trajectories* – curves of evolutionary changes for the polysemy size, sense volume, frequency of use, length, etc.). There are some sound grounds to admit that in any sign ensemble of any national language those *signs which enter a* *language at a specific period of time are not in chaotic, but in rather regular correspondence to each other in an aspect of their ASP, activity and stability.* That is, sizes of ASP, activity and stability of signs should be distributed in a language sign ensemble (e.g. in a lexical vocabulary) in compliance with some probabilistic law. That is, the whole bunch of polysemic, frequency and other mentioned trajectories of the historical development of different signs should also be determined by these fundamental probabilistic distributions. Naturally, it should lead also to the situation of not chaotic, but rather *regular character of those synchronous (momentary) distributions of the mentioned-above features of sign units – synchronous distributions of their polysemy, age, frequency, length, etc.*

3. Mathematical modeling of a sign life cycle and that of the ensemble behavior of signs in language

On the basis of a number of plausible assumptions specified above, an attempt is made to construct a special kind of mathematical model, namely, a *dissipative stochastic dynamic model of signs' ensembles evolution*, which allows for the prediction of a number of important evolutionary system regularities of lexical signs ensembles (e.g. lexical vocabularies) and of languages on the whole. This enables us, further, to predict a number of important synchronous regularities of vocabulary structure, including the specified *synchronous distributions of lexical signs according to their polysemy size and their frequency of use.*

The proposed dissipative stochastic dynamic model of the development of language signs satisfies the *principle of «the least action»,* one of fundamental variational principles of the Nature (Poddubny, Polikarpov, 2011). The model assumes Poisson character of a stream of language signs' births, exponential distribution of signs according to their ASP, and operates with differential stochastic equations of a special kind derived from the principle of the least action for dissipative processes.

Let's write out these equations for ***i***-th sign in an ensemble, having supplied a process of appearance of new meanings by the top index 1, and a process of loss of meanings – by the top index 2:

$$t_{i,k+1}^{(1,2)} = t_{i,k}^{(1,2)} + \tau_i^{(1,2)} / (G_i - k) + \xi^{(1,2)}, \quad k = \overline{1, G_i - 1},$$
$$t_{i,1}^{(1)} = t_i, \quad t_{i,1}^{(2)} = \tau_{0i} + t_i, \quad \tau_i^{(2)} > \tau_i^{(1)}, \quad i = \overline{1, N}. \qquad (1)$$

Here $t_{i,k}^{(1,2)}$ – is the birth moment (an index 1) or the moment of falling out of use (an index 2) of a *k*-th meaning of an *i*-th sign, G_i – random ASP of an *i*-th sign (which is distributed presumably according to the exponential law with an average value $\langle G \rangle$), t_i – the random moment of occurrence of an i-th sign in a language, when $t_{i+1} = t_i + \tau$, where τ is some random interval of time between occurrences of neighbouring signs (it is distributed presumably according to the exponential law with an average value $\langle \tau \rangle$), τ_{0i} is some random delay of the beginning of the falling out of use process for meanings of an i-th sign in relation to the moment of an i-th sign's origin in a language (which is distributed presumably according to the exponential law with an average $\langle \tau_0 \rangle$), $\tau_i^{(1,2)} = c^{(1,2)} \langle G \rangle / G_i$ – are constants of time of birth processes for new meanings of a sign and of time of falling meanings out of use (their values are inversely proportional to ASP values, so they appear at random, and their distributions are defined by the distribution of their ASP), $\xi^{(1,2)}$ – are some random fluctuations of the moments of birth and moments of falling of the sign meanings out of use (which are distributed according to the uniform law with zero averages and semiwidth of intervals of the distribution $\tau_i^{(1,2)} / (G_i - k)$), N is a number of signs (words) in a language (in some lexicon). Obviously, $L_{i,k} = t_{i,k}^{(2)} - t_{i,k}^{(1)}$ is a measure for longevity of k-th meaning of i-th sign. It is easy to see that this size submits to a recurrent parity:

$$L_{i,k+1} = L_{i,k} + \left(\tau_i^{(2)} - \tau_i^{(1)}\right) / \left(G_i - k\right), \quad L_{i,1} = \tau_{0i}, \quad k = \overline{1, G_i - 1}, \quad i = \overline{1, N}, \qquad (2)$$

so that $L_{i,k+1} > L_{i,k}$, i.e. longevity of each meaning of any i-th sign increases with the growth of k. The age of k-th meaning of i-th sign at the moment of time t is equal to $A_{i,k}(t) = t - t_{i,k}^{(1)}$, if at the moment of time t this meaning exists (it means, it already appeared, but did not fall out of use yet, i.e. if $t_i < t < t_{i,G_i}^{(2)}$).

Polysemy of i-th sign develops from the moment $t_{i,1}^{(1)} = t_i$ (of an origin of i-th sign in language) till the moment $t_{i,G_i}^{(2)} = t_i + \tau_{0i} + L_{i,G_i}$ – of a falling out of use of the last (G_i) meaning of an i-th sign. The interval of time in length $\tau_{0i} + L_{i,G_i}$ from $t = t_{i,1}^{(1)}$ till $t = t_{i,G_i}^{(2)}$ is an interval of life cycle of i-th sign.

The model (1) is a dissipative stochastic dynamic model of evolution of language signs ensemble. There are 5 parameters in this model:

– *intensity of a stream of new signs* $1/\langle \tau \rangle$ (or an average interval of time $\langle \tau \rangle$ between occurrences of the neighbouring signs in a stream),

– *average delay of the beginning of the process of sign meanings falling out of use in relation to the moment of the origin of a sign in a stream* $\langle \tau_0 \rangle$,

– *average value of the sign's ASP* $\langle G \rangle$,

– factors $c^{(1)}$, $c^{(2)}$ ($c^{(1)} << c^{(2)}$) of *inversely proportional dependence of constants of time of birth and death processes of sign meanings on a sign's ASP* (these factors define average values of time constants $\langle\tau^{(1)}\rangle = c^{(1)} Ei(1/\langle G\rangle)$, $\langle\tau^{(2)}\rangle = c^{(2)} Ei(1/\langle G\rangle)$, where $Ei(1/\langle G\rangle)$ is a certain integral exponential function, which increases monotonously and is convexed upwards on $\langle G\rangle$, so that $\langle\tau^{(1)}\rangle << \langle\tau^{(2)}\rangle$).

Similarly to the model of the polysemy evolution we construct evolutionary models for the prediction of synchronous distributions of lexical signs' sense volume, their frequency of use, length and age – as some intermediate states within some specific processes (introducing some additional specific parameters into models).

4. Empirical verification of predictions for characteristics of synchronous polysemy distributions of words

For the check of the model adequacy for the lexical data 5 representative explanatory Russian and English dictionaries of different types were used (3 Russian and 2 English):

17-vols Russian Dictionary – "Dictionary of the Modern Russian Literary Language" in 17 vols. (1948-1965), "a large dictionary" type;

4-vols Dictionary of Russian – "Dictionary of Russian Language in 4 vols" (under the editorship of A.P. Evgenieva, 1957–1961), "a medium dictionary";

Russian Ozhegov's Dictionary – "Dictionary of the Russian Language" by S.I. Ozhegov (1972, 9-th edition), "a concise dictionary" type;

Shorter – "Shorter Oxford English Dictionary" (1962), "a medium dictionary" type;

Hornby – A.S. Hornby. "Oxford Advanced Learner's Dictionary of Current English" (1982), "a concise dictionary" type.

Fig. 1 presents the family of empirical curves for the polysemy distributions of the above mentioned dictionaries. Figs. 2 – 6 present polysemy distribution curves, deduced from a stochastic model for predicting some synchronous state (synchronous polysemy distribution) for each of these empirical polysemy curves for several tens of thousands of lexical units. The model for each dictionary was identified by the corresponding selection of values for the above-mentioned five parameters.

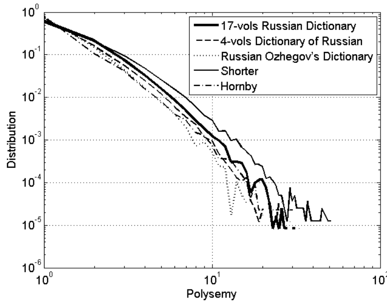

Figure 1. Family of empirical distributions for lexical polysemy of five Russian and English dictionaries.

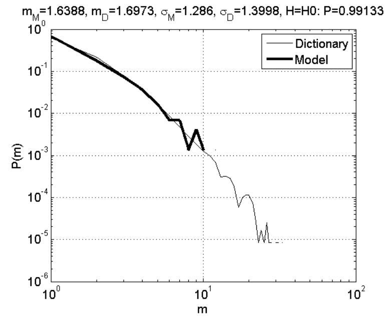

Figure 2. Distribution for lexical polysemy of the model and of the 17-vols Russian Dictionary.

Apparently, curves of polysemy distributions deduced from our model (see fat lines on fig. 2 – 6) don't differ significantly (by Kolmogorov-Smirnov criterion) from the curves of empirical polysemy distributions (see thin lines) drawn on the basis of the data from above-mentioned Russian and English representative explanatory dictionaries. Here m_D, m_M – average values for word polysemy in some dictionary (D) and in the model (M), σ_D, σ_M – standard deviations of polysemy values, H_0 – a zero hypothesis on the identity of empirical and model distributions, p – the reached significance value of the criterion (at $p > 0.05$ zero hypothesis isn't rejected).

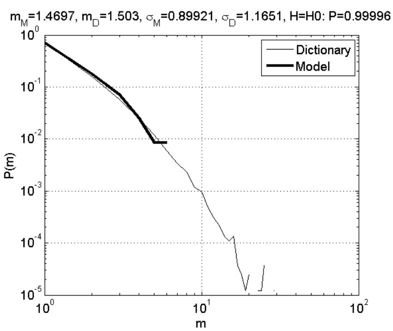

Figure 3. Distribution for lexical polysemy of the model and of the 4-vols Dictionary of Russian.

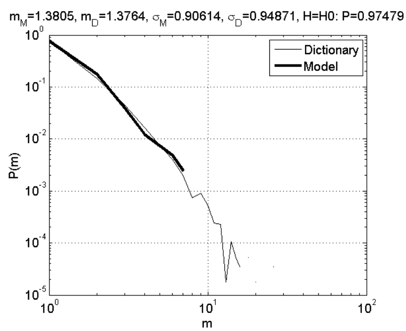

Figure 4. Distribution for lexical polysemy of the model and of the Russian Ozhegov's Dictionary.

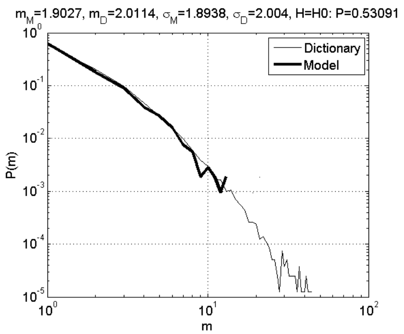

Figure 5. Distribution for lexical polysemy of the model and of the Shorter Dictionary.

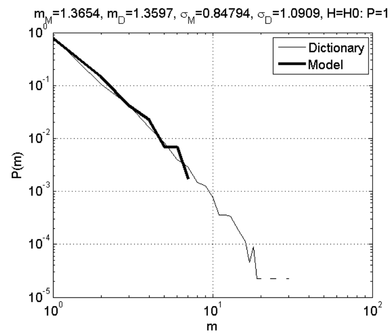

Figure 6. Distribution for lexical polysemy of the model and of the Hornby Dictionary.

The parameter $\langle G \rangle$ directly influences the degree of inclination of the curve of the polysemy distribution in a double logarithmic scale (the greater the parameter, the smaller the inclination of the curve). Parameters $c^{(1)}$ (usually equals to several conditional units) and $c^{(2)}$ (about several hundreds of conditional units) influence the curve form (its camber degree). The parameter $\langle \tau \rangle$ = 0.05 in our model is adhered to a certain conditional time scale, let's say to "linguistic time». Parameters $\langle \tau^{(1)} \rangle$ and $\langle \tau^{(2)} \rangle$ through parameters-factors $c^{(1)}$ и $c^{(2)}$ are also correlated with the parameter $\langle G \rangle$.

Let's notice that polysemy distribution curves of Russian and English dictionaries, even having sometimes close values of the parameter $\langle G \rangle$, differ strongly in values of parameters $\langle \tau_0 \rangle$, $\langle \tau^{(1)} \rangle$, $\langle \tau^{(2)} \rangle$. E.g., curves of the polysemy distribution for The Russian Ozhegov's Dictionary (fig.4) and for The English Hornby Dictionary (fig. 6) have close inclinations, that is close values of $\langle G \rangle$ (1.5 and 2.0 accordingly), but essentially differ in other parameters (in $\langle \tau_0 \rangle$ – approximately in 100 times, in $\langle \tau^{(1)} \rangle$ – approximately in 20 times and in $\langle \tau^{(2)} \rangle$ – approximately in 3 times in favour of the Russian dictionary).

Basing on these results it is possible to come to the conclusion that the evolutionary parameters $\langle \tau \rangle$, $\langle \tau_0 \rangle$, $\langle \tau^{(1)} \rangle$, $\langle \tau^{(2)} \rangle$, $\langle G \rangle$ (i.e. the parameters initially included in the model and responsible for the speed of change of meanings and words in the language, for average and maximum polysemy, etc.) appear having also synchronous, lingo-typological status. Namely, the vocabulary of the English language, as the language obviously having more analytical nature than the Russian language, is more limited in a set of lexical units (but, at the same time, is proportionally richer in phraseological ones). That is why the maximum and also average lexical polysemy, as well as the maximum and average frequency of use, for English lexical units are expected to be greater than for Russian lexical units - in comparable textual materials (at least, in vocabularies from parallel corpora and in explanatory dictionaries compiled on the same principles). That is why a "wear process" of each of lexical units in the English language is supposed to occur noticeably faster than in Russian. In other words, lexical "metabolism" (birth, realization of the associative-semantic potential, aging, falling out of use and replacement of lexical meanings and of lexical signs as a whole by some new lexical units) in the English language is relatively more intensive than in Russian.

5. Empirical verification of predictions for the regularities of words synchronous frequency of use distributions

For the check of our predictions concerning synchronous frequency distributions of English and Russian words the following frequency wordbooks were used:

NP-RusFrqDict – the frequency wordbook based on 1,350 million of running words from Russian newspapers texts of the last decade of the 20th century;

Pushkin Dictionary – DB for Pushkin's lexicon including frequencies of word usage based on texts counts from "Complete Collection of Pushkin's works" (about 500 thousand of words);

BNC-EngFrqDict – the big frequency wordbook based on 100,350 million of running words from English texts of the second half of the 20th century.

Figs. 7 – 8 present empirical and theoretical-computationally deduced curves for frequency distributions for several tens of thousands of words. For each of the above mentioned dictionaries the model was identified by corresponding computational selection of parameters.

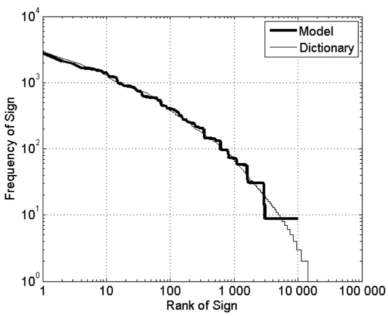

Figure 7. Rank-frequency distributions for Pushkin Dictionary and the model

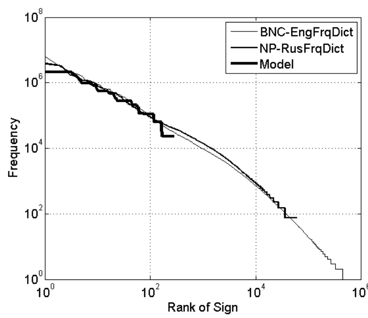

Figure 8. Rank-frequency distributions for NP-RusFrqDict, BNC-EngFrqDict and the model

As seen from figs. 7 and 8, the words distributions deduced from our model (fat lines) statistically don't significantly differ from the empirical distributions received on the basis of the data from Russian and English representative frequency wordbooks (thin lines).

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INTEGRATIVE APPROACH TO DYNAMIC FEATURE OF SYMBOLIC COMMUNICATION SYSTEM

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Human symbolic communication is not just sharing of information but creation of novel expressions and meanings. Humans are able to make s symbolic communication system from scratch. In this paper, an integrative approach to such dynamic feature of human symbolic communication is introduced. The mechanism of production of novel expressions and meanings and that of formation of symbolic communication system are pursued taking such multiple methodologies as constructive modeling, cognitive experiment, and brain measurement.

1. Introduction

The feature of human communication is to use symbols, while we also have non-symbolic communication channels, such as emotional sympathy and physical synchronization. Symbolic communication is usually considered as follows: to transmit and exchange information or intention using symbols between a sender and a receiver, and thereby mutual or common understandings between them are reached or tried. We need to interpret and make sense of symbolic messages by ourselves individually, since the symbols themselves are just physical entities, such as patters of air vibration, blinking light, or ink spots. Further, in human communication, the meaning of symbols changes according to the way of combination and depends mainly on minds' internal states. Human symbolic communication is composed of a series of exchange of expressions between individuals and sense-making within individuals.

Sense-making is a non-trivial task, for it is a subjective and independent (re)construction of sender's intention. Symbolic communication is not just for common understanding and sharing of meanings, but evokes different constructions of intentions, novel expressions, and further mental activities. Therefore, human symbolic communication is a dynamic process of generation and sharing of expressions and meanings. It can be thought of as a manifestation of daily creativity of humans, if we put emphasis on the productive aspect of communication.

Toward the system theoretic understanding of such dynamic process of human symbolic communication and its underlying mechanism, we are doing integrative study on communication system. In this enterprise, we take constructive approach for dynamic systems (Hashimoto, Sato, Nakatsuka, and Fujimoto, 2008), cognitive experimental approach for language evolution (Scott-Phillips and Kirby, 2010), and brain scientific approach for communication (Tsuda, in press).

2. Constructive Simulation of Dynamics of Symbolic Communication

Although dynamics processes of generation and sharing of expressions and meanings in communication in general occur in daily verbal interactions, it is difficult to investigate and analyze such daily and natural processes operationally and explicitly. Constructive approach is suitable for operational study of such dynamic phenomena (Hashimoto, Sato, Nakatsuka and Fujimoto, 2008).

Torii and Hashimoto (2011) model the process of exchange of symbolic expressions between individuals and sense-making within individuals by combining a discrete symbol system implemented by rewriting rule system and a sense-making system implemented by a dynamical system with continuous states, in concrete, a recurrent neural network (Fig.1). The former produces internal representations for given symbolic expressions and acquires a grammar to accept and derivate symbolic expressions. The latter composes internal dynamics for internal representations produced by the symbolic system and produces internal representations corresponding to individual's own utterances. The internal representations are transformed into symbolic expressions by the symbolic system and the expressions transmitted to a partner of communication.

Torii and Hashimoto (2011) showed that generation and sharing of novel expressions and meanings occur in this model. It was clarified that novel expressions and representations are created through "linguistic analogy" (Hashimoto, Nakatsuka and Konno, 2010) in the symbol system, where grammatical rules acquired are applied extensively in the individual's linguistic knowledge. It is also suggested that generation of novel internal representations is caused by bifurcation and orbital instability (chaotic dynamics) occurring in the sense-making system.

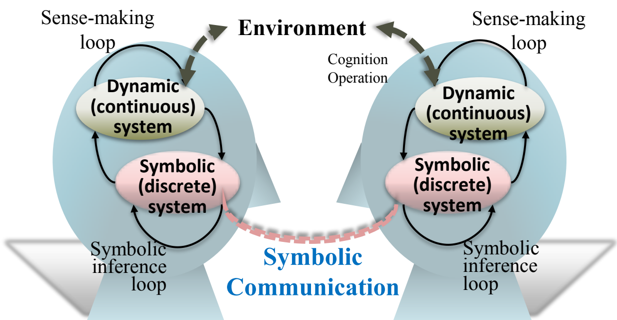

Figure 1. A model of dynamic process of symbolic communication

3. Cognitive Experiment, Constructive Simulation and Brain Measurement of Formation of Communication System

In the constructive model, the existence of communication system is presupposed. How communication system is formed, however, should be clarified. Here, the communication system means a systematic mechanism to make or select signs, to correspond them to references, to compose messages and to transmit intentions. Galantucci (2005) did a pioneering work in experimental study of the emergence of communication system. While Galantucci (2005) suggests important features in the formation of communication system, its experimental paradigm has too many degrees of freedom to investigate the underlying mechanism of the formation. Making the experimental paradigm more operational, observable, and analyzable, we can inquire the mechanism and required ability of humans for dynamic symbolic communication. Further, such simpler experimental paradigm contributes to integrate the constructive, experimental and brain scientific approaches, since we can make computational models which are comparable to experimental data and may make data assimilation possible, and we can develop the paradigm to measurement of brain activities in the formation of communication system.

The cognitive experimental paradigm in which we can investigate and analyze the emergent process of communication system qualitatively and quantitatively was proposed by Konno, Morita, and Hashimoto (in press). In this experiment (Fig.2), as similar to Galantucci (2005)'s setup, participants who do not know the partner's place operate their own agents randomly arranged on one of the interconnecting 2 x 2 rooms from separated sites through network connected terminals. They repeat a coordination task in which they try to meet with each other by one vertical or horizontal movement or staying at the original place, where diagonal movement is prohibited. They send messages composed of two simple figures only once before moving the agents, different from Galantucci (2005)'s condition.

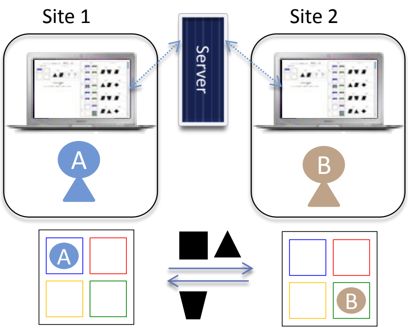

Figure 2.The experimental setup for the quantitative study on the formation of symbolic communication system.

Konno, Morita, and Hashimoto (in press) showed that, from a state with no rule in the usage of symbols, a symbolic communication system is formed through sharing of semantics and syntax, we call the set of semantics and syntax a symbol system. The participants come to transmit not only semantics but also intentions of messages by establishing a division of roles adjusting turn-taking. Quantitative analysis of the experiment clarified that behavioral tendencies not represented in symbol system, such as to make biases in symbol use and in movements among rooms and to shorten the time difference of message sending, contributed to the establishment of symbol system. This implies that the abilities to make regularities in behavior and to connect contingent behaviors play important role in forming a symbol system. The analysis also revealed that such behavioral tendencies were not causes of the division of roles. By further analysis, we found that forming the isomorphic symbol systems between two participants was effective to the division of roles (Konno, Morita and Hashimoto, 2012).

A constructive study corresponding to this experiment of the formation of symbolic communication system is done utilizing ACT-R, Adaptive Control of Thought-Rational (Anderson, 2007), which is a kind of cognitive architecture designed for simulating and understanding human cognition. ACT-R integrates symbolic and subsymbolic learning mechanisms. As we suggested, both symbolic learning and subsymbolic learning represented in the behavioral tendencies play critical roles to form symbolic communication system. Therefore, ACT-R is a good architecture to simulate and analyze the mechanism in the formation of symbolic communication system. Morita, Konno and Hashimoto (submitted) constructed a model simulating the behavior of players of the coordination game with message exchanging. The simulation analysis of the model indicated that imitation mechanism was effective to form isomorphic symbol systems. The comparison between the experimental results and simulation analysis revealed that imitation existed in the process of human symbolic communication system.

We have also developed a simultaneous EEG recording of brain activities of two subjects engaged in the coordination game (Kishino, 2012). This study aims at detecting brain activities characteristic to the formation process of symbolic communication system. In our cognitive experimental study, three stages were found in the process, namely, shaping the behavioral tendencies, sharing a symbol system and arranging the division of roles (Konno, Morita, and Hashimoto, in press). Analyzing event-related potentials of the player in the coordination game, we identified brain activities associated with the three formation stages of communication system. These brain activities are compatible with existing findings in brain researches concerning learning and using language. Especially, at the third stage where participants come to transmit their intentions as well as semantics of symbolic messages, it is suggested that brain regions associated with understanding others were activated.

4. Summary and Conclusion

In this paper, we introduced an integrative approach for the dynamic feature of human symbolic communication. We are doing research on the dynamics and emergence of symbolic communication systems using constructive, cognitive experimental, and brain measurement approaches. Although they are still ongoing projects, we have obtained valuable results for understanding the mechanism of formation and dynamics of symbolic communication. Symbolic communication is, however, dynamic and complex process composed of hetero individuals having complex neural dynamics, therefore, mathematical approach, especially using chaotic dynamical systems, should be integrated (Tsuda, in press) in order for system theoretic full understanding of the symbolic communication.

Acknowledgements

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SYNTHETIC MODELING OF CULTURAL LANGUAGE EVOLUTION

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Recently cultural theories of language evolution have gained significant momentum in explaining natural language. This paper reviews agent-based modeling, one of the key methodologies which is in part responsible for these developments. We discuss the most important challenges for a theory of cultural language evolution and the resulting dominant experimental paradigm. The discussion is framed along examples of experiments conducted within the methodology. We focus, in particular, on spatial language as an example of a complex and cognitively central domain treated in a series of robotic experiments.

1. Cultural Theories of Language Evolution

Cultural theories of language evolution trace, explain and model the cultural development of the languages of the world. Explaining both the past and present of language is a daunting goal. The languages of the world have developed into ingenious systems for communicating enormous subtleties about the inner and outer world. An example of a part of language in which this creativity is very tangible is spatial language (Levinson, 2003; Svorou, 1994; Levinson & Wilkins, 2006). We know now from different studies in spatial language that human languages vary tremendously in how people, for instance, talk about the spatial configuration of objects. The following phrase from Tzeltal which is a Mayan language shows an example of a geocentric spatial language strategy (Brown & Levinson, 1993).

(1)	*ay*	*ta*	*ajk'ol*	*te*	*limite*		
	EXIST	PREP	'uphill'	the	bottle	(=	Figure)

‘The bottle is to the uphill (i.e., south)’

Typologists tell us that languages differ on two levels of organization: *language systems* and *language strategies*. They call systematic subparts of language – systems. For instance, the English proximal spatial relations system consists of two spatial relations “near” and “far”. The Spanish proximal system, on the other hand, features three relationships (Kemmerer, 1999). But languages also differ more drastically in the kinds of strategies they support. Tzeltal, for instance, has no lateral projective system. Other paradigmatic differences can be observed in the syntactic strategies a language supports. Spatial relations in some languages are expressed using verbs, particles or adpositions whereas in German or English adjectives and prepositions are the most important devices.

2. Methodologies

Cultural theories of language have to account for these vast differences. Three main methodological tools which are used to study the cultural origins of language 1) linguistic fieldwork and typology 2) experimental psychology and 3) agent-based modeling. We briefly discuss these three in the following paragraphs.

Linguistic research into the cultural origins of language is primarily driven by two sources of data historical and synchronic. Historical data of language change can be used to trace lexicalization, grammaticalization (Hopper & Traugott, 2003) and creolization processes (Mufwene, 2001) that organize language change. From the data, researchers hypothesize cognitive operations and strategies that orchestrate language change (Heine, 1997). A third source of evidence is synchronic. Comprehensive typological surveys of the languages of the world (Haspelmath, S., Gil, & Comrie, 2005) have revitalized comparative typology and given rise to radically new cultural theories of the origins of language (Evans & Levinson, 2009).

A second big methodological paradigm is rooted in experimental psychology. Galantucci and Garrod (2011), for instance, propose "semiotic experiments" in which human subjects are developing a communication system from scratch. The main manipulation is to prevent the interlocutors from using the language, e.g. English, they already know. These experiments reveal the strategies humans use, in order, to arrive at shared communication systems. Others are interested in how properties of the transmission system affect the emergence of linguistic phenomena (Scott-Phillips & Kirby, 2010) .

The third paradigm and the main focus of this papers is agent-based modeling. Simulated or robotic agents form communities which are put under communicative pressure to solve problems in their environment using language. The experiments start when the experimenter implements a particular proposal of cognitive strategies for learning and formation of language into each agent of the population. The population then goes through a sequence of interactions simulating the emergence of language systems in populations of artificial agents.

3. Language Games

One way to frame agent-based modeling is by using *language games* (Steels, 2001). A language game is a routinized turn-taking interaction. Each agent can take the role of speaker and hearer in such an interaction. Agents share a cooperative goal, the restricted real world context, and the possibility of non-verbal communication, for example through gestures or joint action.

An example of a particular language game is the *spatial language game* (taken from Spranger & Steels, 2012) in which two humanoid robots talk about objects in their environment. The robots try to draw each others attention to objects in the vicinity using language. The set-up is exemplarily shown in Figure 1. The environment consists of a number of blocks of equal size and color (circles), a box (rectangle) and the interlocutors (arrows). The vision system of each robot tracks objects in the vicinity and establishes a model of the environment consisting of blocks (circles) with real-valued distances and orientations of objects with respect to the body of the robot. The environment is open-ended. New blocks, boxes and robots are added or removed and their spatial configuration changed.

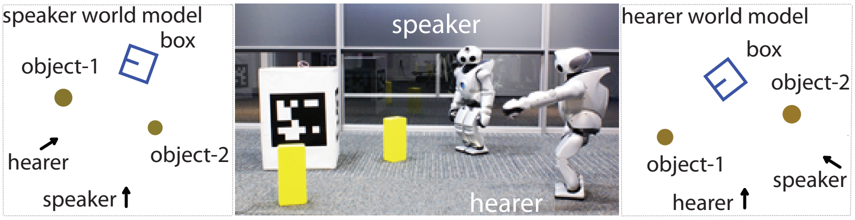

Figure 1. This figure shows the set-up for spatial language game experiments. The images left and right show the internal situation model as perceived by each robot.

1. Each agent perceives the environment after both have established a joint attentional frame (Tomasello, 1995).

2. The speaker randomly selects an object from the situation model. Suppose he picks one of the blocks, e.g. `object-1`.

3. He conceptualizes a meaning which enables him to single out the topic from the rest of the objects in the context. For instance, he could pick discriminating features such as color, size, object type. In the situation in Figure 1 neither color nor size distinguish between the two blocks, so agents might use compositional spatial semantics and combine a spatial relation "in front of" with a reference objects such as "the box".

4. When the speaker successfully constructed a semantic program, he goes on to verbalize his conceptualization of the topic object. Verbalization is a complex process in which the agents make choices about how to express the semantic program. For instance, the speaker might choose to leave certain aspects unexpressed because the language offers no syntactic vehicles to express them or because they are obvious given the context. Once the speaker constructed a string of words it is passed to the hearer.

5. The hearer recovers as much as possible from the semantics underlying the utterance possibly representing semantic ambiguity.

6. This is followed by a process of active interpretation in which the hearer tries to reconstruct the conceptualization the speaker had in mind. This process integrates as much knowledge as possible from the current context to constrain the possible interpretation of the utterance.

7. When the hearer found a possible topic of the phrase, he points to it.

8. The speaker checks whether the hearer points to the object he had in mind when uttering the phrase. If the hearer pointed correctly the game is a success and the speaker signals this outcome to the hearer. If the game is a failure, the speaker points to the topic.

After such an interaction both agents have established success or failure and can update their internal linguistic and conceptual repositories, in order, to be more successful in the future. Agents continuously interact using these scripts and gradually develop adequate syntactic and conceptual means to express themselves. They start with a set of operators that are hypothesized to be necessary and sufficient for seeing the emergence of possible language strategies to be successful in the language game. The agents then play a series of games where they configure possible strategies and try them out. What is not put in these agents are concrete choices, neither for the conceptual building blocks used to formulate meanings (steps 3 and 6), nor for the linguistic choices that they should use to express those meanings (steps 4 and 5), because the goal is to show how these emerge through collective invention and negotiation.

Language games such as the spatial language game are designed with a three important ideas in mind which often (at least in part) overlooked or missing from other approaches.

open-endedness Language is an open system. New technological advances, changing environmental conditions and new topics force communities to expand and adapt their language. For instance, in spatial language games new blocks and boxes can enter the scene and the spatial configuration of objects and robots is constantly changing.

no central coordinator Language is not designed top-down by a central authority that enforces certain conventions. Rather language evolves decentralized. Conventions are typically established locally in small subgroups of the population. For instance, in spatial language games always two agents interact. Any new word or convention established between the two interlocutors still has to stand the test against conventions established between other agents of the population.

no telepathy Language conveys hints at how the speaker conceptualizes reality but it does so without allowing interlocutors direct access to each others internal representations. An utterance conveys pointers or parts of the way the speaker construed the world and the rest has to be actively reconstructed by the hearer against the background of the shared context. So when an agent guesses the meaning of a new word he might be uncertain about the exact meaning and he can make mistakes.

4. Examples of Agent-based Studies

Models in the agent-based paradigm have seen increases in complexity both in terms of semantic and syntactic strategies emerging in experiments. A lot of work initially focussed on perceptually grounded lexicons. Prime domains are color (Steels & Belpaeme, 2005), actions (Steels & Spranger, 2008) and naming (Steels & Loetzsch, 2012). In these experiments, agents co-evolve an ontology of categories (or names) together with a lexicon for expressing these categories. Spatial language has also been treated in this way. Figure 2 shows the dynamics of an experiment in which agents develop a system of projective spatial relations (e.g. front, back, left, right). Agents start without any categories and words (number of construction). Over the course of many interactions, new categories are invented and shaped so as to provide the community with a sufficiently shared lexical system so that communication is successful.

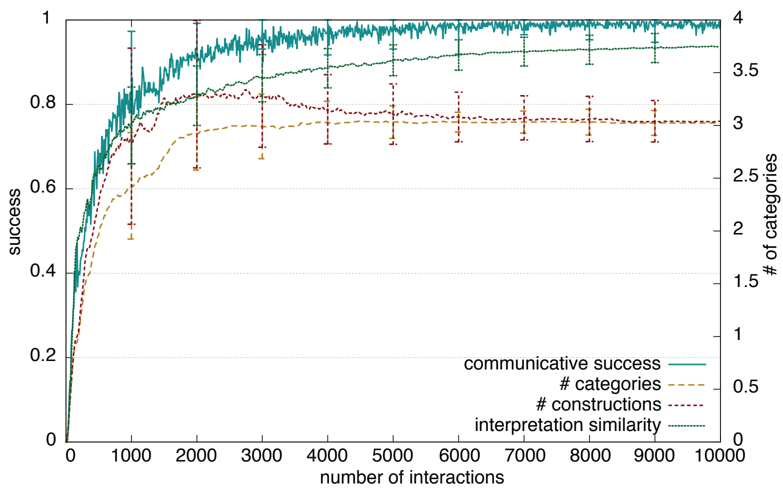

Figure 2. Dynamics of 10 agents interacting in 10000 interactions (multiple trials). The graph shows how communicative success increases with the number of categories and word (constructions) invented and spreading in the population.

In a second step the complexity of meanings was increased, for instance, by using predicates with arguments (Steels & Loetzsch, 2008). Recently, the full complexity of human language semantics is being tackled by using a procedural approach to meaning and by operationalizing basic insights from cognitive semantics (Spranger, Pauw, Loetzsch, & Steels, 2012). These new technological advances allow to study the conventionalization of compositional meaning. Something which so far has received little attention and opens the door for (cultural) evolutionary explanations of conceptualization strategies like the absolute systems of uphill-downhill relations in Tzeltal (see Example 1). First step in this direction show promising results. For instance, Figure 3 (from Spranger, 2011) shows the dynamics of a population which at the same time as building an ontology and lexicon is actually negotiating the conceptualization strategy with which to build the system. Depending on the environment these populations develop proximal (e.g. near, far), projective (front, back) or absolute systems (north,south). In these experiments *discriminative power* is an important factor that determines which system evolves. If there is a global landmark consistently available in many scenes and useful for distinguishing objects then an absolute system develops.

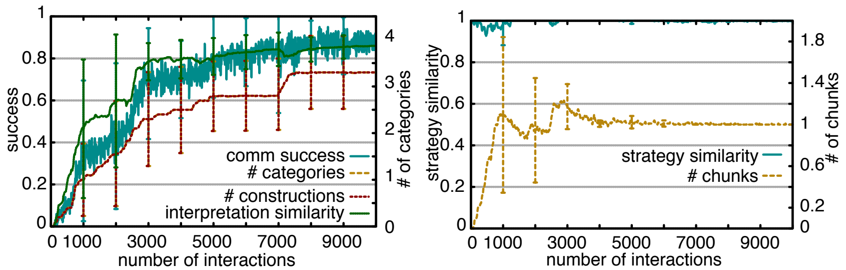

Figure 3. The left image shows the development of success and categories. The right image shows the average number of spatial conceptualization strategies in the same populations (number of chunks). While building a systems, the agents are negotiating which strategy to use.

Finally, the complexity of the syntactic aspects of the evolving languages increases. There are now experiments in which predicate-argument structure and associated problems of search (Steels & Wellens, 2006), semantic ambiguity (Spranger & Steels, 2012) and cognitive effort (Trijp, 2008) are researched. To illustrate this approach, let us consider an example from spatial language (from Spranger & Steels, 2012). The following two phrases are from German.

(2) *der* *linke* *Block*
the.NOM left.ADJ.NOM block.NOM
'The left block',

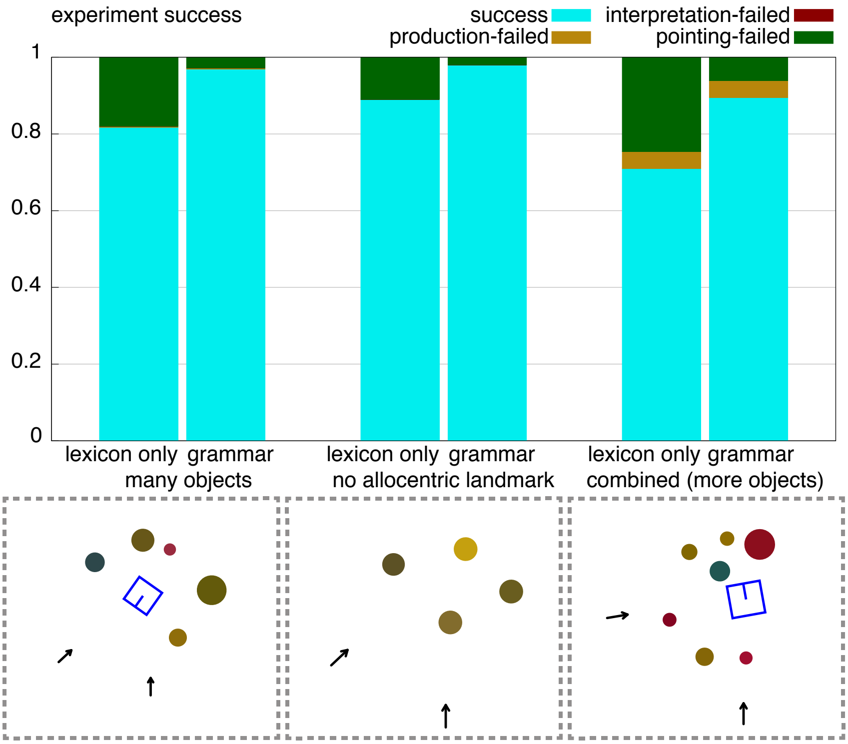

Figure 4. Comparison of lexicon only populations versus populations that are operating a German locative grammar.

(3) *links* *des* *Blockes*
left.PREP.GEN the.DET.GEN block.GEN
'to the left of the block',

Both of these phrases use the same lexical material, but they differ drastically in their grammatical structure. Importantly, these differences in syntax convey subtle differences in semantics. The use of the relation *left* as adjective (Example 2) signals a different construal of reality than the use as preposition (Example 3). In other words, these two phrases have different interpretations which are signaled by their syntactic structure. An agent which only knows the lexicon and is confronted with any of such phrase has to resort to the context to disambiguate the different possible interpretations.

Agent-based models allow us to quantify the impact of grammar. Figure 4 shows a comparison of results from populations which feature only a German lexicon and a population which operates a full German locative grammar. The graph shows a clear communicative advantage for the population with grammar. This fact can be exploited in subsequent grammar formation experiments in which agents start from a lexicon-only stage and develop a system of grammatical markers.

5. Discussion

Agent-based models are seeing an increasing coverage in books (Cangelosi & Parisi, 2002; Lyon, Nehaniv, & Cangelosi, 2007; Nolfi & Mirolli, 2010; Steels, 2012). This is probably due to the important advantages of the agent-based methodology. The most important of these is that any proposal has to be sufficiently specific to be implemented in a computer or on a real robot. As a consequence, every proposal, every instantiated theory that is shown to work using agent-based modeling can immediately be accepted as a coherent and stringent proposal that (at least in principle) reveals all underlying assumptions and provides reproducable and testable dynamics. This is no small achievement. Many theories or contemplations about language evolution are described in textual form without any formalization. While such theorizing is a natural step in any scientific discipline it should only be an intermediate step which is accompanied by or triggers the acquisition of additional data and results from other methodologies.

Ideally, modeling helps us to 1) make implicit assumptions explicit, 2) test theories for coherence and consistency, 3) allow for manipulation of model conditions which are difficult to manipulate with humans and 4) generate new hypotheses. Language game modeling is no exception but it adds an additional point. Because of the realistic setups, any working experiment immediately provides us with actual artificial systems that can interact and evolve language in the real world.

In our view robotic models occupy a special place in agent-based modeling. These models 1) are immediately insightful with respect to foundational problems such as *symbol grounding* (Steels, 2008), 2) they increase the realism of experiments (Loetzsch & Spranger, 2010) and 3) they lead to mechanisms and algorithms robust against noise in perception (Spranger & Pauw, 2012). Every simulation makes assumptions about the structure and behavior of the simulated world. Inadvertently, many of these assumptions are implicit. Experiments in the real world also make implicit assumptions, but, showing that something works in the real world is an obvious existence proof and requires less further justification of assumptions and methods. Just as a hypothesis which is tested in a simulated model gains in validity and justification, so does a model when it stands the test of reality.

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LANGUAGE DIVERSITY IN THE NAMING GAME ON ADAPTIVE WEIGHTED NETWORKS

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A naming game on an adaptive weighted network is examined. A weight of connection for a given pair of agents depends on their communication success rate and determines the probability with which the agents communicate. When the preference toward successfully communicating agents is not so strong, the model behaves similarly to the naming game on a complete graph. In particular, it quickly reaches a single-language state, albeit some details of the dynamics are different from the complete-graph version. Much different behaviour appears when the preference toward successfully communicating agents is stronger and the model gets trapped in a multi-language regime. In this case gradual coarsening and extinction of languages lead to the emergence of a dominant language, albeit with some other languages still being present. A comparison of distribution of languages in our model and in the human population is discussed.

Computer modeling becomes a more and more important tool to address the problem of language origin and evolution. Early theories of language origin and evolution not only were difficult or impossible to test empirically but they tended to be stated in vague and general terms and were unable to generate specific empirical predictions (partially due to the scarcity of empirical evidence). Computer simulations embody theories of the empirical phenomena that are simulated (Cangelosi and Parisi, 2002). They are scientific theories expressed as computer programs. The program incorporates a set of hypotheses on the causes, mechanisms, and processes underlying the simulated phenomena, and its results are predictions derived from the theory incorporated in the simulation. Thus computer modeling gives us the possibility of working in a virtual laboratory and carrying out experiments that would be impossible in real world, in particular, throwing light on the nature of language as a complex system, enabling different interacting parameters to be varied for multiple experiments.

Various levels of descriptions and processes operating at several timescales suggest that to describe adequately the language evolution, extremely complex models must be used. Correspondingly, the analysis of such models and predicting their behavior also seem to be very difficult. Many different kinds of models have been proposed dedicated to particular aspects of the problem of language origin and evolution (de Boer, 2006). It seems that recently the most promising and frequently used approach to examine such complex systems is computational modeling of multiagent systems (Steels, 1997). Using this method one examines a language that emerges in a bottom-up fashion as a result of interactions within a group of agents equipped with some linguistic functions. Then one considers language as a complex adaptive system that evolves and complexifies according to biologically inspired principles such as selection and self-organization.

Language games constitute an important class of such models and they are used to describe, for example, the formation of compositionality, categories or syntactic structures (Steels, 2000; Loreto et al, 2010). One of the most basic language games is the so-called naming game (Steels, 1995; Baronchelli et al., 2006a; Lipowska, 2011). In this game one considers a population of agents that try to establish a common vocabulary for a certain number of objects present in their environment. More sophisticated versions with formation of homonyms and synonyms (Lipowski and Lipowska, 2009) or where biological evolution couples with linguistic interactions (Lipowski and Lipowska, 2008) were also examined. Typically, in the naming game the agents establish such a linguistic coherence rather fast, but the dynamics of this process might depend on some details of the model such as, for example, the topology of interactions between agents (Baronchelli et al., 2006b). A number of results was obtained for the naming game on regular or random graphs, however, linguistic interactions (between people) are of much more complicated nature and it would be interesting to examine the naming game on more complex networks. Some results were already reported for the naming game on small-world lattices and scale-free networks and they also show a fast approach to the linguistic coherence (Baronchelli et al., 2007).

Such a single-language coherence apparently differs from the multi-language structure in (at least current) human population. In the present paper we show that the naming game on an adaptive weighted network might describe such multi-language structures. In our approach we examine a population of agents playing the naming game. More specifically, a pair of neighboring agents is selected and one of them (speaker) communicates a word to the other one (hearer). Communicative success appears when the hearer has this word in its repository and in such a case both agents retain in their repositories only the communicated word. If the hearer does not have this word in its repository (communicative failure), then this word is added to the hearer's repository. Neighborhood relations between agents are of probabilistic nature and form an adaptive weighted network – the larger the communicative success rate of a pair of agents, the larger the weight of their link and thus the probability of communication between them. Thus, the weights of links, which depend on the success rates that pairs of agents have achieved so far, change in time and control the intensity of their subsequent interactions. From the above, it follows that the model constitutes an adaptive weighted network.

Simulations show that in some cases, depending on the parameters of the model, the preference due to successful communication in the past is basically negligible and the model, similarly to other versions of the naming game, quickly reaches the state of a complete single-language coherence, namely, such that all agents share a common vocabulary, i.e., they have only one (and the same) word in their repositories. For some other values of the parameters, the preference due to successful communication in the past is much more relevant and quite different and perhaps more interesting behaviour of our model appears. In this case, our model does not reach complete synchronization but remains trapped in a multi-language state. In this case agents become separated into several groups and a common vocabulary is established only within a group.

The distribution of language users in a multi-language state reasonably agrees with statistical data of G. Weber. In Figure 1, we present the distribution of users of the 20 most common existing languages (Weber, 1997) compared with analogous distributions obtained for our model.

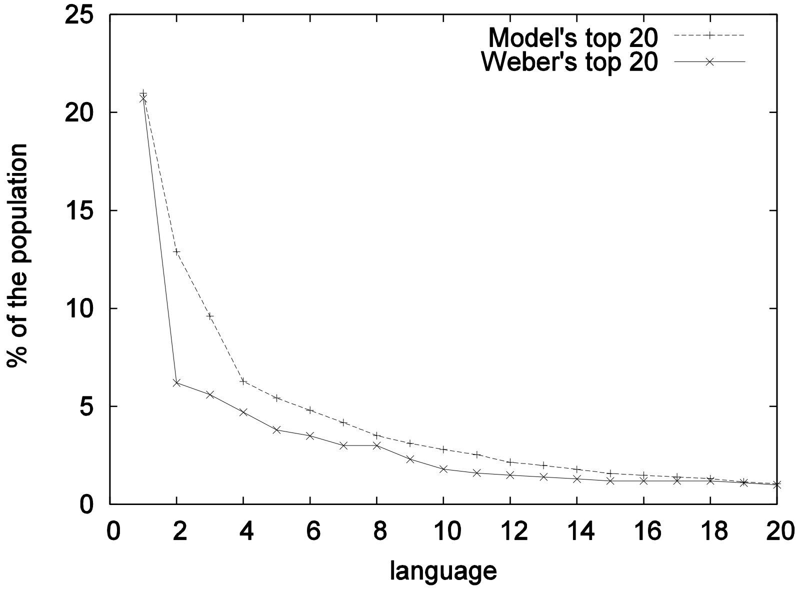

Figure 1. The percentage of population constituted by the users of the 20 most common languages in our model compared with Weber's statistical data. The first three languages according to Weber (1997) are Chinese (20.7% of the population, i.e., $1.1 \cdot 10^9$ speakers), English (6.2%, $3.2 \cdot 10^8$), and Spanish (5.6%, $3.0 \cdot 10^8$).The simulation time was chosen in such a way that the percentage of users of the most common language was equal to 20.7%, i.e., the percentage of speakers of Chinese. Let us notice that there is a reasonably good agreement even for less common languages.

One can speculate about the possibility that human languages evolved similarly to the multi-language scenario. We should emphasize, however, that our model is very simple and its applicability to real linguistic data should be considered with care. For example, a constant number of agents is not consistent with fluctuations in real human populations due to, e.g., demographic processes. Perhaps it would be more appropriate to compare our numerical data rather with the distribution of dialects of a sufficiently widespread language such as, for example, Chinese.

A more detailed description of the model and simulation results can be found in (Lipowska and Lipowski, 2011).

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MULTILAYERED FORMALISMS FOR LANGUAGE CONTACT

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1. Introduction

Since the constructive approach is advantageous for analyzing language evolution, a variety of methodologies have been proposed. However, each of them belongs to a different level of abstraction. Among simulation studies for population dynamics alone, an agent-based model (AM; hereafter) of language acquisition has been one representative as proposed by Briscoe (2002), while the other is a mathematical theory of the evolutionary dynamics of language called the *language dynamics equation* (LDE; hereafter) by Nowak, Komarova, and Niyogi (2001). AM is considered to be a concrete, or less abstract model though LDE is highly abstract. Especially, LDE is so abstract that the change of language is represented as the transition of population among a finite number of languages.

We focus on a series of language contact models in which levels of abstraction are different from each other (Nakamura, Hashimoto, & Tojo, 2003, 2008, 2009). Our purpose in this paper is to show behavioral differences by a parameter, comparing between the models on multiple levels of abstraction.

2. Constructive Approaches to the Emergence of Creoles

Thus far, Nakamura et al. (2003) proposed a mathematical framework for the emergence of creoles based on the LDE, showing that a certain ratio of contact among languages is necessary for creolization. Toward more concrete analyses, Nakamura et al. (2009) introduced Barabási-Albert networks (Barabási & Albert, 1999) (hereafter; BA-networks) as a social network to the framework, where each learning agent located on a vertex initially has one of three languages including a creole, and then chooses one for the next generation according to the probabilistic distribution based on similarity between languages. Experiments showed that local creole communities are organized in the large network, and one of three languages eventually dominates the whole network depending on parameters. Comparing with experiments with two-dimensional square lattice networks (Nakamura et al., 2008), each of whose vertex has immediate eight neighbors, a single language dominates in quite faster generations. Further analysis suggests that agents densely linked to neighbors have an effect on spreading a language, and unlike the lattice networks, such heterogeneous agents may disturb the equilibrium in language communities but in effect they lead to faster convergence. In other words, while the lattice network is analogous to the LDE in terms of conditions for creolization, in the BA network creolization is unlikely to occur, regardless of the contact ratio.

3. An Agent-based Model for the Emergence of Creoles

Since we aim at observing grammatical structures on the process of creolization, we have developed an agent based model with Kirby (2002)'s Iterative Learning Model on the social network, in which language similarity is measured using Levenstein distance between E-languages generated from I-languages. Figure 1 shows examples of the agent based model, where agents are connected to neighbors in the networks.

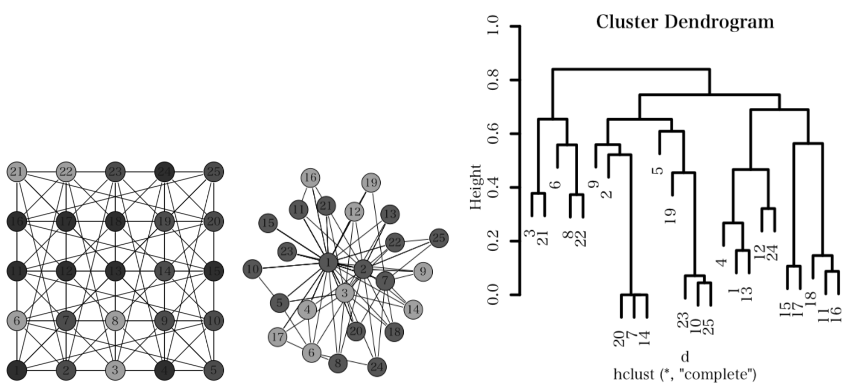

Figure 1. (Left) Language distribution in a two-dimensional square lattice network (Middle) in a BA-Network (Right) Cluster dendrogram, $N = 25$.

Since agents independently invent languages, their acquired languages are different from each other. In order to classify agents into groups of the similar language speakers, we introduce a clustering method, recognizing a cluster as a language group. The relationship among languages is represented by a dendrogram shown in the right hand side of Figure 1, where the vertical axis denotes height of the tree, the definition of which differs dependent on the clustering method. The number of languages, therefore, depends on the cutting point of the tree. In other words, it is possible to represent the dominance by a single language in any trial at the height of a merger of the last two clusters. For example, in the right hand side of Figure 1, the community is regarded as a single language community at the height of 0.84.

4. Conclusion and Future Work

Although we have expected that we acquire initial parameter settings by LDE in common, regardless of variety of model, this exact settings may differentiate the agent communication. We will continue to investigate the causality between parameters and agent models furthermore.

Currently we may be faced with a problem that has been reported by Smith and Hurford (2003); that is, in the case learning agents potentially have more than one cultural parent, the length of the right hand side of rules tends to increase rapidly over generations due to the addition of strings of meaningless terminal characters. Once this problem is solved, we will examine our agent based model with a huge number of agents.

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CONSTRUCTING KNOWLEDGE: NOMOTHETIC APPROACHES TO LANGUAGE EVOLUTION

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Nomothetic approaches identify statistical tendencies from large-scale, cross-cultural data sets. Recently, newly available data and statistical techniques have prompted a number of studies which consider the links between language structure and social structure. This can contribute in two ways to constructive approaches that try to explain how cultural forces shape language. First, it can provide new empirical data on which to test models. Secondly, it can suggest phenomena for constructive approaches to aspire to. Agent-based models provide a good way of identifying mechanisms, but are often too abstract to be tested against real data (Vogt & De Boer, 2010). Results from nomothetic research can guide computational models with regards to the relevant factors that affect language evolution. For example, Lupyan and Dale (2010) show that population size predicts morphological complexity. While many models consider demongraphic data (e.g. Nowak et al., 2001), few consider a realistic notion of morphological versus lexical marking. However, caution is required when using nomothetic results to inform constructive approaches. While nomothetic approaches can identify trends, they provide little explanatory power with regards to the mechanisms which brought about these trends. That is, it's not a straightforward task to convert the phenomena that nomothetic approaches discover into abstract features for a model of a mechanism. This paper discusses some limitations of nomothetic studies and how to interpret their results in the light of constructive approaches.

A century ago, Edward Sapir surmised that "even the simplest environmental influence is either supported or transformed by social forces" and that culture and social structure co-evolve (Sapir, 1912, p.26). This co-evolution may have begun before the evolution of modern language (e.g. Dunbar, 1993). Language, then, is a complex adaptive system: it emerges as a product of its underlying speech community, but also adapts to the very dynamics from which it emerged (Beckner et al., 2009). Constructive approaches to language evolution have been emphasising the importance of cultural transmission in shaping the structure of language (e.g. Smith & Kirby, 2008), as opposed to strong nativist claims. Recently, new statistical techniques and real data have been used to address this issue. This is part of a growing field which be broadly categorised as ‘nomothetic’: Constructing models of general phenomena from large sets of cross-linguistic data. While the use of real data can be an advantage over other constructive approaches, it lacks the careful case-study approach of more traditional ‘idiographic’ research. This paper discusses how nomothetic approaches fit in with other constructive approaches.

These approaches will be briefly illustrated with examples from studies of colour lexicons. MacKeigan and Muth (2006)’s idiographic research reports that speakers of Tzotzil have hundreds of compound forms for describing colour due to their industry of the hand-weaving colourful textiles. The study tracked the spread of individual colour words within the social network of the weavers to assess the affects of social structure on the lexicon and motivate hypotheses. This careful study of individuals in a particular society is a powerful research method, but it is also complex, costly and time-consuming. The naming game paradigm (Steels & Belpaeme, 2005) is a constructive approach to the transmission of colour words, but relies on abstracted assumptions and is difficult to implement and analyse. Given the availability of new electronic resources and the internet, it is now possible to address the same topics simply, cheaply and quickly.

To demonstrate this point, we conducted a nomothetic analysis of the effect of colour terms on cultural aspects of society. We hypothesised that a society’s colour lexicon should effect the range of colours in artifacts whose appearance has been negotiated, such as national flags. Indeed, a multiple regression shows that the number of basic colour categories in a language is a significant predictor of the number of colours in the national flag for speakers of that language ($r=.12$, $F(16,106)=1.86$, $p=.03$, controlling for population size, distance from the equator and per-capita gross domestic product. Data from WALS; Wikipedia, 2011; IMF, 2011). This is an example of a nomothetic study - considering data across many languages and sources (although admittedly using crude statistical techniques). It could be used to support the idea that colour lexicons are grounded in physical objects through negotiation and interaction in a local population (Steels & Belpaeme, 2005). It was done using an ordinary laptop, took less than a day to complete and the data and analysis cost nothing to obtain. The advantages and attraction of such an approach are clear. However, there are many weaknesses, including problems with the data and statistical analyses, the assumptions behind the analyses and the explanatory power of the analyses. These will be discussed below.

Aside from these problems, the role of the nomothetic approach is often misunderstood. Nomothetic research can be exploratory and used to demonstrate features and interactions of interest that other approaches may test, not necessarily a definitive proof in itself. The candid introduction of Hay and Bauer (2007) demonstrates that researchers are aware of this: “We couldn’t resist checking this apparent link ... We do not have well-developed theoretical arguments to offer about why this should be. However the correlation seemed intriguing enough that it was worth simply publishing the result, and leaving it up to readers to draw their own conclusions" (Hay & Bauer, 2007, p.388).

Recently, newly available data and techniques have prompted large-scale statistical investigations of the effect of social structure on language evolution. Two studies will be reviewed here and used as illustrations for the rest of the paper. First, Lupyan & Dale (2010) (LD) show that a community's population size is correlated with the level of morphological complexity in their language . Language typology data from the World Atlas of Language Structures (WALS, Haspelmath et al., 2008) were combined with data on the speaker population and geographic spread from the Ethnologue (Gordon, 2005). A general trend was identified: Languages with a small number of speakers, low geographic spread and few linguistic neighbours tend to have high morphological complexity (esoteric languages). On the other hand, languages with a large number of speakers, large geographic spread and many linguistic neighbours tend to have low morphological complexity (exoteric languages). The Linguistic Niche Hypothesis put forward by LD proposes that there is a pressure for extoteric languages to become more learnable by second-language learners (adults), and so adapt to rely less on complex morphology.This view of language evolution is compatible with the view of language as an organism that adapts to the cognitive niche of human brains (e.g. Christiansen & Chater, 2008; Smith & Kirby, 2008). This is an appealing theory, but its limitations and the most productive methods of testing will be discussed below.

In another study, Atkinson (2011) applies a serial founder effect model to phonemic diversity to infer the most likely origin of modern languages. The analysis shows that languages tend to have a smaller phoneme inventory the further you get from western Africa. Under this model, migrating sub-populations only sample part of the variation in the original population, so that variation is lost through repeated migrations. It is fascinating that such a simple linguistic variable could reflect a key social change after such a long time. However, the analysis has some weaknesses in common with many similar studies, discussed below. The main problem that we see is that, on its own, the explanatory power of nomothetic results are low. There is a temptation, given the relative ease of conducting studies, of coming to rely on such an approach to support the claims of a hypothesis. It is argued that the nomothetic approach is a tool for the construction of hypotheses, not a complete approach in itself. The next sections expand on the problems with the use of statistics, the assumptions made and explanatory power.

1. Use of statistics

Nomothetic approaches typically rely on statistical correlations to support their hypotheses. The amount of data available allows a lot of statistical power, but this should be used cautiously for three reasons. First, the data available for analysis are not necessarily direct measures of the phenomena of interest. Therefore, it is important to control for data quality and covariance. Secondly, the analyses do not necessarily demonstrate *how* the measures are related causally. Furthermore, the explanation is imposed by the researcher, so a careful consideration of competing hypotheses is necessary. While these problems are common to many fields, there are some specific concerns for modern nomothetic approaches, discussed below.

1.1. *Quality of data*

One concern with the nomothetic approach in general is the quality of the data in the analysis. The sampling is poor (LD point out no langauge in WALS has data for all features, and no feature has data for all languages) and there is a lack of temporal depth (Fagyal, Escobar, Swarup, Gasser, & Lakkaraju, 2010), which might obscure a correlation between the rate of change of demographic features and the rate of change in language (Martowicz, 2011). However, longitudinal data is not easily available for analysis. This problem can be addressed using careful statistics or supported with experimental or idiographic approaches.

1.2. *Spurious correlations*

Statistical power can be a weakness. Large datasets will contain spurious correlations which could provide apparent support for any hypothesis against a null-hypothesis. For example, countries in which the acacia tree *Acacia nilotica* grows are significantly more likely to have tonal languages (χ^2=47.1, $p < 0.0001$, data from CPC, 2008; Maddieson, 2008). However, a causal link is, obviously, very unlikely. This problem can be addressed with careful use of statistics or, better yet, testing multiple competing hypotheses against each other.

1.3. *Alternative hypotheses*

When testing a hypothesis with potentially low-quality, covarying data, it is important to consider alternative explanations. For instance, with regards to Atkinson's discovery of a correlation between phonemic diversity and distance from Africa, only the 'out of Africa' explanation is considered. However, considering alternative hypotheses can become complicated. A toy example will be used to illustrate the difficulty of interpreting nomothetic results. Suppose we wanted to test the hypothesis that languages are more morphologically complex the further their communities are from Europe.We can test this using data on number of grammatical categories a verb can take in a given language and the geographic locations of the societies of those languages. Indeed, morphological complexity of a language is significantly correlated with the physical distance of its community from center of the European Union (partial correlation controlling for speaker population, $r = 0.12$, $df = 141$, $p= 0.04$, data from WALS). This evidence rejects a null hypothesis, and so appears to support the hypothesis that linguistic typologies are Euro-centric by showing that a linguistic feature has an 'origin' in Europe.

However, the crucial question is how to interpret the statistic. Using distance from a single point does not allow other hypotheses to compete. A more appropriate baseline may be to consider the probabilities for regularly spaced points across the earth. Doing this, we find that there *is* a region around Europe where the correlation fits. However, there are also similar regions at most extreme latitudes. One possible explanation is that the correlation is significant for locations which maximises the variation in distances, (i.e. locations far away form the co-ordinates of the languages: Extreme latitudes, oceans etc.). This is tested by comparing the current map of correlations to the same map where the values of the data points are randomised. The map of correlations was re-sampled with random feature values using a Monte Carlo method. These maps were compared to the map of true values using a mantel test. 47% of the random maps produced significantly similar ($p < 0.05$) maps to the map with true values. That is, even when the linguistic data is randomised, there is a likelihood that an 'origin' map will look the same. This suggests that there is some amount of structure in the geographic locations of languages in addition to their linguistic variation that could be inadvertently harnessed by an analysis. This argument requires more analysis, however, it does give a flavour of the complexity of handling large statistical analyses. Rejecting a null hypothesis is not enough: considering alternate hypotheses is always necessary.

2. Assumptions

Studies differ with respect to the assumptions they make. For instance, although Atkinson (2011) and LD both incorporate broad demographic variables, their theoretical rationale for the application of these variables differs: whereas the former is interested in how these population dynamics impact upon the distribution of variation, the latter sees social structure as a substantial feature of the linguistic environment in which a language adapts. There are three basic challenges for the nomothetic approach to overcome in terms of the assumptions it makes: Choosing the right typological framework, the linearity of relationships between variables and consideration of the relatedness of languages.

2.1. *Typological frameworks*

One of the challenges for nomothetic approach is that, in comparing feature data across languages, a single analytical framework is required. Measuring complexity across many features of many languages is susceptible to two problems, according to (Miestamo, 2008): First, no single measure can capture the relative complexity of all languages. Secondly, comparing different aspects within a language and how they contribute to overall complexity is very difficult. Dale, Dietrich, and Chemero (2009) would agree with this, however, arguing that many frameworks and levels of explanation are necessary to account for complexity. Despite this, other studies have conflicting conclusions about the effects of population size on grammatical complexity. Nichols (2009), Sinnemäki (2009) and Hyslop (1993) find negative correlations between population size and other measures of grammatical complexity (see also Martowicz, 2011). A consensus on a theory of language complexity is required to make progress, but we suggest that, rather than further nomothetic studies, other approaches could be used to test the different predictions that each study makes against each other.

2.2. *Linearity*

Linearity is an unrealistic assumption for complex adaptive systems. Even if a linear relationship is currently observable, the current snapshot may be unable to detect a more complex relationship over time. For instance, technological and cultural complexity are shown to be drivers of population growth (Richerson, Boyd, & Bettinger, 2009), so the relationship we see between language features and demography could be an artefact of technological sophistication and cultural complexity. Also, although the nomothetic studies above suggest that large-scale changes in the social structure are intricately linked with phonemic diversity and morphological complexity, these features are part of a wider linguistic environment. Changes in social structure, then, may not only pattern variation at multiple-levels of linguistic organisation, but also lead to synergistic adaptation in a language: Here, we would expect to see signatures of adaptive patterning between phonemic diversity, morphological complexity and syntactic structuring. LD already hint at such a relationship when they linked decreasing morphological complexity with an increasing degree of form-meaning compositionality. One way to decrease a language's reliance on inflectional morphology is to shorten word lengths. An information theoretic perspective will show that more phonemes allow for shorter word lengths, as evident in laboratory experiments (Selten & Warglien, 2007) and statistical studies (Nettle, 1999).

Phonemic diversity, then, can in some cases provide the raw material with which a language will systematically restructure itself in accordance to a particular niche. Of course, this is hypothesised to be reasonably path-dependent, in so much as an increase in the phoneme inventory size opens up the potential to explore new adaptive avenues. One general finding places high phonological complexity (large phoneme inventory and high syllable complexity) as feeding through other levels of languages: morphological complexity lowers whilst the introduction of greater degrees of homonymy and polysemy increases semantic complexity (Fenk-Oczlon & Fenk, 2008, see Winters, 2011 for further details).

2.3. *Lineages*

The geographic spread of linguistic features is not an accident - languages and societies expand in lineages. This issue is not addressed directly in LD, in contrast with some previous research. Nichols (1992) finds no significant correlation between population size and their measure of complexity within each macro-continent and suggests that the correlation is an accident of geography. Hay and Bauer (2007) also find that language family explains some of the variance in phoneme inventory size, in addition to population size. Martowicz (2011), looking at the complexity of clause linkers, finds more evidence for the influence of geographic distribution and transmission lineage than population size. Phylogenetic techniques provide important new tools for addressing these issues. For instance, Dunn et al. (2011) use a phylogenetic analysis of real typological data to test nativist theories of word order universals against cultural transmission theories. This is a very productive use of the nomothetic approach as it combines work from constructive approaches, formalist approaches and empirical data.

3. Explanatory power

The relationship between population size and morphological complexity reported above is a trend - there are languages that go against this tendency. However, LD claim that their approach is nomothetic (see LD, supplementary Material S3). That is, the results show a strong tendency which suggests a hypothesis that can go on to be tested directly by other approaches. Although nomothetic approaches are a powerful tool for generating hypotheses, the amount of explanatory power they produce is weak. This can make it difficult to incorporate the findings into an abstract model. As an example, LD suggest the difference between exoteric and esoteric languages is related to the difference between child and adult learning abilities. Although it is generally true that ultimate attainment in language acquisition is correlated with age of first exposure, the cause of this is difference is contested. For instance, the linguistic output of a second language learner (and so the input to the next generation) may be affected by social aspects such as embarrassment (Schachter, 1974), lack of motivation, low self-esteem or anxiety (Krashen, 1982). Furthermore, adults and children interact differently in terms of number of interlocutors, frequency, context and function (Kuhl et al., 1997). At the society level, ultimate attainment is effected by the linguistic distance between the first and second language (e.g. Lado, 1957). This means that it's not just the number of other languages a community has contact with that should affect its evolution, but the properties of those languages.

Thus, identifying the causal factor driving the relationship between second language learners and morphological complexity is not straightforward, meaning that extracting the relevant features of the mechanism for a model is difficult. However, nomothetic approaches can work with idiographic approaches to obtain a better idea of the processes involved. For instance, proponents of the idiographic approach also argue that the amount of language contact has an effect on language complexity (e.g. Trudgill, 2004), although opinions differ on the importance of this factor. Trudgill (2004) argues that population size, network structure and language contact need to be considered together while McWhorter (2008) suggests that the level of non-native language acquisition is the only factor that affects the simplification of grammar over generations. It's worth noting that nomothetic approaches do not always contradict conclusions from other approaches, and are not always the most extreme.Recent experimental evidence also supports the hypothesis that second language learners find morphology more difficult to master than native speakers (Clashen et al, 2010). Also, Little (2011) uses a human language game experiment to test the hypothesis that forigner-directed speech is a driving factor. In conclusion, although the proportion of second language speakers in a community is related to the morphological complexity of its language, the proximate causes of this relationship are complex. This problem holds for many nomothetic studies. Several approaches from many disciplines are required for a full explanation.

4. Conclusion

Through the research reviewed in this paper, a picture is emerging which emphasises a complex interaction between the language of a society and its social structure. This work, together with theoretical and experimental work on cultural transmission, weakens the necessary effects of innate properties of language and demonstrates the importance of the way people interact (e.g. Smith & Kirby, 2008; Dunn et al. 2011). This paper has discussed the nomothetic approach and argued that, while it may inform other approaches, it has a limited explanatory power. A pluralistic approach involving constructive approaches to language evolution is needed. Given the high rate at which cultural processes can change cultural structures (Christiansen & Chater, 2008), there could be a cut-off point in history where the current data can't inform us of aspects of culture in the past in a straightforward way. Constructive and experimental approaches can help support this weakness in the nomothetic approach.

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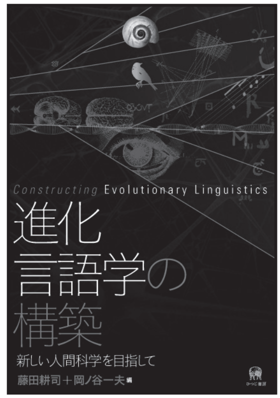

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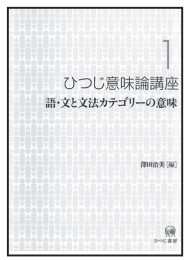

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ひつじ書房

Okanoya Emotional Information Project

岡ノ谷情動情報プロジェクト

about our project

http://www.jst.go.jp/erato/project/ojj_P/ojj_P.html (in English)

http://www.jst.go.jp/erato/project/ojj_P/ojj_P-j.html (Japanese)

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Author Index

Five Approaches to Language Evolution

The 9th international conference on the Evolution of Language was held from the 13th to 16th of March in Kyoto, Japan. The conference program included five independent workshops, each focusing on a different approach to language evolution. This volume records the proceedings of those workshops.

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