EVOLANG X

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WORKSHOPS

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THE COMPARATIVE BIOLOGY OF ARTIFICIAL GRAMMAR LEARNING

CAREL TEN CATE & WILLEM ZUIDEMA

PROGRAM

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INTRODUCTION

CAREL TEN CATE (LEIDEN) & WILLEM ZUIDEMA (AMSTERDAM)

A key property distinguishing language from the vocal communication in other animals is our ability to apply abstract rules to create an unbounded set of linguistic utterances. There is a debate on whether this ability is uniquely human, and evolved in consort with language, or whether it originates from more general cognitive abilities that might also be present in other animal species, either by common descent or by independent evolution. One way to address the evolution of syntax is the comparative approach: can we find some of the cognitive abilities underlying our syntactic abilities in non-human animals and if so, what are the similarities and differences in the way these processes operate in different species. The Artificial Grammar Learning (AGL) paradigm provides a powerful tool to explore the presence of such abilities in animals and lends itself specifically well for such a comparative approach. It examines how humans and animals cope with extracting rules from exposure to input consisting of meaningless syllables ('words'), structured according to particular syntactic rules. Experiments have revealed a variety of processing mechanisms and abilities for syntactic rule extraction in infants and older humans. Such rule extraction is one of the most important elements of language learning. As it is also considered one of the most important features in which human and non-human animals may differ from each other, various researchers are examining these abilities for a number of non-human animals, using similar (and sometimes less similar) experimental techniques. While some claim to have obtained evidence for syntactic rule extraction, others have argued that the existing evidence is not conclusive. As a result, the field is very much alive and hence a workshop on this controversial subject is extremely topical. With this workshop, we aim to assess the current state of knowledge with respect to the rule learning abilities in non-human animals and how do they compare to human infants, children and adults. We bring together leading researchers involved in artificial grammar learning studies in humans as well as in a variety of animal species: monkeys, rats and birds. Using different experimental paradigms and examining both auditory and visual pattern learning of different levels of complexity they collectively give an overview of the most recent state of knowledge. By bringing these researchers together, we hope to foster mutual interactions, providing a sharper delineation of the critical questions for future study. We thus expect our workshop to be able to advance the field.

FROM MEMORY TO GRAMMAR

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Language is clearly specific to humans, but might rely in part on evolutionarily ancient mechanisms. In this talk, I will present two memory mechanisms for encoding sequences, and show that one of them – encoding the positions of elements in a sequence relative to the first and the last one – might play an important role in language. I will then show that this mechanism has similar properties in humans and other primates, and allows some non-human primates to learn simple grammar-like regularities. Some grammatical regularities might thus be expressed using evolutionarily ancient mechanisms.

ARTIFICIAL GRAMMAR LEARNING AND THE PRIMATE BRAIN

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Artificial Grammars (AGs) can be designed to emulate certain aspects of human language syntax. An interesting empirical question is which animal species can learn various levels of AG complexity. Understanding this could clarify the evolutionary roots of human language and facilitate the development of animal models to study language precursors at the neuronal level. In this talk I will first describe the results from behavioral AG learning work that we have conducted with macaque and marmoset monkeys, two species of nonhuman primates representing different primate evolutionary lineages. Here, I will propose a simple quantitative approach to relate our findings to those that have been obtained in other animal species (including songbirds) and with different AGs. Then I will describe neuroimaging results using functional MRI on macaque brain regions that are involved in AG learning and how these results compare to fMRI results in humans and chimpanzees (the latter done in collaboration with Yerkes Primate Research Center, USA). I conclude by overviewing neurophysiology work that is underway in the lab to understand neuronal responses and cortical oscillations associated with AG learning in macaques.

EXPLORING GENERALIZATION USING ARTIFICIAL LANGUAGE LEARNING: COMPARING ADULT AND CHILD LEARNERS

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Successful language acquisition involves generalization, but learners must balance this against the acquisition of lexical constraints. Such learning has been considered problematic for theories of acquisition: if learners generalize abstract patterns to new words, how do they learn lexically-based exceptions? One approach claims that learners use distributional statistics to make inferences about when generalization is appropriate, a hypothesis which has recently received support from Artificial Language Learning experiments with adult learners. Since adult and child language learning may be different, it is essential to extend these results to child learners. This presentation will address this issue.

LACKING LINGUISTIC REPRESENTATIONS, ANIMALS OUTPERFORM HUMANS IN A RULE LEARNING TASK

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Extensive research with human adults and infants suggests it is difficult to learn simple rules over consonants, but not over vowels. Nevertheless, the source of this difficulty is unknown. One possibility is that acoustic differences between consonants and vowels (e.g. vowels tend to be longer and carry more energy than consonants) lead to differences in rule learning. Another possibility is that the observed difficulty for learning rules over consonants is due to how humans represent them, and the role we assign consonants during language processing. In a series of studies, we tested rats' capacity to generalize rules implemented over vowels and consonants. In Experiment 1, rats were trained to discriminate CVCVCV nonsense words in which vowels followed an AAB structure in half of the words and an ABC structure in the other half, whereas consonants were combined randomly. In Experiment 2, rules were implemented over the consonants and vowels varied at random. In the test phase of both experiments eight new test words were presented. Following the presentation of each AAB or ABC word lever-pressing responses were registered and food was delivered. We found that rats could learn the rules and generalize them to new tokens over both vowels and consonants. Using exactly the same materials, humans only learned the rule over the vowels. Our results support the hypothesis that linguistic representations constrain the operation of rule learning mechanisms. Lacking such representations, animals easily learn rules that are difficult for humans.

GEOMETRICAL PATTERNS AS VISUAL GRAMMARS

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Geometrical patterns are traditionally produced in human cultures around the world, and are used to decorate everyday objects and the human body. The production rules underlying regular two dimensional patterns can be fully described with four basic symmetry operations: reflection, translation, rotation and glide. Using such a symmetry based system, seven one dimensional and 17 two dimensional patterns can be derived, all of which are found in real life patterns. Visual patterns can thus be thought of as naturally occurring grammars, that require a de- and encoding of visual generative rules. We have recently begun to test the perception and production of naturalistic visual patterns empirically and to explore to what extent the formal mathematical rules used to describe patterns are consistent with human production and perception data. We found that children and adults can reliably detect structural violations of symmetrical patterns with no instruction on what constitutes a pattern or a violation thereof. Humans have a strong drive to produce visual arrays that have high degrees of order and predictability. The patterns spontaneously produced by participants in the lab are characterised by high degrees of symmetry and regularity. Furthermore, we found that the global properties of the patterns produced depended on the local symmetrical properties of the basic pattern unit. In contrast, pigeons tested with the same patterns failed to distinguish between patterns that did or did not contain rule violations, but succeeded at detecting colour violations, suggesting that regularities based on orientation, rather than colour, are not a salient cue in this species. We conducted comparative work on visual instantiations of AnBn and ABn strings with kea (a parrot species) and pigeons, and found that both bird species generalised to new arrangements, pattern elements, orientations and extensions. Both species found it very difficult to generalise to grayscale stimuli. With extensive training, kea were able to generalise to grayscale images, but pigeons failed. Neither bird species were able to reject foils where the number of As and Bs were mismatched. Humans in contrast, successfully generalised to all classes of stimuli.

AUDITORY PATTERN LEARNING IN BIRDS AND HUMANS

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We examined the strategies for discrimination of sound sequences in Bengalese finches and humans using the same behavioral protocol. Birds were trained on a GO/NOGO task to discriminate between two categories of sound stimulus generated based on an “AAB” or “ABB” rule. The results suggested two discriminative strategies were being applied: (1) memorizing sound patterns of either GO or NOGO stimuli and generating the appropriate responses for only those sounds; and (2) using the repeated element as a cue. Next we examined whether those strategies were also applicable for human participants on the same task. The results and questionnaires revealed that participants extracted the abstract rule, and most of them employed it to discriminate the sequences. This strategy was never observed in bird subjects, although some participants used strategies similar to the birds when responding to the probe stimuli.

WHAT ARE THE RULE LEARNING SKILLS OF BIRDS?

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Birds provide interesting models for understanding the origins of linguistic complexity (Bolhuis & Everaert 2013). Like speech sounds and language, songs of songbirds are learned and are characterized by rapidly produced, structured sequences of more or less stereotyped elements (‘notes’). The similarities most likely arose by parallel, independent, evolution. Birds are therefore important models for comparative studies, providing the opportunity to examine whether properties that seem specific to human language also occur in non-related, non-linguistic species. This can indicate both necessary and enabling mechanisms for producing vocal complexity and hence provide hypotheses about the cognitive and neural building blocks from which human linguistic complexity may have evolved. We explore the rule learning abilities of a songbird, the zebra finch, and the budgerigar, a representative of the parrots (another group of vocal learners), in several artificial grammar learning (AGL) experiments. In particular we focus on the abilities of these species to distinguish XYX from XXY strings (X and Y denoting different vocal elements), an ability demonstrated in human infants (with X and Y being speech syllables) (Marcus et al. 1999). In an earlier study (van Heijningen et al. 2013) we showed that zebra finches trained in a Go-NoGo paradigm discriminated these string types by attending to the presence and position of repeated elements (XX, YY). We now report on subsequent experiments aimed at assessing whether zebra finches and budgerigars generalize the discrimination beyond the items used for training to strings containing novel X and Y-items. We compare our results with those obtained in humans trained and tested with the same stimuli in a similar paradigm. Such generalization is a hallmark of rule learning, but the evidence that birds or other animals are able to do so is limited and controversial (van Heijningen et al 2009; ten Cate & Okanoya 2012). While humans readily generalized string patterns to novel items, both bird species showed only limited abilities to do so. Interestingly, zebra finches and budgerigars differ in the level of abstraction they seem able to achieve. Our results provide a window on what the evolutionary early stages of rule abstraction may have looked like.

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INDIVIDUAL DIFFERENCES & MODEL SELECTION IN ARTIFICIAL GRAMMAR LEARNING

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In Artificial Grammar Learning experiments that test hypotheses about formal classes of strings (e.g., those defined by context-free grammars, non-adjacent dependencies, or "algebraic" rules) researchers face some particular difficulties in deciding on appropriate controls. In my talk I will focus on experiments that test whether humans and songbirds can learn a contextfree language. I will show simulation results that demonstrate that commonly used controls and statistical tests can easily lead to wrong conclusions. A particularly difficult situation arises when there are individual differences in the strategies participants in the experiments use, or when individuals alternate between different strategies. I will argue that in these cases basic model selection techniques offer ways to still make inferences about the abilities and inabilities of different species to learn these formal classes of strings.

EVOLUTION OF SIGNALS, SPEECH AND SIGNS

BART DE BOER & TESSA VERHOEF

PROGRAM

09:00	**Opening** Bart de Boer (& Tessa Verhoef)
09:10	**A laboratory model of sublexical category evolution** Andrew Wedel & Benjamin Martin
09:35	**The role of iconicity in the cultural evolution of communicative signals** Mark Dingemanse, Tessa Verhoef & Seán Roberts
10:00	**Neutral spaces and the evolvability of spoken language** Bodo Winter
10:25	**From silent gesture to artificial sign languages** Marieke Schouwstra, Katja Abramova, Yasamin Mota Medi, Kenny Smith & Simon Kirby
10:50	**Emergence of low-level conversational cooperation: The case of nonmatching mirroring of adaptors** Sławomir Wacewicz, Premysław Żywiczyński & Sylwester Orzechowski
11:15	**Coffee Break**
11:45	**Gene-culture coevolution of a linguistic system in two modalities** Seán Roberts, Connie de Vos
12:10	**On the separate origin of vowels and consonants** Joana Rosselló
12:35	**The effect of physical articulation constraints on the emergence of combinatorial structure** Hannah Little & Kerem Eryılmaz
13:00	**Breath, vocal, and supralaryngeal flexibility in a human-reared gorilla** Nathaniel Clark & Marcus Perlman
13:25	**Overall discussion and closing**
13:45	**End**

INTRODUCTION TO THE WORKSHOP ON SIGNALS, SPEECH AND SIGNS

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1. Aims of the workshop

This workshop aims to bring together researchers interested in the physical signals that are used to convey language and the potential precursors of these signals. The intention of the workshop is not so much to present entirely new results – the main conference would be excellent for that – but to find out which open questions remain, what new approaches would be possible and where (interdisciplinary) cooperations could be useful. Although the content of the workshop is exploratory and perhaps speculative in this respect, the science on which new ideas have to be based will play a central role. One of the workshop's main themes will be to look for new empirical ways to test ideas that have so far received no attention or have only been speculated about.

The focus of the workshop is on physical signals for several reasons. First of all, physical signals are the most directly observable aspect of language. This makes it relatively easy to compare such signals between languages, between modalities and between species. However, another exciting property of the physical signals is that they are pre-symbolic and continuous. Of course, they may be used to express symbolic and categorical information, but this may not be necessarily inherent to the signals. Rather, symbolic or categorical structure needs to be imposed on the signal by the cognitive systems processing them. This transformation from continuous, sub-symbolic signals into categorical, symbolic information is something that humans are very good at (and something which is crucial to language), while other species (even evolutionarily closely related ones) appear to be less skilled at this. Therefore, this is an aspect of language processing that is very relevant from an evolutionary point of view. Related to this is that linguistic signals have elaborate combinatorial structure, whereas non-linguistic communicative signals tend not to, or to a much smaller extent. How we are able to deal with combinatorial structure is also an important open question in the evolution of language, and one whose answer may have repercussions outside the domain of signals, as very comparable cognitive mechanisms may be needed to process the compositional structure of syntax.

Before giving a (very brief) overview of the contributions to the workshop, we will give an equally brief overview of what we think are important open questions in the study of the evolution of speech. Our hope is that the workshop can help to elucidate these questions.

2. Evolution of signals, speech and signs

A lot of work has been done on the evolution of the vocal tract. Although the debate is far from settled, it has become more or less accepted by most parties that the more crucial evolutionary changes were probably cognitive.

An open question, however, is how our abilities differ exactly from those of apes. What exactly are the vocal abilities of apes? What is their neurological basis and is this different for modern humans. Which existing ape behaviours are most closely related to modern language? Ape gestures (orofacial or manual) or vocalizations? It appears that apes have more complex gestural repertoires, but the truth is that even their vocal repertoires are poorly understood.

The role of sign language in the evolution of language is also an open question. Did language start as pure signs? But then why did it ever change into a vocal system? It appears that many researchers appear to favour a mixed system. In any case, we need to investigate what the precursors to linguistic sign could have been and how they changed into linguistic signals. Related to this question is what precisely the role of iconicity was in the evolution of language. Are iconic signals really necessary for getting a language off the ground?

In answering these questions it is important to consider the interaction between individual learning, cultural evolution and biological evolution. All these processes interact and it may be difficult to determine what role each of them plays in explaining observed (linguistic) behaviour. Fortunately, the experimental paradigm of iterated learning or experimental semiotics helps to tease the effects of cultural processes and individual cognitive biases apart. However, this paradigm has only been applied to continuous signals in very few instances. In addition, computer models have successfully been used to gain insight into complex interactions between different processes. Both of these methods are well represented in the workshop.

Although these are a lot of questions, there are certainly more open issues, and we do not expect that they will be easy to answer. However, carefully considering what techniques we have and what evidence is available or can be gathered, should allow us to find ways to answer these questions empirically.

3. Contributions

The contributions to the workshop form an interdisciplinary mix of different research methods and address a wide range of relevant research questions.

From linguistics, there is the contribution by Roselló, which investigates possible evolutionary scenarios by which vowels and consonants could have evolved from pre-existing behaviours. From biology there is the contribution by Clark and Perlman, investigating behaviours in a gorilla that may be related to precursors of speech. Wacewicz et al. study non-verbal behaviour in the visual/postural domain that is potentially pre-linguistic: mirroring behaviour, and propose how to study this experimentally. Schouwstra et al. and Roberts and de Vos' contributions stem from the study of sign language. Schouwstra et al.'s contribution uses an experimental paradigm to investigate the transition from a system of gestures to a conventionalized system that looks much more like a sign language. Roberts and de Vos investigate, using a computer model, the interaction between genes for deafness and the emergence of sign language in a population. Winter also uses a computational model, but investigates the emergence of robustness in systems of signals. Little and Eryılmaz combine computer models with cognitive experiments to investigate how articulatory constraints may influence emergence of structure in speech. The contributions by Dingemanse et al. and Wedel and Martin present other experimental investigations of the emergence of structure in communicative signals, but they do not focus on articulatory constraints, but rather on how signals change over time. Whereas Wedel and Martin look at what happens to real phonemes, Dingemanse et al. look at the structure of signals in artificial languages. Moreover, Wedel and Martin look at how signals change in repeated interactions between the same participants, Dingemanse et al. look at how signals change over experimental "generations".

These contributions represent a rich subset of possible approaches and address a large number of the open questions mentioned above. We hope the interaction between the contributors will result in new directions of research to investigate the evolution of humans' ability to deal with linguistic signals.

A LABORATORY MODEL OF SUBLEXICAL SIGNAL CATEGORY EVOLUTION

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1. Introduction and Background

Human languages are characterized by multiple, nested levels of encoding, such as the division between categories that carry meaning such as words, and the smaller inventory of sublexical, largely meaningless signal categories that can be combined in multiple arrangements to form words (Ladd 2012). Given this relationship, the function of word categories in the transmission of information is dependent on a language perceiver's ability to distinguish sublexical categories within the larger linguistic percept.

A long-standing question is how the inventory of sublexical categories evolves over many cycles of language usage and acquisition. A range of theoretical work proposes that the maintenance of this inventory over generations is causally grounded in the transmission of information in usage (e.g., Trubetzkoy 1939, Martinet 1955, King 1967, Zuidema & de Boer 2009, Wedel 2012), rather than through some directly innate mechanism (e.g., Ni Chiosain & Padgett 2009). Previous modeling work has shown that the well-established perception-production feedback loop in language usage should allow any bias toward selective preservation of signal-quality to influence the evolution of the signal-category inventory over generations (Wedel 2004, Blevins & Wedel 2009, Wedel 2012; cf. work in iterated learning (e.g. Kirby 1999)). If signal-quality is preferentially maintained in relation to the role of that signal in communicating word-identity, we expect the evolution of signal inventories to preferentially preserve the categories that play a larger role in distinguishing word categories.

This hypothesis is supported by recent work showing that sublexical sound category loss is significantly, inversely correlated with the number of words distinguished by that category (also known as minimal pairs; Wedel et al. 2012). For example, the /ɔ ~ ɑ/ vowel distinction in English distinguishes very few minimal word pairs; an example of a minimal pair like this is *caught ~ cot*. Correspondingly, the distinction between /ɔ/ and /ɑ/ has been lost in many North American dialects of English such that cot and caught are now homophonous in those dialects. Conversely, sound categories that distinguish many words appear to be especially protected from loss (Wedel and Jackson, in prep). Findings from recent experimental (Baese & Goldrick 2009, see also e.g., Eisner & McQueen 2005, Kraljic & Samuels 2005, Verhoef et al. 2012) and corpus studies (Wedel & Sharp in prep) are also consistent with the hypothesis that a perceptual cue to the identity of a given word is hyperarticulated if it plays a large role in distinguishing that word from a similar word, and conversely, a perceptual cue that plays a smaller role tends to be reduced.

However, the causal mechanism(s) more directly underlying selective hyperarticulation remains unknown (reviewed in Baese & Goldrick 2009, Wedel 2012). In response, we have developed a laboratory model of naturalistic speech to investigate sound change in response to communicative pressure. Here, we report an investigation suggesting that word pairs do not need to directly compete in context in order to induce hyperarticulation of perceptual cues. This question is relevant because in actual usage, minimal pairs are rarely similarly probable in the same discourse context.

2. Methods

The laboratory model is based on a map-task in which two participants take turns instructing each other to draw a path through a set of landmarks on a map. Each of the landmarks on the map is an object with a monosyllabic English name. The set of landmarks were chosen to provide examples of two kinds of easily measured phonetic contrasts: initial stop-consonant voicing (as in peach ~ beach), and vowel height (e.g, chick ~ check). Participants' speech was recorded through head-mounted microphones, and the relevant phonetic measures were subsequently made using Praat (Boersma & Weenink 2013).

A major cue to the voicing distinction in initial stops in English (i.e., p~b, t~d, k~g) is the ratio of the length of the burst to the entire stop length (Lisker & Abramson 1964). All else being equal, the longer the relative burst length the greater the percept of voicelessness, while conversely the shorter the relative burst length, the greater the percept of voicing. The burst/stop-length ratio for each stop token was normalized by z-scoring within each word, within each participant. Two phonetically-close vowel pairs were also compared, /ɪ ~ ɛ/ and /æ ~ ʌ/. Formants from the central portions of vowel tokens were measured with Praat, and the Euclidean distance was calculated between a given vowel token and the average F1 and F2 values for the comparison vowel, for that participant. These distances were normalized as above. One set of maps consisted of landmarks with no minimal pairs in English in the relevant sounds. As an initial baseline, each pair of participants worked through ten maps with no minimal pairs, split up evenly between two successive days. (Each different map had a different subset of landmarks, arranged differently, with different paths; five maps provided about one hour of conversation.) A prediction of the model is that the measured phonetic cues should become less distinctive over the two days, because these cues contribute little to distinguishing these words within the task. Each pair of participants then did a second set of ten maps on another two subsequent days, where the second set of maps provided one of two different degrees of lexical competition. In the Direct Competition set, lexical minimal pairs (e.g., peach ~ beach, chick ~ check) were both present in the map, and members of each pair were immediately adjacent to each other in half of the individual maps, placing a premium on clear articulation of the phonetic cue. In the Indirect Competition set, the members of each minimal pair were present only in alternating maps, so that clear articulation of the relevant phonetic cues had no direct role in context, yet both minimal pairs were pronounced each day.

3. Results and Discussion

As predicted, in both pairs the phonetic cues of interest are reduced in the initial no-minimal pair condition on the second day, relative to the first. Figure 1 shows the relative shift in burst/length ratio from Day 1 to Day 2 for voiced and voiceless stops; note that the ratio grows larger (i.e., more voiceless-like) for the voiced stops, and conversely grows smaller for voiceless stops. The vowel pairs also reduce, becoming less distinctive on the second day relative to the first. Linear mixed-effects modeling (Barr et al. 2013) indicates that this pattern is statistically significant for these participants.

For both the Direct and Indirect Competition conditions in the second set of maps for the participant pairs, the opposite occurs: on the second day, each phonetic contrast has become greater, and when the data is pooled across the set of participants, this is again statistically significant; Figure 2 shows the change in burst/length ratio for stops, and Figure 3 shows an interaction plot for vowel-vowel distances comparing the first set of maps without minimal pairs, to the second set of maps with minimal pairs, pooling over the Direct and Indirect Competition conditions. There is no visual or statistical evidence in this dataset that the Direct and Indirect Competition conditions produce different degrees of phonetic cue hyperarticulation. This initial exploration suggests that multi-day trajectories of phonetic reduction and hyperarticulation in response to the existence lexical competitors can be investigated in the laboratory. Further, the finding of strong hyperarticulation in the Indirect Competition condition suggests that lexical minimal pairs do not need to directly compete within context in order to induce hyperarticulation. This is consistent with a model for sublexical contrast maintenance deriving from competition in articulatory planning, rather than through listener-orientation (reviewed in Baese & Goldrick 2009). We are currently carrying out additional studies in which lexical competitors are not present in the task at all, to ask whether the simple existence of lexical minimal pairs within the language is sufficient to prevent reduction.

Figure 1

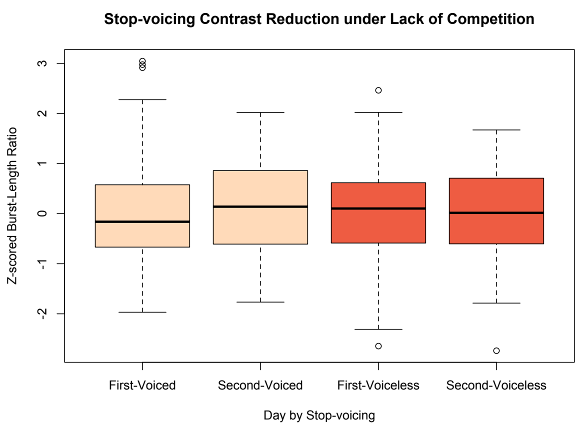


Figure 2

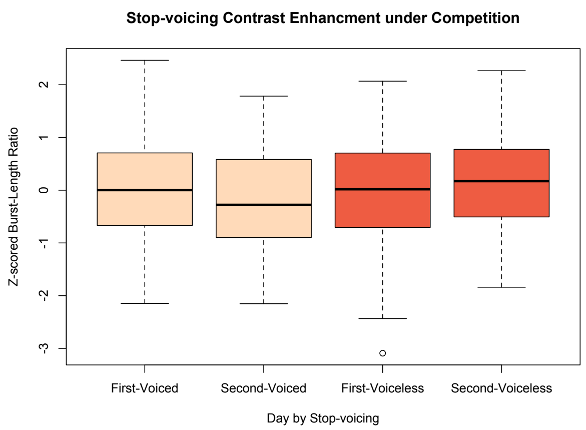
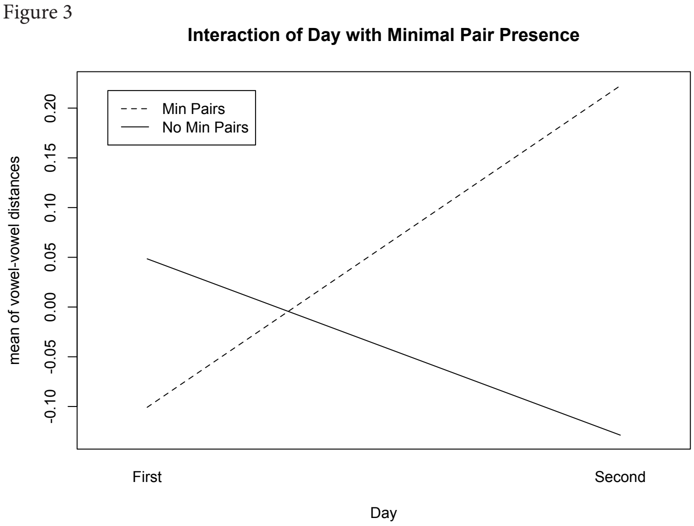


Figure 3



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THE ROLE OF ICONICITY IN THE CULTURAL EVOLUTION OF COMMUNICATIVE SIGNALS

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1. Introduction

The languages of the world vary in the extent to which they utilise iconic signals, in which there is a perceived resemblance between form and meaning. Sign languages make common use of iconicity, for instance by mapping motion in the world to motion in the signing space (Taub 2001). Spoken languages may also make extensive use of iconicity, for instance by depicting intensity or aspectual meanings in ideophones or sound-symbolic words, as in Japanese, Siwu, or Quechua (Dingemanse 2012). However, how iconicity emerges in a language, how it relates to the affordances of the medium of communication, or how it may bootstrap communication systems is unclear. One obvious suggestion is that the ease of mapping a semantic domain onto the signalling medium is a factor that affects the emergence of iconic signals. For example, mapping spatial relations in the world onto spatial relations in the sign space is easy to produce and to comprehend, whereas mapping spatial relations in speech is not so easy.

Here we explore this suggestion using an artificial communication game. Pairs of participants were asked to communicate about a set of meanings using whistled signals. We designed the meaning space so that some meanings would be easy to map onto the medium of communication and some would be difficult to map. The communication game was iterated, so that a pair was trained on the signals used by the previous pair. In this way we could observe how the communication system evolved over time.

We predicted that iconic signals would be more likely to emerge for the easily mappable meanings, and that easily mappable meanings would be communicated with greater accuracy. In contrast, conventionalised and possibly compositional signals would be more likely to emerge for non-mappable meanings. What is less clear is how the two types of signal would interact. Iconic signs might form part of the building blocks for conventionalised signs, or perhaps a compositional system would eventually replace the iconic one. There may be founder effects that determine the amount of iconicity in a system, which might be analogous to the variation we see in spoken languages. It is also not clear how iconic signals would change over time. On the one hand, they should be easy to learn and easy to extrapolate, but there is also evidence that signals that combine iconic mappings with arbitrary features are less easy to learn than non-iconic signals (Ortega & Morgan 2010). Iconic signals may not be subject to the same kind of drift as arbitrary signals because their transparent form-meaning mapping allows learners to regenerate them from scratch. This experiment explores some of these possibilities.

2. Methods

We use an iterated learning experiment with communication (e.g. Tamariz et al. 2012) to explore how iconicity affects the evolution of signals in a whistled language (e.g. Verhoef et al. 2012).

2.1 Materials

Participants communicated about artificial meanings. Each meaning was a picture of a well known animal facing either left or right (see Figure 1). There were two 'mappable' animals and two 'non-mappable' animals. The mappable animals had shapes that were assumed to be easily mappable to the medium of communication (the slide whistle). The non-mappable animals had shapes that were assumed to be more difficult to map onto the medium of communication.

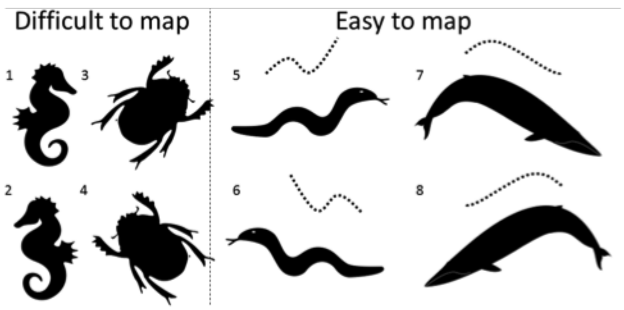

Figure 1. The meanings in the artificial language, consisting of four animals in two orientations. Meanings 1 to 4 are difficult to map onto the slide whistle space. Meanings 5 to 8 are easy to map onto the slide whistle space. The suggested mapping from meaning to tone contour is given above meanings 5 to 8. Note that animal and orientation are conveyable in iconic ways.

2.2 Procedure

Pairs of participants played a communication game via a touch-sensitive pad. In each round, one participant was chosen as the 'speaker' and the other as the 'listener'. The speaker was presented with a target meaning to communicate to the listener. The pad allowed the participants to communicate using a digital slide whistle. Moving a finger across the pad from left to right made a signal going from a low tone to a high tone.

The listener listened to the speaker's signal and was presented with a randomly ordered array containing the target meaning and 5 distractor meanings. The listener then guessed the target meaning. The pair were told whether they were correct and shown the target and the guessed meaning. After each round the speaker and listener roles were switched. Participants completed 16 rounds (each meaning twice) in a random order.

Pairs in later generations underwent a training phase before the guessing game where they saw meanings and heard the last signal used for that meaning by the previous pair in the previous generation. Participants only saw a random half of the previous meanings. This procedure differs from many iterated learning experiments because the initial input set of signals was not created by the experimenters but emerged in the interaction of the first pair.

3. Preliminary results

We ran a pilot experiment of 4 chains of between 8 and 10 generations. Participants were recruited at a museum in Utrecht and included children and adults. Easily mappable meanings were guessed correctly in 33% of trials, while non-easily mappable meanings were guessed in 22% of trials ($t = 2.9$, $p = 0.003$). We used a mixed effects logit model to predict communicative success based on the mappability of the target, the orientation, the generation, the age of the participant and the interaction between mappability and generation. The animal depicted in the meaning and the chain number were entered as random effects.

We found no main effects, but there was a significant interaction between mappability and generation ($z=2.4$, $p=0.02$). This suggests that while bootstrapping a linguistic system may not be easier with easily mappable meanings, signals for easily mappable meanings evolve to fit the communicative needs faster than signals for meanings that are not easy to map (see Figure 2).

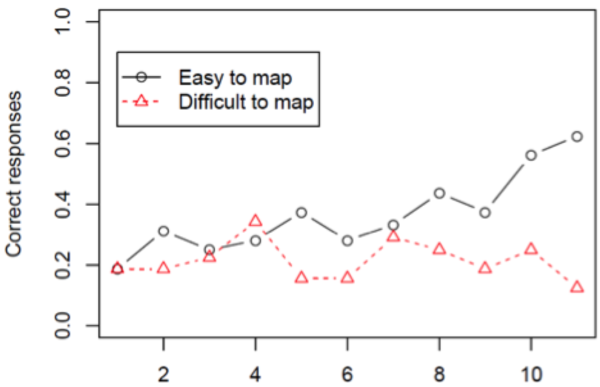

Figure 2. Proportion of correct guesses for different types of meaning over generations.

4. Discussion and future work

We used an iterated learning paradigm to explore how iconic mappings between meanings and signals can be used during the initial stages of language emergence. The results suggested that how easy a meaning can be mapped to an articulation space can affect the cultural evolution of a language.

Although in the beginning of a chain, there seems to be no difference in the proportion of correct responses for the two types of meanings, after some generations of transmission and use a clear effect appears. This is interesting, since the possibility of using iconic signals was present from the beginning. In a further analysis of the data we want to explore possible reasons for the later emergence of success in communicating easily mappable meanings. It may take time for participants to coordinate on their strategy, leading to clashes in the earliest trials that are avoided only when participants converge on the same strategy. Participants in later chains have the advantages of a learning phase which serves to create the common ground required for quick strategic convergence. A possible iconic strategy may therefore need to be used more systematically and occur in a pattern before it actually makes learning and recall easier. Such systematic patterns in the use of strategies are expected to emerge through cultural evolution and social coordination. We are currently in the process of analysing the signals used in the experiment to assess to what extent iconic mappings were utilised. We will also analyse whether signals for easily mappable meanings are more similar across chains than signals for meanings that are difficult to map. A future version of this experiment will be conducted in a more controlled laboratory environment and will involve longer training and interaction sessions with a larger set of meanings and signals.

Acknowledgements

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NEUTRAL SPACES AND THE EVOLVABILITY OF SPOKEN LANGUAGE

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1. Neutral spaces

Many systems have to resist changes from within and without. One way in which this is achieved is via neutrality (Wagner 2005). For example, in biology, Kimura's neutral theory of molecular evolution (1983) states that most genetic mutations are effectively neutral with respect to evolutionary fitness; most mutants are not 'seen' by natural selection. This makes biological systems robust against mutations. In general, biological systems frequently occupy **neutral spaces**, which are collections of "equivalent solutions to the same biological problem" (Wagner 2005: 195).

Spoken language is another system that has to resist internal and external perturbations. For speech communication to be effective in a noisy world, it needs to be robust (Winter & Christiansen 2012). And, just as with biological systems, one way to achieve robustness is via neutrality: If speech sounds occupy neutral spaces, underlying variation may have little or no effect on the outcome of communication. At least two phonetic phenomena create such neutral spaces:

First, **quantality**, which refers to non-linear mappings of articulatory input to acoustic output (Stevens 1989). Quantality says that there are regions of articulatory space where variation has no discernible acoustic effect (in Figure 1a, regions I and III). Take, for example, /s/ as in *sell*, and /ʃ/ as in *shell*. If one slowly moves one's tongue from /s/ to /ʃ/, there is a sudden transition between the two sounds, with large regions that render equally good instantiations of either /s/ or /ʃ/.

A second phenomenon is **categorical speech perception**, which refers to non-linear mappings between acoustics and perception (for review, see Harnad 1990). Take, for example, voicing (e.g., ***b**ear* vs. ***p**ear*), for which voice onset time (the time between the release of a stop and the beginning of the following vowel) is a crucial cue. If we manipulate voice onset time to create a continuum between the words *bear* and *pear*, participants hear either one word, or the other, with a sudden transition at the category boundary (see Figure 1b).

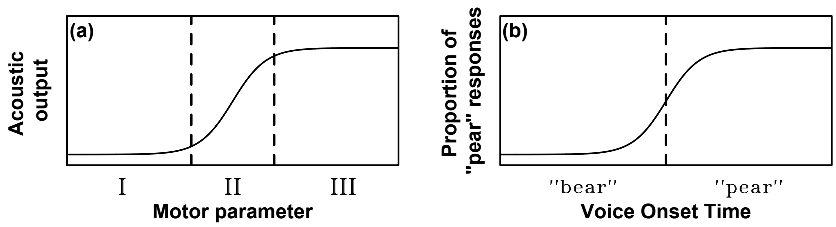

Figure 1. Schematic representations of (a) quantality and (b) categorical perception.

Neutrality unifies both quantality and categorical speech perception, because variation in an underlying parameter is neutral with respect to communicative outcomes. Neutrality assures that most perturbations result in linguistically equivalent signals.

Intuitively, one might think that robustness to noise could mean that a system cannot change easily. At first sight, the "requirements to be both robust and adaptive appear to be conflicting" (Whitacre 2010: 1). In fact, though, robustness and evolvability are not mutually exclusive. Instead, they may even enhance one another (Wagner 2005; Whitacre 2010). The following simulation demonstrates this.

2. Simulation

The goal of the simulation is to show that non-linearity leads speech signals to have *less* communicatively relevant variability (i.e., more robustness), but *more* underlying, cryptic variability. As any evolutionary system needs variation for subsequent change (including sound systems, Wedel 2006), this underlying variability can be seen as 'fodder' for elvovability.

In the simulation, 100 linguistic signals are initiated. Each signal is a value drawn from a uniform distribution with the range [-10,10]. For quantality, this represents the range of possible motor inputs. For categorical perception, this represents the range of possible acoustic inputs. The input is transformed either non-linearly (see Figure 2a) or linearly (as if no neutrality existed, see Figure 2b)

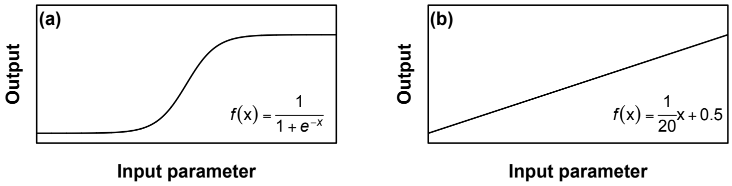

Figure 2. (a) Non-linear transform (logistic function) and (b) linear transform.

Non-linearity is implemented via the logistic function (shown in Figure 2a). This function mirrors categorical perception curves and quantally divided acoustic spaces. The linear function (Figure 2b) was chosen to keep inputs between -10 and 10 constrained to outputs within the range [0,1].

Change is implemented the following way: Signals are biased towards conformity, as if agents were imitating each other. One could imagine the 100 signals to be 100 slightly different phonemes (e.g., /s/) used in the same word (e.g., *sell*) by 100 different agents. The agents try to converge on the same output value for this word, that is, they try to pronounce /s/ as similarly as possible to what others say. Such an artificial conformity bias can be implemented via any clustering algorithm that finds the most frequent cluster in the output space.

In the present simulation, k-means clustering is used as one particular clustering algorithm. A two cluster solution is sought. Signals that are not classified as belonging to the more frequent cluster are adjusted upwards if they are below the centroid, and downwards if they are above the centroid. A crucial component of the model is that clustering acts on output space, but adjustments are done in input space. Figure 3 shows two representative runs.

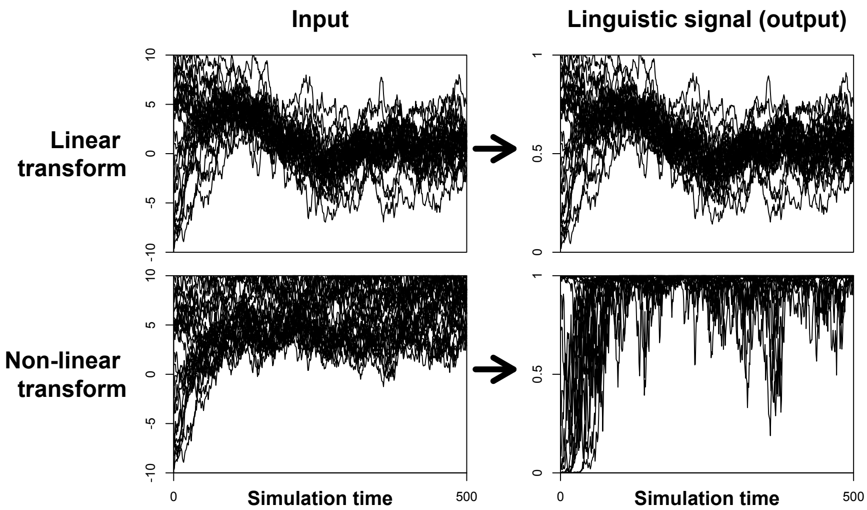

Figure 3. An example simulation of linear and non-linear simulation runs of 30 signals evolving over 500 simulation steps in underlying parameter space (left column) and output space (right column).

1,000 linear and 1,000 non-linear simulations with 500 time steps each show that non-linear transforms create more *output* **stability** in the linguistic signal, as well as more underlying *input* **variability** (see Figure 4). At the 500th time step, non-linearly transformed signals have *higher* underlying variability (as measured by standard deviations over all signals) than the linearly transformed ones ($t(1998)=54.18$, $p<0.0001$). For output variability, non-linear signals have *lower* values ($t(1998)=45.5$, $p<0.0001$). In these simulations, underlying parameter values are bounded to be within [-10,10]. This invites the concern that there are artificial biases due to boundary conditions (see, e.g., Bullock 1999). However, an equivalent simulation run without restricting inputs produces qualitatively similar results.

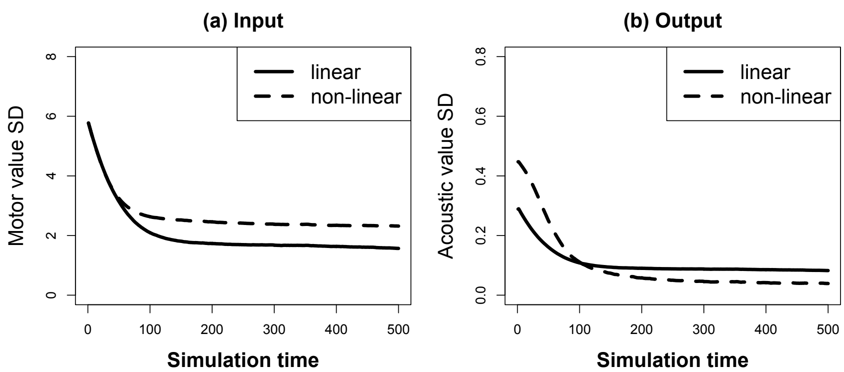

Figure 4. Standard deviations of motor input values and acoustic output values over simulation time, for simulations with linear and logistic transformation.

The simulation demonstrates that evolving signals have more cryptic underlying variability if the conformity bias acts on non-linearly transformed spaces, hence, they have more 'fodder' for subsequent evolution. At the same time, signals have less communicatively relevant variability, making the underlying variation more neutral. Thus, a biological aspect of the speech apparatus (quantality) and a cognitive aspect of the language users (categorical perception) create neutral spaces that drive robustness and evolvability of spoken language.

What are the ultimate origins of these non-linearities? Categorical speech perception has been reported for many non-human animals (see reviews in Harnad 1990), including monkeys. It thus seems safe to assume that early humans already had the capacity to divide a signal space into categories. Through historical sound change, categorical speech perception boundaries may shift, as is evidenced by the fact that different languages have strikingly different voice onset times to distinguish between voiced and voiceless stops (Lisker & Abramson 1963). Thus, for categorical speech perception, it is realistic to assume that cryptic variation may surface when conditions change, such as when the category boundary between two sounds shifts as a result of historical change. This is different from quantality. The quantal nature of speech is determined by vocal tract physiology and therefore, it cannot be changed throughout a speaker's lifetime. This means that the non-linearity for quantality is rigid, and underlying variation in articulation cannot surface. While cultural evolution may drive signaling systems to live within the quantal regions of motoracoustic space (because they afford a high degree of motor variability), the fact that these quantal regions exist may need to be explained via biological evolution. This would thus represent another way in which the physiology of the vocal tract is optimized for speech. However, the rigid nature of quantality means that for this phonetic phenomenon, the cryptic variability demonstrated in the above simulations does not impact evolvability—in contrast to the cryptic variability in categorical speech perception.

To conclude, this paper argues that non-linear phenomena in speech create neutrality, which is key to understanding how speech communication can be robust and at the same time evolvable. The robustness of speech is not only an *explanandum* in language evolution research—something that needs to be explained evolutionarily—but it is also a driver of language evolution.

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FROM SILENT GESTURE TO ARTIFICIAL SIGN LANGUAGES

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1. Introduction

Language evolution can be described as the transition from something that is not language to something that is language. This definition allows us to remain agnostic about the mechanisms (biological or cultural) involved in the emergence of language. Moreover, the definition marks the boundary between language evolution and language change: the latter is a process that takes place when there is already a language (see the description in Scott-Phillips & Kirby 2010). Finally, language evolution is not something that only happened in pre-history: the emergence of new languages can be observed in the present day, with newly-emerging sign languages providing the best example of such a process.

In this paper we will sketch a methodology to study the transition from no- language to language. More specifically, we will show how combining different laboratory methods will allow us to observe the transition from 'silent gesture' (the behaviour observed in naive hearing participants who are asked to convey meanings while using only gesture) to artificial sign language. By allowing silent gesturing participants to interact and learn from one another via iterated learning, artificial sign languages emerge which, we will claim, share crucial properties with existing languages. Thus, the emergence of artificial sign language in the lab can help us to understand some of the mechanisms involved in the emergence of language in the human species.

2. Silent gesture: improvised communication in the lab

Silent gesture is the behaviour observed in naive participants who are asked to convey meanings (by describing simple events) while using only gesture and no speech. Constituent order in silent gesture is independent of the native language of the gesturer: Goldin-Meadow, So, Özyürek, and Mylander (2008) found that 'motion events' (such as 'captain swings pail' or 'boy tilts glass to mouth') are consistently ordered in SOV word order. Moreover, silent gesture shows structural variability based on the semantic properties of the message to be conveyed, a kind of variability that is not observed in full language: Schouwstra (2012) found that whereas motion events lead to SOV ordered strings, more abstract intentional events (such as 'man searches for guitar' or 'woman thinks of apple') are gestured in SVO order.

Silent gesture experiments can tell us something about the way in which people represent information in strings (linearly ordered messages) in the absence of language conventions. The fact that gesture sequencing is relatively consistent across participants, and independent of the dominant word order of their native language, suggests that silent gesture experiments can tell us something about cognitive biases that play a role in communication in the absence of conventional systems for constituent ordering.

3. From gesture to sign language in the lab

The communicative behaviour of silent gesturers is unidirectional: they only produce gesture sequences, but do not interpret them.[1] We will describe how the silent gesture method can be combined with the methodologies from the Iterated Learning paradigm, in order to study the evolution of silent gesture systems.

Iterated learning is the process by which an individual acquires a behaviour by observing a similar behaviour in another individual who acquired it in the same way (Kirby, Cornish, & Smith 2008). This definition captures two prominent types of cultural transmission, vertical and horizontal. Vertical transmission happens when new learners come into an existing linguistic community and acquire the linguistic system of that population. Horizontal transmission occurs within generations, through interaction between peers. Both processes have been studied in laboratory experiments. Vertical transmission has been shown to result in languages which become more learnable, more compressible, and thus more systematic (Kirby et al. 2008). Horizontal transmission, when studied in a graphical communication task, leads to the emergence of communicatively functional, efficient graphical conventions (Garrod, Fay, Lee, Oberlander, & MacLeod 2007). A combination of vertical and horizontal turnover shows that linguistic structure, the presence of regularities in the way in which complex signals are constructed to convey complex meanings, arises when both horizontal and vertical transmission are at work (Smith, Tamariz, & Kirby 2013; Kirby, Tamariz, Cornish & Smith, submitted). These findings demonstrate that we need to develop flexible experimental methodologies that allow us to investigate the relative contributions of horizontal and vertical transmission.

Experiments in the mixed paradigm proposed in this talk (silent gesture plus iterated learning) have a very natural starting point, beginning with the communicative gestures used when a single participant communicates solely according to his own cognitive biases. These individual-based gestures subsequently come under pressures for learnability and expressivity when participants interact with, and transmit their gestural repertoire to, other participants in dyadic, closed group and replacement designs.

1 Although interpretation experiments have been reported (Langus & Nespor 2010, Schouwstra 2012), in these publications production and interpretation were observed separately.

Combining silent gesture and iterated learning methods yields a suite of experimental methods that we can use to study how the products of the cognitive biases of individuals, through social transmission, develop into conventionalised language systems. In other words, it offers ways to create artificial sign languages in the lab. An additional advantage of studying emerging languages in the manual modality is that it gives us the possibility to compare it directly to natural data.

4. From gesture to sign language: natural data

Recently emerged sign languages, such as Nicaraguan Sign Language (NSL, Senghas & Coppola 2001) are a valuable source of information about language evolution in the real world, and potentially reveal mechanisms by which a fully conventionalized language emerges from earlier improvised forms of communication.

NSL is an example of a community sign language: a sign language that emerged over the past 30 years from the homesigns of deaf individuals that were put together in a group. Homesigns are spontaneous, improvised sign systems developed by deaf children who grew up in hearing families, and had no access to an existing conventional sign language. Although homesign is generally highly iconic and improvisation based, different homesign systems show some similarity in utterance structure. Like in silent gesture, semantic and pragmatic principles play a role in the organisation of utterances (Benazzo 2009).

NSL is structurally independent of the spoken languages that surround it, and has become more richly structured and increasingly systematic over the generations. Because much is known about the social dynamics under which it emerged, it is a valuable source of information about how different kinds of social transmission shape language. Laboratory studies in which silent gesture and iterated learning are combined offer a controlled environment in which phenomena observed in natural data can be studied in further detail.

5. Back to the lab: case studies in emergent structure

We will demonstrate the validity of our experimental methodology by showing that linguistic phenomena that have been observed emerging in this natural data also arise in the laboratory context. For example, Senghas, Kita, and Özyürek (2004) have noted that later signers of Nicaraguan Sign Language develop a way of signaling complex motion events by separating manner and path. For example, a ball rolling down a hill would be expressed using a roll gesture followed by a down gesture. Importantly, the same meaning early in the development of the language would have been expressed 'holistically' with manner and path signed simultaneously. We will show, using our iterated methodology, the same transition from holistic to compositional expression of manner and path arising in the lab. Intriguingly, we find this result does not arise universally—it is a solution to expressing events that is 'lineage specific', occurring in some runs of the experiment and not others. This is interesting because such a compositional strategy is also not universal across sign languages.

In addition to these specific syntactic properties of the emerging artificial sign systems, we will also look at the phonetics of the languages that evolve. We will give quantitative evidence (extracted directly from video) that the form of the signaling in our experiments is changing to become less pantomimic and more sign-like as the systems our participants use become conventionalized and energetically efficient. In order to quantify the efficiency of gestures, we calculate the amount of movement in each gesture video, based on pixel-by-pixel comparisons of adjacent video frames: gestures at later generations feature less movement. We can use similar techniques to quantify the extent to which a set of gestures exhibits systematic structure: we define the similarity between two gestures videos as the extent to which they involve similar movements (again, identified based on frame-by-frame comparison within each video), and then feed these similarity measures into standard techniques for quantifying systematic structure which we have developed for studying written miniature languages (specifically, the structure measure presented in Kirby et al. 2008).

By comparing the effects of horizontal interaction with vertical transmission, we will discuss the ways in which pressures from communication and from learning impact on the process that takes us from no language to language.

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EMERGENCE OF LOW-LEVEL CONVERSATIONAL COOPERATION: THE CASE OF NONMATCHING MIRRORING OF ADAPTORS

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Like all signalling, language involves several classes of constraints, such as the physical constraints of signal production, reception and noise; and the cognitive constraints related to the content of the message or inferences in the hearer's mind. However, a third, and more fundamental, type of constraints refers to honesty and stability of signalling. In what follows, we describe a research programme, currently underway, that will address the origins of stable cooperative signalling in conversation. We aim at shedding light on the mechanisms that enable and govern cooperation at the basic, low-level, layer of the communicative interaction, and their implications for the successive layers of communicative cooperation. Secondly, in line with recent trends in the area of language evolution, we put our research on an empirical footing. We target one specific type of nonverbal behaviour for experimental investigation, i.e. we purport to test empirically the influence of nonmatching mirroring of adaptors on the flow of conversation and the formation of the disposition to cooperate. The proposed research has a novel character, since non-matching mirroring of adaptors is a hitherto unexplored phenomenon.

1. Introduction

Cooperation is a foundational feature of human linguistic communication, and one whose evolutionary bases are still an unresolved question. In conversation it is most clearly visible on the 'Gricean' level, i.e. the level of content, which is described by the Cooperative Principle and itemised by the four Gricean maxims. However, the general cooperative character of conversation extends well beyond the transmission of meaning. The underlying layer of mechanics and structuring of interaction – including phenomena such as synchronisation, turn-taking, backchannelling or various kinds of mirroring, which are not directly related to the content of messages or inferences – shows patterns of organisation that can be described as cooperative.

We suspect the abovementioned relation to be hierarchical, with the level of mechanics/structuring being primary and forming a basis for the higher-level, Gricean cooperation (and beyond, i.e. the actual cooperation over achieving common goals in extralinguistic reality). We hypothesise that the stability of human verbal cooperative signalling depends on the low-level coordinaton mechanisms; these include *adaptor mirroring* and specifically *mirroring of non-matching adaptor behaviours*, such as e.g. head movement performed in response to hand movement. We further suspect that the level of mechanics/structuring may be primary in an evolutionary sense, i.e. may have been an evolutionary precursor for the progressively more advanced forms of cooperation.

2. Low-level coordination

What we mean by 'low-level coordination' is a broad and heterogeneous class of phenomena that are not directly involved in the transmission of propositional content but facilitate focused interaction (*sensu* Goffman 1963). We deliberately start from a possibly encompassing approach. A systematic comprehensive treatment is somewhat difficult because of the vastness of the area and multitude of traditions, and the resulting "scattered terminology" (Paxton & Dale 2013), with partly overlapping notions such as accommodation, alignment, emulation, mimicry, synergy, etc. (see e.g. Paxton & Dale 2013; Lakin et al. 2003). A more developed and principled typology is in order, but we provisionally distinguish three categories of phenomena of interest:

(i) *Alignment*, related to spatial-orientational behaviours which serve to maintain sustained interaction (such as interactants arranging themselves into an L dyadic formation or a *vis-vis* dyadic formation, cf. Kendon 2009: 5ff);

(ii) *Interactional coordination*, which refers to "the degree to which the behaviors in an interaction are nonrandom, patterned, or synchronized in both timing and form" (Bernieri & Rosenthal 1991: 403). It can be divided into *synchrony* and *matching* (see below), and probably extended by *affect coordination* (Goffman 1967);

(iii) *Conversation-specific* norms for upholding focused interaction, which primarily concern how talk is organised into turns and how turn transitions are effected – e.g. *local management* system, *turn-taking* rules, meeting *projectability* requirements (Sacks et al. 1974).

The coordinative mechanisms in question are not unique to humans or to the context of conversation, and some forms can be observed in other primates or very early in human ontogeny. For example, Meltzoff & Moore (1977) found mimicry (facial imitation) in prelinguistic infants under 1 month of age. Takahashi et al. (2013) report coordination in vocal exchanges in common marmosets that they compare to turn-taking and explicitly label as cooperative. But, as noted above, a more careful typology is required to assess the significance of such findings.

Importantly, low-level coordination – such as the synchronisation of adaptors – entails little cost, is easily repeatable, and can be used by the conversants to diagnose their mutual commitment to engage in future cooperation involving higher cost (e.g. sharing important information). As such, it is an interesting candidate for bootstrapping cooperative signalling in conversation.

3. Adaptor mirroring

Two major types of interpersonal coordination are distinguished – *interactional synchrony* and *behaviour matching* (Bernieri & Rosenthal 1991). Although both of these types perform a variety of roles in regulating social activities, they express one – characteristically human – motif, that is, cooperative intent. Interactional synchronisation, defined as the degree to which interactants' behaviours are temporally coordinated, plays a vital role in the organisation of the communicative process, allowing for example the smooth exchange of conversational roles. Matching – also referred to as mimicry or emulation – consists in mirroring (*sensu* adopting) the behaviours of another interactant, which may take the form of, for example, unconscious adoption of someone else's accent, tempo of speech, facial expression, posture, or mannerisms (Lakin et al. 2003). The main function of behaviour matching seems to be liking, rapport, and affiliation. Both these mechanisms are focused on interactants' joint goal, which is to engage in the communicative activity and to promote mutual understanding (the rapport-making function).

Adaptors are a class of behaviours or actions that are nonintentional, often nonconscious and (primarily) non-communicative, often reflecting bodily needs or arousal (Ekman & Friesen 1969) – e.g. scratching oneself or biting the lip. They may occur in a suppressed form, usually as only the initial stage of the target action. So far, adaptor synchrony has been studied mostly with regard to matching behaviour (see Chartrand & Bargh 1999). But preliminary results from our pilot study strongly suggest *non-matching adaptor mirroring* also occurs naturally; for example, it has been observed that postural re-alignment of one participant can elicit face rubbing or shoulder raising in the other. Interactions of that sort require a more thorough analysis as to their sources, mechanism, structure and function, with particular emphasis placed on their role in the structure of conversation, as well as their possible effect on affiliation and cooperative intent.

4. Project outline

Research in this project will be based on methods and procedures developed within linguistics (Conversation Analysis and corpus linguistics) and psychology (experimental psychology of nonverbal behaviour). Its experimental core will consist of two experiments as well as a possible third experiment. It will be followed by a theoretical elaboration of the results and their integration with the state-of-the-art language evolution research.

Experiment 1. Hypothesis: non-matching mirroring of adaptors is a process spontaneously occurring in conversation. It builds on our pilot study; it replicates Chartrand & Bargh (1999), but with the inclusion of non-matching mirroring.

Experiment 2. Hypothesis: the degree of mirroring is correlated with the degree of disposition to cooperate. The degree of mirroring will be calculated through segmentation and BAP (The Body Action and Posture Coding System). The degree of disposition to cooperate will be calculated *via* the public goods/social dilemma game paradigm.

Experiment 3. Hypothesis: the mirroring of adaptors is partly independent of the focus of visual attention. The assumed goal of this experiment is to test the assumption of the automatic character of mirroring.

The experimental procedures will consist in: collecting and analysing an audio-visual corpus; annotating the registered behaviours with BAP; segmentation of the stream of behaviours; microanalysis (slow-motion behavioural analysis); analysis of conversational structures focused on the use of turn-taking rules, adjacency pair formats, preference phenomena, and pre-sequences. The above steps will be followed by a statistical analysis and evolutionary interpretation.

5. Conclusion

Human language is unique in nature as a cheap but honest cooperative signalling system. Based on evolutionary logic and available evidence from the linguistic and psychological study of conversation, we suspect that this cooperative character rests on a scaffolding of lower-level mechanisms: human verbal communication depends on various forms of coordination of mostly nonverbal signals. In our project, we will test the influence of one such mechanism, mirroring of non-matching adaptors, on the dynamics of conversational interactions. We see that as a first step in the direction of empirical study of this proposed dependence.

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GENE-CULTURE COEVOLUTION OF A LINGUISTIC SYSTEM IN TWO MODALITIES

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Complex communication can take place in a range of modalities such as auditory, visual, and tactile modalities. In a very general way, the modality that individuals use is constrained by their biological biases (humans cannot use magnetic fields directly to communicate to each other). The majority of natural languages have a large audible component. However, since humans can learn sign languages just as easily, it's not clear to what extent the prevalence of spoken languages is due to biological biases, the social environment or cultural inheritance. This paper suggests that we can explore the relative contribution of these factors by modelling the spontaneous emergence of sign languages that are shared by the deaf and hearing members of relatively isolated communities. Such shared signing communities have arisen in enclaves around the world and may provide useful insights by demonstrating how languages evolve as the deaf proportion of its members has strong biases towards the visual language modality. In this paper we describe a model of cultural evolution in two modalities, combining aspects that are thought to impact the emergence of sign languages in a more general evolutionary framework. The model can be used to explore hypotheses about how sign languages emerge.

One of the great linguistic discoveries of the 20th century has been that our linguistic abilities are, to an extent, independent of the natural language mode through which it is expressed and understood. That is to say, sign languages parallel spoken languages in terms of the areas of the brain that are involved in production and processing, in the patterns of language acquisition, as well as the degree of grammatical diversity among them (Meier, Cormier & Quinto-Pozos 2002). Sign languages may emerge spontaneously in at least two types of settings. Urban sign languages often emergence in response to the congregation of deaf individuals at government institutions for the deaf, as for instance in the well-documented case of Nicaraguan Sign Language (Senghas & Coppola 2001). Alternatively, sign languages may arise in communities with an exceptionally high incidence of (often hereditary) deafness (Zeshan & de Vos 2012). In the latter type of setting the sign language is used by both deaf and hearing community members, engendering a high degree of social integration for deaf individuals. Such so-called shared signing communities may therefore provide unique insights into the relative contribution of biological, cultural, and social biases in the emergence of signed languages.

However, the cases of signing communities documented so far show a striking diversity in their social attitudes to deafness, demography, history, ecology and the proportion of hearing L2 speakers (Zeshan & de Vos 2012). There are also structural differences between the languages, such as differences in phonology or spatial grammar, possibly due to different amounts of cross-modal contact. The diversity makes it difficult to make generalisations about how these factors affect the emergence of a signing community. For example, the critical mass of deaf people that is needed for a shared signing community to emerge is not known. Models can help researchers think about these questions.

1. Model

We use a model adapted from Burkett & Griffiths (2010) and Smith & Thompson (2012) which simulates gene-culture co-evolution in an iterated learning framework (for a full description, see Roberts, Thompson & Smith 2013) Individuals are modelled as Bayesian agents who must decide what proportion of each modality to use in communication, given their prior bias and their observations of the behaviour of other agents. Since hearing communities tend to have an audible linguistic system as an important part of their communication, hearing agents have a bias favouring the auditory modality. It is obviously a weak bias, because both hearing and deaf learners can learn non-audible (signed) languages. It is also well-documented that speakers generally distribute the message over both auditive and visual forms (Enfield 2009; Kendon 2004). At any rate, deaf learners can be characterised as having a very strong bias towards the visual modality (learning an audible language is hard).

The agents reproduce biologically, according to a fitness function that gives a higher probability of reproduction to individuals who can socialise successfully through language. The prior bias is inherited biologically (with some chance of mutation). This means that offspring of deaf individuals will inherit the bias against audible languages (deafness is hereditary).

We can use this model to explore the emergence of deaf communities within hearing communities, or to model the competition between auditory and visual modalities. In a community of deaf individuals, we would expect a mainly non-audible language to emerge. However, what happens in a community with mixed biases where modalities might be in competition?

Since the dynamics of this kind of model are not well understood analytically, we obtain results by numerical simulation. We run the model with hearing individuals until it converges (around 200 generations). At this point, deaf individuals are introduced into the simulation who have a strong bias against learning an audible language. We can then observe how the community changes, both in terms of the number of deaf individuals, and the use of each modality. Since deaf individuals essentially cannot learn an audible language, the two aspects will be correlated. However, we also show that this is not always the case.

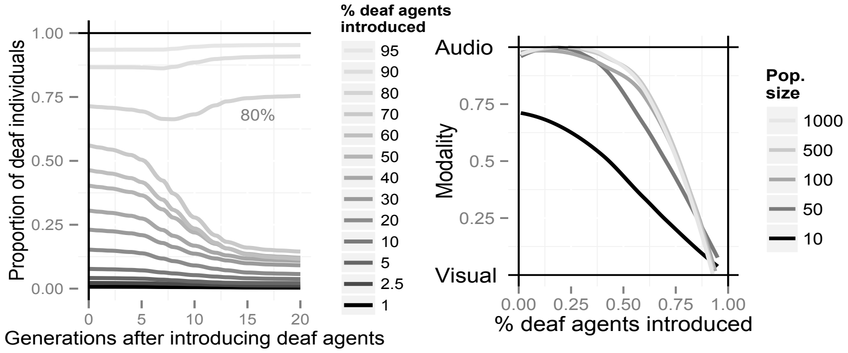

Figure 1. **Left:** Deaf individuals are introduced into a hearing population 200 generations after initialisation. The graph shows how the proportion of deaf individuals changes over generations depending on the initial number of deaf individuals introduced (lines are LOESS fits of 10 independent runs). Between 70% and 80% of the population needs to be deaf for deaf individuals to remain stable or increase. **Right:** The average modality used in a population for different population sizes, under the standard fitness function. Means are taken from 8 generations after introducing deaf individuals. Larger populations require a greater proportion of deaf individuals to affect the overall modality.

1.1 Results

The results demonstrate that in a wide range of scenarios, communities of hearing individuals using primarily audible communication are resistant to deaf individuals (see Figure 1a). Shared-sign languages are unlikely to survive except when the initial proportion of deaf individuals introduced into the community is very high. The weak bias for audible languages is amplified over generations of cultural transmission so that the majority of the communication system is audible. The average modality of communication used by the population reflects the number of deaf individuals, with a large number of deaf individuals required to change the modality of the population (see Figure 1b). However, in very small populations, a smaller proportion of deaf individuals may influence the modality of the language in the short-term (up to ten generations).

These results suggest that a monolingual signing community is unlikely to emerge. However, there are conditions under which a bimodal-bilingual shared-signing community can emerge and where deaf individuals can thrive. If the ability to communicate in both modalities is prestigious within a society, then a communication system that uses both visual and auditory modalities will emerge. This is independent of the community having deaf individuals (although the presence of deaf individuals is an obvious motivation for the prestige of a multi-modal ability).

The social structure of the community also makes a difference. In stratified communities where agents' fitness is only derived from the communicative success between a few nearest neighbours, the community maintains a non-audible component in the language for longer. This happens because small 'enclaves' of deaf individuals can be maintained, where using a non-audible language leads to good communicative success and high probability of reproduction.

The dynamics of social interaction make a difference, too. Communities with deaf individuals are sustainable when linguistic differences lead to higher fitness (Figure 2a). This can happen, for instance, if linguistic differences are perceived as resources rather than limitations (as is the case in some sign language communities). In this case, the linguistic system of the community as a whole utilises both modalities equally. The number of deaf individuals oscillates with a phase determined by the initial number of deaf individuals introduced.

Finally, if the fitness function is neutral with regards to the modality of communication (the 'parity' function, where reproduction is linked to the ability to communicate effectively, regardless of modality), the proportion of deaf individuals and non-audible language increases in small, structured societies. In fact, in this social setup, the modality of communication is predominantly visual and the community is resistant to hearing individuals (see Figure 2b). This happens because deaf select the same proportion of each modality (all visual), and so maximise their communicative fitness with other deaf individuals. Hearing individuals are more likely to select a range of proportions of each modality, meaning that they have weaker fitness.

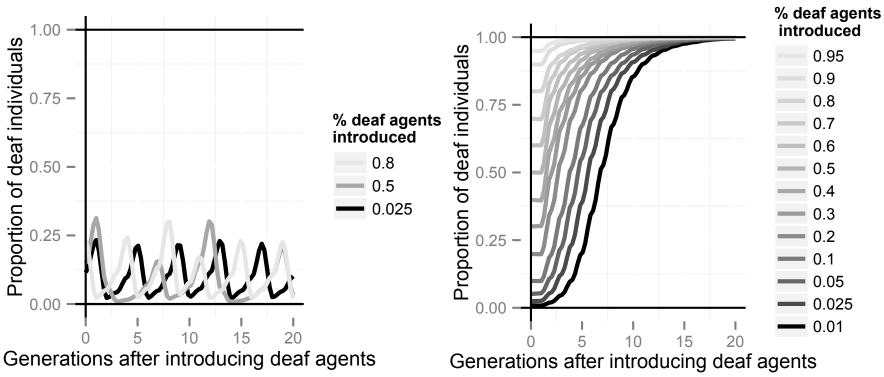

Figure 2. **Left:** Results from the model where there is a social prescription against marriage between deaf individuals. The population size matches that of the Kata Kolok community. **Right:** Results from the model using the 'parity' fitness function and a structured population of the same size as the Kata Kolok community (2189). Even very small numbers of deaf individuals introduced into the model will increase within a few generations.

2. Conclusion

The extent to which modalities are exploited in communication systems depends on genetic constraints, cultural transmission and social factors. We demonstrated that the links between learning biases, modality, communicative success and the social perception of language can be complex. We hope this model can help frame the exploration of demographic differences between different types of sign languages. Future improvements could include more realistic genetic inheritance and social structures. We also hope that this paper demonstrates the relevance of shared sign languages for language evolution: given their relatively limited time depths and relative isolation, the diffusion of structural features within these communities could be charted to track their historical development.

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ON THE SEPARATE ORIGIN OF VOWELS AND CONSONANTS

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A non-controversial claim on oral language phonology is that there are consonants (C) and vowels (V) which organize themselves into syllables. This notwithstanding, how the difference between vowels and consonants came about in evolutionary terms is unknown. Departing minimally from the frame-content theory of speech (Macneilage 1998, 2008), this work puts forward the conjecture that vowels and consonants have a different origin, neither of which traces back to primate calls: vowels —in an instance of convergent evolution—, come from vocal learners' primate song units which are analog to those of birdsong of vocal-learning birds; consonants, instead, evolved by common descent from some visual communicative displays (lip smacking, teeth-chattering, etc.). This proposal fares better than those relying on primate calls because, while avoiding their pitfalls, it automatically derives other necessary properties of speech, namely discreteness, seriality, direct cortico-laryngeal connections and repetitive babbling. Additionally, it (i) paves the way to a musical (syllabic) protolanguage, and (ii) can be a good clue on the categorical neuropsychological divide between vowels and consonants.

1. Introduction

The fact that vocal signals are made up of vowels and consonants constitutes a phylogenetic novelty that although of paramount importance not only for speech (externalization) but possibly for language (as a cognitive system) has been neglected. Of note, in this connection, is that our big public lexicons are not even imaginable without the join concurrence of both, vowels and consonants. It seems, indeed, that in linguistics, phonologists take the distinction for granted and that in the field of language evolution, the description of birdsongs in terms of syllables (syllables$_{birdsong}$) has obscured that speech syllables (syllables$_{speech}$), unlike syllables$_{bird}$, are typically made up of consonants (C) and vowels (V). Still in the evolutionary field, the often tacit commitment to the continuity hypothesis has contributed to the current situation. Fitch (2013: 434) summarizes it: "The origins of the periodic oscillations that produce the alternation of consonants and vowels that make up syllables a central feature of all spoken languages have remained mysterious, because most primate calls are produced with just a single opening of the mouth." To complete the picture, it comes out that (neuro)psychologists seem to be the most concerned with the distinction between vowels and consonants (Caramazza et al. 2000). They go as far to claim that V and C are categorically distinct and functionally specialized.

2. The received view

The contentions that (i) syllables are present in birdsong and that (ii) speech has some kind of primate call as a precursor are both commonly accepted. However,

2.1 Syllables$_{birdsong}$ ≠ Syllables$_{speech}$

Birdsong, as speech, presents a serial organization which can be seen as possessing a syllabic frame/content mode of organization (MacNeilage 2008: 303) where the frame is the result of a beak open-close cycle. Syllables$_{birdsong}$, unlike syllables$_{speech}$, however, are usually defined acoustically rather than articulatorily —the opposite of what is found for syllables$_{speech}$. This means that units of sound are separated by silent rests. A syllable$_{birdsong}$ can contain more than one note. Crucially, the notes (the content) are the result of variations on the source (syrinx). In other words, birdsongs' content is exclusively vowel-like.

2.2 Primate calls do not lead to speech

That speech derives from non speech is indisputable but this does not mean that holistic signals are at its origin (but see Zuidema & de Boer 2009). Yet, deriving it from primate calls is virtually impossible. The pitfalls seem insurmountable. Calls, in contrast to songs, are inarticulate, innate, under subcortical control and, although repressible, non structurally modifiable. By adding to certain laryngeal calls, as Fitch (2013) suggests, a co-opted visual display such as lip-smacking, which will provide the consonant (and the syllabic frame), we do not get rid of the just mentioned difficulties. Furthermore, this combination would still be in need of "a second evolutionary step" consisting of "our unique cortical-brainstem connections" (Fitch 2013: 435).

3. Primate songs + lip-smacking as the foundation of V/C distinction

Although syllables$_{birdsong}$, because of lacking consonants, do not amount to syllables$_{speech}$, songs are a much better basis for speech than calls. Primate songs are not as common as birdsongs but they are not limited to gibbons' duets either. Singing is present in 26 monogamous species of primates and has evolved four times within the taxon (Ghazanfar & Santos 2003: 7). Many properties of songs (and vocal learning animals) fit in with what we know on speech (and Sapiens). Structurally, in either song or speech, discreteness, seriality and repetitiveness in the babbling stage are obtained. Ontogenetically, a babbling stage is innate to both non human vocal learners and humans. Neurally, all vocal learners – even mice with innate songs (see Arriaga et al. 2012)–, seem to share a neural circuitry with forebrain/cortico-bulbar-laryngeal connections to motor nuclei responsible of motor learning and fine control of vocalization. Functionally, songs (and duets in particular) reinforce pair bonding. All in all, all these commonalities suggest that a homoplasy, i.e. an instance of convergent evolution, is in place. As said in 2.1, however, songs only give us vowels.

Where do then the consonants come from? In line with recent findings (Ghazanfar et al. 2012, Fitch 2013), consonants would be originated in lip-smacking, a visual communicative display very common among primates. The main rationale for this common descent view of consonants is that syllables$_{speech}$ and lip-smacking seem to be perfectly tuned (6-hertz rhythm). Ingestive cyclicities, instead, are slower. This, by itself, makes them unnecessary as a basis for the frame in the frame-content theory. Nicely enough, having songs in the scenario would lead to the same conclusion as, in birdsongs in particular, no ingestive cyclicity (chewing, sucking, etc.) is involved, as MacNeilage (2008: 306) observes.

It is also worth to emphasize that Sapiens are vocal learners and vocal learners produce songs, not calls. Singing, in turn, automatically guarantees the existence of cortico-bulbar-laryngeal connections. By contrast, in a scenario in which calls are complemented with lip-smacking (Fitch 2013), this neural equipment calls for an extra evolutionary event. In this connection, the fact that a dorsal-laryngeal cortical connection seems exclusively human among primates (Bouchard et al. 2013) needs to be qualified. As far as it is known, cortices of singing non-human primates have not been examined in this regard. The prediction entailed by the present proposal is that cortico-bulbar-laryngeal connections have to be present in these species. Although the importance of these neural connections has come into question (Lieberman 2013), neglecting them does not seem justified (Brown et al. 2009).

Finally, apart from getting rid of the shortcomings listed in 2.2, resorting to songs has a further advantage, namely to provide a basis for phonology (via perhaps a musical protolanguage) completely devoid of any referential meaning. If primate calls, instead, which are stimulus-driven and perception-related, had been the point of departure to speech, a complete turnaround as far as linguistic meaning is concerned would have had to take place, which seems as much costly as implausible.

4. Further expectancies

This proposal opens some interesting avenues which will be touched on in the talk.

The first one deals with the foundational divide between vowels and consonants for which psychologists have found strong evidence. According to them (Bonatti et al. 2005), vowels are universally —not only in Semitic languages— tied to grammar, in part through prosody. Consonants, instead, are bound to lexicon. In particular, the individuation of words in continuous speech relies on them. It has been shown that in order to segment the continuous stream of (artificial) speech into words, subjects use transitional probabilities between consonants, but not between vowels. The claim goes further: the V/C divide is categorical since it has been shown that in selective impairments of either vowels or consonants, the causal factor does not depend on either the sonority value or the feature properties (Knobel & Caramazza 2007). An investigation which suggests itself from the present proposal would rely on their different neural correlates which would trace back to their different origin. Interestingly, there is recent evidence in favor of this claim. Bouchard et al. (2013: 331) not only state that “vowels and consonants occupy different regions of the cortical state-space” but also that all their findings are in accordance with gestural theories of speech production.

The second is related to the holism *vs.* discreteness issue. The contention is that it is an advantage that song provides us with a discrete origin. Speech started discrete as it was to go on. Is sign (gestural-visual modality) in contradiction with this claim? Seemingly, ABSL (Al-Sayyid Bedouin Sign Language) as presented by Sandler et al. (2011) started being holistic. Contrary to this claim, I will present some evidence that a video-recorded deaf woman belonging to the second generation was combining discrete elements.

Finally, the plausibility of a syllabic musical protolanguage in line with Darwin (1871) who considered an analog of birdsong as a plausible step in the way to a full-fledged language, will be examined.

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THE EFFECT OF PHYSICAL ARTICULATION CONSTRAINTS ON THE EMERGENCE OF COMBINATORIAL STRUCTURE

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1. Introduction

Language has 'duality of patterning', which is structure on both a compositional and a combinatorial level. Compositional structure is the combination of meaningful elements into bigger meaningful structures. Combinatorial structure is the phonological combination of small meaningless units into a potentially infinite number of meaningful units.

Despite "duality of patterning" being named by Hockett (1960) as one of the basic design features of human language, empirical work exploring the emergence of combinatorial structure is still very much in its infancy. Techniques to test existing hypotheses regarding the emergence of phonological structure have only recently been developed, and the strengths and weaknesses within this ongoing work are generating new hypotheses which also need to be tested. The current contribution will outline the existing hypotheses on how combinatorial structure first emerged in language before focusing on hypotheses pertaining to the modality, size and shape of the articulation space. We will then outline existing experimental and computational work which tests the effects of physical articulation constraints on the emergence of combinatorial structure, along with our own ongoing work, and the scope for future work in this area.

2. Existing hypotheses

Hockett (1960) hypothesised that the emergence of structure on a phonological level is the result of pressures for expressivity and discriminability imposed when the number of meanings increases, as language needs a more efficient way to create new word forms. More recently, Verhoef (2012) has shown experimentally that combinatorial structure can emerge as the result of cognitive learning constraints and biases. However, recent evidence from Al-Sayyid Bedouin Sign Language, which is a newly emerging language, suggests that languages can have thousands of words without a level of phonological patterning (Sandler, Aronoff, Meir, & Padden et al. 2011). In a recent paper, Del Giudice (2012) considers that the lack of phonological patterning in emerging sign languages could be because the articulation space in sign languages is much larger than that used in spoken languages, and this allows for a greater number of distinct signals without the need for combinatoriality. This hypothesis is dismissed by Del Giudice (2012) as established sign languages have been shown to have a similarly sized phoneme inventory to those found in spoken languages (Rozelle 2003). However, this is not evidence to suggest the size of articulation space, as well as other physiological factors, are not important factors in the emergence of combinatorial structure in language. Hypotheses regarding the effects of the modality, shape and size of an articulation space have yet to be empirically tested which is what we aim to rectify with this contribution.

3. Experimental work

Artificial language learning experiments are often used in evolutionary linguistics to show how structure emerges on a compositional level. Work is now appearing on emerging combinatorial structure, started by Verhoef (2012) who used signals created by slide whistles in an iterated learning paradigm. Whistled signals are ideal for the purposes of investigating the emergence of speech as they use a continuous articulatory space, but limit interference from participants' existing linguistic knowledge. In Verhoef's (2012) experiment, participants learned whistled signals and their resulting reproductions became the input for the next participant. Del Giudice (2012) has since carried out a similar iterated experiment where participants created graphical symbols using a moving stylus which limited the use of iconic representation, and found that participants did not use the entirety of the signal space as one would expect if Hockett's (1960) hypothesis were true. Footnotes are denoted by a character superscript in the text.

To test the effects of the size of articulation space on the emergence of combinatorial structure, we extended Verhoef's (2012) experiment by running a new condition where the slide whistle was restricted with a stopper, as well as an unrestricted condition. The shape of the whistle's articulation space was kept the same, only differing in size on one dimension. Comparison of combinatoriality between conditions eliminated the problem of an articulation space having some trajectories which are more likely to be produced, which is a problem for analysis when only one condition is being tested. We show that the size of articulation space does indeed have an effect on the emergence of combinatorial structure.

There is a large scope for future experimental work on the effects of physical articulation constraints. A whole host of electronic musical instruments and digitally generated signals are enabling more easily manipulated signal spaces and easily analysable signals. Our next steps are to experimentally test the effects that modality and the dimensionality of a signal space have.

4. Computational work

The computational work deals with four main issues: the representation of signals, the selection process through which some signals persist while others fall into disuse, the distance and similarity measures between signals, and measures of structure.

4.1 Signal space and signals

Earlier models of the evolution of combinatorial structure abstract away from the internal structure of signals, representing them as unique symbols (Nowak, Plotkin, & Krakauer 1999). In such models, the variation in signals necessary for evolution arises from errors in probabilistic learning, and not from comparison of the signals involved. To deal with structure, many later models use signals represented as points or trajectories in an N-dimensional feature space, which may be abstract and not correspond to any actual features of an acoustic signal (de Boer & Zuidema 2010). The current work deals exclusively with the interplay between the shape of an artificial feature space and the combinatorial structure of signals in that space, abstracting away from the acoustic nature of the features. Each signal consists of a fixed number of ordered points in the feature space, forming a

4.2 Signal selection

The signals evolve within a multiagent imitation game. Agents start with a fixed number of randomised signals, and utter them with small, random, shape-preserving mutations as described by de Boer and Zuidema (2010). All signals are further subject to environmental noise but preserve their shape. As in de Boer and Zuidema (2010), each round, a chosen performer agent utters their repertoire , then the imitating agents utter the closest signal they know to the performer's signal. If the imitation is closer to the original signal than any other in the performer's repertoire, the round is successful. If more imitators are successful using the performer's mutated signal than using the original signal, the performer replaces the original with the modified signal.

4.3 Signal distance and confusion

For signals represented as trajectories, the easiest distance metric is point-to-point Euclidean distance. However, this may result in overestimation of the distance between similar signals with different timings. We estimate the distance between signals using Dynamic Time Warping (Sakoe & Chiba 1978), also used in the analysis of some experimental studies. When a signal, X , is emitted, the probability of that signal being identified correctly varies with its distance d to the original position of the signal. This probability is chosen from a Gaussian distribution around X, with the spread δ (i.e. noise level), as in de Boer and Zuidema (2010).

$$f(d) = \int_{x=\frac{1}{2}d}^{\infty} \frac{1}{\sqrt{2\pi\delta}} e^{\frac{-x^2}{2\delta^2}} dx$$

The probability of perceiving the uttered signal X as $Y \in L$ becomes:

$$P(Y_{perceived}|X_{uttered}) = \frac{f(d(X,Y))}{\sum_{Z \in \mathrm{L}} f(d(X,Z))}$$

4.1 Measure of structure

We propose investigating the amount of structure in the agents' repertoires based on measures motivated by information theory. Specifically, we claim that for signals that can be well-represented by a few data points per signal, such as those in this study, entropy rate of an agent's repertoire is a feasible measure of combinatorial structure.

Choosing a measure of combinatorial structure is far from trivial. It is possible to assume that combinatorial building blocks have greater power to predict what comes next than non-building blocks. However, combinations of these building blocks can also have considerable predictive power. Conversely, trends that appear on very small time scales as opposed to communicatively relevant time scales (combinatorial building blocks) can be artefacts of the articulatory apparatus (or a mathematical or computational proxy). To create a balance between problems at these two extremes, we propose focusing on quantifying the predictability of the signal-generating process per unit time, instead of the predictability of individual signal occurrences. More formally, we propose using a weighted mixture of variable-depth context trees to estimate the entropy rates, given different maximum context depths (Kennel, Shlens, Abarbanel, & Chichilnisky 2005). By looking at the changes in the estimated entropy rate under different context depths, it is possible to estimate the maximal length of the building blocks. Any part of a signal longer than the longest building block will contain at least two (possibly partial) building blocks. Building blocks have less internal variation than combinations of building blocks, since the blocks themselves do not contain combinatorial parts. Thus, a notable decrease in the estimated entropy rate at a certain depth increment, which is not followed by a comparable decrease at the next depth increment, can be used to estimate the maximum length of a building block.

Theoretically, it is also possible to have an unbounded tree that uses complete trajectories instead of bounded contexts extracted from parts of signals. However, for inventory sizes greater than three or four, such trees becomes impractical both in memory and time complexity, as the context tree can consist of $(A^D)^D$ nodes for an alphabet of size A and a maximum depth of D, depending on the contexts observed.

5. Conclusion

We have argued that physiological constraints are important factors affecting the emergence of combinatoriality within different modalities. We have also outlined problems in existing work which use proxies for articulatory spaces to investigate the emergence of combinatorial structure, and shown how recent experimental and computational techniques can be implemented to test hypotheses pertaining to how physiological constraints can affect the emergence of combinatorial structure. The evolution of speech, as a field, is currently divided between work dealing with the emergence of phonological structure and the cognitive capacity for speech, and work dealing with human phonetic capabilities and the physiological capacity for speech. Fitch (2002) states that some researchers do not even regard phonological evolution as part of speech evolution at all. However, we show that it is important to consider phonetic capabilities when considering the emergence of combinatorial structure.

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BREATH, VOCAL, AND SUPRALARYNGEAL FLEXIBILITY IN A HUMAN-REARED GORILLA

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'Gesture-first' theories dismiss ancestral great apes' vocalization as a substrate for language evolution based on the claim that extant apes exhibit minimal learning and volitional control of vocalization. Contrary to this claim, we present data of novel learned and voluntarily controlled vocal behaviors produced by a human-fostered gorilla (G. gorilla gorilla). These behaviors demonstrate varying degrees of flexibility in the vocal apparatus (including diaphragm, lungs, larynx, and supralaryngeal articulators), and are predominantly performed in coordination with manual behaviors and gestures. Instead of a gesture-first theory, we suggest that these findings support multimodal theories of language evolution in which vocal and gestural forms are coordinated and supplement one another.

1. Introduction

Theories of language evolution frequently take as a starting point the assumed fact that nonhuman primates, including the great apes, lack the ability to exercise volitional control over their vocal and breathing-related behavior or to learn new behaviors (e.g., Corballis 2002; Tomasello 2008). In this paper, we present video evidence documenting eight types of learned vocal and breathing behaviors produced by Koko, a human-reared gorilla (G. gorilla gorilla), which are predominantly performed in coordination with manual gestures and actions. Along with accumulating evidence of vocal and breathing flexibility across the great apes, the strong starting assumption of great ape vocal inflexibility is clearly untenable. We discuss the ramifications of its falsification for theories of language evolution, specifically in favor of multimodal accounts.

1.1 Vocal and breathing behavior

Human speech production requires fine-grained control over a complex production apparatus, from the diaphragm through the lips. Technically speaking, vocalization refers only to a sound produced through vibration of the larynx, excluding sounds produced through the vocal tract that employ different mechanisms (e.g., whistling), and non-audible behaviors that demonstrate control over aspects of the production apparatus (e.g., blowing out a candle). We use the broader term vocal and breathing behavior (VBB) to refer to behaviors that employ any part of the speech production apparatus. Particular VBBs vary in their articulatory demands, reflected, for example, in voiceless blowing (control over breath and lips) versus voiced grunts (control over breath and larynx). The broad set of behaviors described in the current study illustrate the important point that the diaphragm, lungs, larynx, and supralaryngeal articulators are not a homogenous system. Given the different demands for different behaviors, the extent of control over different effectors will vary, and will recruit different neural systems.

1.2 Flexibility in great apes' VBB

Among 'gesture first' theories of language evolution (e.g. Arbib, Liebal, and Pika 2008; Call & Tomasello 2007; Corballis 2002), there is a common assumption that the ape homologue to the human speech apparatus is a poor substrate for language evolution. These theories build on the claim that ape vocal calls are innate and stimulus-driven, and that apes lack voluntary control of the larynx (vocal chords). The preferred evolutionary scenario is one in which speech supplants gestures at a later stage in language evolution, rather than vocal and manual modalities being interconnected throughout their evolutionary history (cf. McNeill 2012).

However, contrary to the assumption of inflexible breathing and vocalizations, a large body of evidence shows that great apes are capable both of learning new VBBs and exerting voluntary control over them. Notable examples of captive and human-reared apes include Bonnie, a whistling orangutan (Wich et al. 2009), Kanzi, a bonobo who acquired four novel peep vocalizations (Taglialatela et al. 2003), and Viki (Hayes & Hayes 1951), a chimpanzee who learned to produce 4 amodally voiced English words. Leavens, Russell & Hopkins (2010) reported captive chimpanzees adjusting their communicative signals: the chimpanzees used visual signals when a human faced them, but auditory signals when the experimenter turned away. These included novel learned vocalizations like raspberries and elongated grunts, both of which have not been observed in wild chimpanzee populations.

In addition to these observations of captive and human-reared apes, observations of wild animals also contradict the claim that breathing and vocalizations are inflexible. One major research area in support of VBB flexibility is fieldwork observing dialectal variation or different vocal traditions across great ape communities. Van Schaik and colleagues (2003) reported regional variations in wild orangutans' production of raspberries. Dialectal variation has also been observed in the pant-hoot calls of several communities of chimpanzees (e.g. Crockford et al. 2004). The differential use of calls across communities, particularly as ecological and genetic factors have been ruled out, indicates that wild great apes can socially learn to modify existing VBBs, and may even socially learn new VBBs.

Another research area supporting VBB flexibility in wild great apes is fieldwork exploring the tactical suppression and production of calls. Wild chimpanzees have been particularly well studied, with evidence of tactical suppression observed during territorial patrols near other chimp communities (Goodall 1986), and interactions between individuals of the same community (Laporte & Zuberbuhler 2010). Further, a recent experiment on wild chimpanzees' alarm calls shows that individuals only call when other group members have neither seen the snake nor been in hearing range of previous calls (Crockford et al. 2012). Chimpanzees gave an alarm call less than half the time, indicating that voluntary production may be a more parsimonious explanation than voluntary suppression. Overall, the tactical deployment of calls suggests that wild great apes may exert volitional control over their VBBs.

2. The current study

Previous research makes a strong case for learning and volitional control of VBBs in the genera Pan and Pongo. We extend this case to the genus Gorilla, spanning another branch in the hominid family. We examined a video corpus spanning 3 years of interaction between a human-reared gorilla and its human caregivers, and found more than 400 tokens of novel VBBs distributed over 125 sessions. These comprise 8 categories of VBB, which exhibit several dimensions of contrast used in human phonology, including voicing (voiced and voiceless), place (labial, linguolabial, glottal), manner (stop, fricative), lip roundedness (rounded, unrounded) and nasality (present or absent).

2.1 Koko's VBB and implications for language evolution

Table 1 presents a description and the frequency of Koko's VBBs, which demonstrate an impressive range of flexibility across the various effectors of the speech apparatus. She performed these behaviors in a variety of contexts, and they appear to be under her volitional control, with the majority of instances produced spontaneously without elicitation and some (e.g., playing wind instruments) often without any apparent social attention or expectation of reward. Although these behaviors have sometimes been subject to training and reinforcement over the years, they are not the result of rigorous operant conditioning, and some appear to contain elements of imitation (e.g. talking on the phone, huffing on eyeglasses). Given the contested status of laryngeal control, it is worth noting that approximately 25% of VBBs involved voicing, and approximately half involved glottal frication. While Koko's unique ontogeny cannot be overlooked, it is clear that a substantial degree of laryngeal control is learnable by non-human great apes.

Category	# of sessions	Description	Active articulators
Blow/huff (transitive)	15	Sometimes voiced glottal fricative w/ object-directed gesture, optional lip rounding	Glottis, (lips)
Blow/huff (intranstive)	27	Same as above but voiceless and rounded & w/ object-less manual gesture	Glottis, lips
Raspberry	17	Voiceless linguolabial fricative produced with tongue folded through lips	Lips, tongue
Cough	14	Glottal plosive, with gesture towards mouth	Glottis
Blow nose	5	Nasal frication achieved through manual pressure on nasal passage	Velum
Phone	11	Voiced glottal fricative while cradling phone-like object against ear/cheek	Glottis
Clean glasses	12	Voiceless glottal fricative w/ unrounded lips, directed at glasses, then rubbing them	Glottis
Play instrument	24	Blowing into a recorder, harmonica, or other instrument	Lips

Table 1. Frequency and Description of VBB Categories

More than 95% of Koko's VBBs were accompanied by manual gestures or routines involving the manual manipulation of objects. As McNeill (2012) notes, the close coordination of vocal and manual modalities is a hallmark of human communication, and theories of language evolution must explain this fact. The evidence provided here shows that non-human great apes share our ability to intertwine these modalities, underscoring the suitability of the vocal modality as a substrate of language evolution. But despite Koko's impressive coordination of vocal and manual modalities, it's clear that her flexibility in these behaviors is less than that of humans. Linguolabial fricatives, the most complex supralaryngeal articulation she performs, were never accompanied by manual behaviors, perhaps because of the difficulty in coordinating the hands while also coordinating breath, tongue, and lips.

While this data stems from a single individual with a highly unusual life history, when combined with data from other hominids, it is clear that the strong assumption of vocal inflexibility is definitively false: great apes both learn new VBBs and exert volitional control over them. Moving forward, we emphasize two main points. First, researchers must treat the evolution of vocal control with more anatomical nuance, considering separately the control of breathing, the larynx and various supralyaryngeal articulators. Second, researchers of language evolution must consider the vocal and manual modalities together as the substrate of language evolution. Speech did not supplant gesture; rather, they have always been supplementary.

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EVOLUTIONARY LINGUISTICS AND HISTORICAL LANGUAGE STUDIES

MELANIE MALZAHN & NIKOLAUS RITT

PROGRAM

09:00	**Introduction**
09:15	**Evolutionary approaches to (socio-)historical linguistics: some case studies** William Croft
09:35	**Small Data: Cultural evolution, lexical replacement, and the problem of margin of error in large time depths** Johanna Laakso
09:55	**What were they thinking? Phylogenetic comparative methods and language history** Michael Dunn
10:15	**Everything must change so that everything can stay the same – the social factor in language change and language evolution** Melanie Malzahn
10:35	**Discussion of papers 1–4**
11:05	**Coffee break**
11:25	**Why historical linguists don‘t do experiments and why they might want to** Gareth Roberts
11:45	**The concept of ‘Emergent Grammar’ and its potential for evolutionary linguistics** Anneliese Kuhle & Ferdinand von Mengden
12:05	**Computational phylogenetics for linguistic reconstruction: quantitative tools for a qalitative problem?** Kevin Stadler
12:25	**Evolutionary game theory in historical language studies** Nikolaus Ritt & Andreas Baumann
12:45	**Discussion of Papers 5–8**
13:15	**Final discussion and closing of the Workshop**
13:45	**End**

EVOLUTIONARY APPROACHES TO (SOCIO-) HISTORICAL LINGUISTICS: SOME CASE STUDIES

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Evolutionary models can be applied to language change in modern human languages as well as to the evolutionary origin of language. Evolutionary models of language change are basically models of cultural transmission of the cultural trait of language. Perhaps the most important advantage of an evolutionary approach to language change is that it provides a unification of "traditional" historical linguistics, which is focused on what kinds of change occur in languages (that is, how variation is generated in the first place), and socio-historical linguistics, which is focused on how linguistic variants are propagated in a speech community, or across speech communities in the case of contact-induced change (that is, what variants are selected in a speech community). Nevertheless, the question remains, how does an evolutionary framework actually help us to address specific questions about the mechanisms of language variation and change that (socio-) historical linguists have debated? In this talk, I will describe a number of case studies (published and in progress) of how an evolutionary framework helps to address these questions. Modeling the population dynamics of speech communities and the linguistic forms they use suggests answers to questions about the mechanisms by which change is propagated. Recasting the question of how linguistic variation is generated in a way coherent with socio-historical linguistics sheds new light on the origins of grammatical change.

SMALL DATA: CULTURAL EVOLUTION, LEXICAL REPLACEMENT, AND THE PROBLEM OF MARGIN OF ERROR IN LARGE TIME DEPTHS

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The Uralic language family can be used as an example of the controversy between scarcity of lexical data and well-established relatedness over a large span of time, uncontested in the research community. (Alongside numerous pseudo-linguists, Marcantonio (2002) has attempted to refute the validity of Proto-Uralic; her arguments, however, are flawed and based on misinterpreted data, see e.g. Aikio (2003), Bakró-Nagy (2005), Laakso (2004).) In most modern chronologies, Proto-Uralic is dated to appr. 6,000–4,000 years BP and often, more or less explicitly, considered a contemporary and, possibly, a neighbour of Proto-Indo-European. Yet, the number of valid and generally recognised etymologies for Proto-Uralic is relatively small in comparison with Indo-European, ranging between less than 150 (Sammallahti 1988) to a few hundreds, depending on the strictness of phonological criteria and whether a binary taxonomy (proto-languages always dividing in two) or more "bush-like" models are used. Especially in the Samoyedic branch, the conservativity of grammar is in clear contrast with massive lexical replacement (Janhunen 2008, Häkkinen 2009). As suggested by Bowern & al. (2011), this scarcity of etymological data may lack a general explanation (hunter-gatherer languages are not in general more prone to lexical replacement); thus, a more detailed investigation of possible environmental and cultural motivation is needed.

What, then, can be made out of this "Small Data"? In this paper, I will attempt to critically assess the risks of quantitative and evolutionary accounts of the history of Uralic, as e.g. in the BEDLAN project (http://kielievoluutio.uta.fi/). How seriously does massive lexical replacement affect our chances of applying quantitative methods on etymological data?

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WHAT WERE THEY THINKING? PHYLOGENETIC COMPARATIVE METHODS AND LANGUAGE HISTORY

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There is a significant gap between the earliest documentation of a language family and the oldest reconstructible form of those languages as inferred by historical linguists using the Comparative Method. For a small group of dialects without a written tradition this gap might only be a few hundred years, from the date of the first language description back to their mutual ancestor language in the recent past. For larger families, such as Austronesian or Indo-European, this gap is longer, spanning the period from the earliest written texts to the proto-language spoken several thousand years earlier. Within this gap the Comparative Method tells us something about the nature of these languages, including lexical forms, morphology, and some constructions. But there is a great deal about what the speakers were saying, thinking and doing which has not been recorded, and which does not emerge from Comparative Method reconstruction. In particular, the higher order aspects of grammar, semantics, and social structure may not leave any obvious physical or linguistic trace.

This is not to say, however, that these non-material aspects of human experience have left no trace at all. On the contrary, the observed variation in human culture and language in the historical record is the endpoint of an evolutionary process originating much deeper in the past. And precisely due to the work of historical linguists, a great deal can be inferred about the genealogical processes that brought this variation into being. Phylogenetic comparative methods (no relative of the linguistic "Comparative Method") are a family of statistical techniques, coming out of evolutionary biology, which use the known genealogical relationships and history of a set of taxa to model the evolutionary processes acting on specific features of those taxa.

In the domain of language evolution, phylogenetic comparative methods can be used to infer the processes of language change acting upon typological features of languages in the family. Given a set of observations of language structures and a known set of relationships between those languages, phylogenetic comparative methods can uncover pathways of grammatical change, explore rates of change, and test hypotheses about functional dependencies. Dunn et al. 2011 analysed constituent order typology (following Dryer 2007) in this framework, showing that the evidential basis for some claimed universals of language was weaker than supposed, and that the role of family-specific contingencies was very strong. Evolutionary anthropologists have used phylogenetic comparative methods to investigate the evolution of kinship terminologies (Jordan 2011) and social structure (Jordan et al. 2009, Fortunato 2011). Current work in the phylogenetic comparative framework has investigated change in the abstract structure of pronominal paradigms, and has uncovered the relative contribution of inheritance and contact to systems of lexical classification.

Phylogenetic comparative methods put historical linguistics to the forefront of the modern endeavour to understand language structure and the mechanisms linguistic and cultural change.

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EVERYTHING MUST CHANGE SO THAT EVERYTHING CAN STAY THE SAME – THE SOCIAL FACTOR IN LANGUAGE CHANGE AND LANGUAGE EVOLUTION

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The language faculty is an important (maybe even the most important) characteristic of humans, and its evolution is tightly connected with the essential and fascinating question of the descent of the human species. The essence of language is both a biological and a cultural phenomenon. To find out to what extent language is biologically and culturally determined is one of the main challenges of evolutionary linguistics, which is per se an interdisciplinary field constituted by evolutionary anthropology and evolutionary psychology, cognitive science, and linguistics.

The field of historical linguistics focuses on the question of how and why languages change over the course of time, and comparative philology, by studying changes attested in specific real languages forms an empirical basis for tackling that question. But even the most refined methods of historical linguistics and comparative philology do not allow us to reach far back in time. Most comparative philologists agree that the common ancestor of the Indo-European languages, which constitute one of the best studied language families there are, has to be placed in the 4th millennium BCE. And even if one accepts the claims of less conservative phylogenetic studies dating the beginning of PIE into the 9th and 8th millennia, there is still a huge time gap between this date and the emergence of the language faculty at some point of the development of homo sapiens (certainly long before 40.000). Accordingly, there is a consensus in evolutionary linguistics that comparing languages in the way historical linguists can has no impact on the question of the development of the language faculty itself (cf. McMahon 2013: 55-70 with refs.).

Nevertheless I want to argue that the findings of historical linguistics can have an impact on some questions of language evolution.

In a programmatic paper from 2009, Evans/Levinson raised the question of the value of language diversity for cognitive science. They argue that given the fact that there is a huge diversity in the world's languages and that at the same time surface language universals are scarce, the concept of Universal Grammar must be wrong, so that cognitive science ought to pay more attention to the diversity of languages instead of basing itself on the "dogma" of UG. Evans/Levinson acknowledge UG simply as "the programmatic label for whatever it turns out to be that all children bring to learn languages".

The denial of UG has been much criticized by linguists (cf., e.g., the open peer commentaries to Evans/Levinson 2009 by Baker, Freidin, and Nevins among others); in my paper I want to focus on the diversity argument, disregarding the question whether UG exists or not.

Evans/Levinson regard language diversity as a consequence of language being a "bio-cultural hybrid", and they stress the importance of viewing languages as "social artefacts", and diversity being "structured very largely in phylogenetic (cultural-historical) and geographical patterns". What they do not discuss, however, is the fact that current language diversity is evidently quite often the result of language change. Accordingly, the quite important question of why there is such a great diversity in the world's languages ought to be split into two questions:

a) why is the language faculty (which is doubtlessly somehow rooted in human biology) so flexible that it can produce an (infinite?) number of languages;

b) why do languages change and thereby produce diversity.

In my paper I want to talk about one of the main factors of language change, namely the selection of variants as social markers signaling group identity. Signaling hierarchy and group identity in return is an important factor in language evolution per se. The main question for language change and language variation is whether these are essential traits of the language faculty or rather epiphenomena, and there is much reason to believe that the latter applies.

The language faculty is a by-product of social behavior of humans, and language change is a by-product of social interaction. The flexibility and variability of the language faculty gives humans a tool for social interaction, and languages constantly change in order to keep that tool functional within the constraints of the language faculty.

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WHY HISTORICAL LINGUISTS DON'T DO EXPERIMENTS AND WHY THEY MIGHT WANT TO

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Historical linguistics is rarely thought of as an experimental science. Even within the discipline there is a long-held assumption that historical linguists have no control over their data (Labov 1972: 100) and cannot do experiments (Kroch 1989: 199). This is not surprising. While it is well accepted that experimental methods can been used to obtain reliable synchronic data, it is far from obvious how experiments might directly answer diachronic questions, given how fast language changes. As Thomason (1991: 251) put it, "the only relevant generations are human ones, so we have to wait several hundred years to see the final outcome of a particular complex set of linguistic changes."

The answer to this pessimism might seem to have arrived in the recent development of paradigms for studying language evolution in the laboratory (Galantucci et al.,2012; Scott-Phillips & Kirby 2010). However, such methods have yet to be widely adopted by historical linguists, and—with very few exceptions (e.g. Roberts 2010)— the focus of those experiments that have been conducted is on either language emergence (e.g. Galantucci 2005; Scott-Phillips et al. 2009) or the emergence of fundamental design features (e.g. Galantucci et al. 2010; Kirby et al. 2008; Theisen et al. 2010), which are well established in modern languages. There are several possible reasons for this discrepancy. On the one hand, it may reflect reluctance on the part of historical linguists who are not trained in experimental methods, or on the part of experimental sociolinguists committed to studying "language produced in authentic contexts by authentic speakers" (Bucholtz 2003: 398), for whom experiments involving "laboratory languages" and which compress long-term processes of language change into the handful of hours available for an experiment may be somewhat too artificial. On the other hand it may simply reflect the fact that, while historical linguists have a wealth of realworld data at their disposal, evolutionary linguists have been forced to be more resourceful. Those researchers concerned with understanding language change on an evolutionary timescale, moreover, may find themselves less drawn to the comparatively petty timescales of historical linguistics, or may assume that the latter are subsumed by the former.

However, experimental studies of modern language change have much to offer both traditional historical linguists and experimental evolutionists. First, it is not the case that experiments in language evolution are already historical-linguistic in character. While the factors behind phonological change might be related to the behind phonological emergence, there is a good chance they are not. Furthermore, the availability of well researched real-world data sets offer an important opportunity to validate experimental methodologies. To the historical linguist, on the other hand, experiments offer replicability and the chance to manipulate and separate variables that in the real world are fixed and tightly entangled. This is well worth the loss of a small amount of authenticity.

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THE CONCEPT OF 'EMERGENT GRAMMAR' AND ITS POTENTIAL FOR EVOLUTIONARY LINGUISTICS

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The main claim of this paper will be that a usage-based perspective on language change and variation will provide clues on early stages of human language and on pre-language stages.

The canonical view in structuralist frameworks of language sciences takes language change as a path from stage A (old) to stage B (new). More recent, functionalist oriented approaches have acknowledged that this path requires an intermediate stage in which A and B coexist and form a variable. However, this refined picture still insinuates that there is a telicity in language change in that once some variable has emerged, the innovated form B by default prevails over the earlier form A. As a basis of our line of argument we will employ a view on language that takes the coexistence of two (or more) variants as the norm and the idea of monolithic 'stages' as random, non-significant snapshots of language description. We take variables, ambiguities and instability – rather than stable structures assuming a one-form-one-function ideal – as defining features of human language. This view corresponds with Paul Hoppers concept of 'Emergent Grammar' that describes linguistic systems as "temporal, emergent" and constantly renegotiated (Hopper 1987: 141). We will argue in this paper that this dynamic (or 'emergentist') model of the linguistic system provides clues to the evolution of human language. We will mainly draw on examples of semantic change, but the general principle will also hold for changes on the expression side.

Meaning change is believed to take place via metaphorical extensions which are first context dependent and then may become conventionalized (i.e., more independent of an individual usage event). Any conventional meaning of some expression is, in turn, always liable to new interpretations, which can be enforced, invited, discouraged or ruled out by context information during discourse (von Mengden/Coussé 2014). This phenomenon has been described with varying foci and varying terminology in the literature ('invited inferences', 'bridging contexts', etc.), but common to all these discussions is the assumption that an overlap of two (or more) variants is required. We will refer to this pattern of transfer from one context to another as 'recontextualization', thus deliberately alluding to the notion of 'decontextualization' in developmental psychology (Wertsch 1991).

This dynamic notion of language suggests that there cannot possible be any proto-meaning or proto-form, nor any original form-meaning pairing which is closest to some linguistic big-bang: if a conventional expression or meaning is by nature constantly renegotiated, a stable stage of a one-to-one form-meaning pairing cannot possibly have existed. This is compatible with (and actually suggests) the idea that linguistic signs have emerged out of other, non-linguistic systems. This, in turn means that we must be able to find analogous 'recontextualizations' both in other (non-linguistic) cultural or behavioural domains of both humans and non-human primates.

Along these lines, Kuhle (2013a; 2013b) has recently shown striking parallels between patterns of recontextualizations in the development of language structures and recontextualizations ('flexible transfer'; cf. Boesch 2013) in non-linguistic tool use of wild-living chimpanzee populations. Based on examples of this kind, we will argue that human language, if seen as a dynamic system, displays a number of significant features that parallel in other, related systems and that these parallels provide important clues to our knowledge of the evolution of human language.

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COMPUTATIONAL PHYLOGENETICS FOR LINGUISTIC RECONSTRUCTION: QUANTITATIVE TOOLS FOR A QUALITATIVE PROBLEM?

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The past decade has seen a rise in applications of computational tools originally developed for phylogenetic reconstruction in biology to linguistic data, leading to enthusiastic exclamations by the methods' proponents, scepticism from traditional linguists, and little to no consensus between the two. Constructive interactions appear to be hindered by mutual accusations of misunderstanding each other's fields – biologists not understanding (or trivialising) the nature of linguistic data, and linguists not understanding (or questioning the applicability of) the computational methods involved.

This talk is an attempt to understand and reconcile the two positions where possible, first and foremost by paying close attention to how different types of linguistic data are obtained, and how these match (or don't match) the kind of input data that the methods are devised for. I will highlight how the purely symbolic encoding used in computational studies does not differentiate between cognacy judgements and descriptive or typological traits, two types of data which are of a qualitatively very different nature. After arguing that the use of the former is in fact tautological I discuss how reconstructions based on the latter fall prey to Galton's problem, i.e. they cannot determine whether similarity between languages is due to common descent, horizontal transfer (borrowing), or parallel evolutionary developments.

While anthropologists working with cross-cultural data are well aware of Galton's problem it is interesting to note that it is virtually unheard of in linguistics. I will show how linguistic reconstructions can escape Galton's problem thanks only to the duality of patterning of human languages, and how the Comparative Method has been leveraging this little noted fact since its very inception. I conclude by looking at some very recent endeavours in computational reconstruction that take into account the internal structure of words, showing how they successfully address some, but not all, of the issues raised.

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EVOLUTIONARY GAME THEORY IN HISTORICAL LANGUAGE STUDIES

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Recent work in evolutionary linguistics has demonstrated how methods that had previously been tested and successfully applied in the natural sciences can enrich not only the study of the biological emergence of the language faculty, but also the study of cultural language transmission and thereby increase our understanding of the historical development of specific languages. These methods include quantitative cladistics, computer simulation, strictly controlled laboratory experiments, population dynamics, or (evolutionary) game theory (cf. e.g. Hofbauer & Sigmund 1998, Nowak 2006). At the same time, and given that the main body of insights accumulated in the field of historical linguistics have been developed by means of specifically linguistic and philological methods, the question arises how the benefits to be gained through the adoption of methods from other disciplines compare to the unavoidable costs involved in such transfer and adaptation.

By way of example, this paper reports on an attempt to employ Evolutionary Game Theory for modeling and explaining English word stress and its historical development. (Ritt & Baumann 2012, Baumann & Ritt in prep.) It outlines the model, points out in what way the predictions it makes differ from those of traditional models, and shows that one of its assets is that it correctly predicts historically stable variability among stress patterns (such as ˈrobust vs. roˈbust, ˈhotel vs. hoˈtel, ˈconcert vs. conˈcern, etc.) for languages that – like English – contain many monosyllables.

The main focus of the talk, however, will be on some of the difficulties one necessarily faces when one attempts to address issues in linguistic history in terms of rigorous and domain-unspecific mathematical models. In order to make observed changes in the stress patterns of English words amenable to mathematical modelling, for example, we have had to carry out a few rather radical abstractions, such as assuming that all major class items are disyllabic, that the lexicon is infinitely large, or that all are equally likely to co-occur with one another. Furthermore, our model was naturally incapable of taking specific historical events, such as the Norman Conquest or the lexical enrichment of English during the Renaissance, into account, which obviously affected the make-up of the English lexicon. Finally, our model forced us to factor out the role of individual speakers using language for specific communicative purposes in specific contexts of use more or less completely. Instead we had to define words and themselves as 'players' and beneficiaries of any utility function incurred by the assumption of one or the other stress pattern.

Since the predictions implied by our model have turned out to be qualitative and highly general, the question to what extent they can actually be used to account for the specific developments to be observed in the history of a specific language such as English raises itself and turns out to be challenging. While we intend to argue to argue that our attempt has been meaningful and fruitful, we concede that the issue is open for discussion, and are curious to hear the comments from the workshop participants.

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EVOMUS: THE EVOLUTION OF LANGUAGE AND MUSIC IN A COMPARATIVE PERSPECTIVE

ANDREA RAVIGNANI & BRUNO GRINGRAS

PROGRAM

09:00	**Introduction** Andrea Ravignani & Bruno Gingras
09:10	**Musical Animals. Can there be? Are we?** Henkjan Honing
09:50	**Drumming in wild chimpanzees (Pan troglodytes) is individually distinctive – implications for the evolution of music** Magdalena Babiszewska
10:10	**Short break**
10:15	**The biology and evolution of music: The comparative approach** W. Tecumseh Fitch
10:55	**Cognitive representation of fractal music: an empirical approach to music recursion** Mauricio Martins
11:15	**Coffee break**
11:45	**Which came first, music or language? Revisiting the Darwin-Spencer debate in light of modern empirical research.** Aniruddh D. Patel
12:25	**Musical and linguistic pattern emergence in the lab** Tessa Verhoef
12:45	**Rhythm-driven evolutionary dynamics of lexical stress in natural languages** Andreas Baumann
13:05	**Learning music and language with stochastic transduction grammars** Dekai Wu
13:25	**Round table discussion – How can evolutionary linguistics and evolutionary musicology inform each other?**
13:45	**End**

THE EVOLUTION OF MUSIC AND LANGUAGE IN A COMPARATIVE PERSPECTIVE

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Keywords: language-music interface; recursion; music cognition; primates; cultural evolution; protolanguage; evolution of cognition; biomusicology; rhythm; comparative psychology; agent-based modeling; cognitive neuroscience; grammars.

Language and music are some of the most prominent and unique features of human cognition. Similar formalisms are used to describe them, with musicology borrowing approaches, terminology and methodologies from linguistics. Music and language research share interests in both evolutionary origins and cognitive underpinnings of their respective objects of inquiry.

The purpose of this workshop is to:

i. provide a common platform for researchers from a range of fields (syntax, phonology, typology, biomusicology, ethnomusicology, neuroscience, etc) to compare results and methodologies,
ii. discuss and integrate findings from different disciplines within the evolutionary and cognitive frameworks,
iii. develop critical hypotheses whose empirical testing can shed light on issues at the frontier between the evolution of language and music.

This workshop will compare recent findings on language and music along three lines of inquiry: evolutionary, cognitive and methodological.

(1) The evolutionary approach. What is the relationship between the origins of language and music? Can findings in one discipline inform the other? Which experiments are crucial to reject or accept hypotheses of common origins?

(2) The cognitive approach. To what extent do language and music processing overlap in the brain and mind? How can experimental studies inform us about shared neural resources? In particular, do structural similarities in language and music map to shared processing mechanisms?

(3) The methodological approach. Current research on language evolution makes, among others, broad use of agent-based modeling, iterated learning experiments and comparative research in non-human animals. How are similar techniques used to investigate the evolution of music? What kind of models and computer simulations could be "imported" from language to music research (and vice versa) successfully and meaningfully?

DRUMMING IN WILD CHIMPANZEES (PAN TROGLODYTES) IS INDIVIDUALLY DISTINCTIVE – IMPLICATIONS FOR THE EVOLUTION OF MUSIC

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Production of structured and repetitive sounds by striking objects is a musical behavior found not only in humans, but also in a variety of other species including chimpanzees (Arcadi et al. 1998). In this study we examined individual and social factors that may influence the frequency with which individuals engage in drumming behaviour when producing long distance pant hoot calls and analysed the temporal structure of drumming bouts. Males from the Budongo Forest, Uganda drummed significantly more frequently during travel than feeding or resting contexts and older individuals were significantly more likely to produce drums than younger ones. In contrast, we demonstrated that the presence of oestrus females, high ranking males and preferred social partners did not have an effect on the production of drums. In terms of temporal structure, we demonstrated through acoustic analysis that drumming sequences were individually distinctive and that there was qualitative individual variation in the complexity of the temporal patterns produced. We conclude that drumming patterns may act as individually distinctive long-distance signals that, together with pant hoot vocalisations, function to coordinate the movement and spacing of individuals within a community. We argue that understanding the function and structure of drumming behaviour in our closest living relatives may shed light on the function and complexity of the earliest human music.

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COGNITIVE REPRESENTATION OF FRACTAL MUSIC: AN EMPIRICAL APPROACH TO MUSIC RECURSION

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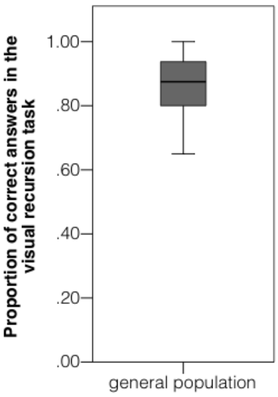
The human ability to process hierarchical structures has been a topic of research since decades. However, despite intense debate, the cognitive machinery underlying this ability remains controversial. For instance, language, music, and motor sequencing seem to require a special memory device to keep track of non-adjacent hierarchical relations (Fitch & Friederici 2012; Friederici 2011; Koechlin & Jubault 2006; Koelsch, Rohrmeier, Torrecuso & Jentschke 2013). However, these abilities *per se* do not explain the human capacity to use patterns and regularities in the generation of hierarchies (Martins 2012).

Recursion, the ability to embed structures within structures of the same kind, has been considered as key component of our ability to parse and generate complex hierarchies (Hauser, Chomsky, & Fitch 2002). Recently, we have devised an empirical paradigm, based on the properties of fractal geometry, which can be used to test for the ability to represent recursion (Martins & Fitch 2012). Results in the visual domain suggest that human adults can represent hierarchical self-similarity and use this information to generate new hierarchical levels (Figure 1 left).

Here we extended this paradigm to the musical domain. We devised a two-alternative forced-choice paradigm in which participants were asked to complete sequences generating musical fractals. 30 participants without musical training performed the music recursion task and the majority (20 out of 30) scored above chance (Binomial test: 67%, $p<0.05$) ($M=71\%$, $SD=18\%$). Crucially, participants' performance followed a typical learning curve and was consistent across different foil categories. This suggests that they acquired an abstract rule to solve the task, rather than used simple heuristics. We also present preliminary data on musicians ($n=18$), which on average scored higher than non-musicians ($M=85\%$, $SD=20\%$) (t-test$=-2.5$, $p=0.017$). Interestingly, musicians' accuracy in our musical task was similar to the overall population score in the visual task ($M=86\%$). This suggests that the effects of expertise might be stronger in the auditory domain than in the visual domain. We will conclude by discussing interesting parallels between visual and music recursion.



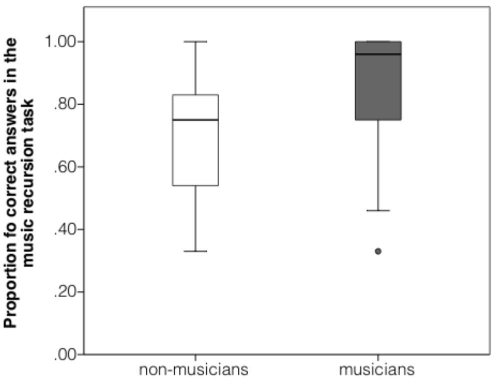


Figure 1. Performance in the visual recursion task (left) and in the music recursion task (right).

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MUSICAL AND LINGUISTIC PATTERN EMERGENCE IN THE LAB

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Both language and music are characterized by combinatorial structure. In language, discrete sets of basic phonemes are combined and reused to form words. In music, melodic and rhythmic primitives are combined and reused to form compositions and characterize style. Although language and music are different in many ways, there are parallels as well, both in the combinatorial way the signals are formed (Fitch 2010) and in how humans process these signals (Patel 2003).

In this abstract, data is presented from an experiment that was originally conducted to study the emergence of combinatorial structure in speech sounds (Verhoef, Kirby & Padden 2011; Verhoef, Kirby & de Boer 2013). Here, this data is additionally evaluated in the context of the emergence of patterns in music.

These experiments use the iterated learning paradigm. Participants were asked to memorize and recall a set of twelve sounds that were produced with a slide whistle. One participant learned from the set of sounds the previous participant had reproduced. In a first experiment, the sounds had no meaning. Four transmission chains were created with ten consecutive participants in each. In a follow-up experiment, the sounds referred to novel objects with no conventional names in existing languages. There, eight chains were created with ten consecutive participants in each.

In both experiments the emergence of combinatorial structure could be observed. Figure 1 shows a fragment of a whistle set that emerged after ten transmissions in the first experiment. A set of basic building blocks can be identified that are systematically reused and combined. Similar emergence of basic elements and systematic recombination can be observed in the chains of the second experiment. Each chain, however, has a different set of elements and a different way of combining them. Quantitatively, in both experiments it was demonstrated that the sets of whistles became easier to learn and reproduce as well as more compressible, measured in terms of decreasing entropy.

We concluded that combinatorial structure in language may emerge through the process of cultural transmission and as an adaptation to human cognitive biases on memorizing systems of auditory signals.

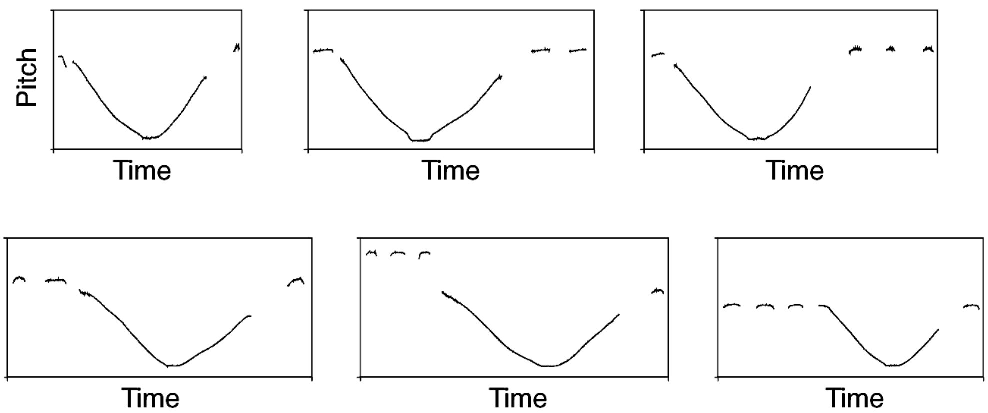

Figure 1. Fragment of emerged whistle contours. Basic elements are systematically recombined.

However, as was pointed out by Henkjan Honing (personal communication), this experiment uses a musical instrument and analyses musical features (pitch, contour). Therefore, especially given the commonalities between linguistic and musical structure at this combinatorial level, the results should be informative about the evolution of musical patterns or distinct musical styles as well. Are the findings of these experiments in line with the expectations based on mechanisms that characterize human musicality (Honing & Ploeger 2012)?

It will be discussed how established biases in music perception and cognition relate to the experimental findings and to what extent these findings are actually about music as much as they are about language, without disregarding the important differences between these two systems. To conclude, the experimental method of studying cultural transmission in the lab seems to be a suitable method for studying pattern emergence in music as well as language and could perhaps be utilized more in the field of music evolution.

Acknowledgements

I thank Henkjan Honing for valuable suggestions and discussion.

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RHYTHM-DRIVEN EVOLUTIONARY DYNAMICS OF LEXICAL STRESS IN NATURAL LANGUAGES

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In this paper we propose a game theoretic approach to the assignment of lexically fixed word stress driven by rhythmical constraints. In contrast to previously proposed theories (such as Chomsky & Halle 1968, Hayes 1981, or Schane 2006), which derive lexical stress by means of rules operating on isolated lexical items, and which typically fail to handle variability (as in English $[\text{re.ˈsearch}]_N$ vs. $[\text{ˈre.search}]_N$) satisfactorily, in the present approach the assignment of lexical stress is seen as adaption to utterance rhythm.

Words together with their memorized phonological structure – including their respective stress patterns – are modeled as replicating competence constituents (similarly as in Nowak 2000) whose reproductive success depends on their faithful expression and transmission. Since rhythm is a property of sequences of words – as opposed to single items – it is assumed that the rhythmic well-formedness of an utterance contributes to the reproductive success of all words it is built up with. This assumption is supported by results about articulatory mechanics, speech segmentation and perception (see Patel 2008). Hence, it is reasonable to assume that words should be adapted to rhythmic structures in which they come to be uttered. Crucially, utterance rhythm does not only represent the environment to which words must adapt, but is itself constituted through the combination of words. Due to the complexity of this interaction, modeling via evolutionary game theory (cf. e.g. Hofbauer & Sigmund 1998) suggests itself.

In our model, which is an extension of Ritt and Baumann (2012), disyllabic words figure as players, which can choose among different stress placement strategies (e.g. always stress the first syllable). They combine to form utterances together with (potentially unstressed) monosyllabic words, and receive payoffs reflecting the rhythmic quality of the utterances they form. More precisely, payoff is modeled as a function of the number of clashes and/or lapses occurring in a formed utterance. Notably, the shape of this payoff function is determined by theoretical considerations and empirical results about rhythm in speech alike. In accordance with the assumptions of evolutionary game theory, choosing a stress placement strategy incurring a higher payoff will promote the faithful transmission and utterance frequency of a word.

We will demonstrate, that analyzing the evolutionary dynamics of the model, interesting and testable predictions about probable distributions of stress patterns in the lexica of natural languages as well as about potential diachronic changes on the time scale of cultural evolution can be derived. In particular, the model shows that the distribution of stress placement patterns among polysyllabic words should crucially depend on the frequency of monosyllabic words. We will see that the model can account for phenomena such as the shift from homogenously initial stress to mixed stress patterns in the history of English (Ritt 2012) as a reflex of phonetic erosion in combination with an invasion of Latinate words, or the stability of homogenous stress patterns in Austronesian languages, which are characterized by a high frequency of disyllabic words (Brunelle & Pittayaporn 2012). Finally, due to its analytic simplicity we believe that our model can turn out to be a useful tool for testing the plausibility of rhythmic constraints.

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LEARNING MUSIC AND LANGUAGE WITH STOCHASTIC TRANSDUCTION GRAMMARS

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We discuss how our computational models for learning probabilistic structural relationships between *pairs* of compositional languages reflect fundamental cognitive capacities that underlie both human language and music processing. Formally, a single language can be described by a (probabilistically weighted) set of patterns; likewise, a bilingual/bimodal *transduction* can be described by a set of structurally related *pattern pairs*. The probabilistic rules in *stochastic transduction grammars*, which we pioneered and are widely used in statistical machine translation, associate compositional patterns between two representation languages—a generalized version of Saussurean signs. Our cognitively motivated *transduction grammar induction* methods learn by bootstrapping progressively more complex classes of transductions, from finite-state to linear to inversion transductions. Linguistically, *inversion transduction grammars* explain via combinatorial efficiency principles why natural languages evolved universally to impose a long-unexplained empirical limit on the number of core arguments in semantic frames to the "magic number 4". Musically, our work demonstrates that the same transduction grammar induction processes model the learning and use of compositional relationships between parallel musical representation languages—languages for example like hypermetrically structured rhythm parts in flamenco, or lines and rhymes in hip hop.

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HOW GRAMMATICALIZATION PROCESSES CREATE GRAMMAR: FROM HISTORICAL CORPUS DATA TO AGENT-BASED MODELS

LUC STEELS, FREEK VAN DE VELDE & REMI VAN TRIJP

PROGRAM

09:00 **Welcome & Introduction**
Luc Steels

Session 1: Finding footprints of grammaticalization

Theme: What are novel techniques for empirically tracking grammaticalization?
Chair: Gerhard Jaeger (University of Tübingen)

9:20 **Evolutions of Chinese characters 'Zai' and 'Ren' in co-occurrence networks**
Xingying Chen & Tao Gong

9:30 **Phylogenetic comparative methods**
Annemarie Verkerk

Session 2: Mechanisms underlying grammaticalization

Theme: What cognitive mechanisms play a role in grammaticalization?
Chair: Katrien Beuls (Vrije Universiteit Brussel)

2.1 Recruitment: How can existing materials be exapted for new grammatical functions?

9:45 **A possible source for definiteness: possessor markers in Uralic**
Doris Gerland

9:55 **Emergence of quantifiers: computational and robotic modeling of grammaticalization**
Simon Pauw & Michael Spranger

10:05 **Changing or re-arranging? Constructional changes in perfect constructions**
Josep M. Fontana

2.2 Analogy: How is analogy used for expanding grammatical structure?

10:20 **Development of new grammatical categories: articles and auxiliaries in Romance**
Anne Carlier & Beatrice Lamiroy

10:30 **Analogy expands and generalizes case frames**
Remi van Trijp

10:40 **Semantic competition and (inter)subjectification in the system of Dutch modals**
Jan Nuyts

2.3 Learning bias: How do learning biases play a role in language change?

10:50 **English WH-relatives: towards an aetiology of a gradual syntactic change**
Robert Truswell & Nikolas Cisborne

11:00 **Word order changes and grammaticalization in Germanic verbal clusters**
Jelke Bloem, Arjen Versloot & Fred Weerman

Coffee Break & Poster Session (11:15–11:45)

- **Interpretation process: Analysis of the complexity for different language systems**
  Emília Garcia Casademont
- **Cases, prepositions, and in-betweens: sketching a model of grammatical evolution**
  Benjamin Fagard, Elisa Omodei & Miquel Cornudella Gaya
- **Modelling the role of Russian verbs in the evolution of Russian aspect**
  Yana Knight & Michael Spranger
- **Entrenchment vs. transparency. Modelling the Dutch strong-weak past tense competition in an agent-based simulation**
  Dirk Pijpops, Katrien Beuls & Freek van de Velde
- **Emergence and (co-)evolution of tense, aspect and modality**
  Paul Van Eecke

Session 3: Effects from the population level

Theme: What is the role of population structure in the propagation and convergence of languages?
Chair: Bernat Corominas-Murtra (Medical University of Vienna)

11:45 **Using models to relate individual linguistic behavior to the population dynamics in language**
Richard Blythe

11:55 **When do Creole languages emerge?**
Francesca Tria

12:05 **Tracing real-life agents' individual process in ongoing grammaticalization**
Peter Petré & Freek van de Velde

Session 4: Biological foundations

Theme: What kind of unique capacities does the human brain have that make it 'ready' for language?
Chair: Luc Steels (Universitat Pompeu Fabra Barcelona)

12:15 **Evolutionary dynamics. What is it and how is it relevant for understanding the functioning of the brain and the evolution of language?**
Eörs Szathmáry

12:40 **What does a brain need to support FCG-like capability?**
Michael Arbib

Session 5: Concluding perspectives

Theme: What are linguistic challenges that agent-based models should address?
Conclusion by Salikoko Mufwene (University of Chicago) and a final discussion with all participants

TALKS

UNDERSTANDING LANGUAGE EVOLUTION REQUIRES UNDERSTANDING LANGUAGE CHANGE

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Evolutionary biology starts from observations of how species have evolved and then tries to come up with a general theory of the mechanisms that could explain how new species, and ultimately life itself, have originated. Success of evolutionary theory comes from its ability to explain concrete features of organisms, for example why cichlid fish have egg spots on their back fin, as well as general phenomena, for example why multicellular organisms have evolved. The success of evolutionary biology is undeniable. It has revolutionized all of biology and is still rolling forward at a rapid speed, aided these days by the very powerful use of computational modelling and advances in genome sequencing. Why should Evolutionary Linguistics not strive for the same level of excellence? And how could it achieve it?

Researchers in language evolution often ignore entirely the past and ongoing change in language, despite the fact that historical linguistics has done a great job in amassing large amounts of typological and historical data and that these data prove important clues on the mechanisms that give rise to the remarkably complex structures found in human languages. Many studies of language evolution also tend to avoid using the currently available scientific methods made possible by advances in computer science: statistical analysis of language change in corpora, computer simulations, and agent-based models.

The present workshop brings together exciting work that might help to show researchers in language evolution that historical linguistics is not only relevant but indeed central and that the scientific modeling of language evolution is not only possible but in many cases highly insightful.

The workshop is organized in 5 sessions and a poster session that contains additional proposals and results. The first session (*Finding footprints of grammaticalization*) uses novel techniques from complex systems science to identify grammaticalization trends. The second section (*Mechanisms underlying grammaticalization*) looks at various cognitive mechanisms (recruitment, analogy, learning bias) that help to explain why certain grammaticalization paths have happened. Section 3 (*Effects from the population level*) investigates the role of population structure and dynamics on language convergence and divergence. And section 4 examines the biological foundations of human language from the viewpoint of grammaticalization and ongoing evolution. The workshop ends with an overall perspective and concluding discussion.

1. Finding footprints of grammaticalization

The field of complex systems science has given rise to a whole battery of novel techniques based on analyzing the network structure of a particular phenomenon and this has been applied intensely to questions of ecology and evolution in biology. These techniques have now been applied to ongoing language change, particularly for studying the impact of linguistic context. An example of this is provided in the contribution of Chen and Gong who investigated the evolution of Chinese characters. Another battery of analysis techniques pioneered in evolutionary biology has come from the analysis of phylogenetic trees. New advances provide more sophisticated forms of analysis and they are discussed in a contribution by Verkerk.

2. Mechanisms underlying grammaticalization

Agent-based modeling is a particularly appropriate method to understand the cognitive mechanisms underlying phenomena leading to the emergence of grammatical structure in human languages. Various contributions at the workshop focus on specific examples of mechanisms and combine empirical observation with attempts to create agent-based models explaining them.

2.1 Recruitment

Recruitment means that there are existing forms that are used for a new purpose and then these forms begin on an evolutionary path of their own. Often the word form erodes, the meaning becomes more restricted (bleaching), and the syntactic potential more limited. An example is the evolution from demonstratives to articles. The session on recruitment discusses several case studies of this phenomenon. There are contributions on how possessor marks can become expressions of definiteness (by Gerland), how adjectives can evolve into quantifiers (by Pauw and Spranger) and how perfect constructions have evolved (by Fontana).

2.2 Analogy

Analogy is another cognitive mechanism that clearly plays a role in the formation of new grammatical structure. Analogy works by reorganizing certain grammatical forms so that they become similar to other ones and thus form a particular paradigm. Carlier and Lamiroy give examples of this phenomenon for the emergence of articles and auxiliaries in Romance languages, van Trijp shows how analogy is fundamental for the structure of case paradigms, and Nuyts uses corpus data to track the evolution of meaning of the Dutch modals.

2.3 Learning bias

Many approaches to language learning assume a particular bias on the learning process, which then impacts how new grammatical structures are inductively inferred or re-arranged. The workshop shows two contributions in this direction: Truswell and Gisborne tackle change in English WH-relatives, Bloem, Versloot and Weerman look at word order change in verbal clusters.

3. Effects from population level

Besides the cognitive mechanisms used by speakers and hearers to extend, shape and reshape their language, there is also an obvious impact of population structure, for example on which choices become dominant in a population. The work of complex systems scientists is particularly relevant for this topic and there are contributions by Blythe (who has studied the convergence of New Zealand English) and Tria (who has modeled the influence of population structure on the formation of creoles in the United States).

4. Biological foundations

Once we understand better the cognitive mechanisms that underlie the emergence of grammar, we can ask the question whether that helps us to understand the nature of the language faculty, in other words what neural mechanisms are required to support a 'language-ready' brain, that can participate in the cultural dynamics supporting language evolution. Two eminent biologists give their views on this matter: Eörs Szathmáry discusses neuronal evolutionary dynamics and Michael Arbib explores the biological bases of constructional processing.

5. Concluding perspectives

The workshop ends with a perspective by S. Mufwene and a final discussion involving all participants.

EVOLUTIONS OF CHINESE CHARACTERS 'ZAI' AND 'REN' IN CO-OCCURRENCE NETWORKS

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The approach of network analysis, already applied in Chinese linguistics (Li & Zhou 2007; Peng et al. 2008; Liu 2008), remains less-widely used in diachronic studies, except for one work (Liang et al. 2014). Here, we adopted this approach to study Chinese functional characters/words and evaluate their evolutions and the efficiency of this approach. We built four Chinese character co-occurrence networks based on the articles from four historical periods including ancient Chinese, middle ancient times Chinese, modern times Chinese, and modern Chinese, and then, analyzed the features of the whole networks and two characters 在 ***zai*** (a verb, meaning 'to exist', 'be living', 'to stay or remain'; or a preposition, meaning '(to be located) in or at') and 人 ***ren*** (a noun, meaning 'human being or people'). For the sake of comparison, the chosen articles from each period had similar sizes and numbers of characters, and the two characters were frequent both in these articles and in general. In history, z***ai*** underwent a grammaticalization process, whereas ***ren*** remains as a content word. This allows us to compare the different evolutionary tendencies between the two characters.

Based on the network features (degrees, path length, density, diameter), we found that ancient Chinese underwent important changes as moving into middle ancient times, and evolved in different directions and gradually changed back, thus making modern Chinese more similar to ancient Chinese than those in the other periods. In the middle ancient times, the writing system emerged, and became more and more distinct from the oral Chinese for a long time before starting to adapt to the oral Chinese again in the modern times, and changed into modern Chinese after the reform starting in 1919 (Wang 1980). Analyses on these networks reflect such evolution of the writing system.

We also traced the evolution speeds or degrees of Chinese characters/words via these quantitative data that were rare in traditional research. We found that the changes of the degrees of ***zai*** and ***ren*** both fit the changing tendency as described above. Two additional findings caught our attention. First, although the features of the two characters changed back after middle ancient times, the shapes of the curves were distinct. Previous research found that modern Chinese shared similar ordinate with ancient Chinese. In our study, however, the ordinates of both characters in modern Chinese were significantly higher than those in ancient Chinese, indicating that the evolution speeds or degrees of the two were higher than the average. Second, the degree of ***zai*** had a significant increase from modern times Chinese to modern Chinese, while ***ren*** had a relatively smaller increase. This could be due to the increase in the speed of the grammaticalization of ***zai*** during the time. In Solé et al.'s (2002) and Chen's (2013) work, functional words were the hubs of either the whole network or a local community. Solé et al. (2002) also suggested that hubs could indicate the grammaticalization process and its starting points. Hubs could be functional or potential functional words to undergo future grammaticalization. Then, by analyzing the centrality of a functional word in a language network and the change of the centrality over time, we could infer the speed or degree of the grammaticalization process. Although our work showed the feasibility of using network parameters to describe the grammaticalization process, more work is needed to transform the notion of "centrality" into a numerical value for comparing words and using it to describe the evolution of functional words.

Our study showed that the network features offered a new source of information to clearly distinguish evolutions of different characters, which are relatively hard to obtain in traditional research. The network approach allowed using advanced analysis to obtain novel insights on the evolutionary tendencies of a language. This approach has enormous potentials in evolutionary research.

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PHYLOGENETIC COMPARATIVE METHODS

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1. Introduction

The emergence of morpho-syntactical systems and the results of grammaticalization processes can be investigated through a range of different and relatively new methods, including 1) agent-based modeling (Beuls & Steels 2013), 2) corpora of historical language (Van de Velde 2010), and 3) selectionist theorizing (Steels 2011). In this paper it will be argued that there is a fourth method of interest in this respect, namely the use of phylogenetic comparative methods (Levinson and Gray 2012). Data from three different case studies are provided to illustrate the use of phylogenetic comparative methods in the study of diachronic change in morpho-syntax and grammaticalization.

2. Phylogenetic comparative methods

There are three scientific fields that undertake comparative analysis: biology, anthropology, and linguistics. Conceptual parallels between diachronic comparative studies in biology, anthropology and linguistics have been cross-fertilizing these three fields throughout history (Atkinson & Gray 2005). This is happening again with the recent adoption of phylogenetic methods from biology into linguistics. First, this was limited to the use of statistical methods for phylogenetic tree inference, i.e. analyses of how languages are related (Nichols and Warnow 2008). More recently, methods for the comparative analysis of linguistic features on the branches of a phylogenetic tree have been adopted as well (Dunn et al. 2011; Levinson & Gray 2012). These latter types of methods are called 'phylogenetic comparative methods' (Harvey & Pagel 1991).

These methods can be used to investigate a range of diachronic inquiries, including questions about 1) homelands of language families, 2) sequences of linguistic change, 3) dating language family trees, 4) rates of linguistic change, 5) correlations between linguistic features, and 6) ancestral states of linguistic features (Gray et al. 2007). Whereas the methods cited in the introduction are primarily used to study change within a single language, phylogenetic comparative methods complement these by investigating change within genealogical unities such as language families. How this is done and why this is relevant for the study of morphosyntactical systems and grammaticalization will be explained by means of three case studies.

3. Case studies

3.1 Indo-European motion event encoding

Motion event encoding in the Indo-European languages is extremely varied (Slobin 2004; Verkerk 2014). A range of different construction types can be used to code the same event (the following list is not exhaustive):

(1) satellite-framed construction:
Mary **ran** *into* the room

(2) verb-framed construction:
Mary *entered* the room (**at a run**)

(3) deictic construction:
Mary went *into* the room (**at a run**)

(4) coordinate construction:
Mary **ran** and went *into* the room

Germanic and Balto-Slavic languages prefer to use the first construction type; Romance languages prefer to use the second construction type; and several others, including Hindi and Armenian, prefer to use the third and fourth construction types (Verkerk 2014). Most of the attested variation is due to the merging of directional preverbs and verb roots, which affected each branch of the Indo-European family differently (Verkerk to appear). In this case study, the focus will be on how the directionality of this grammaticalization process can be incorporated into the phylogenetic analysis of construction usage.

3.2 Oceanic secondary predicates

Similar to motion event encoding in Indo-European, secondary predications of manner and result in Oceanic can take a set of different forms (Verkerk & Frostad 2013). The most important construction is the serial verb construction:

TOQABAQITA

(5) Teqe	kini	[e	qai	baqita]$_{SVC}$	mai.
one	woman	3SG.NFUT	shout	be.big	VENT

'A woman shouted loudly this way.' (Lichtenberk 2006:270)

In several languages, verbs from serial verb constructions have grammaticalized into adverbial particles that can no longer function as independent verbs:

MEKEO

(6) Imi	[e-	biau-	lobia].
child	3SG-	run-	good

'The child ran/has run well.' (Jones 1998:418)

Phylogenetic comparative methods can be used to infer the behavior of Proto-Oceanic and changes in construction type along the branches of the Oceanic tree from Proto-Oceanic to the contemporary Oceanic languages (Verkerk & Frostad 2013). However, it is also possible to incorporate information on the grammaticalization of verbs from serial verb constructions into adverbial particles into the phylogenetic analysis. How this is done is shown by revisiting some of this material.

3.3 Bantu noun-classes

Whereas diachronic change in motion event encoding and secondary predicates has not been intensively researched, change in the Proto-Bantu noun class system has been well described (Katamba 2003, Maho 1999). However, there are still several unanswered questions: What is the nature of the relationship between noun class morphology and verbal morphology? Why are some noun classes lost more frequently than others? Can the discrepancy between SOV word order and noun class prefixes as proposed for Proto-Niger-Congo (Katamba 2003: 106-107) be unified? Answering these questions constitutes a test for the application of phylogenetic comparative methods: Are these methods able to resolve these questions and add something of importance to the study of Bantu noun classes, or does traditional comparative reconstruction suffice?

4. Discussion

The use of phylogenetic comparative methods complements the other approaches covered in the current workshop. They can be used alongside historical corpora, such as those used by Van de Velde (2010), to test claims about the history of individual languages against evidence from closely related languages. Studies of the emergence and loss of specific linguistic features in language families can be checked against findings about what drives these processes from agent-based models such as those used by Beuls & Steels (2013). The value of the selectionist criteria driving language change proposed by Van Trijp (2013) and others can be assessed by looking how these criteria have interacted on the branches of phylogenetic trees of different language families. It will be demonstrated that phylogenetic comparative methods are able to incorporate information on grammaticalization in motion event encoding and secondary predication and that they have something to add even to a well-researched domain such as Bantu noun classes.

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A POSSIBLE SOURCE FOR DEFINITENESS: POSSESSOR MARKERS IN URALIC

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The goal of this paper is firstly to show that definite articles can evolve from possessive markers and secondly to explain why this source is a suitable starting point for the evolution of definite articles.

1. Introduction

Languages with definite articles can be found in different areas of the world and in different languages families (Dryer 2013). Most of these definite articles evolved out of demonstratives as in Indo-European languages but some of them have other sources (Himmelmann 2001). In the Samoyedic and Ob-Ugric branches of the Uralic language family, for example, possessive suffixes are applied for indicating definiteness of the host noun (Fraurud 2001, Nikolaeva 2003, Schroeder 2006). These suffixes occur in all uses regarded as typical for definite articles (Hawkins 1978), e.g. in deictic and anaphoric uses (1), in associative anaphoric uses (2) and with uniques (3). In the following referring expressions from Samoyedic languages the 3rd person singular possessive suffixes do not refer to a possessor but signal the non-ambiguity of the referent of the noun just like Indo-European definite articles do.

(1) Selkup (NOS , text2.010/2.012)
Ima […].Ima-tɨ nɪk kəti-ŋ-ɨ-tɨ
woman […].woman-3SGsosay-PRS-EP-3SGOBJ
A woman […]. The woman says [to him].'

(2) Nganasan (NoS, meu djamezi.003)[1]
tahariaa büübtar-tu tərəd`i kərutətu
now start-3SG such ordinary
mou-ntənu s'iti maʔ ən`d`i-t3
earth-LOC two tent stand-PRS
'Well in the beginning [of the tale] there are two tents simply standing on the ground.'

(3) Nganasan (Wagner-Nagy 2002:79)
Kou-δu kantü"ə čiirü" tagə
Sun-3SG disappeared cloud.PL.GEN behind
'The sun disappeared behind the clouds.'

These uses raise different questions: What are the differences and similarities between definite articles like those found in Indo-European languages and the definiteness markers in Uralic languages? What are the differences and similarities of their respective grammaticalization pathways? What licenses possessive suffixes and especially 3rd person possessive suffixes as definite articles? And what can we learn about definiteness in general when looking at definite articles that emerged from a different source? Besides these questions with regard to content the analysis of the Uralic definiteness markers raises another important question and problem: Since we lack historical data we can only formulate assumptions about the diachronic development and possible pathways. So how can we find evidence for hypotheses about grammaticalization in languages where no diachronic data is available?

2. Differences and similarities between Indo-European and Uralic definiteness markers

The definite articles of Indo-European languages such as German, English, and French cover a wide range of referential use. They indicate semantic definiteness, i.e. the inherent uniqueness of the referent of the nouns they occur with: *the sun, the first man on the moon*. They also indicate pragmatic definiteness, i.e. uniqueness that comes from the context, not from the semantics of the referent of the definiteness marked noun*: the man I met yesterday, I saw a dog […] the dog was really big* (cf. Löbner 2011 for semantic and pragmatic uniqueness). The former uses can be regarded as reflections of the high grammaticalization status of the definite article, its use is obligatory even though it is redundant. The application of the definite article started with pragmatically unique nouns in deictic and anaphoric uses and spread from there to semantically unique nouns via analogy (cf. Demske 2001 for a case study on German; Ortmann 2014).

The possessive suffixes of the Uralic languages do not differ from Indo-European definite articles in their range of use but in their obligatoriness. The analysis of different synchronic corpora shows that their application as definite article seems not to be obligatory, neither with semantic nor with pragmatically unique referents (cf. also Fraurud 2001, Nikolaeva 2003). Thus their status of grammaticalization is controversial in the literature, the non-obligatoriness speaks against a fully grammaticalized status (Lehmann 1995, Fraurud 2001) on the one hand; their occurrence with pragmatic and semantically unique referents on the other hand favours the assumption of full grammaticalization. Moreover, the Uralic possessive suffixes are still applied for indicating possession, unlike Indo-European definite articles, which differ in form and function from their original demonstrative source. However, the co-occurrence of two functions and the non-obligatoriness of a marker do not necessarily speak against a grammaticalized element. Bisang (2004) gives examples for grammaticalization without co-evolution of form and meaning and without obligatory use of the respective element. Thus it is feasible to assume that the possessive suffixes have a grammaticalized definiteness marking function as they cover all typical uses of definite articles.

Their evolution pathway might be comparable to that of definite articles in Indo-European languages if we assume

1 NOS: Data of the Project "Typology of Negation in Ob-Ugric and Samoyedic languages", University of Vienna.

general grammaticalization processes (as formulated e.g. by Hopper & Traugott 1993) without a co-evolution of form and meaning. The first step would then be the generalization and extension of the function of the element. Both demonstrative and the possessor agreement marker are anaphoric but in different ways, the former indicates the anaphoric resumption of the marked noun, the latter indicates the anaphoric resumption of the argument of the marked noun. Hence, the starting point of the grammaticalization of possessive suffixes is not "plain" anaphora as for demonstratives but associative anaphora (Fraurud 2001). From there the use might be extended and the original function might be bleached out in different ways, respectively. Data from Finnish dialects suggest that first the number specification of the possessor suffix was lost und later the person specification (see below). In a second step the source function of the element is bleached out. Demonstratives lose their primary deictic function as they became definite articles (Himmelmann 2001), possessive suffixes in definiteness marking lose their primary possessor agreement function. However, for both elements the original function is still available; most Indo-European languages allow definite articles in demonstrative function, the co-occurrence of both functions in Uralic is described above.

3. What licenses 3rd person possessor suffixes as definite articles?

With demonstratives it is mostly the distal form that is the source of definite articles (Himmelmann 1997). The application of the 3rd person possessor suffixes as definiteness marker is comparable since this form can also be conceived of as the most distal among the singular person markers (cf. the person scales proposed e.g. by Comrie 1981); the plural markers are ineligible because of their non-unique reference. However, the two main reasons why the 3rd person possessor suffix is qualified for definiteness marking are the following: (i) As a possessive pronoun the suffix originally refers to an already established and unique entity, it functions as anaphor and indicates both possession and definiteness (like associative anaphor does: My car is old. Its engine is broken.). Marked with this suffix the whole NP is definite, too. Therefore the marked head noun is interpreted as unique. In this sense the suffix marks uniquely referring expression like definite articles in other languages do. (ii) The original and still remaining function of the suffix is to indicate a possessor argument. This does not apply in cases where no relation of possession is available; with uniquely referring expressions the function of indicating a possessor is lost completely. This way, the use of the suffix is extended to contexts without a possessor, and what applies is the common denominator of indicating (either semantic or pragmatic) uniqueness.

The use of 3rd person possessor suffixes in some dialects of Finnish and Estonian can be considered as reflection of the intermediate steps of the grammaticalization pathway. In these Uralic languages the suffix is not used as a definite article but as a kind of default possessor marker (Toivonen 1998), irrespectively of the person of the possessor, as is illustrated in (4).

(4) South-West Finnish (Toivonen 1998:44)

No	täälläkö	sinä	vielä	asut	emäntine-nsä?
well	here.Q	you.SG	still	live	wife-3[SG]

'So, do you still live here with your wife?'

The person specification is already bleached out but the indication of an argument is still present. Note, that according to Toivonen (1998) the number specification is completely lost in South-Western Finnish, thus the suffix can also be used with plural possessors. This kind of application might display how the use of the possessive suffixes was extended.

In languages where the possessive suffixes are used both as possessor agreement marker and as definite article, the core function of the suffix seems to be to link two entities. In a possessive construction the suffix indicates the possessor and the link between possessor and possessum. In a non-possessive construction the indication of any possessor is not relevant. What remains is the function of establishing a relation, either to the discourse situation (with pragmatically unique referents) or to cultural knowledge (with semantically unique referents). This way the definite articles with possessive sources function in the same fashion as definite articles with demonstratives sources do.

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EMERGENCE OF QUANTIFIERS – COMPUTATIONAL AND ROBOTIC MODELLING OF GRAMMATICALIZATION

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The semantics of gradable quantifiers (such as “many” and “few”) depends on a number of factors ranging from size and density to expected norms. Importantly, gradable quantifiers play an important role in alleviating effects of *perceptual deviation* (Spranger & Pauw 2012) typically occurring in grounded language use scenarios such as interactions about the real world. Interlocutors in such interactions often have different perspectives on the scene and therefore divergently perceive and estimate the objects and their properties in the world. In such cases, a graded notion of quantifiers that allows for lenient interpretation, i.e. margins of deviation, becomes an important communicative tool.

In the first part of the talk, we will present a computational investigation that argues how to model the semantics of quantifiers using a novel vagueness algorithm. The computational model is compared to traditional type-theory based models. We show that our notion of vagueness performs better with respect to success in communication then traditional approaches (Pauw & Spranger 2012). The main argument from this line of research is that given the right notion of vagueness, quantifiers can be cognitively efficient and successful communication tools (Pauw & Hilfery 2012).

Starting from the modelling of the semantics of quantifiers, we then go on to explore the emergence and grammaticalisation of graded quantifiers. The first line of experiments builds directly on the result of the semantic modelling and shows that the efficiency of graded quantifiers can be a driving force for their emergence (Pauw & Hilfery 2012). A second line of experiments goes on to trace the dual nature of graded quantifiers. Quantifiers such as “few” and “many” can be used both as adjectives and quantifiers. Historically speaking they started out as adjectives and later took on additional functions (Solt 2009). We explore the idea that the *cognitive overlap* (Durgin 1995) of “few” and “many” with the adjectives “big” and “small” can account for their adjectival use and how *cognitive effort* and the interaction with existing quantifiers can give rise to historically attested grammaticalisation trajectories (Pauw 2013).

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CHANGING OR REARRANGING? CONSTRUCTIONAL CHANGES IN PERFECT CONSTRUCTIONS

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One of the diachronic syntactic phenomena that has been most widely studied is the emergence of the so called *perfect tense* in modern Romance and Germanic languages. While they differ on essential points such as the gradualness or the abruptness of the change, proponents of the traditional grammaticalization or reanalysis approaches assume that at some point what was a lexical verb with a possessive meaning equivalent to contemporary English HAVE in (1a) was transformed into a fundamentally different type of expression, the functional category known as perfect tense auxiliary HAVE. Implicitly or explicitly most authors also consider that there was also a change in the category of the participle which went from being an adjective to becoming a verbal participle. Thus the construction illustrated in (1b), often referred to as a *resultative* and sometimes also as a *stative* construction, forms a minimal pair with the the *perfect construction* in (1c) and they are assumed to illustrate the grammatical reanalysis that gave rise to the modern perfect construction.

(1) a. I have a nice home

b. Ic hæfde hine gebundenne
I had him tied (from Denison 1993)

c. I have tied him

In this talk I will discuss diachronic data from Latin and medieval Romance languages such as Old Catalan or Old Spanish together with theoretical constructs from contemporary work on lexical semantics to argue that in fact there has been no such emergence and that the way in which modern Romance languages Germanic languages express the perfect tense does not radically differ from the way in which Latin and probably also the precursors of medieval Germanic languages expressed this same tense.

The main goal of the presentation will be to show that the diachronic data involving constructions with HAVE or BE and a participle strongly support the view of syntactic/semantic change defended in Traugott and Trousdale (2010) in conjunction with a constructional view of syntax such as the one proposed by Goldberg (2006). On the basis of a discussion of data such as (2)-(3), I will argue that rather than the emergence of a new periphrastic perfect tense these changes are better analyzed as a rearrangement of different components of already existing periphrastic perfect constructions which can be considered cases of constructional change and constructionalization (Traugott and Trousdale 2013). Crucially, though, these processes do not involve any significant change in the grammatical category of the different components of the constructions.

(2) a. Quae si quis evasit, multo tamen patentiorem fistulam habiturus est rupta cervice, quam habuisset incisa. (De medicina. Aulus Cornelius Celsus (ca 25 BC—ca 50)

b. Epulatus ipse es impia natos dape
(Seneca. Thyestes. Act V. 1034)

(3) a. hon foren molts cavallers morts e nafrats
(Tirant lo blanch)
(where were many knights dead-Msc-Pl and wounded-Msc-Pl)

b. Quant lo pastor víu que·l lop havia mortes les ovelles (Llibre de Sancta Maria)

(4) a. de commo el Rey don alfonso querjendo partir parel jnperio ouo cartas escriptas en araujgo
(Crónica de Alfonso X)

b. Y se echaua myo çid despues que fue çenado (Poema Mio Cid)

A discussion of the contexts in which examples like those in (2) appear will show that already in classical Latin the verb HAVE did not have a purely possessive meaning and participated together with BE in the creation of two basic types of construction that were used to express tense/aspect values identical to those expressed with the so-called HAVE perfect. The examples in (3) and (4) from Old Catalan and Old Spanish illustrate the use of other auxiliary-like verbs (TENER (“have”) and ESTAR (“be”) in contexts where they can be shown to convey the same type of semantic interpretations as constructions involving HAVE and BE. Crucially, these interpretations are not possible with constructions involving these verbs in modern Catalan and Spanish.

After examining the qualitative data I will present the results of a quantitative study conducted in Sánchez-Marco (2012).

As the discussion of data such as that displayed in Figure 1 below will show, after a period in which the different constructions involving participles and the verbs HAVER/HABER, SER, ESTAR and TENIR/TENER (see examples in 4 below) competed for some of the same interpretations they gradually became specialized to convey the meanings they have today. As is well known, SER appears in the so-called passive constructions as well as the copula in predicative constructions involving adjectives (participles as well as non-deverbal adjectives); ESTAR is also found in predicative constructions argued to have the interpretation of stage level predicates and TENER is found in constructions that given their interpretation should be considered resultative or stative constructions as the one in (1a). I will use basic standard linguistic argumentation to refute current standard analyses of some of these constructions and show that there is no reason why we should not conclude that all of them, including the so-called passive constructions, are also perfect tense constructions. In essence I will argue that, when they are studied carefully, what the patterns of evolution of these constructions suggest is not a radical reanalysis of HAVE and BE as most authors have suggested until now but rather a case of related constructional changes, crucially not involving any change in the grammatical categories of the constructions involved. I will discuss the data from some Spanish dialects and French as well as some Germanic languages where HAVE + participle constructions have come to convey the perfective aspect to determine whether in these cases we could talk about cases of constructionalization where some type of reanalysis of the grammatical categories has taken place.

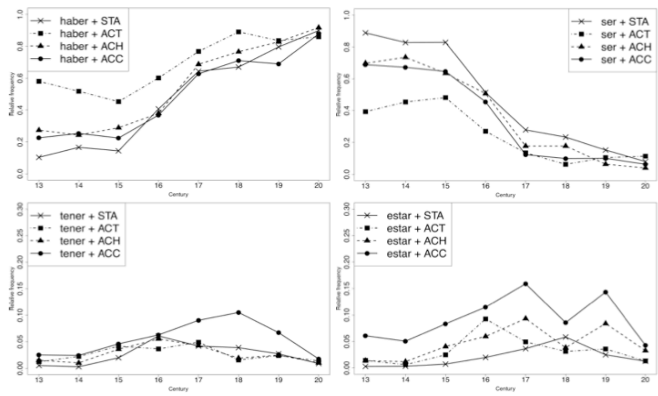

Figure 5.1: Frequency of ***haber*** (top left), ***ser*** (top right), ***tener*** (bottom left) and ***estar*** (bottom right) plus aspectual classes of predicates from the 13th to the 20th century. In the legends 'STA' stands for IL-states, 'ACT' for activities, 'ACC' for accomplishments and 'ACH' for achievements.

Figure 1. From Sánchez-Marco (2012)

(5) a. Martín *fue* condecorado
Martin was condecorated

b. La Marta *és* educada
The Martha is educated

c. La Marta *està* cansada
The Martha is tired.

d. *Tengo* el brazo roto
I-have the arm broken

e. En Pere *ha* arribat
The Peter has arrived

The rest of the talk will be devoted to provide the missing pieces to this account:

a) Show that there has been no reanalysis in the grammatical category of the participles: i.e. if one adheres to current categorical views of lexical categories or parts of speech, it can be shown that all participles are and they have always been deverbal adjectives. That is, there is no distinction between adjectival participles and verbal participles. There is only one class of words that are syntactically and semantically adjectives created out of verbal roots via derivational morphology.

b) Show that all BE + participle constructions in Latin as well as in the modern Romance and Germanic languages are instances of copular BE constructions involving adjectives derived from verbal roots. This includes the BE passive constructions as well as the BE perfect constructions.

c) Show that the eventive interpretations associated with both BE and HAVE perfect and with BE "passives" are consistent with an analysis of the participles as adjectives when we take into account the lexical semantics of the verbal roots, the interaction of the tense/aspect morphology in BE and HAVE with the lexical semantics of those verbal roots, the modification of the constructions by different types of adverbials and the two possible interpretations of some of the participles as *resultant states* and *target states* Kratzer (2000). In essence, what I will try to demonstrate is that even adhering to the most strict formal linguistics approaches, a constructional analysis that allows for all of the semantic interpretations traditionally associated with what were assumed to be different constructions is not only possible but more accurate and desirable. Finally, I will show that this analysis:

a) helps to explain the gradience phenomena displayed by auxiliary selection in the different Romance and Germanic languages.

b) makes it possible to relate mechanisms of syntactic change to the better studied mechanisms of sound change. Given the view of syntactic change as constructional change that will be defended in this talk, it becomes easier to explain why both sound changes and syntactic changes typically display the well-known S-shaped curve that is displayed by many changes related to social phenomena that don't have anything to do with language. Adopting an agent based perspective on the study of language we can study the competition between different constructions to convey the same interpretations in a similar way we study other social phenomena involving competition between different alternatives. Network theory can thus provide useful models that can help us understand how linguistic changes spread through time and space. While these two perspectives are not frequently found in combination, I will make extensive use of constructs and argumentation from formal linguists to lend additional support for a constructional, gradient and agent based view of syntactic/semantic change and of language in general.

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DEVELOPMENT OF NEW GRAMMATICAL CATEGORIES: ARTICLES AND AUXILIARIES IN ROMANCE

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According to Meillet (1912), who distinguishes two major mechanisms for the constitution of grammatical forms, viz. analogy and grammaticalization, only the latter can create new grammatical categories. The hypothesis we want to argue for in this paper is that analogy plays a major role in the development of new grammatical categories. Evidence will be provided by a diachronic and comparative analysis of two newly created grammatical paradigms in Romance which were inexistent in Latin, articles and auxiliaries.

1. Grammaticalization and analogy: two distinct mechanisms

In his pioneering 1912 paper, Antoine Meillet makes the following crucial distinction between analogy and grammaticalization:

> Tandis que l'analogie peut renouveler le détail des formes, mais laisse le plus souvent intact le plan d'ensemble du système existant, la 'grammaticalisation' de certains mots crée des formes neuves, introduit des catégories qui n'avaient pas d'expression linguistique, transforme l'ensemble du système. (Meillet 1958 [1912]: 133)

Analogy and grammaticalization are thus considered to be two essentially distinct processes, since only grammaticalization can create new grammatical categories, i.e. categories previously unexpressed in the language. In recent work, although the role of analogy in grammaticalization has been widely acknowledged (Fisher 2012), some researchers (e.g. Lehmann 2004) still distinguish between 'pure grammaticalization without analogy' and grammaticalization steered by analogy. Examples of the former include the grammaticalization of the numeral 'one' into an indefinite article and that of the demonstrative into a definite article.

Latin did have neither articles nor auxiliaries. All Romance languages however develop, at a different rate (Lamiroy & De Mulder 2012) and to a different extent, both grammatical categories. These two grammatical categories have a functional similarity: the main function of articles within the NP is to ensure the anchorage of the referent in the situational or textual context; similarly, the *raison d'être* of auxiliaries within the VP, is to anchor the verbal situation in the situational or textual context by specifying its tense, aspect and modality Zooming in on the emergence and historical development of these two categories will allow us to take a stand in the ongoing debate on the role of analogy in grammaticalization. Three Romance languages will be considered here: Italian, French and Spanish.

Romance languages offer a privileged area of investigation for diachronic and comparative linguistics and hence, for general linguistics. On the one hand, linguists have at their disposal a nearly uninterrupted documentation of two millennia, which is extensively accessible by means of electronic corpora. This allows us, on the one hand, to set up a fine-grained analysis of all or most of the different steps of linguistic change and on the other hand, to compare languages belonging to the same genealogical family but with contrasting typological tendencies. For these two reasons, Romance languages are an ideal testing ground for verifying general hypotheses about language and language change.

2. Analogy: a driving force for grammaticalization

Fisher (2007) has made a major contribution to highlighting the role of analogy in linguistic change. She argues that analogy acts both on the syntagmatic and the paradigmatic axis and affects the linguistic sign in its double-edged nature of form and function.

We argue here that nominal and verbal phrases evolve towards a similar abstract pattern on the syntagmatic axis: anchorage in the textual or situational context is increasingly expressed by grammatical elements at the left of the nominal and verbal head, by articles and auxiliaries respectively. On the paradigmatic axis, there is for both categories a tightening of the paradigm, i.e. reduction of number of members of the class, restructuring of the paradigm in terms of a limited number of binary features, adjustment of semantic features in order to fit in the paradigm.

In our view this striking parallelism is due to the pervasive action of analogy. We thus show that analogy is as powerful as to create new grammatical categories, challenging Meillet's fundamental distinction between grammaticalization and analogy.

3. Asymmetry between NP and VP

Despite the action of analogy in both cases, NP and VP did not evolve in a strictly parallel way, i.e. the evolution occurs earlier and is more radical in the case of the NP than in the VP. For instance in French, zero marking disappeared completely and marking of the N by a formal determiner became obligatory. For the VP on the contrary, a mixed system survives in all Romance languages: TAM marking is partially expressed by suffixes on the verb and in part by free morphemes preceding the verb.

4. Different rates in genetically related languages

The correlation between the development of the articles and the auxiliaries is all the more salient when we compare different Romance languages. Grammaticalization of articles is in a more advanced stage in French than in Italian, which in turn is in a further stage than Spanish; a similar scale is observed for the auxiliaries (Lamiroy & De Mulder 2012).

4.1 Articles

French, Spanish and Italian develop a definite article from the distal Latin demonstrative *ille* and an indefinite article derived from the unity numeral *unus*, which is also attested in its plural form (Carlier & De Mulder 2011, Carlier 2013). In French, a third article is created, combining the spatial preposition *de* 'from' and the definite article, which entails the elimination of the plural form (Carlier 2007). As to Spanish, exploratory occurrences of the partitive are attested in the medieval language, totally in parallel with those that emerged in Old French. However, the partitive did not grammaticalize into a full-fledged article, while the plural form of the article derived from the unity numeral is conserved. As to Italian, the partitive did develop into an article, but it remains optional in Modern Italian and is perceived as a regional feature of the North (Carlier & Lamiroy 2014). Interestingly, the pattern with the determiner in initial position of the NP extends to demonstratives and possessives. The evolution with respect to the possessives is completed in French, but not in Italian and Spanish, where there is still a double system of prenominal possessive determiners and post-nominal possessive adjectives (Van Peteghem 2012).

4.2 Auxiliaries

All three languages developed temporal, aspectual and modal auxiliaries by grammaticalization out of Latin full lexical verbs (Heine 1993, Lamiroy 1999), e.g. Fr. *aller* and Sp. *ir,* which both function as an auxiliary of future tense, originated in the Lat. motion verbs *ambulare* 'to walk around' and *ire* 'to go' respectively. In Italian, *andare* whose etymology presumably also goes back to (a suppletive form of) the motion verb *vadere* 'to go, to proceed', viz. *ambitare,* is mainly a modal auxiliary with deontic value. However, of all three languages, French has the most grammaticalized auxiliary system, which is reflected on the syntagmatic axis by a reduction of the diversity of syntactic patterns and on the paradigmatic axis by a tightening of the paradigm, *i.e.* a reduction of the number of verbs which belong to the class (*paradigmatization* in Lehmann's (1982) terms, compared to a larger class in Italian and an even larger one in Spanish, a restructuring of the paradigm in terms of binary parameters, and an adjustment of the semantic features of these verbs in order to fit in the paradigm.

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ANALOGY EXPANDS AND GENERALIZES CASE FRAMES

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Empirical observations across the world's languages have shattered the decade-long assumption that grammatical case should be explained in terms of innate knowledge (Croft 1991; Dryer 1997; Haspelmath 2007), whether this knowledge takes the form of abstract categories, thematic hierarchies or a shared conceptual space. It is therefore crucial to understand the processes that may give rise to new case systems if we want to find solid explanations for them.

This presentation focuses on the role of *analogy* in the emergence of a case system. Analogy is widely accepted among historical linguists as an important mechanism in language change, but so far it has typically been conceived as a trigger for small, local changes that leave the overall grammatical system intact (see e.g. Meillet 1921). Through multi-agent experiments, I will demonstrate that analogy may fundamentally restructure the grammar of a language.

More specifically, I will present experiments in which autonomous artificial agents engage with each other in language games about real-world events (Steels 2004; van Trijp 2010, 2012). In these experiments, agents are provided with an associative lexicon (but no grammar) for describing events to each other. In order to avoid cognitive effort in semantic interpretation, the agents can invent new case markers for indicating a particular participant role (e.g. the "pusher" of a "push"-event), or they can recruit existing markers through analogical reasoning on event structures, grounded in the agents' sensorimotor experience.

The results show that a case strategy based on analogy has a distinct selective advantage for communication over event-specific marking: general case frames require a smaller inventory size, they propagate more easily in the population because their larger distribution comes with increased frequency, they facilitate the interpretation of novel forms, and so on. More importantly, as a side-effect of exploiting analogy in locally situated interactions, coherent case systems emerge on the population level that look from the outside as if they are manifestations of a universal semantic map. Instead of resorting to innate knowledge, similarities across languages can therefore be explained in terms of convergent evolution.

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SEMANTIC COMPETITION AND (INTER)SUBJECTIFICATION IN THE SYSTEM OF THE DUTCH MODALS

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1. Topic

This paper presents the results of an investigation into the diachronic semantic evolution of the Dutch modal auxiliaries *kunnen* 'can', *mogen* 'may' and *moeten* 'must', focusing on the interaction in them between processes of (inter)subjectification (in the sense of Traugott 1989, 1995, 2010, Traugott & Dasher 2002) on the one hand, and a process of competition for semantic ground on the other hand. (See also Nuyts & Byloo, submitted.)

2. Data

The semantic evolution in the three modals is investigated by comparing their semantic profile in 4 stages in the language's history, viz. Old Dutch (OD, before 1200), Early Middle Dutch (EMD, 1250-1300), Early New Dutch (END, 1550-1650), and Present Day Dutch (PDD, after 1950). The analysis is based on 200 instances per modal per period (but for OD the samples include all instances found in the few remaining texts, which never amounts to 200). But for PDD two separate sets of 200 instances are used: one, like for the earlier periods, exclusively written (henceforth PDDW), and one exclusively spoken (PDDS). Given the quite different nature of spoken and written language, these two sets are kept separated in the analyses. The samples are selected randomly from the full range of digitally available text sources for each of the periods, yet is subject to a balanced concern for representativity and reasonable spreading for each period, geographically and in terms of text types and authors, and for comparability between the periods (with PDDS) as an exception of course).

3. Findings

The data are summarized in Tables 1-3. The meaning categories are ordered from top to bottom in terms of increasing (inter)subjectification (in the interpretation of it discussed in Nuyts 2012, Nuyts & Byloo submitted). (All interpretations below are supported by statistical testing, by means of Fisher Exact and the Spearman Rank Coefficient of Correlation.)

Table 1. Meaning development of *kunnen*.

	OD		EMD		END		PDDW		PDDS	
	n	%	n	%	n	%	n	%	n	%
'know'	2	12	7	4	1	1				
dynamic-inherent	9	53	120	60	87	44	55	28	33	17
dynamic-imposed	6	35	70	35	85	43	71	36	104	52
dynamic-situational			3	2	22	11	33	17	25	13
deontic					4	2	24	12	21	11
epistemic					1	1	10	5	4	2
directive							7	4	13	7
total	**17**		**200**		**200**		**200**		**200**	

Table 2. Meaning development of *mogen*.

	OD		EMD		END		PDDW		PDDS	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
dynamic-inherent	9	16	6	3	8	4				
dynamic-imposed	27	47	45	23	72	36	19	10	23	12
dynamic-situational	12	21	59	30	43	22	11	6	2	1
deontic			3	2	5	3	27	14	26	13
epistemic			4	2	5	3				
volitional	2	4	10	5	22	11	10	5	9	5
directive	6	11	64	32	39	20	115	58	132	64
concessive			2	1	4	2	9	5	1	1
conditional	1	2	7	4	1	1	9	5	3	2
other					1	1			4	2
total	**57**		**200**		**200**		**200**		**200**	

Table 3. Meaning development of *moeten*.

	OD		EMD		END		PDDW		PDDS	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
dynamic-inherent			2	1			1	1	3	2
dynamic-imposed	3	60	17	9	66	33	47	24	79	40
dynamic-situational			29	15	35	18	39	20	9	5
deontic			5	3	25	13	38	19	27	14
evidential					5	3	7	4	7	4
volitional			44	22	15	8	5	3	7	4
intentional			1	1	1	1	12	6	4	2
directive	2	40	100	50	52	26	45	23	58	29
conditional			2	1			2	1	2	1
other					1	1	4	2	4	2
total	**5**		**200**		**200**		**200**		**200**	

It turns out that, in their development from Old Dutch onwards, *mogen* and *kunnen* do, but *moeten* does not, show a clear pattern of evolution in terms of (inter)subjectification. (Detailed discussion and interpretation will be offered in the talk.) But the developments in the former two modals also show clear signs of an effect of the fact that historically they largely share the same set of meanings: both *kunnen* and *mogen* are 'weak' modals, but *moeten* is a 'strong' modal. This appears to trigger some kind of competition, whereby *kunnen* gradually acquires these meanings and *mogen* gradually loses them through time – cf. Table 4 ('m%' = share in each meaning of *mogen*, 'k%' = share in each meaning of *kunnen*).

Table 4: Evolution in share of *mogen* vs. *kunnen* per meaning category

	OD			EMD			END			PDDW			PDDS		
	m%	k%	n	m%	k%	n	m%	k%	n	m%	k%	n	m%	k%	n
dyn-inh	23	77	**18**	5	95	**126**	8	92	**95**	0	100	**55**	0	100	**33**
dyn-imp	57	43	**33**	39	61	**115**	46	54	**157**	21	79	**90**	18	82	**127**
dyn-sit	100	0	**12**	95	5	**62**	66	34	**65**	25	75	**44**	7	93	**27**
deo	--	--	**0**	100	0	**3**	56	44	**9**	53	47	**51**	55	45	**47**
epi	--	--	**0**	100	0	**4**	83	17	**6**	0	100	**10**	0	100	**4**
dir	100	0	**6**	100	0	**64**	100	0	**39**	94	6	**122**	91	9	**145**

There is no comparable competition for semantic ground in *moeten*.

4. Discussion

These observations strongly suggest an interaction between the element of semantic competition – which may be considered an effect of the principle of isomorphism/'no synonymy' – and the process of (inter)subjectification, whereby the former may actually be the trigger of the latter. In other words: although the (inter)subjectification hypothesis explains quite well the semantic developments in the modals when they occur (viz. in *kunnen* and *mogen*, but not in *moeten*), these processes are most probably sensitive to other diachronic forces, quite notably forces pertaining to the mutual effects of forms in a linguistic system, including, e.g., analogy (see Nuyts 2013 on the role of analogy in (de-)grammaticalization processes in the system of the Dutch modals), or, in the present case, the principle of isomorphism/'no synonymy'. Even if we have no indications that these forces affect the actual course of the (inter)subjectification process, they quite likely do affect whether it happens or not.

Maybe the specific interaction of forces observed in the present case study should not come as a surprise, at least not if one adopts a functionalist perspective on language: the principle of isomorphism is very directly related to basic elements of communicative efficiency (avoid semantic unclarity), but (inter)subjectification is much less so, hence it would only seem 'functionally logical' if the former is more 'agentive' than the latter in shaping the linguistic system. This line of thought will be explored further in the actual presentation.

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ENGLISH *WH-RELATIVES*: TOWARDS AN AETIOLOGY OF A GRADUAL SYNTACTIC CHANGE

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We discuss a series of changes in the English relative clause system over c.1000–1500AD, and the prospects for modelling those changes. We show that subtle differences in the linguistic analysis can substantially affect the approach to modelling, and argue for a new understanding of these changes.

1. Wh-relatives and Indo-European

Headed *wh*-relatives, like (1), have a phrasal filler which reflects properties of the gap site. In contrast, fillers like *that* in (2) are monomorphemic and indeclinable. These contrasts motivate an analysis where *whose brother* in (1) moves from the gap site to [Spec,CP], while *that* in (2) is base-generated in C^0.

(1) $[_{NP}$ The guy $[_{CP}$ **whose brother** $[_{IP}$ **I met** _]]] was charming.

(2) $[_{NP}$ The guy $[_{CP}$ **that** $[_{IP}$ **I met** _]]] was charming.

We call elements like *whose brother* relative specifiers. These are a largely Indo-European phenonenon: De Vries (2002) shows that 67.5% of IE languages have relative specifiers, but only 5.3% of non-IE languages. Although his sample omits several well-known cases of relative specifiers, for example in Finno-Ugric languages, they are still clearly concentrated in IE languages.

However, IE languages did not inherit their relative specifiers from Proto-Indo-European. Rather, the analogues of today's headed relatives are adjoined relatives, either clause-initial and marked with *$*k^wo$-/k^wi-* or clause-final and marked with **yo-* (Clackson 2007). Neither type is embedded within NP, unlike (1)–(2).

In sum, relative specifiers are largely confined to IE, but not because of direct inheritance from PIE. Rather, other properties of IE languages make it particularly likely for learners of IE languages to introduce this construction, leading to parallel evolution of similar systems in several IE languages. By exploring this phenomenon, we hope to learn about the biases which predispose learners to introduce this construction into certain grammars, but not others.[1]

1 Comrie (1998) claims that relative specifiers are a European, rather than IE, phenomenon: they occur in Finno-Ugric but are rare in Indo-Aryan. This implicates constructional borrowing in their distribution. However, there are clear indications that relative specifiers have repeatedly evolved in parallel among genetically related languages. For example, English and French developed relative specifiers at roughly the same time, but neither borrowed the construction from the other.

2. English *wh-relatives*

English has had two sets of relative specifiers in its history. Until c.1200AD, English could form headed relatives using inflected demonstrative phrases (3); while the modern headed *wh*-relative system emerged slowly over c.1150–1500AD.

(3) Her feng to Dearne rice Osric
Here succeeded to Deira kingdom Osric
[**þone** Paulinus ær gefullode]
[that.ACC Paulinus earlier baptized
"In this year Osric, whom Paulinus had earlier baptized, succeeded to the kingdom of Deira"
(Peterborough Chronicle, 12th century, Allen 1977)

Several differences exist between headed relatives with filled specifiers and without. Most importantly for us, relatives without filled specifiers contain only NP gaps, while relative specifiers can correspond to gaps of a range of categories (Allen 1977).

2.1 The genesis of headed *wh*-relatives

Old English (OE) used *wh*-phrases as indefinites, and in questions and generalizing free relatives, inheriting all three functions from PIE *$*k^wo$-/k^wi-*. English headed *wh*-relatives most likely developed out of postposed free relatives: there are several examples which are both syntactically and semantically indeterminate between analysis as appositive generalizing free relatives and extraposed definite headed relatives.

(4) and eow **ealle þing** geswutelað,
and you all thing show
[swa hwæt swa ic eow secge]
so what so I you say
"and [he] explains everything to you that I tell you", or
"and [he] explains everything to you, whatever I tell you" (Ælfric Homilies, late 10th century)

Semantically, this is a case of **quantificational variability** (Caponigro 2003): it makes no difference to the interpretation of (4) whether *hwæt* is definite or universal. Syntactically, the ambiguity reflects a competition between two analyses: either the final relative in (4) is a (nominal) free relative in apposition to *ealle þing*, or it is an extraposed headed relative modifying *ealle þing*. The frequency of clause-final *wh*-relatives with nonadjacent antecedents (c.14% of *wh*-relatives) is intermediate between extraposed CPs (c.30% of adnominal CPs) and NPs in apposition (c.6% of adnominal NPs). This could suggest to a learner that not all *wh*-relatives are nominal; that some are headed relatives. This provides a plausible basis for the genesis of headed *wh*-relatives.

2.2 The spread of headed *wh*-relatives

Headed *wh*-relatives initially had only oblique or adverbial gaps, complementing *that*-relatives with argumental NP gaps. Headed *wh*-relatives with argumental NP gaps initially occur in the 14th century, c.200 years after the first oblique headed wh-relatives (Figure 1).

Figure 1. Frequency of *wh-relatives* by grammatical function in Middle English

3. *Wh*-relatives and Indo-European

The above description differs from the received wisdom in two ways. First, it downplays the similarity between different types of headed relatives: rather than asking "What can English speakers use to form headed relatives", we ask "What do English speakers do with *wh*-phrases". Second, we interpret Figure 1 as showing two discrete changes, while previous accounts (Romaine 1982) have construed this as a single, gradual progression of a *wh*-relative construction up Keenan and Comrie's (1977) Accessibility Hierarchy. As the Accessibility Hierarchy is related to processing ease (Hawkins 2004), the received wisdom therefore suggests a functionalist account, perhaps focusing on communicative need and processing ease.

However, functionalist accounts run into the problem that most of the world's languages do not have relative specifiers, and do not need them. Any functionally motivated bias in favour of this construction must therefore be very weak, or headed relatives with filled specifiers would be typologically more common. It is also unclear why specifically *wh*-phrases were co-opted for this purpose, and so often in IE. The present approach removes these obstacles, by demonstrating clear links with PIE *k^wo-/k^wi*-forms and OE *hw*-forms.

Subtle refinements of the empirical picture therefore significantly affect our analytical and modelling options. On our account, the genesis of *wh-relatives* reduces to an instance of choosing between two competing structural analyses of a surface phenomenon, a classic application of Bayesian reasoning. Meanwhile, the spread of *wh*-relatives plausibly reflects the tension between various learning biases. For example, learners are biased towards associating a single form with a single function (**mutual exclusivity**, Markman & Wachtel 1988). This predicts that learners are biased against extending *wh*-relatives to functions clearly associated with *that*-relatives. The subsequent, possibly analogical, spread from oblique to argumental *wh*-relatives exemplifies the general problem of how tightly a learner's grammar should fit the input. Again, this is a classic Bayesian problem. An improved empirical description therefore leads to a more tractable modelling challenge.

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WORD ORDER CHANGES AND GRAMMATICALIZATION IN VERBAL CLUSTERS

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1. Introduction

In this work, we model the historical development of verbal cluster order in Germanic languages. While there is an ongoing debate on the syntactic structure of these clusters, we created a simple model of surface patterns in which we view each order as a separate outcome, with a probability distribution over the outcomes. Using this model, we show that the current order in German and Frisian verbal clusters may have developed partly due to increased grammaticalization of embedding over time, and increased grammaticalization of tense and aspect. Subordinate clauses (to express embedding) and verbal clusters with 'have' (to express tense and aspect) became more frequent, leading to changes in verbal cluster word order.

2. Verbal clusters

The basic word order of the Proto-Germanic language is generally assumed to be Object-Verb (OV), though both OV and VO orders were probably possible. Modern Germanic languages adopted one variant without much variation — OV in the case of German, Dutch and Frisian, or VO for English and the Scandinavian languages. While all of these languages have verbal groups, in the OV languages they take the form of impenetrable verbal clusters at the end of clauses. For these clusters, different word orders are attested (Wurmbrand 2006). We will limit our discussion to two-verb clusters, in which the finite verb can be positioned before or after the infinite:

(1) Ik denk dat ik het **heb begrepen**.
I think that I it have understood
'I think that I have understood it'

(2) Ich denke, dass ich es **verstanden habe**.
I think that I it understood have
'I think that I have understood it'

In the literature, construction 1 is called the ascending order (1-2 order or green order), and construction 2 is called the descending order (2-1 order or red order). In English, the Scandinavian languages, and sometimes in Dutch (as in 2), the ascending order is used (I *have understood*), while the default form of Frisian and German is the descending order as in 1. We limit our analysis to the OV languages, because the verbal groups in the VO languages are technically not clusters, and the descending order hasn't been attested in any VO language.

In this work, we will model the diverging development of verbal clusters in these languages using an agent-based model, taking a reconstruction of the state of verbal clusters in Proto-Germanic as a starting point.

3. Model structure

We define a basic model of verbal clusters in terms of realizations with production probabilities. The model structure is based on the bidirectional model in Versloot (2008), though our models learn by interacting rather than iterating. Several instances of the model (agents) exchange verbal cluster realizations with each other, changing the probability distributions. The verbal cluster realizations depend on two features: construction **type** and construction **context**. Our model has three different construction types, reflecting the historical sources of verb clusters:

1. modal + infinitive: the origin of verb clusters in Germanic
2. 'to have' + PP: arose only later in history to extend the possibilities of expressing temporal and aspectual features
3. PP and copula + PP: originally a passive, predicative, construction — not purely verbal, rather adjectival.

As construction contexts, we consider main clauses and subordinate clauses, which differ in their word order in some Germanic languages. Furthermore, two realizations are possible for each of these constructions: the ascending and the descending order. Table 2 shows the structure of this model. The model thus produces exemplars of verbal clusters according to one of the two realizations.

We initialize the model with (relative) frequency figures that we reconstructed for 6th century Germanic, based on a comparison of Old English, Old High German and Old Frisian. Furthermore, Germanic languages have shown an increase over time of the number of subordinate clauses and the number of 'to have' + PP construction types. We simulate this by increasing the totals for these features (proportional over the two realizations). The model is run by having two model instances (A and B) exchange realizations. Model A produces a realization of a construction according to its probability distribution, and subtracts it from its frequency figures (it is given away). Model B then adds to its stored frequencies, and replies with a realization according to its own probability distribution. The models thus develop their probability distributions in the same way. This happens even though the models are only exchanging realizations, no information on the probabilities of individual features encoded in that realization.

The models converge from their predefined, proto-Germanic probability distribution to a state in which probabilities are distributed based on the features of the model. We then compare the resulting model output with actual Germanic language texts to see how well we have modeled the real state of these languages.

4. Realization probabilities

A realization probability is based on the probabilities of its features. An ascending realization may be produced according to the following:

$P(asc|x) = P(asc|x_{mc}) * P(asc|x_{modinf})$

where x is a set of feature values. $P(asc|xmc)$ represents the level of ambiguity of the ascending order as a main clause, $P(asc|x_{modinf})$ for the modal+infinitive construction type. These probabilities are calculated from the stored frequency of the features in ascending context, i.e.

$P(asc|x_{mc}) = F(mc,asc) / F(mc)$

The results from mixed combinations ($P(asc|x_{mc})$ * $P(desc|x_{sub})$), etc. are neglected. The effect is that constructions which are relatively unambiguous because they show a strong form-function correlation, are favoured, others are disfavoured, i.e. the different features that these realizations encode, become well represented in the two forms.

5. Results

Table 1. Descending output probabilities from early-Modern Frisian text c. 1550.

%descending	*Mod+inf*	*Habba+PP*	*Cop+PP*
main	100%	100%	100%
sub	100%	33%	20%

Table 2. Descending output probabilities of model

%descending	*Mod+inf*	*Habba+PP*	*Cop+PP*
main	100%	92%	70%
sub	98%	33%	9%

We compared the model to frequency figures for early-Modern Frisian (ca. 1550) once the proportions *main clause–subordinate clause* and the proportions between the three constructions were comparable to those in our Frisian dataset (table 1 and 2). As such, the results are promising. Tuning of the model – e.g. by a slower or quicker rise of the amount of subordinate clauses – shows that it in the long run it tends to produce 100% ascending or 100% descending realizations for all feature sets. The situation with 100% descending realizations reflects basic word order in German and Frisian, although then V2-movement is needed to get the finite verb in the second position in main clauses. We assume V2 to be a grammaticalised side effect of the asymmetries as reconstructed for Proto-Germanic, where ascending orders were dominant in the combination of modal+inf, which happened to occur more often in what we call main clauses from the modern perspective than in subordinate clauses. The current model is probably too crude to model more complex word orders.

According to our model, different speed of grammaticalization of have+pp and increase of subordinate clauses (both represented by increased frequency) may affect the balance between ascending and descending orders. The descending order is supported by the grammaticalization of embedding. Due to V2 movement in these languages, the finite verb precedes the other verb in main clauses. This ascending order differentiates main clauses from subordinate clauses, motivating the preservation of a descending order in the subordinate clauses. Increased use of subordinate clauses may then have supported the descending order as the base order. However, if have+pp grammaticalizes earlier, the ascending order is supported. Other syntactical or stylistical differences between languages may also explain whether a language moves towards ascending or descending orders.

Our model cannot yet account for the current state of the Dutch language, which first moved towards mainly descending orders like German, and then shifted towards ascending orders again, a change that is still in progress, considering the current state of variation (example 2 and 1) (Coussé 2008). There is evidence that the ascending order has become the default form (Evers 1975), and this second change was likely caused by a factor outside the scope of our model.

Overall, it can be concluded that the interaction of basic probabilistic choices of constructions with shifting input and shifting preference of constructions may be a key to understanding different word orders in the Germanic languages.

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USING MODELS TO RELATE INDIVIDUAL LINGUISTIC BEHAVIOUR TO THE POPULATION DYNAMICS OF LANGUAGE

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Language is a system of behaviour that is shared by members of a speech community. A key question is how the collective dynamics of language (e.g., changes in grammatical structure) are shaped by individuals' cognitive apparatus and interactions between speakers. Can certain linguistic structures and changes be assigned primarily to universal factors, or are culturally-specific factors also at play? I will discuss how mathematical models may be used to help answer such questions. I will focus on the intuition gained from modelling complex systems in the physical sciences in identifying the key drivers of a collective phenomenon, how the resulting models can be related to theories in linguistics, and how to make effective use of the sparse data that is typically available for historical language change processes.

WHEN DO CREOLE LANGUAGES EMERGE?

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In the framework of language games I will investigate the emergence of a new language out of the contact of two preexisting ones. In particular, I will show how a simple variant of the Naming Game, enriched by a suitable contact ecology, can predict in what conditions there is the emergence of creole languages in surprisingly agreement with real data.

TRACING REAL-LIFE AGENTS' INDIVIDUAL PROGRESS IN ONGOING GRAMMATICALIZATION

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We present a longitudinal corpus-based analysis of 15 authors writing in the 17th and 18th century in an ongoing grammaticalization process (c.q. the auxiliarization of *be going to*). Our aim is to arrive at a fine-grained analysis of the micro-changes involved in this kind of language change. In this way, we hope to help bridge the gap between the agent-based modelling and the more traditional grammaticalization studies.

1. Intro: Breaking down the aggregate view on grammaticalization

Investigating individual differences in language behaviour by looking at non-elicited 'naturalistic' data has recently been made easier by the increasing availability of large-scale corpora, especially for English (Barlow 2013). Recently, some interesting diachronic corpus studies in this field have been carried out (Nevalainen et al. 2011; De Smet, ms.), to arrive at the constraints individual variation is subjected to. These studies, however, do not take a longitudinal perspective, in which individuals are followed through time, to see how they shift their behavior, accommodating to or diverging from particular ongoing changes. The few longitudinal studies that we have (Bergs 2005; Raumolin-Brunberg 2009; Hendriks 2013), are typically small-scale. The present study tries to combine the longitudinal approach with large-scale corpus analysis. We present longitudinal individual data on what is perhaps the most iconic of grammaticalization cases: the rise of *be going to* as a marker for future in English. We make use of the large-scale EEBO corpus, to see how individual languages users behaved in the seventeenth and eighteenth centuries, a crucial period in the evolution of *going to*.

Breaking down the aggregate view on the grammaticalization of *be going to* into individual users' behavior may help bridge the gap between 'traditional' diachronic linguistics and agent-based modeling. Agent-based models (Steels 2011) are able to show how emergent properties of language structure arise from well-defined individual interactions (Landsbergen et al. 2010; Beuls & Steels 2013), but are sometimes criticized for the allegedly artificial nature of the communicative setting. On the other hand, traditional corpus-based diachronic linguistics often fail to specify the precise conditions of naturalistic settings between real-life agents partaking in ongoing language changes. At present, it is debated whether adults, adolescents or children are the main instigators of language change. Some scholars argue that language change primarily happens over generations (e.g. Lightfoot 1999), while others argue that it takes place during lifetime (Croft 2000; Bergs 2005).

2. Methodology

2.1 Corpus description and data extraction

In order to examine if micro-steps in the grammaticalization (or grammatical constructionalization Traugott & Trousdale 2013) of *be going to* occur within real-life agents' lifetimes, we selected 15 prolific authors from EEBOCorp 1.0 (Petré 2013), a half billion+ corpus based on the EEBO-database (eebo.chadwyck.com), containing English books printed between 1473-1700. Selection criteria were: (i) Sufficient material is available for the first and second halves of writer's careers; (ii) Constant register over time; (iii) Writers are from roughly the same social status. Posthumously published works in EEBO not included in EEBOCorp 1.0, and translations done by one of the selected authors were also included. The post-1700 output of Burnet, D'Urfey and Dunton was added from the *Eighteenth Century Collections Online* database (ECCO).

The resulting corpus consists of about 31 million words, with individual author word counts ranging between *ca.* 300,000 and 10,000,000 words. All forms of *going* were extracted from this corpus by means of Perl scripts (n = 5821), taking into account variant forms identified in an exhaustive token list. Additional scripts and manual analysis was used to filter out a total of 1591 instances of *be going*.

2.2 Data coding and analysis

We coded the EEBO datapoints for several formal and semantic features that are commonly associated with the grammaticalization of *be going to*, and can serve as diagnostics to assess the level of grammaticalization reached in a particular individuals, which serves as the dependent variable in our inquiry. Each of these features is analyzed with a level of granularity that allows us to pick up small increments in the level of grammaticalization. In the analysis, we both looked at the behaviour of each feature separately, and at their combined value, by computing a summative measure of grammaticalization. For each of the authors, we divided the collected data in half, to arrive at two categories 'earlier work' and 'later work', in order to check whether differences occurred through the years.

3. Findings

The scatterplot in the left panel in Figure 1 brings out the aggregate view on grammaticalization: the score on the Y-axis is a summative measure of how many grammaticalization features a certain datapoint displays. The regression line (lowess) has an s-shaped curve, typical of language change. The rise is significant (Kendall tau = 0.126, $p < 0.0001$ – the relatively weak effect size is not surprising, considering that we only look at a time window of 50 years). The right panel breaks the data down into the two periods for each author. Authors with an increased grammaticalization score in their later work are indicated in red. As can be appreciated, they form the majority of the individuals investigated. Overall, we see an increase in grammaticalization scores through time (lowess regression line). In our paper, we will investigate the differences between the authors in depth.

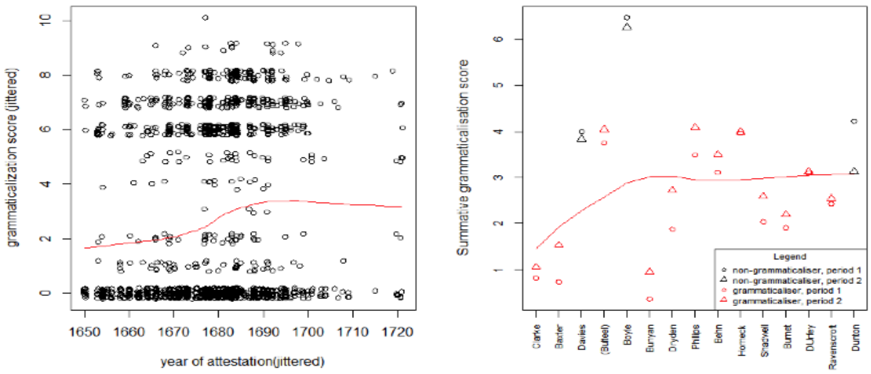

Figure 1: Grammaticalization of *be going to* in EEBO

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POSTERS

INTERPRETATION PROCESSES: ANALYSIS OF THE COMPLEXITY FOR DIFFERENT LANGUAGE SYSTEMS

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There is a wide consensus in evolutionary linguistics that the evolution of language is constrained by the cognitive capabilities of language users, who must be able to acquire and process language given the limited resources they have at their disposal. It is therefore crucial to analyze the computational complexity of possible language systems in order to explain why we might (or might not) expect such systems to emerge in a speech community.

This poster presents such complexity analyses for language comprehension, using an agent-based model of cultural language evolution in which a population of autonomous artificial agents engage in multireferential language games with each other (Steels and Casademont 2013). In our experiments, we first show how these agents can self-organize four different language systems: a lexical (pidgin) language, a word grouping language, a sequencing language, and a patterning language (which all four progressively scale towards the kinds of constituent structures found in most human languages). Through a complexity analysis of semantic interpretation, we show that each system progressively increases interpretation efficiency, which may explain why almost all human languages have evolved constituent structure.

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CASES, PREPOSITIONS, AND IN-BETWEENS: SKETCHING A MODEL OF GRAMMATICAL EVOLUTION

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Most languages either have case marking, adpositions, or both. Languages with case marking can 'lose' their case system, which is then generally replaced by adpositions. Despite the enormous amount of work done on the subject, we still cannot figure out completely how the process of case-loss takes place (Hagège 2010). In this research we present two agent-based models of case-to-adposition change in languages, inspired on our experience (Fagard 2010) in diachronic studies of cases and adpositions in languages. The first model is a simple approximation that uses neural networks to model the introduction of adpositions to desambiguate ambiguous sentences. Based on the results obtained and the limits of our first model, we present the design of a new experiment inspired on cultural language evolution experiments (Steels 2012; van Trijp 2010) to model the process of grammatical change in case marked languages.

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MODELLING THE ROLE OF MOTION VERBS IN THE EVOLUTION OF RUSSIAN ASPECT

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Motion verbs occupy a special place in Russian. It is believed that historically such verbs grounded in embodied movements served as prototypes for other, non-motion verbs by providing a concrete ground as events that allowed profiling of the beginning, middle and end of the motion, as well as its goal-directedness (Janda 2008), (Janda 2010). In non-motion verbs goal-directedness was extended to completability – whether a verb could be associated with a result – and became expressed with a pair of distinct verb stems describing the same event that differed only in aspect (Janda 2008).

While the majority of the verbs eventually lost such lexical stem differences through grammaticalisation of aspect, lexical aspect was retained in around a dozen motion verbs in Modern Russian (Janda 2008). It is believed that these verbs of motion, through their prototypical role, facilitated the transfer not only of goal-directedness from motion to non-motion verbs but also of lexical aspect to grammatical thereby reducing the number of verbs with distinct stems (Janda 2008). Possibly due to their importance as prototypes, they preserved their own lexical aspect marking

The present work is part of a larger project dedicated to modelling this historical phenomenon. We intend to accomplish our goal by initially re-constructing the current state of verbs of motion in Russian and in the later stages, tracing historical developments through modifications to the current grammar. At the present stage, we demonstrate a grammar of Modern Russian verbs of motion implemented with the Fluid Construction Grammar formalism (Steels 2011a). In future experiments, agent-based models and language game paradigm (Steels 2011b) will be employed in order to simulate the grammar and its historical development in use.

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ENTRENCHMENT VS. TRANSPARENCY. MODELLING THE DUTCH STRONG-WEAK PAST TENSE COMPETITION IN AN AGENT-BASED SIMULATION

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Typically, Germanic verb inflection falls into two main classes: strong and weak verb inflections. At present, the strong verb inflection system has lost most of its original transparencies and disintegrated into an intricate patchwork of distinct classes and irregularities (Haeseryn et al. 1997, 87-94; Lieberman et al. 2007; Mailhammer 2007). Yet, although the alternative "weak" inflection system – which also developed quite early – is much more transparent and highly productive, the strong verb inflection continues to show itself remarkably resilient. Not only has it resisted the strong regularization pressure of the weak verbs relatively well, it incidentally even shows some signs of expansion (Salverda 2006, 170-179).

In order to investigate how such an untransparent system can survive and even incidentally expand in a population, we have constructed an agent-based model of the competition between the strong and weak verb forms in Dutch. In our current model, the agents are embedded in a world of events, which they need to communicate to one another in a language game (Steels 1995). These events are typically expressed by strong verbs in Dutch and their frequency correlates with the frequency of the verbs describing them in the Corpus of Spoken Dutch (CGN, cf. Van Eerten 2007). The more often an agent hears the strong or weak form of a particular verb, the more likely he is to use this form in a future game. While the agents start with an outspoken preference for the strong forms – corresponding to the current situation in Dutch – the weak forms benefit from being more transparent. That is, while the use of a strong form only affects its direct counterpart in the lexicon of the hearer, the use of a weak form also slightly raises the probability of all other weak forms in the hearer's lexicon due to the transparency of weak inflectional endings.

Although the current state of our model is too simple to accurately model the historical competition, it is our aim to ultimately compose a truly realistic model. To achieve this, we mean to go as far as possible in incorporating the vast body of knowledge already available on the strong-weak verb competition.

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EMERGENCE AND (CO)-EVOLUTION OF TENSE, ASPECT AND MODALITY

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Language users of different languages employ many different strategies to express tense, aspect and modality (Comrie 1976, 1985). This poster presents the first results of a research project that aims to show how a population of language users may self-organize such tense-aspect-modality (TAM) systems from scratch through agent-based modeling.

More concretely, we will present a computational reconstruction of the Dutch TAM-system in Fluid Construction Grammar (Steels 2011a 2012) that works for both parsing and production. The reconstruction demonstrates that TAM-systems of human languages go well beyond simple associative communication systems in which there is a one-to-one mapping between meaning and form. Instead, grammatical TAM-systems consist of an abstract and hidden layer of semantic and syntactic categories that mediate between rich conceptualizations and their morphosyntactic realization.

In future work, we will incorporate our processing model in agent-based experiments based on the language game paradigm (Steels 2011b). This work will proceed in a stepwise fashion, whereby first the necessary learning mechanisms are operationalized that enable autonomous artificial agents to acquire a sophisticated real-world TAM-system. Secondly, we will investigate how agents can self-organize their own TAM-system of human language-like complexity.

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