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Faculty of Philosophy
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Language Evolution WiSe 2023/2024

Lecture 15: Animal Communication

12/12/2023, Christian Bentz

Overview

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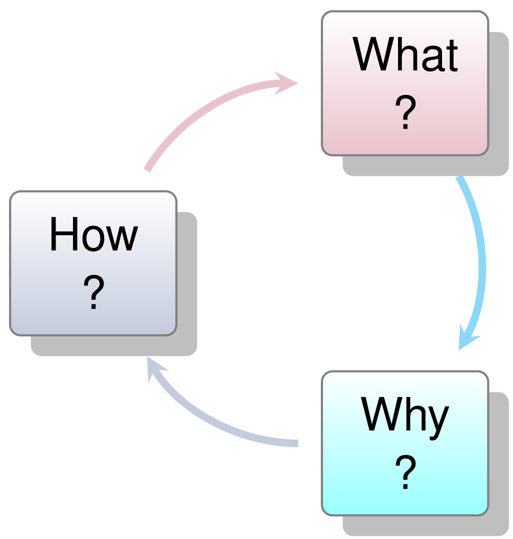
Introduction

Three Questions

1. **What** evolved, i.e. what is “language” in the first place?
2. **Why** did it evolve, i.e. did it have particular functions?
3. **How** did it evolve?



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Competing Definitions of *Language*

- **Formal Language Theory**
- **Faculty of Language**
  - Recursion
  - Rich Language Faculty (Narrow Sense)
- **Minimalism**
  - Strong Minimalist Thesis
  - Minimalist Layers Hypothesis
- **Usage-Based Grammar**
- **Combinatoriality** and **Compositionality**

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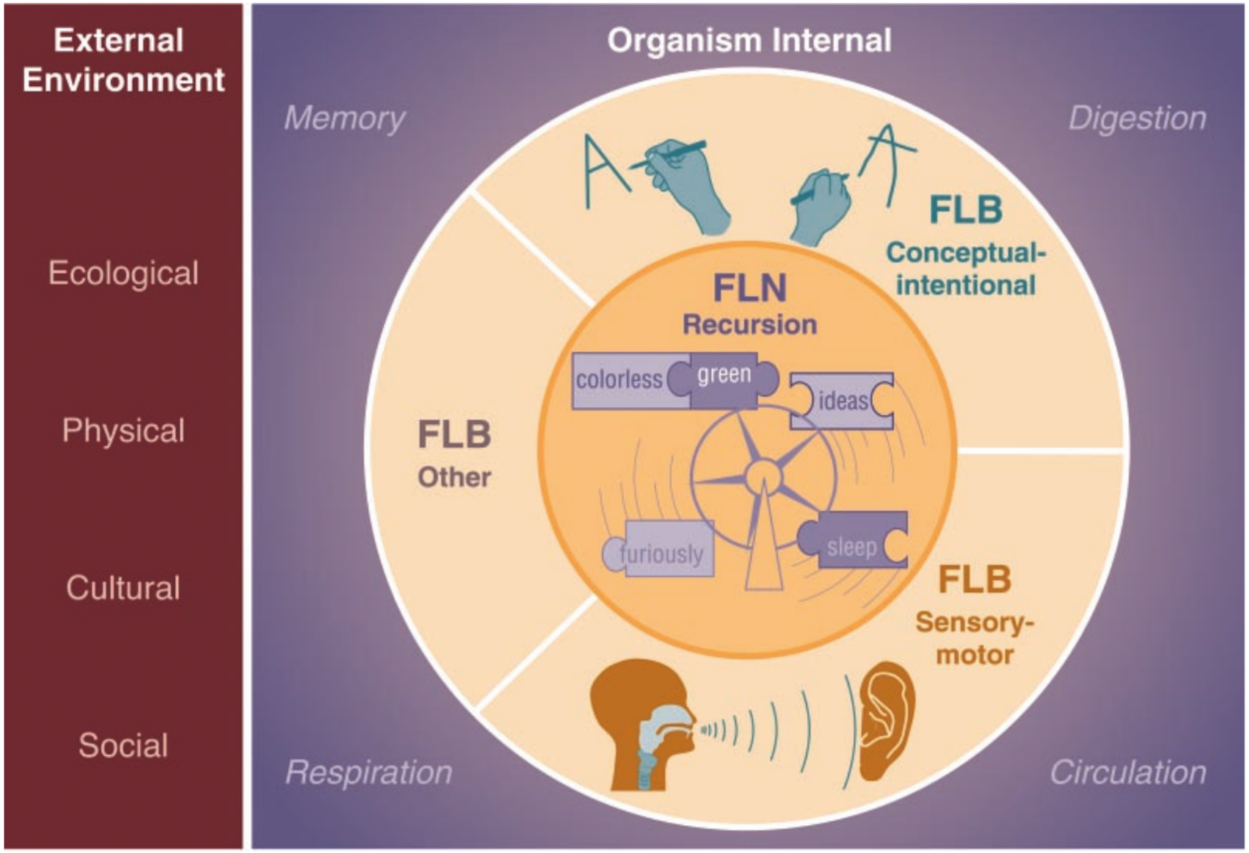
Formal Language Theory

Faculty of Language (Narrow and Broad)



Hauser, Chomsky & Fitch (2002). The faculty of language: What is it, who has it, and how did it evolve?

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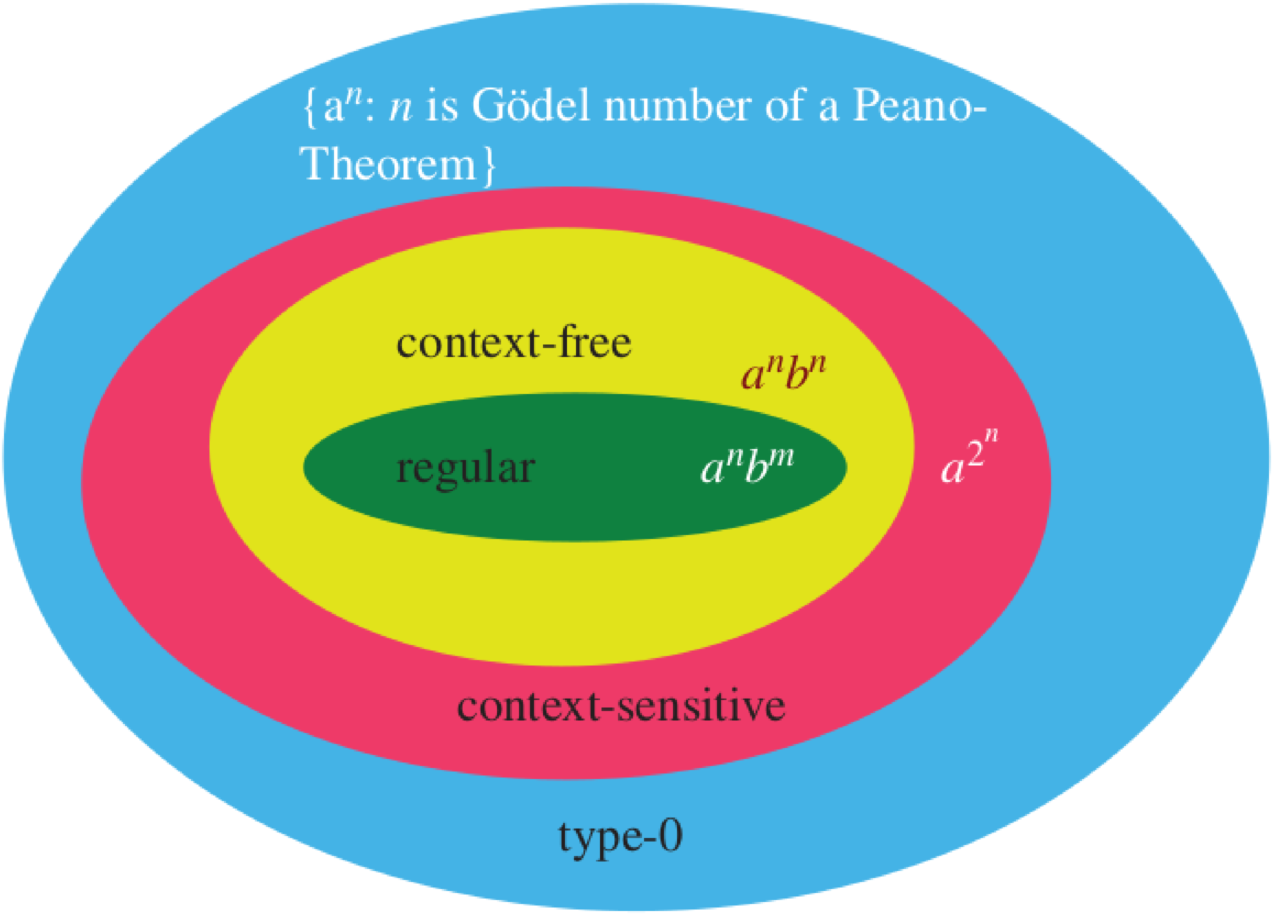
The Classical Hierarchy



Jäger & Rogers (2012), p. 1959.

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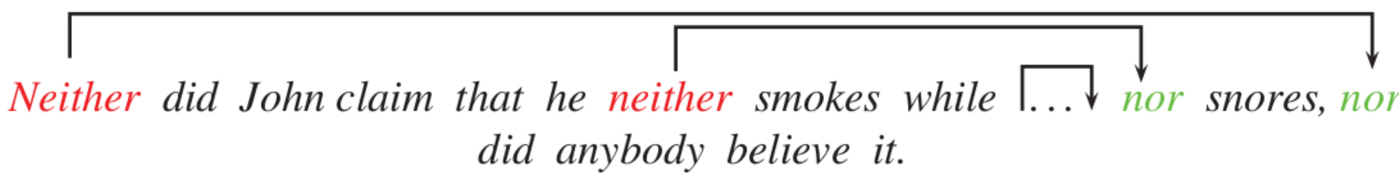
The Non-Regularity of Natural Languages

"English is not a finite-state language, and we are forced to reject the theory of language under discussion [i.e. language as a Markov process] [...]"

Chomsky (1956). Three models for the description of language.



Note: The structure here is aabb, more generally this could be extended to $a^n b^n$.

Jäger & Rogers (2012). Formal language theory: refining the Chomsky hierarchy.

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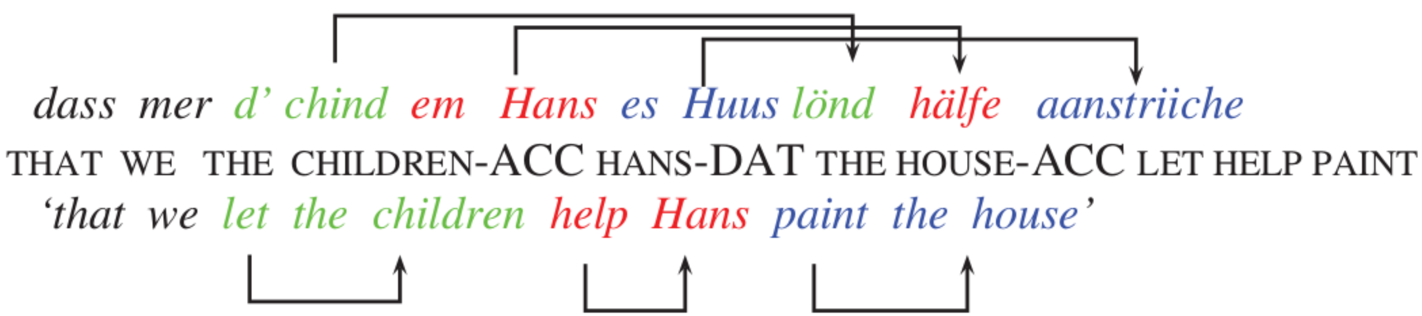
The Context-Sensitivity of Natural Languages

It was later shown that natural languages might also display structures that cannot be generated by context-free grammars. Hence, it is assumed that languages are **mildly context-sensitive**.



Note: The structure in the Swiss German example is abcabc, while for the English translation it is aabbcc.

Jäger & Rogers (2012). Formal language theory: refining the Chomsky hierarchy.
Shieber (1984). Evidence against the context-freeness of natural language.

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Animal Communication: Problem

Based just on a set of strings, there is **no way** to automatically identify the level of the hierarchy a given string generating mechanism is on.

abb, aabbb, aaaabbbbb, aaab, aab, aab, aabbb, abb, ab, aaaaaaabbbb, abbbbbbbbbbb, aabbbb, aaabbbbb, abbbb, aaaaaaaaaaaaaabbbbb, aaaab, abbbbb, aaaaabbbb, aaabb, abb

ab, aabb, aaaabbbb, ab, aabb, ab, aaabbb, aabb, ab, aaaabbbb, ab, aabb, aaabbb, ab, aaaaabbbbb, ab, ab, aaaabbbb, aaaaaaaaaaabbbbbbbbbbb, ab, aabb, aaaaabbbbb

aab, abb, aaaabbbb, ab, aaabb, abb, aabbb, aaabb, abb, aabbbb, abb, abb, aaabbb, ab, aabbbbb, abb, aab, aaaabb, aaaaabbbbb, abbbb, aabb, aaaab

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Some Reasons

- A finite-state automaton (regular grammar) **can generate** $a^n b^n$ sequences (either coincidentally or by implementing a simple counter).
- The argument that language is not regular is based on the assumption of **potentially infinite dependencies** (or at least an arbitrarily large number *n* of them). However, empirical data are always finite.
- In natural languages – and in animal communication – there can be **intervening symbols** as in the example above (*neither* ... *neither* ... *nor* ... *nor*).
- In natural languages, the structural property of $a^n b^n$ does not necessarily refer to **"surface" properties** of the string (e.g. sequences of characters or phonemes), but higher order structures such as NP (noun phrase) or VP (verb phrase).

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Animal Communication: Experimental Solutions

Different species of animals have been tested as to whether they can **systematically produce or identify** strings generated (arguably) by a given grammar.

aaabbb ✓
acabbbb
aabb ✓
ccccdddd ✓
aacc ✓
abcbbc
edfccccf
aaaaaaabbbbbbb ✓
cccccbcaaaaaaca
ab ✓
etc.

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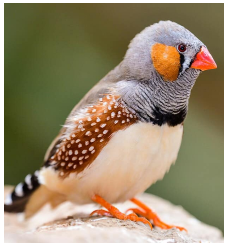
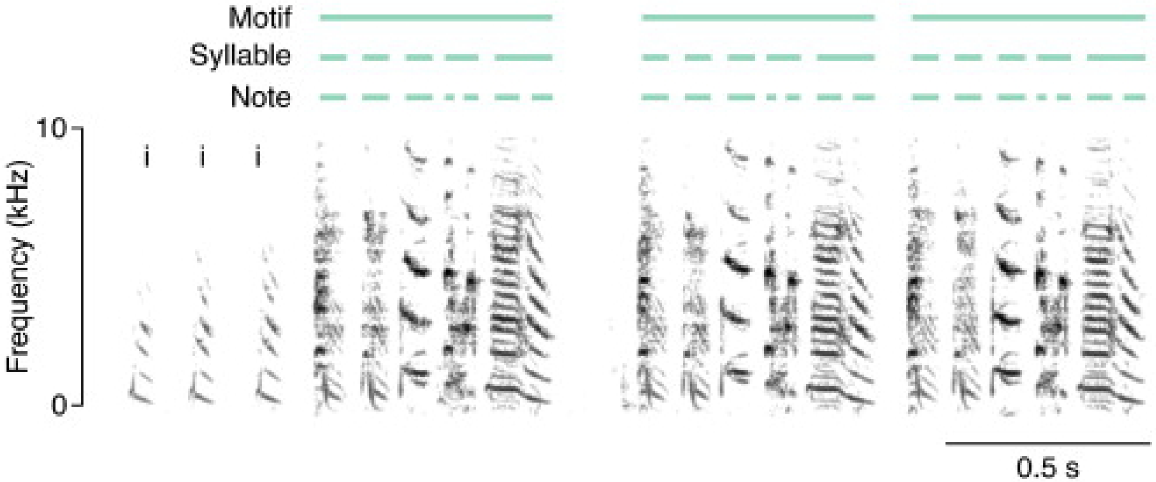
Comparative Studies using FLT

Birdsong: Zebra Finches





"Sound spectrogram of a typical zebra finch song depicting a hierarchical structure. Songs often start with 'introductory notes' (denoted by 'i') that are followed by one or more 'motifs', which are repeated sequences of syllables. A 'syllable' is an uninterrupted sound, which consists of one or more coherent time-frequency traces, which are called 'notes'. A continuous rendition of several motifs is referred to as a 'song bout'."

Berwick et al. (2011). Songs to syntax: the linguistics of birdsong.

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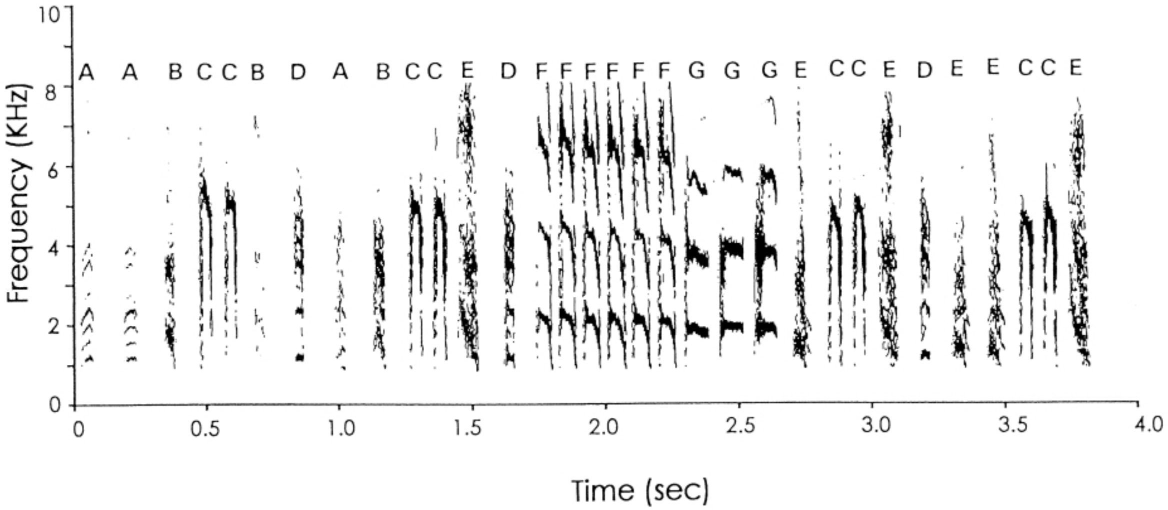
Birdsong: Bengalese Finches



"Representative sonagrams of the songs taken from a Bengalese finch [...] Each note type was identified by a separate alphabet. A note was defined as a continuous trace of a sonagram that was separated by clearly visible silent intervals."

Honda and Okanoya (1999). Acoustical and syntactical comparisons between songs [...]

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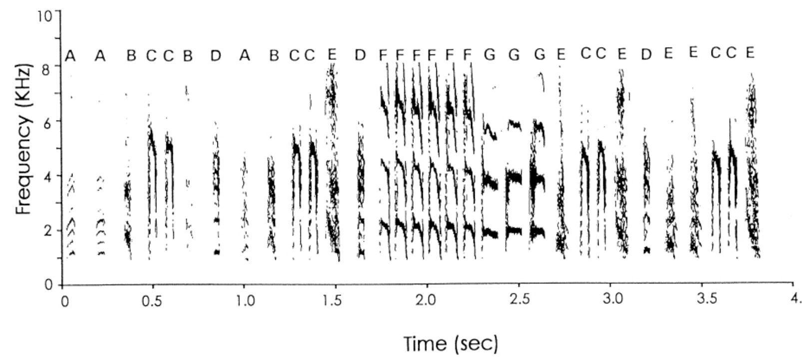
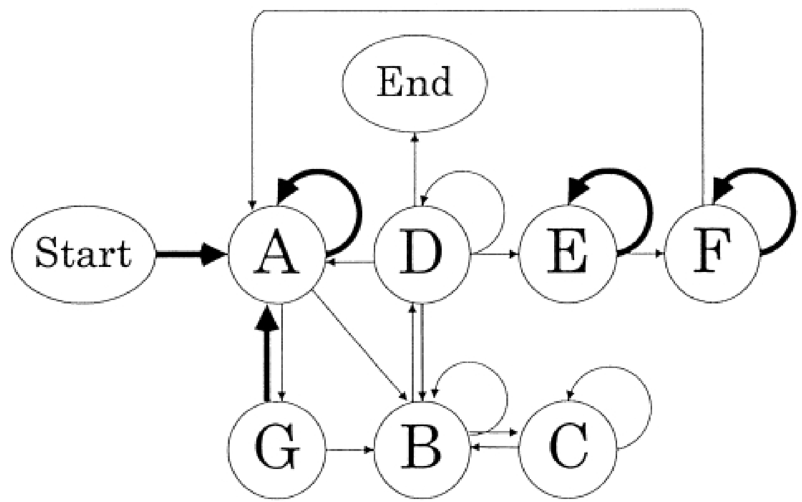
Birdsong: Bengalese Finches

Example of transition diagram of Bengalese finch song. Bengalese finches have somewhat complex patterns of note-to-note transition.

Honda and Okanoya (1999). Acoustical and Syntactical Comparisons between Songs [...]





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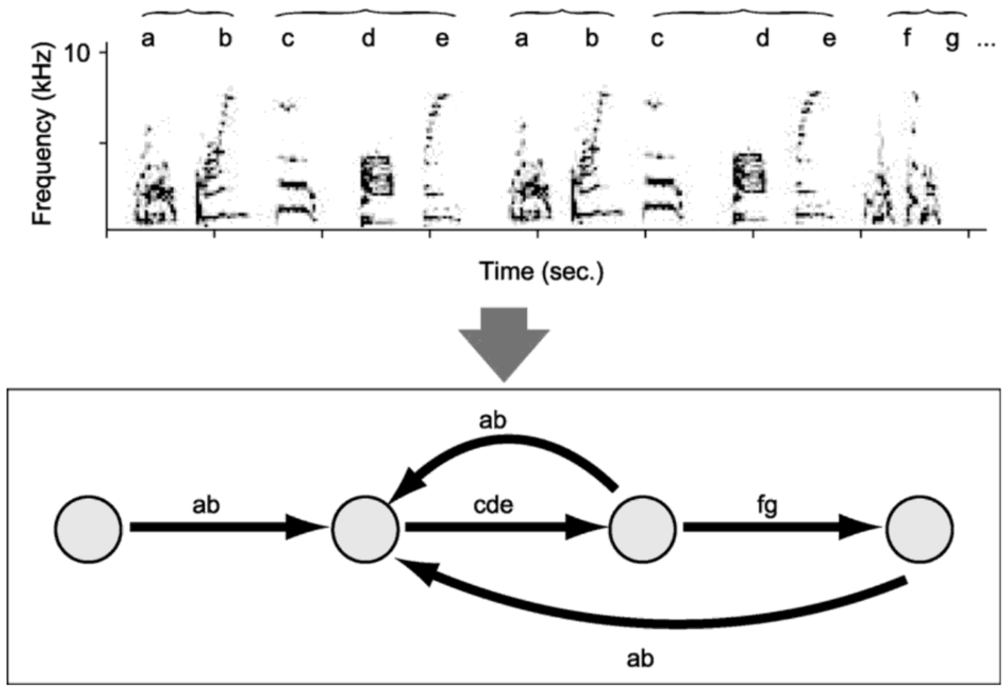
Regular Bird Song (?)

Finite state (regular) syntax derived for a Bengalese finch song by Okanoya (2004). Note that this is just a song for one individual. The chapter states that the "strings are statistically analyzed and song notes that occur together are chunked."

Okanoya (2004). Song syntax in Bengalese finches.



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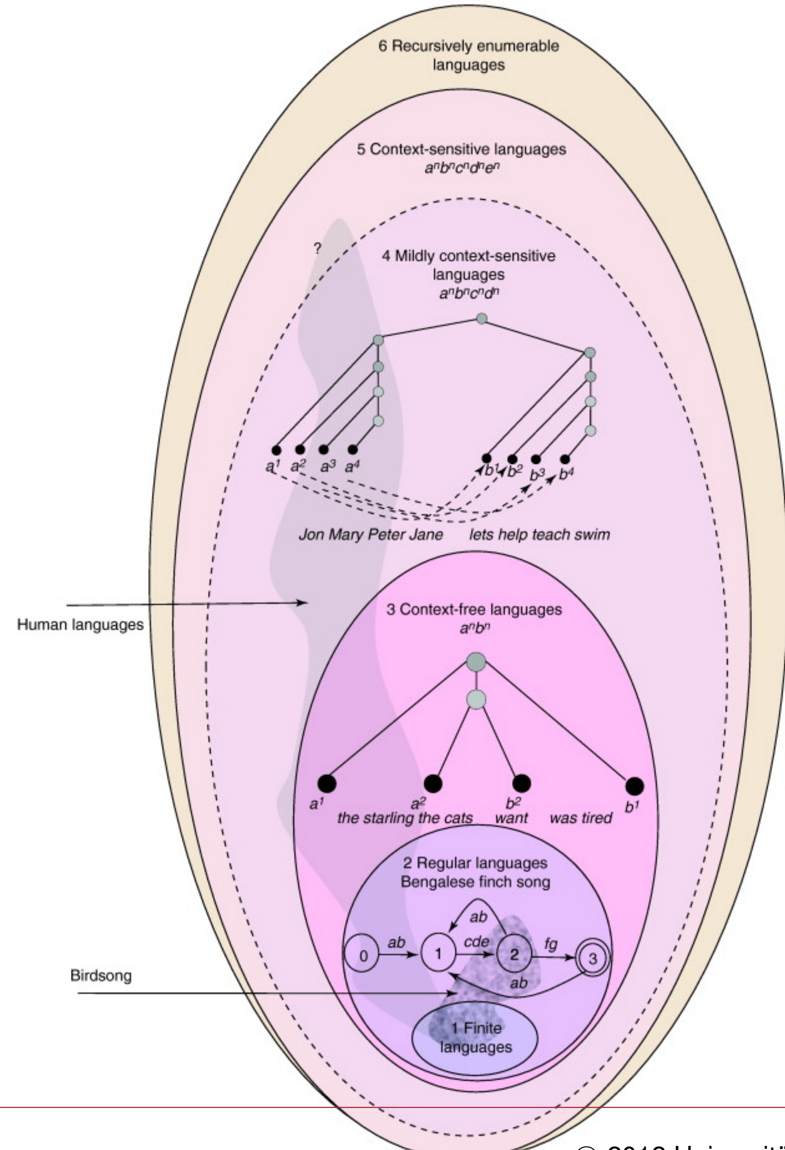
Chomsky Hierarchy

"The Chomsky hierarchy of languages along with the hypothesized locations of both human language and birdsong. An example of the state transition diagram corresponding to a typical Bengalese finch song is shown [...] corresponding to some subset of the regular languages."

Berwick et al. (2011).

Note: "Finite language" is not to be confused with "finite state language". The former is literally a language made up of strings of **finite length**. The latter is a regular language with recursive structures which allow for aribtrary (infinte) lengths of strings.



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Summary: Birdsong

- If the interpretation of bird song patterns in bengalese finches is correct, i.e. they are indeed generated by **regular grammars**, then *recursiveness* of vocal communication signals is not unique to humans.
- This would mean that the **recursion only hypothesis of FLN** (proposed by Hauser et al. 2002) is refuted.
- The **uniqueness of the human language capacity** is then potentially related to higher levels of the hierarchy (e.g. *context-freeness*, *mild context-sensitivity*).

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Further Questions in Comparative FLT

Further Questions in Comparative FLT

- Are context-freeness/mild context sensitivity **domain-specific**?
- Are context-freeness/mild context sensitivity **species-specific**?

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Is the Human Language Capacity Domain-Specific?

"Here, we explored human pattern-processing capabilities in the **visual domain** by generating abstract visual sequences [...] Participants successfully acquired all three grammars after only minutes of exposure [...] cognitive mechanisms with the computational power to process linguistic syntax are **not specific to the domain of language** [...]"

Westphal-Fitch et al. (2018).

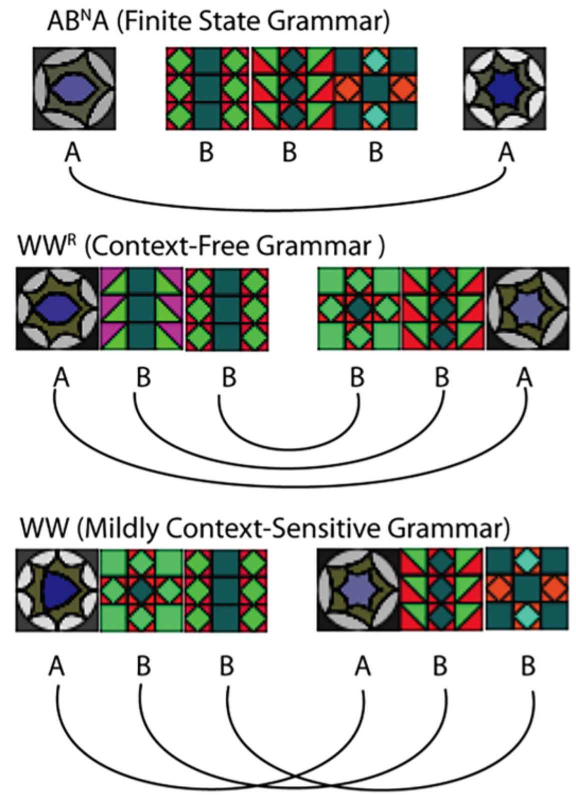

FIGURE 2 | Examples of stimuli sequences for all three grammars with $N = 3$.

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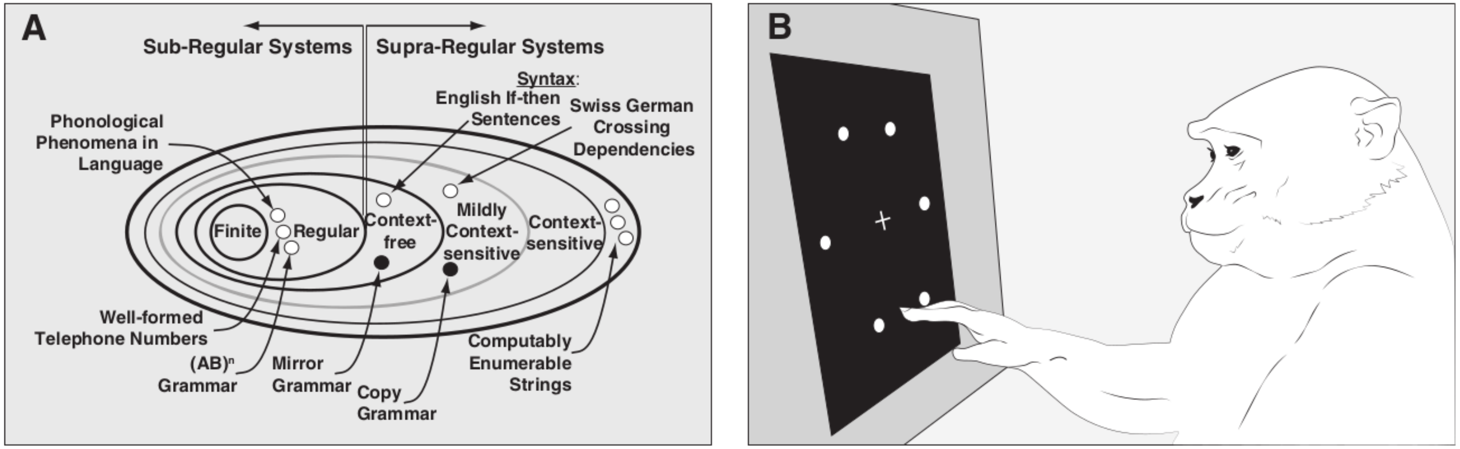
Is the Human Language Capacity Species-Specific?



"Macaque monkeys can be trained to produce complex spatial sequences beyond the simplest levels of grammar previously known from animal studies. This indicates cognitive capabilities in the spatial-motor domain that approach the computational complexity level of human syntax."

Fitch (2018). Bio-linguistics: Monkeys break through the syntax barrier.
Jiang et al. (2018). Production of supra-regular spatial sequences by Macaque monkeys.

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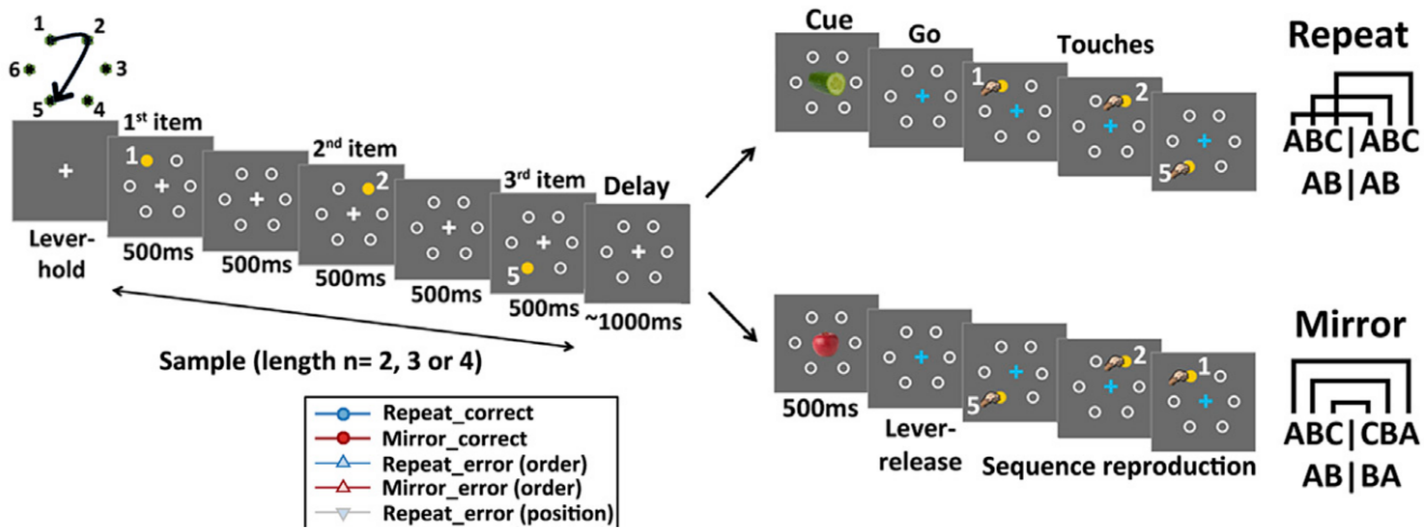
Is the Human Language Capacity Species-Specific?



"Using a production task, we show that macaque monkeys can be trained to produce **time-symmetrical embedded spatial sequences** whose formal description requires **supra-regular grammars** or, equivalently, a push-down stack automaton."

Jiang et al. (2018). Production of supra-regular spatial sequences by Macaque monkeys.

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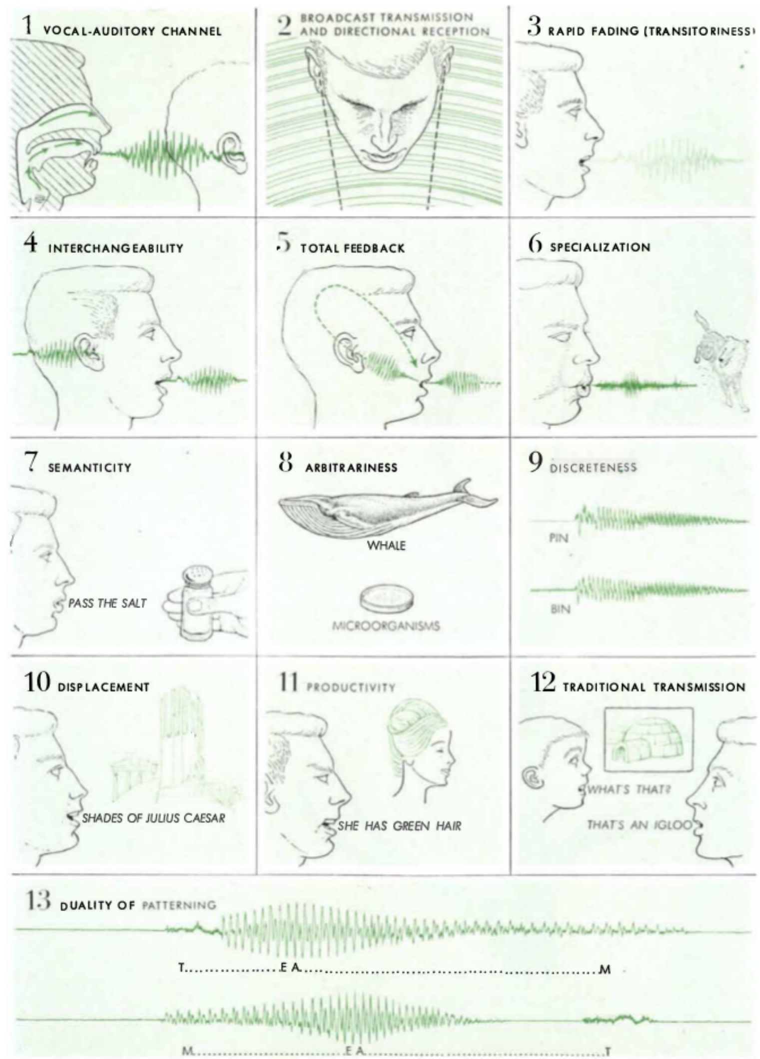
Combinatoriality and Compositionality

The Design Features of Human Language

"A set of 13 design-features is presented in the illustration on the opposite page. There is solid empirical justification for the belief that all the languages of the world share every one of them."

Hockett (1960). The origin of speech, p. 90.



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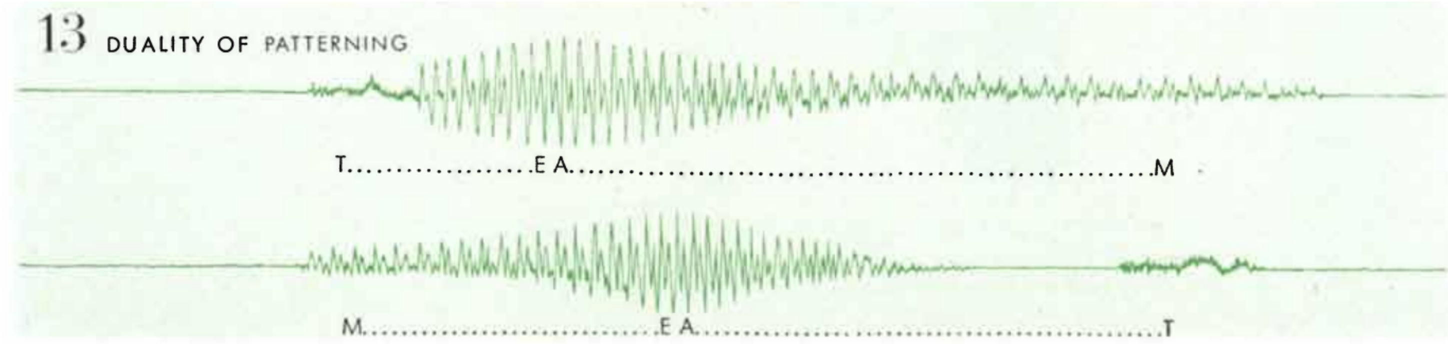
Duality of Patterning



"The **meaningful** elements in any language [...] constitute an enormous stock. Yet they are represented by small arrangements of a relatively very small stock of distinguishable sounds which are themselves wholly **meaningless**."

Hockett (1960). The origin of speech, p. 90.

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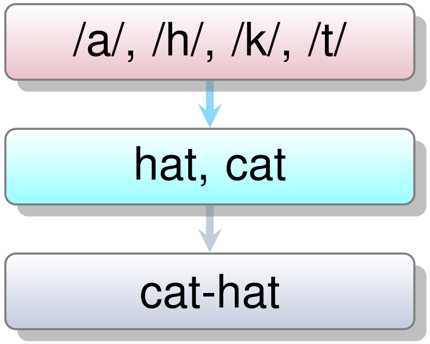
Duality of Patterning

"Language is structured on at least two levels (Hockett, 1960). On one level, a small number of meaningless building blocks (phonemes, or parts of syllables for instance) are combined into an unlimited set of utterances (words and morphemes). This is known as **combinatorial structure**. On the other level, meaningful building blocks (words and morphemes) are combined into larger meaningful utterances (phrases and sentences). This is known as **compositional structure**."

Little et al. (2017), p. 1.



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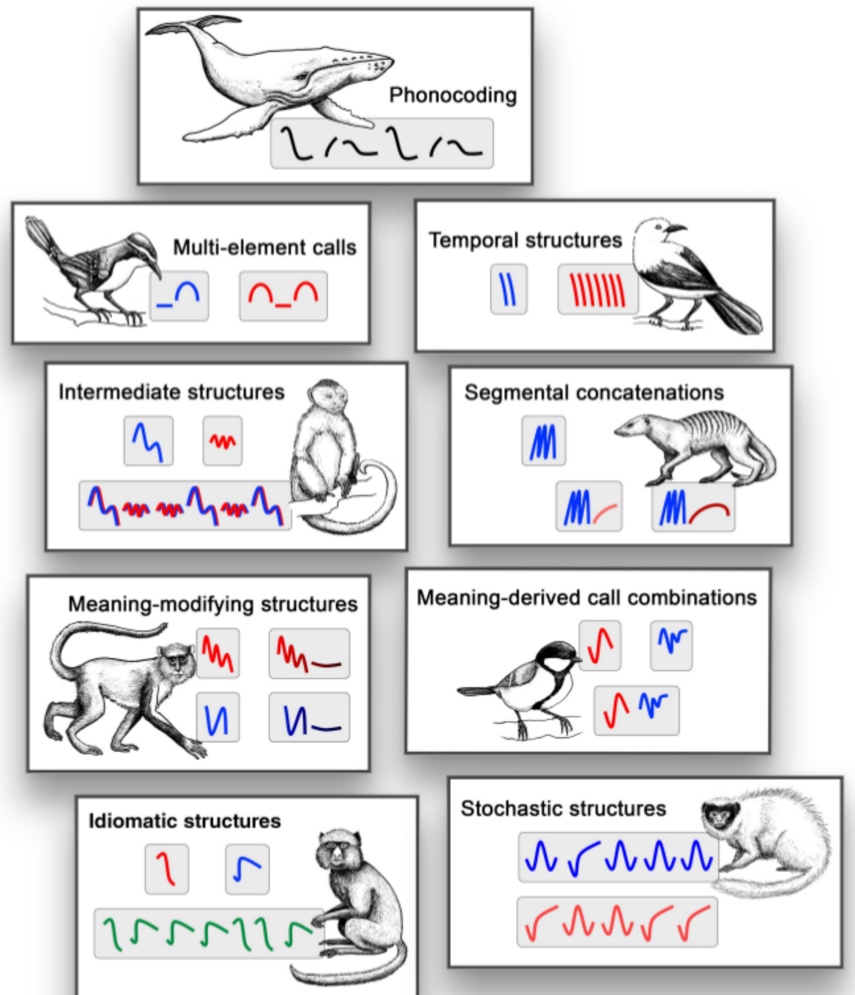
Combinatoriality in Animal Communication

"Graphical illustration of combinatorial structures in nonhuman vocal systems. Shapes distinguish sound elements, colors distinguish meaning (black indicates absence of functional- or context-specific meaning)."

- **Phonocoding**: combination of meaningless elements into sequence that lacks functional- or context-specific meaning (e.g., whales, songbirds).
- **Multi-element calls**: combination and reuse of meaningless elements to generate context-specific/functionally meaningful calls (e.g., chestnut-crowned babblers).
- **Temporal structures**: meaning-differentiating temporal variation (e.g., number of element repetitions) within a string of repeated sounds (e.g., pied babblers, Mexican free-tailed bats).
- **Intermediate structures**: combination of meaningful calls into sequence reflecting intermediate stages experienced by the caller (e.g., wedge-capped capuchins, gorillas).
- etc.

Engesser & Townsend (2018).



Introduction
Formal Language Theory
Combinatoriality and Compositionality
References

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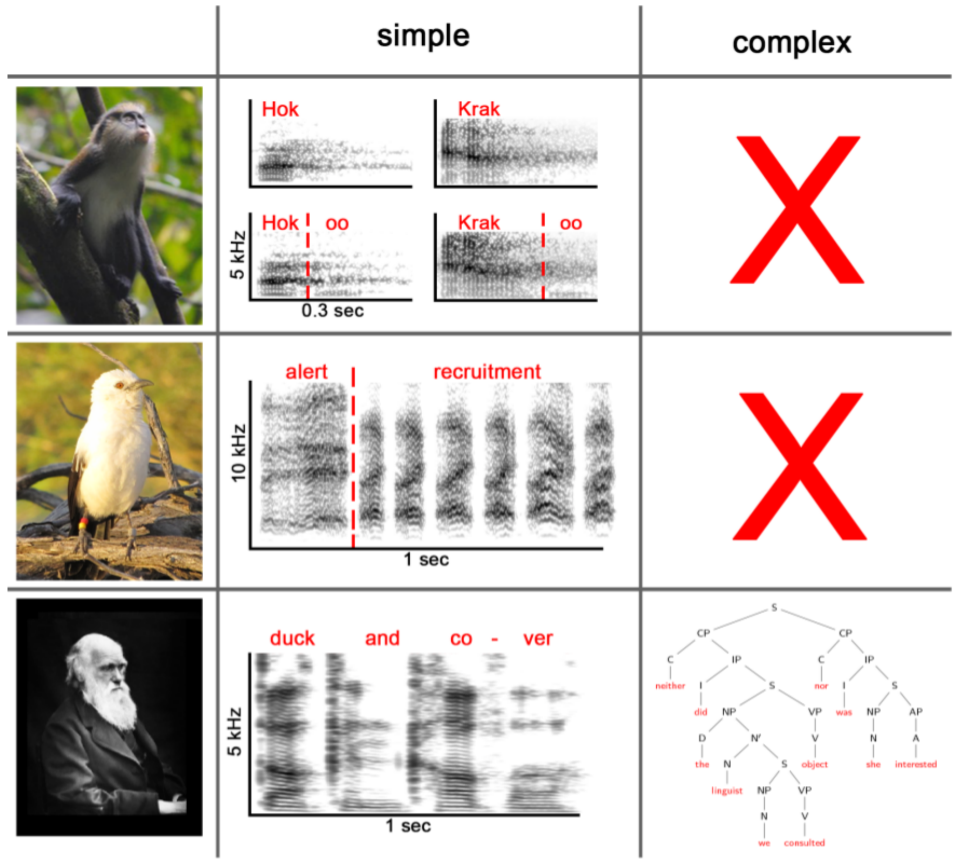
Compositionality in Animal Communication

- a) **Compositionality in primates**: Male Campbell's monkeys produce 'krak' alarms (to leopards) and 'hok' alarms (to eagles), but both calls can also be merged with an '-oo' suffix to generate 'krak-oo' (to a range of disturbances) and 'hok-oo' (to non-ground disturbances) [...]
- b) **Compositionality in birds**: Pied babblers produce 'alert' calls in response to unexpected but low-urgency threats and 'recruitment' calls when recruiting conspecifics to new foraging sites. When encountering a terrestrial threat that requires recruiting group members (in the form of mobbing), pied babblers combine the two calls into a larger structure, and playback experiments have indicated that receivers process the call combination compositionally by linking the meaning of the independent parts.
- c) **Compositionality in humans**: humans are capable of producing both simple, nonhierarchical compositions (e.g., 'Duck and cover!') and complex hierarchical compositions and dependencies.



Townsend et al. (2018), p. 4.

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Combinatoriality and Compositionality: Some Problems

- There is a fundamental difference between what **enculturated animals** (i.e. captured in a lab) can learn, and how **wild animals** behave naturally.
- Observations in the wild, however, are **time consuming**, **expensive**, and **cannot be manipulated systematically** to test specific hypotheses.
- The distinction between **meaningful** and **non-meaningful** elements of animal calls/gestures (i.e. combinatoriality vs. compositionality) is hard to establish. Often, **play-back experiments** are used.

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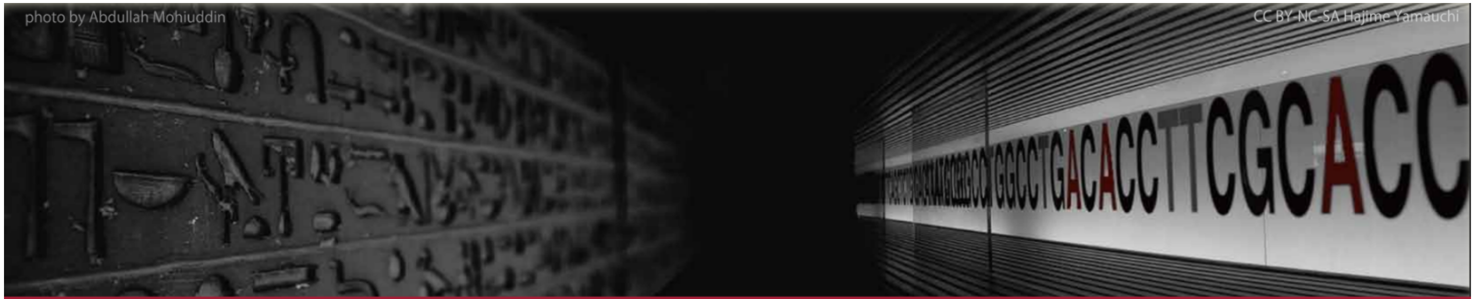

Gestures and Sign Language

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Enculturated Apes

Gestural Communication

Our closest relatives (i.e. gorillas and chimpanzees) have demonstrated considerable **gestural** learning capacities **in captivity** (enculturated apes).

Koko, a female gorilla, learned approximately 1000 words in American Sign Language (ASL).

Bonvillian and Patterson (1997).

Kanzi, a male Chimpanzee, learned approximately 500 symbols, and was able to combine these to sentences using a keyboard.

Savage-Rumbaugh et al. (1989).

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Enculturated Signing: Neam Chimpsky

It has long been shown that **enculturated primates** (chimpanzees, gorillas) can learn to use **compositional signs** of sign languages (e.g. ASL).

Fig. 1. Nim signing the linear combination, *me hug cat* to his teacher (Susan Quinby). (Photographed in classroom by H. S. Terrace.)

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Compositional Examples

"More than 19,000 multisign utterances of an infant chimpanzee (Nim) were analyzed for syntactic and semantic regularities. Lexical regularities were observed in the case of two-sign combinations: particular signs (for example, *more*) tended to occur in a particular position [...] That conclusion, however, was invalidated by Videotape analyses, which showed that most of Nim's utterances were prompted by his teacher's prior utterance [...]"

Terrace et al. (1979). Can an ape create a sentence?

Table 4. Twenty-five most frequent two- and three-sign combinations.

Two-sign combinations		Frequency	Three-sign combinations			Frequency
play	me	375	play	me	Nim	81
me	Nim	328	eat	me	Nim	48
tickle	me	316	eat	Nim	eat	46
eat	Nim	302	tickle	me	Nim	44
more	eat	287	grape	eat	Nim	37
me	eat	237	banana	Nim	eat	33
Nim	eat	209	Nim	me	eat	27
finish	hug	187	banana	eat	Nim	26
drink	Nim	143	eat	me	eat	22
more	tickle	136	me	Nim	eat	21
sorry	hug	123	hug	me	Nim	20
tickle	Nim	107	yogurt	Nim	eat	20
hug	Nim	106	me	more	eat	19
more	drink	99	more	eat	Nim	19
eat	drink	98	finish	hug	Nim	18
banana	me	97	banana	me	eat	17
Nim	me	89	Nim	eat	Nim	17
sweet	Nim	85	tickle	me	tickle	17
me	play	81	apple	me	eat	15
gun	eat	79	eat	Nim	me	15
tea	drink	77	give	me	eat	15
grape	eat	74	nut	Nim	nut	15
hug	me	74	drink	me	Nim	14
banana	Nim	73	hug	me	hug	14
in	pants	70	sweet	Nim	sweet	14

Note: Nim learned around 125 signs of ASL in total.

- Introduction
- Formal Language Theory
- **Combinatoriality and Compositionality**
- References

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Repetitiveness

Utterances of length > 3 are essentially just repetitions of shorter utterances.

Terrace et al. (1979). Can an ape create a sentence?

Table 5. Most frequent four-sign combinations.

Four-sign combinations	Frequency
eat drink eat drink	15
eat Nim eat Nim	7
banana Nim banana Nim	5
drink Nim drink Nim	5
banana eat me Nim	4
banana me eat banana	4
banana me Nim me	4
grape eat Nim eat	4
Nim eat Nim eat	4
play me Nim play	4
drink eat drink eat	3
drink eat me Nim	3
eat grape eat Nim	3
eat me Nim drink	3
grape eat me Nim	3
me eat drink more	3
me eat me eat	3
me gum me gum	3
me Nim eat me	3
Nim me Nim me	3
tickle me Nim play	3

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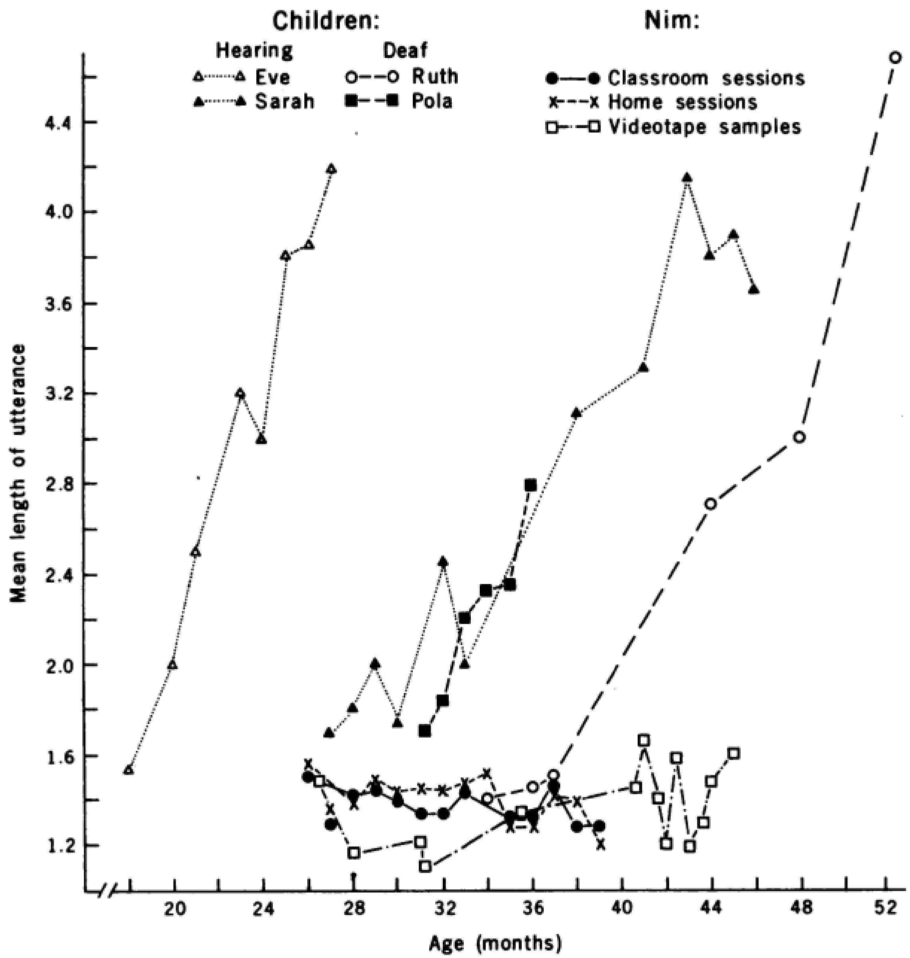
Comparison to Children

At the age of around 24 to 48 months human children learning ASL (both hearing and deaf) will start to use longer utterances, i.e. with mean lengths > 3, while Nim's mean length of utterances (MLU) would remain below 2.

Terrace et al. (1979). Can an ape create a sentence?



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Exercise

Given the table of ngrams produced by Neam Chimpsky below, try to answer the following questions:

- Does he understand the difference between a verb (action) and a noun (object)?
- Does he understand the difference between a pronoun and a proper name?
- Does he understand the concept of word order?

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tickle	Nim	107	yogurt	Nim	eat	20
hug	Nim	106	me	more	eat	19
more	drink	99	more	eat	Nim	19
eat	drink	98	finish	hug	Nim	18
banana	me	97	banana	me	eat	17
Nim	me	89	Nim	eat	Nim	17
sweet	Nim	85	tickle	me	tickle	17
me	play	81	apple	me	eat	15
gun	eat	79	eat	Nim	me	15
tea	drink	77	give	me	eat	15
grape	eat	74	nut	Nim	nut	15
hug	me	74	drink	me	Nim	14
banana	Nim	73	hug	me	hug	14
in	pants	70	sweet	Nim	sweet	14

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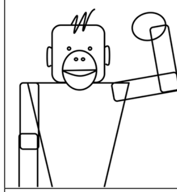
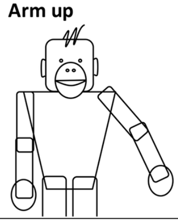
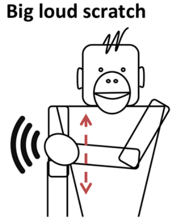
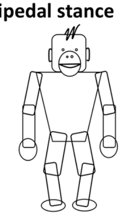
Wild Apes

Gestural Communication
(Current Research)

While gestural communication has been studied extensively in the second half of the 20th century for primates **in captivity**. Only in the last decades have projects emerged which study natural gestures of primates **in the wild**.

See videos at:
`https://greatapedictionary.ac.uk/gesture-videos2/`

Gesture Type	Bonobo ASOs	Chimpanzee ASOs
Arm raise 	Climb on you 34% Initiate grooming 22% Initiate copulation 20% Initiate GG-rubbing 16% Contact 6% Climb on me 2% *Ambiguous* [9(50): f=3.13, df=12,96 p=0.0009]	Acquire object 48% Move away 19% Move closer 15% Stop behaviour 11% Climb on you 7% *Ambiguous* [χ2=65.71, df=14 p<0.0001]
Arm up 	Contact 80% Climb on me 20% *Tight* [3(15): f=85.14, df=12,24 p<0.0001]	-
Big loud scratch 	Initiate grooming 100% *Tight* [10(41): f=893.1, df=12,108 p<0.0001]	Initiate grooming 82% [1] Travel with me 16%[1] Follow me 2% Climb on me 1% *Tight* [f=45.33, df=14, 238 p<0.001]
Bipedal stance 	Initiate copulation 50%, Initiate GG-rubbing 50% *Loose* [4(12): f=4.46, df=12,36 p=0.0002]	-

Graham et al. (2018).

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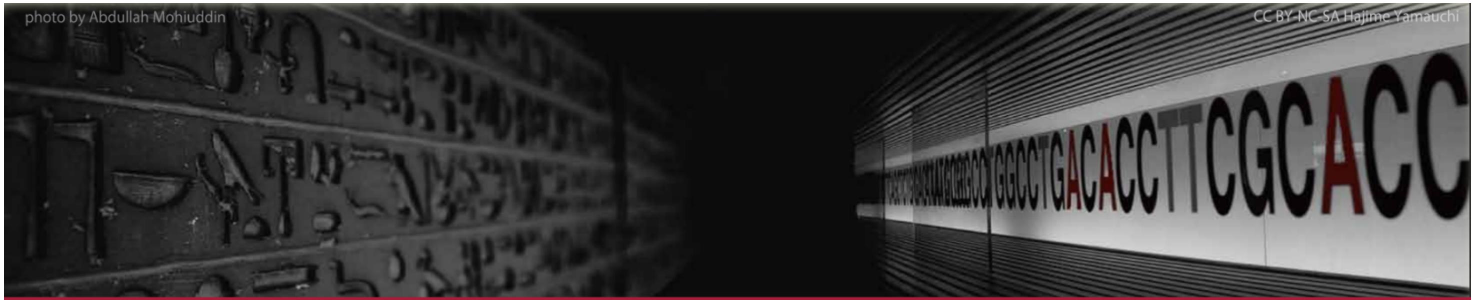

Vocal Communication

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Enculturated Apes

Viki

"Our subject, Viki, was adopted a few days after birth, and has now spent the first three years of her life in our home. She has been treated as nearly as possible like a human child [...] When Viki appears markedly inferior in some respect, special training is usually given, to determine whether the deficiency can be overcome."

Hayes and Hayes (1951). The intellectual development of a home-raised chimpanzee.

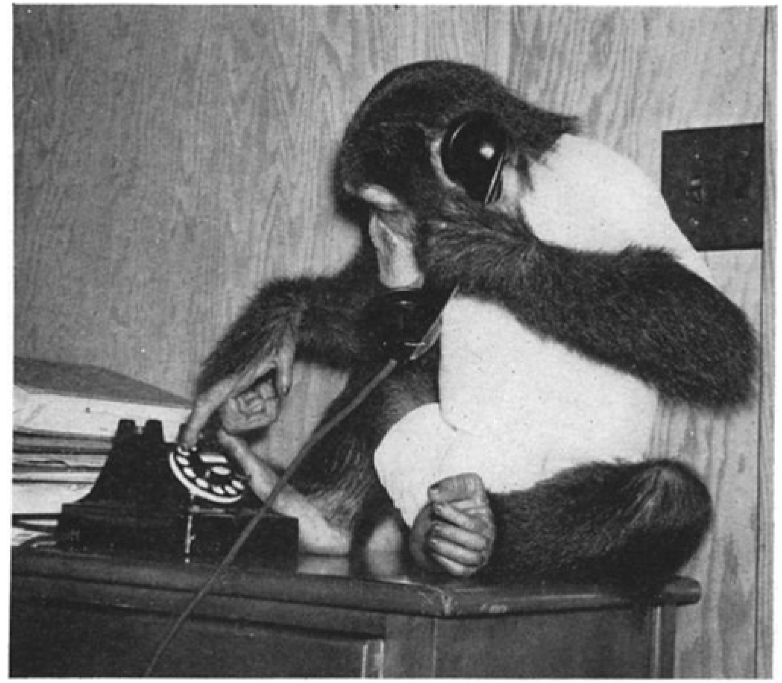

FIG. 2. The phone is a favorite plaything at three, though she seldom says anything into it.

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Viki's words

"She did not use her three words meaningfully at first; but when we required her to employ them appropriately, she soon learned to address the proper experimenter as "mama" or "papa", and to say "cup" when she wanted something to drink."

Hayes and Hayes (1951). The intellectual development of a home-raised chimpanzee.

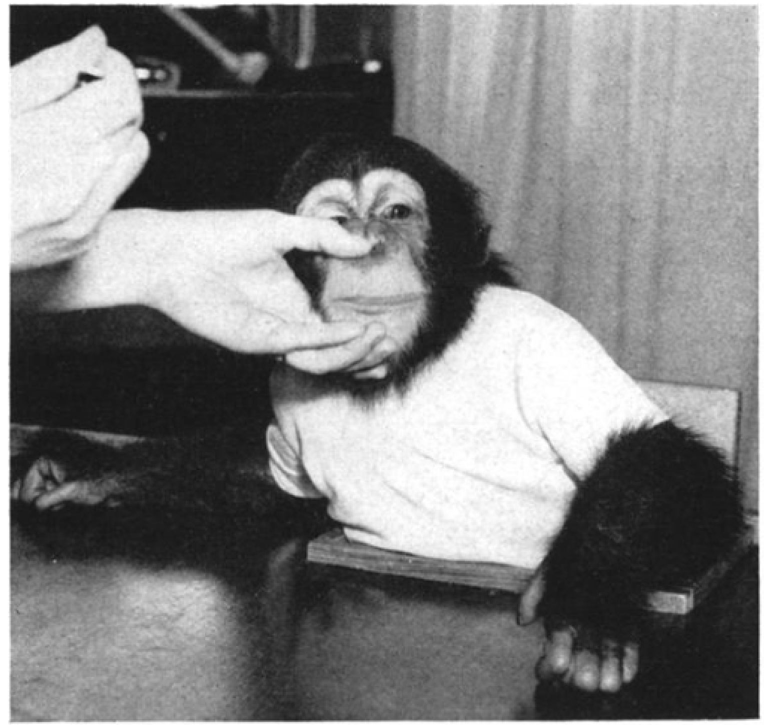

FIG. 3. We help her to say "mama," at fourteen months.

See video at https://www.youtube.com/watch?v=V7QM97fnypw.

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Wild Apes

Chimpanzee Call Types

Chimpanzees of the Tai National Park, Ivory Coast (West Africa) exhibit 15 different call types (590 hours of recordings on six adult males, and 520 hours for 10 adult females).

Crockford and Boesch (2005). Call combinations in wild chimpanzees.

Table 3. Number of vocalisations and drums occurring alone and in combination with other vocalisation types.

Signal types	Occurring singularly	Occurring in combination
Bark	320	185
Short bark	48	8
Tonal bark	30	11
Grunt	581	156
Deep grunt	400	56
Aaa grunt	724	97
Hoo grunt	146	13
Hoo	872	143
Laugh	18	–
Pant grunt	963	162
Pant hoot#	456	1496
Pant	126	46
Scream	286	1381
Squeak	31	5
Whimper	13	37
Drum	63	1101
Total signals produced*	5077	4899
Total number of signal episodes**	5077	1978
% of all signals produced*	51%	49%
% of all signal episodes**	72%	28%

See also videos at: `https://www.youtube.com/@taichimpanzeeproject7916/videos`

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Chimpanzee Call Combinations

They used these 15 different call types in overall 88 different call combinations.

Crockford and Boesch (2005). Call combinations in wild chimpanzees.

Note: Without further research it is not clear to what extend these call combinations constitute *combinatoriality* or *compositionality*, or to what extent these are even "meaningful", that is, interpreted by others, or even used by the signaller to manipulate the behavior of others.

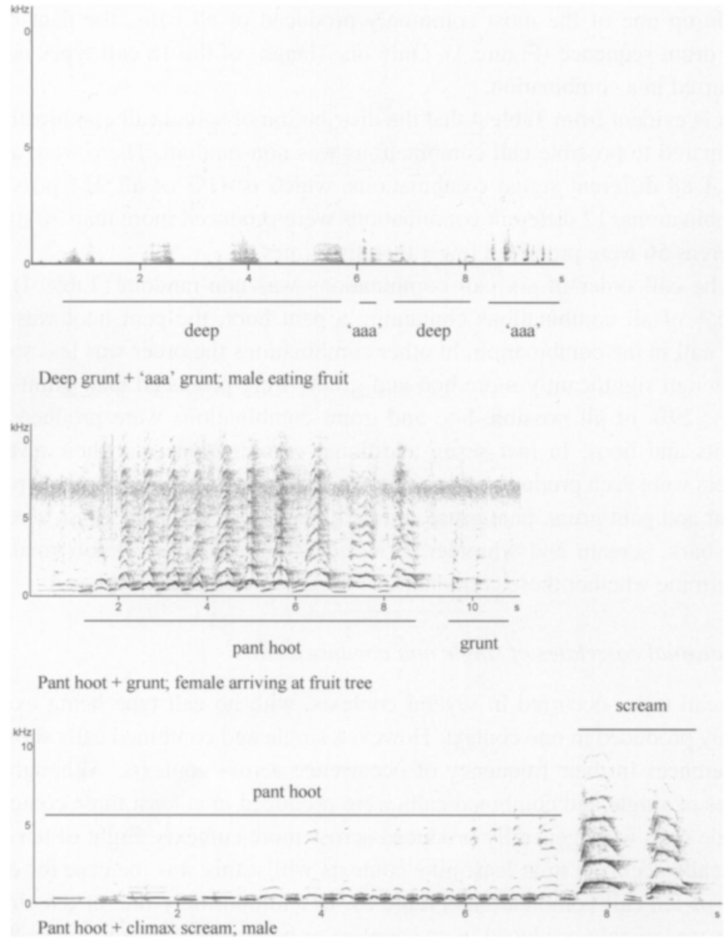

Figure 1. Spectrograms of call and drum combinations, shown in Table 8. Vertical axes (Hz); Horizontal axes (sec).

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Compositionality (?)

- Pant hoot-food call combinations are composed of individually occurring meaning-bearing units.
- Call combinations are more likel when feeding on larger patches and when a high-ranking individual joined the feeding party

Leroux et al. (2021). Chimpanzees combine pant hoots with food calls into larger structures.

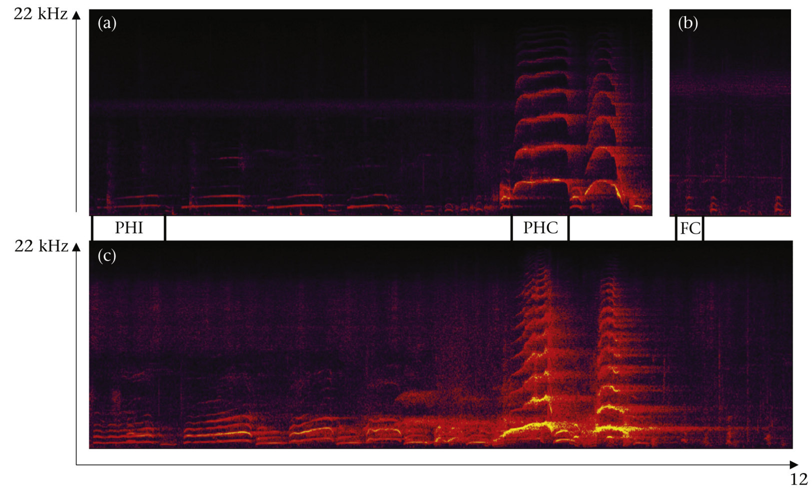

Figure 1. Spectrograms of (a) a pant hoot and (b) a food call produced in isolation and (c) a pant hoot-food call combination. Acoustic analyses were performed on the first element of introduction (PHI) and climax (PHC) of the pant hoot and the first tonal element of a food call bout (FC) for both the calls in isolation and in combination.

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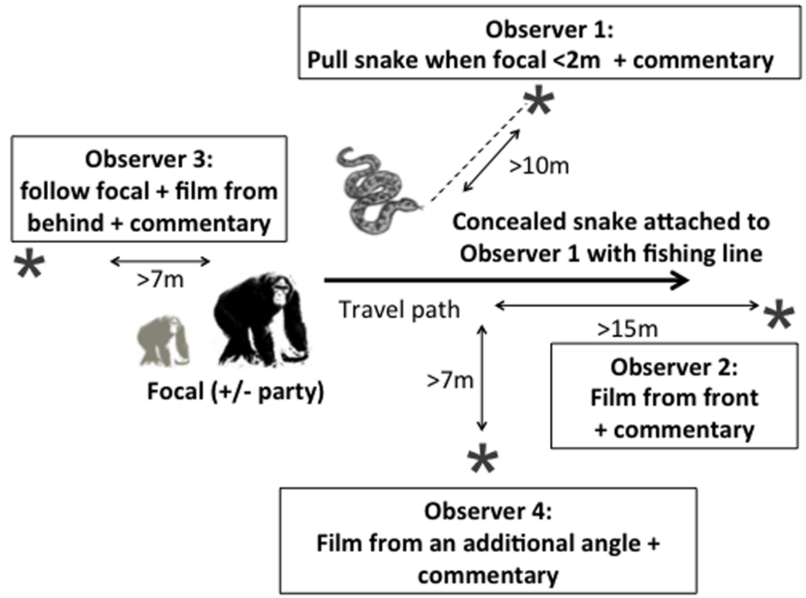
Compositionality (?)

"Chimpanzees produce "alarm-huus" when surprised and "waa-barks" when potentially recruiting conspecifics during aggression or hunting. [...] Using snake presentations, we confirm call combinations are produced when individuals encounter snakes and find that more individuals join the caller after hearing the combination."

Leroux et al. (2023). Call combinations and compositional processing in wild chimpanzees.

Schel et al. (2013). Chimpanzee alarm call production meets key criteria for intentionality.



See supplementary for videos: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0076674#pone.0076674.s001

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Summary: Combinatoriality and Compositionality

- Early experiments (mid 20th century) on **vocal learning** of chimpanzees failed largely to illustrate capacities anywhere close to human infants.
- At roughly the same time, it was illustrated that chimpanzees (and other apes) can **use gestures and signs** in **combinations** (compositionality) in an **enculturated** context.
- Systematic observations and experiments **in the wild** have been conducted since the early 21st century.
- Very recently, some evidence has been brought forward suggesting that chimpanzees use gesture types and vocalizations in **meaningful combinations**.

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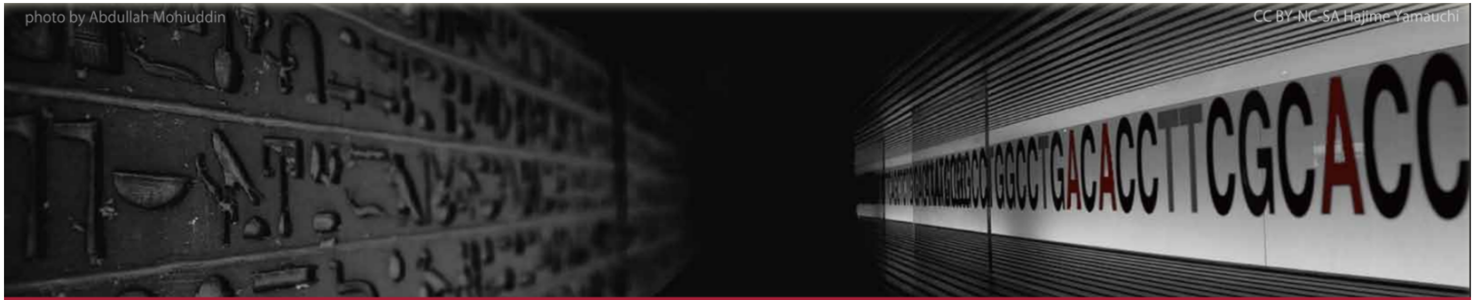

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Thank You.

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