

Milestones in the Evolution of Semantically Interpreted Language: Compositionality, Topic-Comment Structure, Propositions

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What is compositionality?

Compositional interpretation:

- ▷ The meaning of a syntactically complex expression is determined by the meaning of its immediate parts and the way how they are syntactically combined.
- ▷ Historical source: Frege ("Frege's principle"), Carnap, Katz, Montague, Davidson, Cresswell, Partee ...
- ▷ Known exception: Idioms, e.g. *a red herring*
- ▷ Recent overview:
 - E. Machery, M. Werning, W. Hinzen: *Oxford Handbook of Compositionality*.
- ▷ Examples of compositional interpretation:

$$\begin{array}{r}
 \text{two times three plus four} \\
 \text{[two times [three plus four]]} \\
 \hline
 2 \times 7 = 14
 \end{array}
 \qquad
 \begin{array}{r}
 \text{two times three plus four} \\
 \text{[[two times three] plus four]} \\
 \hline
 2 \times 6 + 4 = 10
 \end{array}$$

Why compositionality?

Why is compositionality a central principle of interpretation?

- ▶ Decrease of acquisition effort;
 - ▷ in typical languages and under most assumptions, we have
 - ▷ About 10^5 to 10^6 morphemes and lexemes.
 - ▷ About 10^2 morphological and syntactic rules.
- ▶ Increase of expressive power:
 - ▷ With recursive rules and non-bounded expression length, an infinity of concepts.
 - ▷ With non-recursive rules: still a very high number.
- ▶ Solves a bottleneck in cultural evolution (cf. Smith & Kirby 2012):
 - ▷ need to express an increasingly large number of concepts
 - ▷ need to increase learnability
 - ▷ need to increase ease of memorization
 - ▷ need to form new concepts, to adapt to new situations
 - ▷ need to increase decoding speed (Pagin 2012)

Frege on compositionality:

It is astonishing what language can do. With a few syllables it can express an incalculable number of thoughts, so that even a thought grasped by a terrestrial being ("Erdenbürger") for the very first time can be put into an outfit ("Einkleidung") which will be recognized by someone to whom the thought is entirely new. This would be impossible, were we not able to distinguish parts in the thoughts corresponding to the parts of a sentence, so that the structure of the sentence serves as the image of the structure of the thoughts. (1923, Logische Untersuchungen, 3. Teil, Gedankengefüge):

3 / 28

Compositionality vs. Contextuality

A counteracting principle (also called "Frege's principle"):

- ▶ The meaning of an expression depends on the context in which it is used.
- ▶ Frege:
 - Never ask for the meaning of a word in isolation, but only in the context of a sentence.
- Intense discussion in philosophy and logic in the 19th century (cf. Janssen 2013):
 - ▶ Schleiermacher:
 - Knowledge of the whole determines knowledge of the parts, and vice versa.
 - ▶ Frege, Wundt:
 - Primacy of judgement vs. primacy of component concepts
- Reconciliation in formal semantics:
 - ▶ The meaning of many expressions embodies their combinatorial potential
 - ▶ Context-dependent expressions, e.g. indexicals.

4 / 28

Compositionality before human language?

The genetic code

Similarities between genetic code and human language, cf. Krifka (1983).

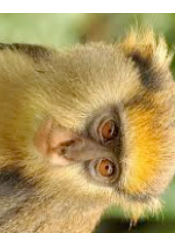
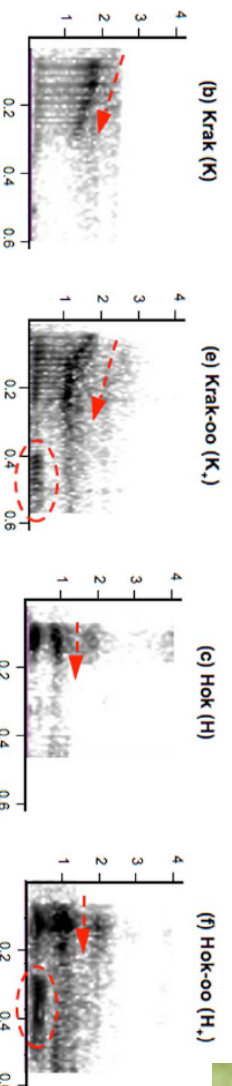
- ▶ Double articulation in DNA/RNA:
 - ▷ In DNA/RNA: sequences of 3 nucleotides form a codon “denoting” an amino acid;
 - ▷ in language, sequence of phonemes form a morpheme denoting a concept
 - ▷ Advantage: a few distinguishable nucleotides (4) / phonemes (10^1 - 10^2) denote a lot of amino acids (20) / basic concepts ($10^5 - 10^6$)
- ▶ Compositionality:
 - ▷ In DNA/RNA, a sequence of **codons** “denotes” a sequence of **amino acids** that represents (part of) a protein;
GAU CAC UUA G UU
Asp — His — Ser — Val
 = Denot(Codonstring-Codon) — Denot(Codon)
 in language, a sequence of morphemes denotes a complex concept; but we find a hierarchical organization and different combination rules, allowing for syntactic ambiguity.
[[old men] and women]
OLD(MEN) ^ WOMEN
- ▶ Additional similarities:
 - ▷ Start/Stop codons (AUG / UAA...) to identify a gene;
 - ▷ boundary symbols (prosody, punctuation signs) in language.
 - ▷ Scopal operators and to enhance / suppress expression of gene.

5 / 28

Compositionality before human language?

Evidence for compositionality in non-human communication is scarce:

- ▶ Suffix in Campbell monkeys' alarm calls (Oatara e.a. 2009):
 - ▷ Two specific alarm calls can be extended by a particular continuation leopard alarm call



- ▷ Meaning in all cases: broadening of concept, e.g. 'eagle' vs. 'possible danger from above', e.g. 'sudden flying animal'
- ▷ Cf. attenuative affixes in human language: *green* vs. *greenish*, rather meaning modification than meaning combination
- ▶ Meaningful repetition of calls (Stephan & Zuberbühler 2008)
 - ▶ Sequences of basic calls in bird and whale song, in primates
 - ▷ Such sequences are very limited (Hurford 2009)
 - ▷ and are interpreted holistically, not compositionally (Arnold & Zuberbühler 2012)
- ▶ But there is evidence for the ability of certain animals to acquire compositional rules:
 - ▷ Understanding: Two-word commands for dogs (Ramos & Ades 2012):
 - ▷ training of {point/fetch} {ball, key, stick, bottle, bear},
 - ▷ extension to new verb-noun combinations
 - ▶ Production: Bonobo Kanzi (Savage-Rumbaugh 1993; Anderson 2004).

6 / 28

From holistic to compositional meaning: examples

Assume a communication system with holistic meanings;

- ▶ Question: How can a compositional system arise?
- ▶ Holistic symbols → decomposed into parts with their own meaning.

Holistic (e.g. mimetic) symbols:

- ▶ Ildefonso, a deaf person who grew up in a community of non-signers, cf. Schaller 1991 – a novelistic account; is it reliable?
- ▶ Other “feral children” – little exposure to symbols of any kind

Spontaneous development of compositionality

- ▶ In home signers (Goldin-Meadow 2007):

“The surprising result was that the deaf children’s gestures did not look like the gestures their hearing parents produced. Their gestures had language-like structure; the parents’ gestures did not. The children combined gestures, which were themselves composed of parts (...), into sentence-like strings that were structured with grammatical rules for deletion and order. For example, to ask me to share a snack, one child pointed at the snack, gestured eat (a quick jab of an O-shaped hand at his mouth), and then pointed at me.”

- ▶ In artificial language learning experiments by humans (Selten & Warglien 2007), by persons that, of course, already spoke compositional languages.
- ▶ In iterated learning experiments by algorithms (Smith and Kirby).

7 / 28

From holistic meaning to compositional meaning: Theoretical aspects

Making use of **accidental** similarities between holistic symbols and their meaning, plus analogical extension

- ▶ Logic of the argument:
 - ▷ Two signs α , α' differ in one recognizable feature, ‘
 - ▷ Their meanings $\llbracket \alpha \rrbracket$, $\llbracket \alpha' \rrbracket$ differ in one recognizable feature: $\llbracket \alpha' \rrbracket = f(\llbracket \alpha \rrbracket)$
 - ▷ The sign α' is analyzed as complex, $[\alpha']$, the feature ‘ gets interpreted as f , a compositional meaning rule is applied: $\llbracket [\alpha'] \rrbracket = \llbracket ' \rrbracket(\llbracket \alpha \rrbracket) = f(\llbracket \alpha \rrbracket)$
- ▶ Further development: ‘ is applied to other expressions β , with $\llbracket [\beta'] \rrbracket = \llbracket ' \rrbracket(\llbracket \beta \rrbracket)$
- ▶ A hypotheticalal example:
 - ▷ $\llbracket \text{ear} \rrbracket$ = ‘ear’, $\llbracket \text{hear} \rrbracket$ = ‘perceive by ear’, = ‘hear’
 - ▷ reanalysis: *h-ear*, interpretation $\llbracket h \rrbracket(x)$: ‘perceive by x’
 - ▷ new hypotheticalal application: $\llbracket h\text{-eye} \rrbracket = \llbracket h \rrbracket(\llbracket \text{eye} \rrbracket) =$ ‘perceive by eye’ = ‘see’
- ▶ A real example: backformation
 - ▷ $\llbracket \text{ham} \rrbracket$ = ‘ham’, $\llbracket \text{hamburger} \rrbracket$ = ‘sandwich with ham’ (not quite, but close enough)
 - ▷ reanalysis: *ham-burger*, interpretation $\llbracket \text{burger} \rrbracket(x)$: ‘sandwich with x’
 - ▷ new application: $\llbracket \text{cheese-burger} \rrbracket = \llbracket \text{burger} \rrbracket(\llbracket \text{cheese} \rrbracket) =$ ‘sandwich with cheese’

But:

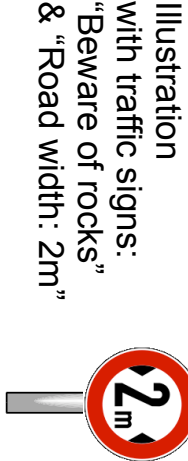
- ▶ this presupposes a compositional language faculty, or at least a “compositional mind”!
 - ▶ How did this compositional mind develop in the first place?
- First, let’s look at various types of composition!

8 / 28

Composition types: Accumulation

A very simple sort of composition,

- If $\llbracket S_1 \rrbracket = C_1$ and $\llbracket S_2 \rrbracket = C_2$, then $\llbracket S_1 \circ S_2 \rrbracket = C_1 \& C_2$
- simple due to iconicity of \circ and $\&$



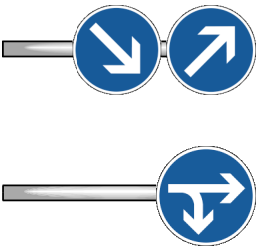
“Accumulation” rather than “Conjunction”:

- Conjunction and disjunction: operations for propositions
- whose meanings are defined by truth tables
- and which are equally complex

ϕ	ψ	$\phi \wedge \psi$	$\phi \vee \psi$
t	t	t	t
t	f	f	t
f	t	f	t
f	f	f	f

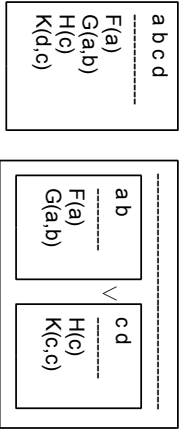
Accumulation is a simpler operation than conjunction and disjunction.

- Disjunction cannot be expressed by simple juxtaposition



- “Conjunctive” concepts much easier to learn than disjunctive ones (e.g., Feldman 2000)

- In DRT, dynamic semantics: “Conjunctions” simpler than disjunctions



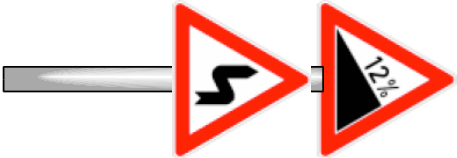
9 / 28

Composition type:

Accumulation with excessive meaning

Accumulated signs might have more meaning, than the simple sum of the individual signs

- they lead to behavioral consequences that exceed the consequences of individual signs.



Possible development of idiomatic, non-compositional meanings

Composition types: Sequencing

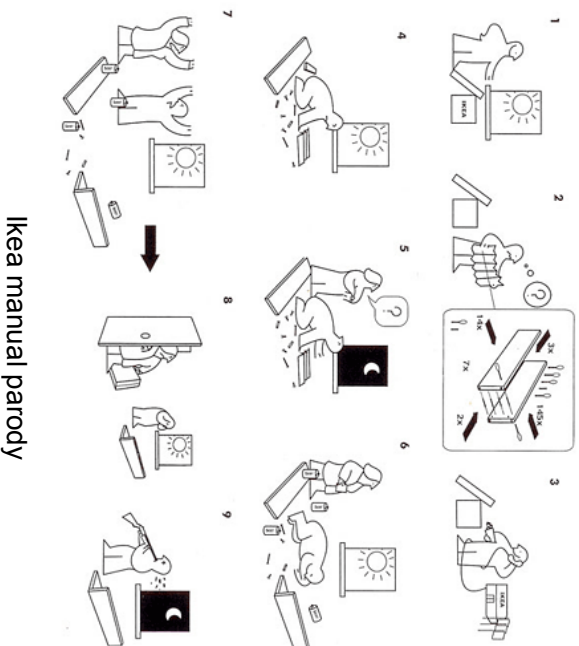
Composition, with <: temporal order

- If $\llbracket S_1 \rrbracket = C_1$ and $\llbracket S_2 \rrbracket = C_2$, then $\llbracket [S_1 < S_2] \rrbracket = C_1 < C_2$
- simple due to iconicity of < and <

No explicit marking in language in narrative sequences,

cf. German *erzählen*, French *conter*

- *He took off his shoes and went to bed.*
- *He went to bed and took off his shoes.*



Ikea manual parody

- Special sequencing in genetic code:
- Sequence of codons in DNA/RNA correspond to sequence of amino acids in the protein

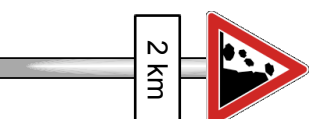
11 / 28

Composition types: Modification

Concept modification:

- $\llbracket [\text{Modifier Head}] \rrbracket = \llbracket \text{Modifier} \rrbracket (\llbracket \text{Head} \rrbracket)$
- the modifier adds meaning to a head that carries meaning already.

Example traffic sign:
- “Beware of rocks”
- for the next 2 km



Varieties of modification:

- **Intersective**: no special role of head, rather: accumulation, e.g. *female human*, = *human female*, inference pattern: If x is a female human, then x is female, and x is human
- **Subsective**: special role of head, e.g. *huge mouse*, *skillful surgeon* inference pattern: If x is a skillful surgeon, then x is a surgeon; the modifier *skillful* is dependent on the head: ‘skillful as a surgeon’
- **Non-subsective**: e.g. *alleged thief*
 - Subclass: **privative**, e.g. *fake money*, *former president* inference pattern: If x is a former president, then x is not a president

Modification in language:

- Structure in X-bar-Theory: $[_{XP} [_{YP} \alpha] [_{XP} \beta]]$
- Examples: *[Adjective [N]], [Adverb [V]], [Sentence adverb [S]]*

Modification in animal communication?

- Attenuative modifiers (e.g. -oo in alarm calls of Campbell monkeys)
- Intensive modifiers – greater signal strength?

12 / 28

Composition types: Saturation

Concept saturation:

- $\llbracket \text{[Head Argument]} \rrbracket = \llbracket \text{Head} \rrbracket (\llbracket \text{Argument} \rrbracket)$
- The argument saturates a slot provided by the head
- Head is incomplete, resulting expression is complete (cf. Frege, saturated/nonsaturated meanings)

- For indefinite argument: dummy expression, e.g. Chinese *chi fan* 'eat rice', 'eat'



Saturation in language:

- Structure in X-bar-Theory: [_{XP} [_X α] [_{YP} β]]
- Examples: [Verb Object], [Preposition Object]
- Multiple saturation?
 - [Subject [Verb Object]]
- Structure in X-bar-Theory: [_{XP} [_{YP} α] [_{X̄} β] [_{ZP} γ]]]
 - alternatively: [_{XP} [_{YP} α] [_{XP} [_X β] [_{ZP} γ]]]

Saturation in animal communication?

- apparently does not exist.

Composition types: Boolean operations

Boolean concept combinations are complex,

- Negation as erasure, with conventionalized erasure sign
- Conjunction expressed by accumulation (see above)
- Disjunction? (see above)



Don't turn left






Why not:
Forbidden to turn left?
No double negation!

German sign:
Turn left
or
turn right

- Implication (if-then)? Attempts e.g. conventionalized signs in pictopen.com

beware of... kids

forbidden for... cars

  = 



sign in Spreewald

If I do this, you will do that :
 $s \rightarrow \rightarrow \rightarrow \square, r \rightarrow \rightarrow \rightarrow \square$

Composition types: Precursors?

Question:

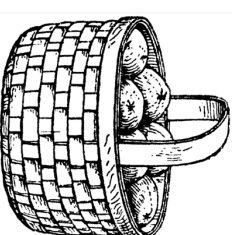
- ▶ Are there functional homologues of the composition types that may be understood as precursors to linguistic compositionality?
- ▶ Possible answers:
 - ▷ Action sequences, e.g. hunting, collecting, preserving, food preparation, fire making
 - ▷ Conceptualization and creation of tools.

Some proposals:

- ▶ Accumulation: Very basic; production of A and production of B is production of A and B
- ▶ Sequencing: production of A followed by production of B is production of A followed by B
- ▶ Modification:
 - When modifying an object (e.g. polishing a handaxe surface, putting ochre on face) one keeps the object constant but changes certain properties of it.
- ▶ Saturation: Composite tools, e.g. stone axe, harpoon, basket

Tool making (and perhaps other complex activities) lead to a “compositional mind”

- ▶ Cf. Stout e.a. 2008 on functional correlates between tool making and language



15 / 28

Topic-Comment Structure

Topic-comment structure in human communication

- ▶ Hockett (1958):
 - The most general characterization of predicative constructions is suggested by the terms “topic” and “comment” [...]: The speaker announces a topic and then says something about it.
- ▶ Long established history (cf. Krifka & Musan 2012)
 - ▷ underlying subject/predicate distinction in Aristoteles
 - ▷ “mubtada” and “xabar”, ‘beginning’ and ‘message’ in Arabic tradition,
 - ▷ “psychologisches Subjekt” and “psychologisches Prädikat”, Georg.v.d.Gabelentz (1869), Hermann Paul (1880)



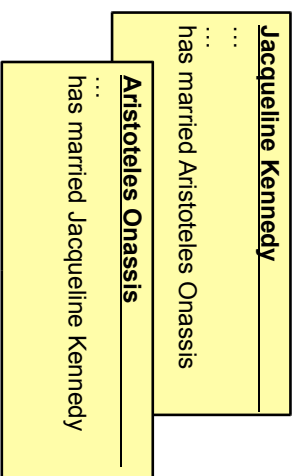
Me Tarzan, you Jane

16 / 28

Topic-Comment Structure

Suggested modeling in Reinhart (1982): File Cards

- ▶ *Jacqueline Kennedy married Aristoteles Onassis.*
Topic: Jacqueline Kennedy
Comment: that she married Aristoteles Onassis.
Topic: *Aristoteles Onassis married Jacqueline Kennedy.*
Comment: that he married Jacqueline Kennedy.
Influence on ease of recall:
▶ Cf. Repp & Drenhaus 2011 on object left dislocation as a topic marker in German



- Properties of topic:
- ▶ Tendency for initial position (e.g., Rizzi 1997 for Italian, Frey 2001 for German); also in artificial languages, e.g. algebra: $f(x) = x^2 + x + 1$
 - ▶ Default information status of subjects
 - ▶ Direct topic marking, e.g. Japanese *wa*, Tagalog *ang*.
 - ▶ Topics are typically given (definite, deaccented)

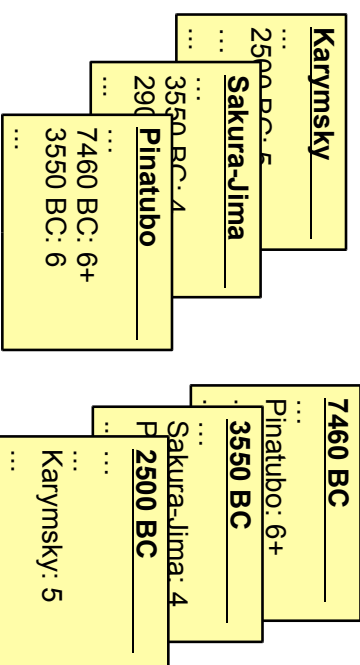
17 / 28

Topic-Comment Structure and information storage

Nature of topic-comment structure

- ▶ Reinhart suggests that topic-comment structure appeals to a way how information is organized in the human mind
- ▶ Bear in mind that this is not the only way how information can be organized, cf. e.g. file cards vs. relational database.

Volcano	Year	Strength
Pinatubo	7460 BC	6+
Sakura-Jima	3550 BC	4
Karymsky	2500 BC	5
Pinatubo	3550 BC	6
Sakura-Jima	2900 BC	4



Relational database
about volcano eruptions

File cards
about volcanoes

File cards
about years

Topic-comment structure in animal communication?

- ▶ as far as I know, does not exist
- ▶ e.g., apes do not point (Tomasello & Zuberbühler 2002), probably a prerequisite for drawing attention to a topic.

18 / 28

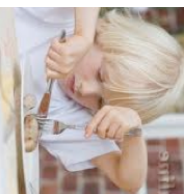
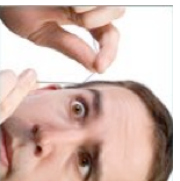
A precursor for topic/comment structure: bimanual manipulation

Asymmetry in hand use:

- ▶ Human hands are symmetric, but are used in different ways:
 - ▷ About 90%: right hand to throw a stone, to eat with a spoon, to write with a pen etc.
 - ▷ This dominance is evident from fragments for stone tools, from hand paintings etc. for > 20,000 years (Faurie & Reymond 2004, Steele & Uomini 2009) and is certainly much older (e.g. Neanderthals; Uomini 2011)
- ▶ Role of hand asymmetries in brain lateralization, crucial for neurophysiology of language (strong left lateralization, for right handers; less strong for left handers)

Explanation of asymmetry:

- ▶ MacNeillage e.a. (1984), MacNeillage (1998): Frame-Content model, non-dominant hand creates a frame into which the dominant hand adds content.
- ▶ Guiard (1987): Kinematic chain model, the motions of the dominant (right) hand find its spacial reference in the results of the motions of the non-dominant (left) hand:



19 / 28

A precursor for topic/comment structure: bimanual manipulation

Krifka (2008) proposes a functional similarity of topic/comment and non-dominant/dominant hand in bimanual actions:

- ▶ Basic similarity:
 - ▷ Non-dominant hand fixates an object, dominant hand operates on it and changes it.
 - ▷ Topic expression identifies a concept, comment modifies it by adding information.
- ▶ Temporal sequencing:
 - ▷ Non-dominant hand acts first by grasping an object, followed by dominant hand to operate on the object (kinematic theory, Guiard)
 - ▷ Topic expression identifies a concept first, modification by comment follows, hence topic-comment sequence.
- ▶ Coarseness of operations:
 - ▷ Non-dominant hand performs more coarse-grained operations, dominant hand is able to perform finely controlled movements.
 - ▷ Topics are typically shorter, less complex, deaccented; comments are more complex, prosodically more prominent.

Asymmetric hand use in language: Sign and Gesture

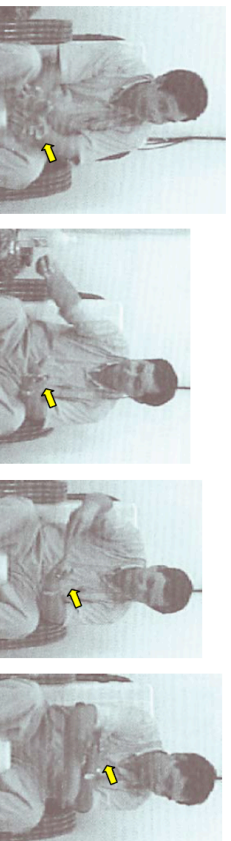
Sign languages:

- ▶ Liddell (2003): so-called “buoys”, signs that structure discourse, by non-dominant hand, so-called “theme buoys” for non-dominant hand.



Gesture in spoken language:

- ▶ Enfield (2004), gestures in speech of Laos fishermen describing their traps: Non-dominant hand keeps holding information, while dominant hand adds new information



21 / 28

Topics and hand use: *take*

The verb *take* can be grammaticalized as a discourse topic marker: (M. Haspelmath, pers. communication):

- ▶ *I don't think that people will like this kind of food. Take John. He is a vegetarian.*

This use of 'take' verbs is not well recognized:

- ▶ Not mentioned in Heine & Kuteva, *World lexicon of grammaticalization* (2002)
- ▶ Mentioned by Hopper (2008, mainly about the *take X and ...* construction)
- ▶ May be widespread – perhaps including 'take' as marker for definite objects, e.g. Chinese.

Analysis:

- ▶ 'Take' verbs basically denote grasping an object.
- ▶ One purpose for grasping an object is to modify it.
- ▶ A topic-comment structure consists in an instruction to identify an object and assign information to it.

▶ The identification of the object can be categorized as a taking of the object.
 ▶ Commands of the form 'take x' can grammaticalize to instructions to make x a topic.
 Use of 'take' and hand asymmetry:

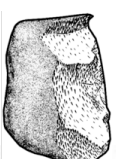
- ▶ Topic-use of 'take' should relate to non-dominant hand
- ▶ Non-topic use of 'take' should relate to dominant hand:
Hungry? Take an apple!
- ▶ Can models of embodied cognition tell whether there's a difference? (That's a real question.)

22 / 28

Bimanual coordination → Topic/Comment

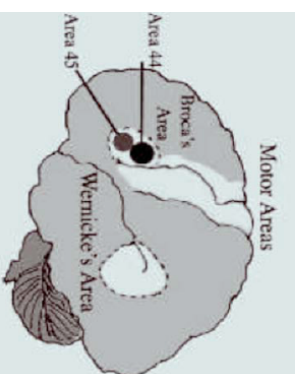
Time depth of asymmetric bimanual manipulation to produce artifacts:

- ▶ Australopithecus species (4 – 2 million years), Homo habilis, Homo ergaster (2,3-1,3 million years) tools: stone flakes (choppers) made by hitting a core (Oldowan)
- ▶ Homo erectus (1,8 million years – 150,000 years): tools that were successively formed by “adding” features to an object (Acheulean)
 - ▷ hand axes
 - ▷ sharpened blades



Bimanual manipulation as pre-adaptation for topic/comment structure:

- ▶ Increasing lateralization of hands for asymmetric bimanual work
- ▶ concomitant lateralization of brain, development of specialized brain area for manipulation
- ▶ this area was co-opted for the development of topic/comment structures in communication
- ▶ Broca area controls object combination and word combination (Greenfield 1991), is “the action-orchestrating area of the brain” (McNeil 2005), is related to tool making (Stout e.a. 2008, 2012)



Bimanual manipulation and compositionality:

- ▶ Combination Topic + Comment is necessarily compositional,
- ▶ Comment is an unsaturated concept, saturated by the topic.

23 / 28

Propositions: Their nature and their benefits

What are propositions?

- ▶ Propositions have truth values; they can be true or false w.r.t. a particular situation.
- ▶ With expressions that denote propositions, one can lie; with non-propositional expressions one can deceive, not lie.
- ▶ Example: Assertions vs. exclamatives:
 - ▷ A: *This is an expensive car.* B: *You are lying.*
 - ▷ A: *What an expensive car!* #B: *You are lying.*

Communication does not depend on propositions

- ▶ Campbell Monkey alarm call *kraak* probably does not mean: ‘there is an eagle in the air’, but rather something like ‘beware of eagle’, or pointing towards the sky.
- ▶ Many other forms of communication are not propositional, e.g. wearing a tattoo, expressing amazement about something, waving goodbye.

Communication presumably did not start out as propositional

- ▶ A recent example: programming languages, imperative programming (Algol, Fortran) vs. declarative programming (Prolog)

What are the benefits of propositional communication?

- ▶ Assume: benefit of communication consists in influencing the behavior of others
- ▶ This can be achieved directly (commands) or indirectly (e.g. by showing some attitude), from which the addressee can draw certain inferences to form beliefs.
- ▶ Propositions: Allow to express these beliefs directly, hence allow a more direct modulation of the beliefs of others.

24 / 28

Propositions, reference and compositionality

A first take:

- ▶ Assume that propositions represent believes.
- ▶ Believes are “about something” – this something can be referred to (cf. Reinhardt’s metaphor of a file card)
- ▶ Primacy of propositions (Frege: “judgements”) and reference; from that: properties (concepts) can be derived:
- ▶ If there is a proposition p that is about an object x, then there is a concept c such that, when combined with x, results in p

Declarative sentences:

- ▶ instructions to change believes, i.e. to attribute a property to an entity.
- ▶ topic-comment (categorical) sentences directly express a proposition
- ▶ so-calledthetic sentences (e.g. *it is raining*) attribute a property to a given situation.
- ▶ Explains Strawson’s observation:
 - ▷ *The exhibition was visited by the King of France*.False, as the property of being visited by the KoF cannot hold of the exhibition.
 - ▷ *The King of France visited the exhibition*.No truth value, as the entity the property is attributed to does not exist.

25 / 28

Wrapping up

- ▶ Compositionality as an essential feature for human language
- ▶ Compositionality can arise when a compositional mind deals with holistic symbols
- ▶ Production of complex tools (and perhaps other complex actions) can lead to a compositional mind
- ▶ One important action consists in grasping an object and modifying it; this was argued to be a functional analogue to topic-comment structure
- ▶ and this might even explain lateralization of the hands and linguistic lateralization of the brain.

26 / 28

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