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# THE COGNITIVE FUNCTIONS OF INNER SPEECH

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# Overview

- In a first step, statements by Peirce and by Wittgenstein will be related to contemporary *cognitive conceptions of language*.
- In a second step I shall characterize cognitive mechanisms involved in language evolution and development, such as statistical, pattern-detecting learning mechanisms (“inferential machinery”) and specialized working memory.
- Main arguments will flow into questions concerning *preparatory functions* of inner speech: “Preparatory” not only with respect to forthcoming utterances and arguments in more or less foreseeable debates. I shall suggest a much more general “side-effect” of this ongoing activity: *It provides continual updating and increased readiness of our highly developed symbol-manipulating system, thus preparing it for a wide spectrum of possible demands of future communication.*

# “Minds who think in words”?

- “Language and all abstracted thinking, such as belongs to **minds who think in words**, [are] of the symbolic nature”, says Peirce (1976: 243). But words, “though strictly symbols”, may realize additional semiotic functions as well: Many of them “are apt to determine iconic interpretants / .../; that are *onomatopoetic*, as they say.” And there are also words acting “very much like indices. Such are personal demonstrative, and relative pronouns”.
- Thus language provides all the tools necessary for communication and abstracted thinking. But note that Peirce admits the possibility of forms of thinking that are not of the symbolic nature.

# “Minds who think in words”?

- Early Wittgenstein takes on a more radical position: “The boundaries of my language are the boundaries of my world” (5.6 in the *Tractatus*).
- In the *Philosophical Investigations* he is distancing himself from this position; but especially talking to oneself remains inextricably linked with thought and *Verstand*: “When I think in language, there aren’t ‘meanings’ going through my mind in addition to the verbal expressions: the language is itself the vehicle of thought” (§329). And “... couldn’t we imagine God’s suddenly giving a parrot understanding [*Verstand*], and its now saying things to itself?” (§346).

## “Minds who think in words”?

- Wittgenstein’s dictum on the boundaries of his language as the boundaries of his world is in line with what is known – and criticized (Holenstein 1980) – as the doctrine of the *Nichthintergebarkeit* of language. This doctrine is avoiding well-known problems with the empirical basis of linguistic representation.
- In Peirce, Wittgenstein’s “closest precursor” (Moyal-Sharrock 2003) , the “object of a representation can be nothing but a representation of which the first representation is the interpretant” (CP 1.339). Mitterer’s (1992: 56, §13) contemporary non-dualistic description of *description* as a continuation of an already given description is reminiscent of Peirce’s (CP 1.339) characterization of *representation* as a representation of the representation behind it in a series of representations.

## Peirce: CP 1.339

“The object of representation can be nothing but a representation of which the first representation is the interpretant. But an endless series of representations, each representing the one behind it, may be conceived to have an absolute object at its limit. The meaning of a representation can be nothing but a representation.”

## Mitterer 1992: p. 56, §13

“Das Objekt der Beschreibung ist nicht beschreibungs- oder ‘sprachverschieden’, sondern jener Teil der Beschreibung, der bereits ausgeführt worden ist.

*Die Beschreibung ist nicht auf das Objekt gerichtet, sondern geht vom Objekt der Beschreibung aus; sie führt die schon geleistete Beschreibung fort; sie ist die Fortsetzung der vor ihr schon vorliegenden Beschreibung.”*

## The *cognitive conception of language*

- Contemporary authors propose a ***cognitive conception of language*** as opposed to a purely communicative conception.
- Carruthers (2002) distinguishes between weak and strong versions. The strong version of the ***cognitive conception*** claims that “*all* thought requires language”, says Carruthers and places Wittgenstein among the proponents of this “anti-realist” position. “Weak versions”(???) view language, for instance, as a cognitive scaffold for the build-up of more complex thoughts.
- His own hypothesis figures somewhere between strong and weak versions: Language is the medium of *conscious* propositional thinking and, moreover, of “*all* non-domain-specific reasoning of a non-practical sort (whether conscious or non-conscious)”.



## The *cognitive conception of language*

- Frankish (2010) characterizes the *linguistic mind* as a *level of mentality* “which operates by accessing and manipulating representations of natural language sentences”; “early humans learned to engage in private speech and to regulate it using metacognitive skills originally developed for use in public argumentation.” (p. 206) “Language-based reasoning will thus be ***genuinely computational***, though the computation in question will be carried out at an explicit, personal level.” (p. 213)
- One of the main assumptions of the famous Russian school associated with the names Vygotsky, Luria, and Sokolov: “In planning the spoken or written utterance, inner speech has an essential rehearsal or speech preparatory role.” (Guerrero 2005)

# How to grow a linguistic mind

- The oldest mechanism required is pattern-detecting, inferential machinery. Its inferences go far beyond the data available. It is not purely data-driven but incessantly generating top-down processes, i.e. “hypothesis-testing”.
- Powerful statistical learning and pattern recognition show in infants’ “co-occurrence statistics between words and referents” (Vouloumanos and Werker 2009), in their acquisition of rudimentary phrase structure (Saffran 2001), and, already in the age of eight months, in the separation of words (Saffran et al. 1996).
- Saffran et al. characterize this “as resulting from innately biased statistical learning mechanisms”. A functionalist interpretation of Chomsky’s innate *Language Acquisition Device*?

# How to grow a linguistic mind

- Experiments using transcranial magnetic stimulation (TMS) indicate “a direct link between the language and the manual/facial action system” (Rogalewski et al. 2004).
- But a predominantly auditory-articulatory communication is, other than predominantly visual-gestural communication, functional even without inter-visibility (Wilson 1975). And the hands, the eyes, and thus also the “eye-hand dyad” remain, where necessary, free for other (visually guided) activities such as the flight through the branches or the use and making of tools.

# How to grow a linguistic mind

- The detection of patterns in the sound stream requires, however, a selective “echoic memory”. Such a sensory memory retaining vocal utterances seems to be quite common in a wide range of species but was most probably augmented in the course of language evolution, and, moreover, specialized for verbal utterances of increasing complexity and duration.
- Echoic memory is assumed to contribute to the recency-effect in the serial position curve, and cumulative rehearsal to the primacy-effect. In the recall of sentences the recency-effect goes even further back than in series of unconnected words (Fenk & Fenk-Oczlon 2006).

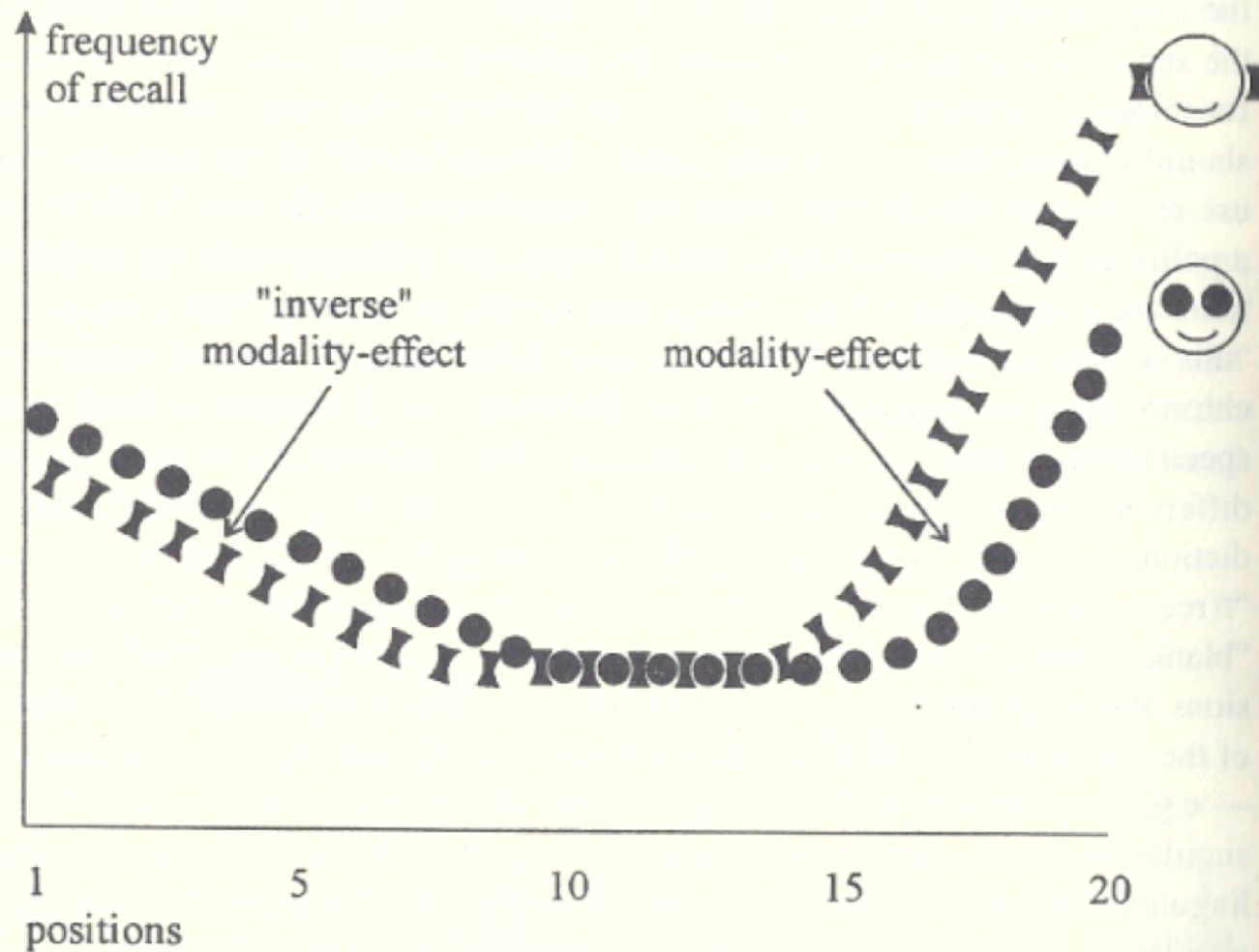
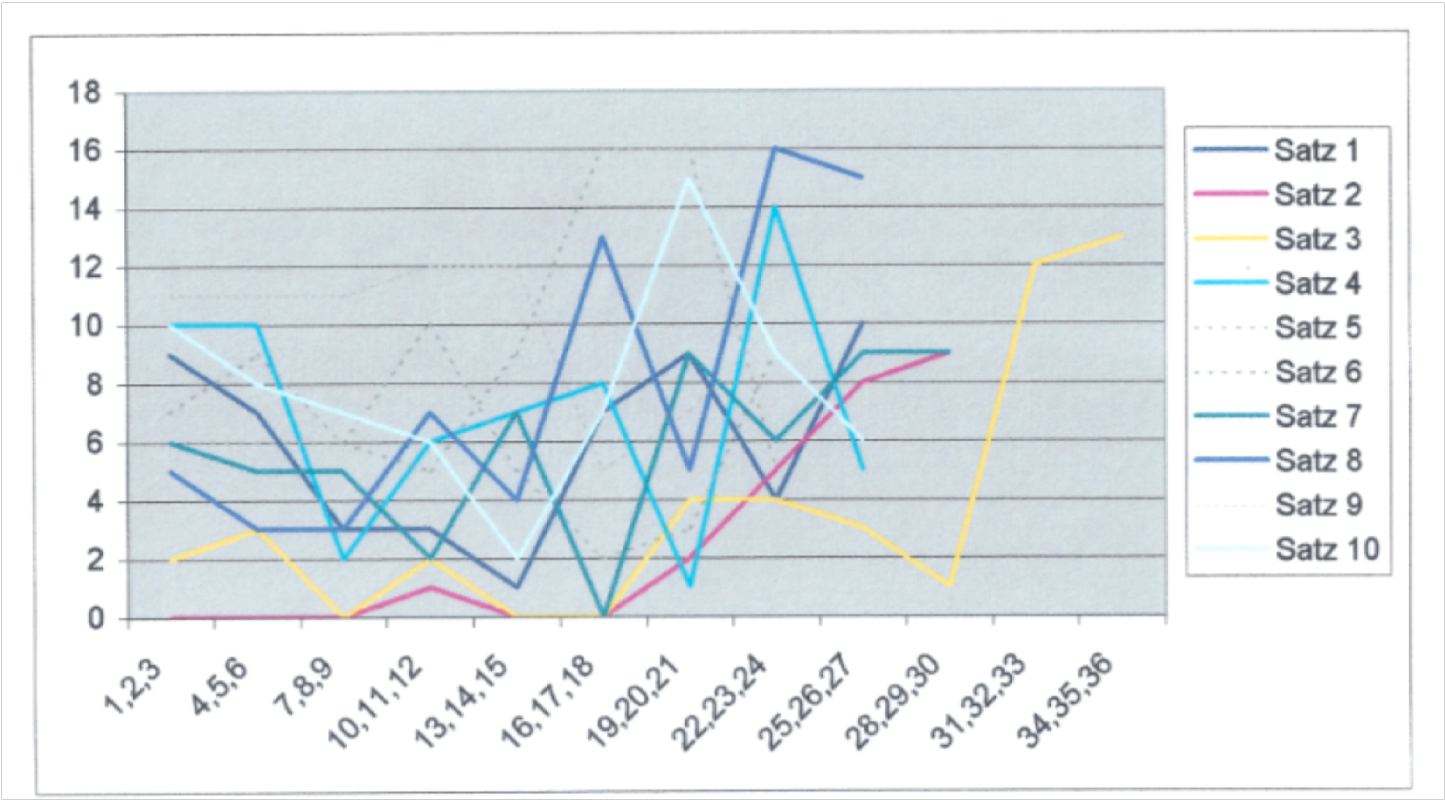


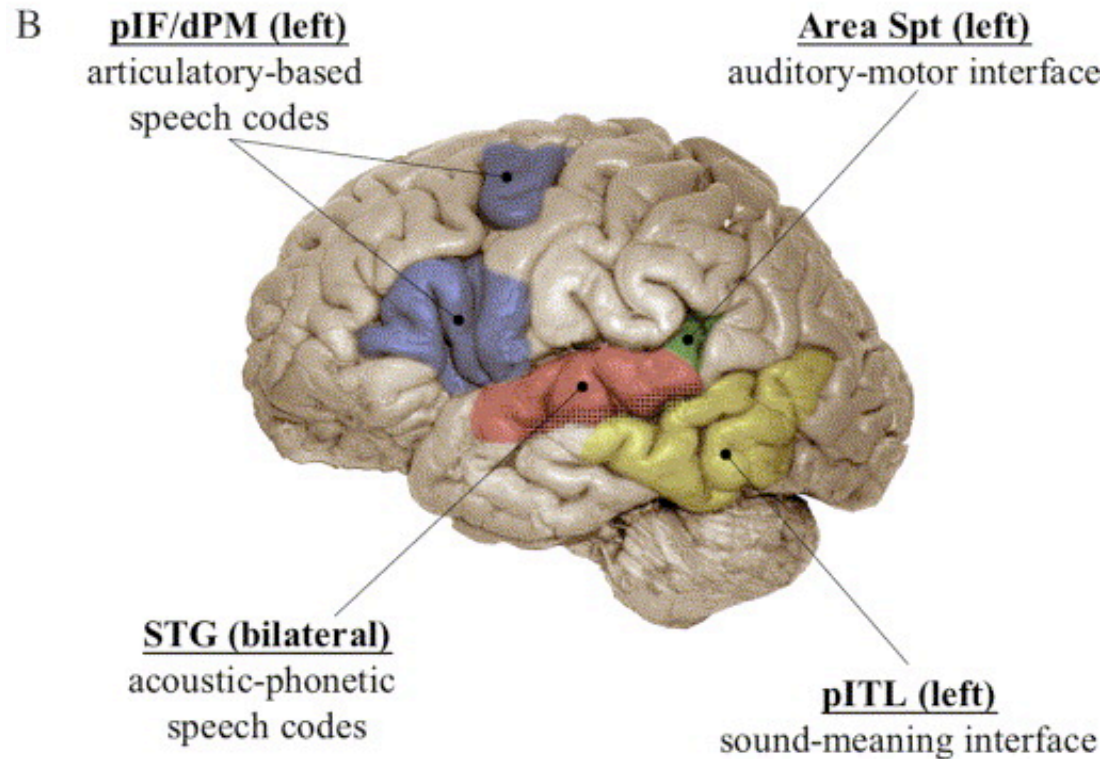
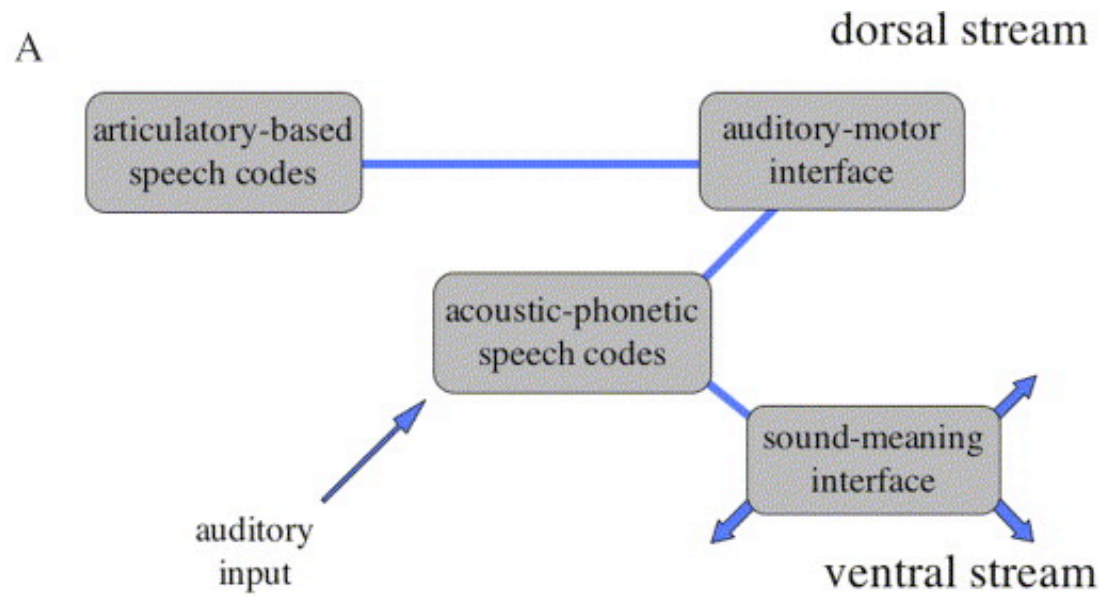
Figure 3. *Serial position curves in immediate free recall of either visually or auditorily presented words (from Fenk 1981: 223; modified)*



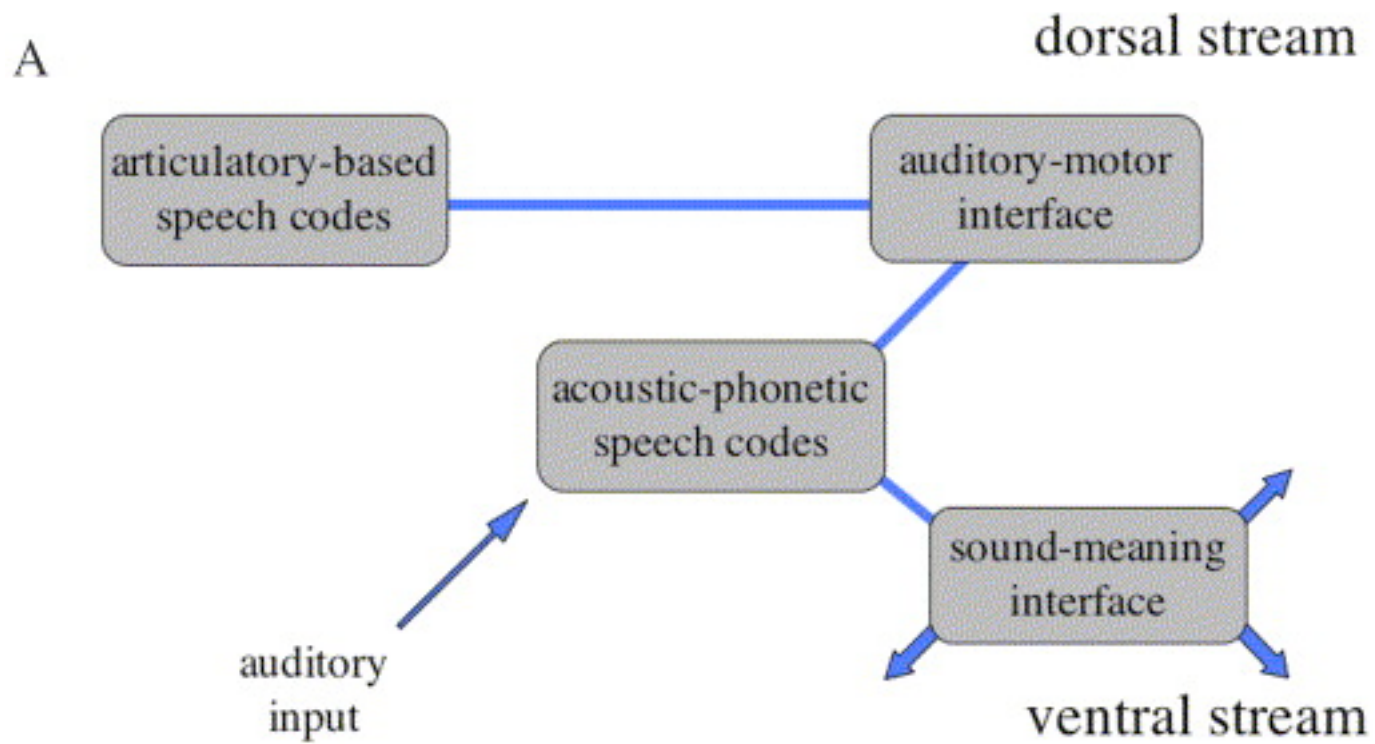
## How to grow a linguistic mind

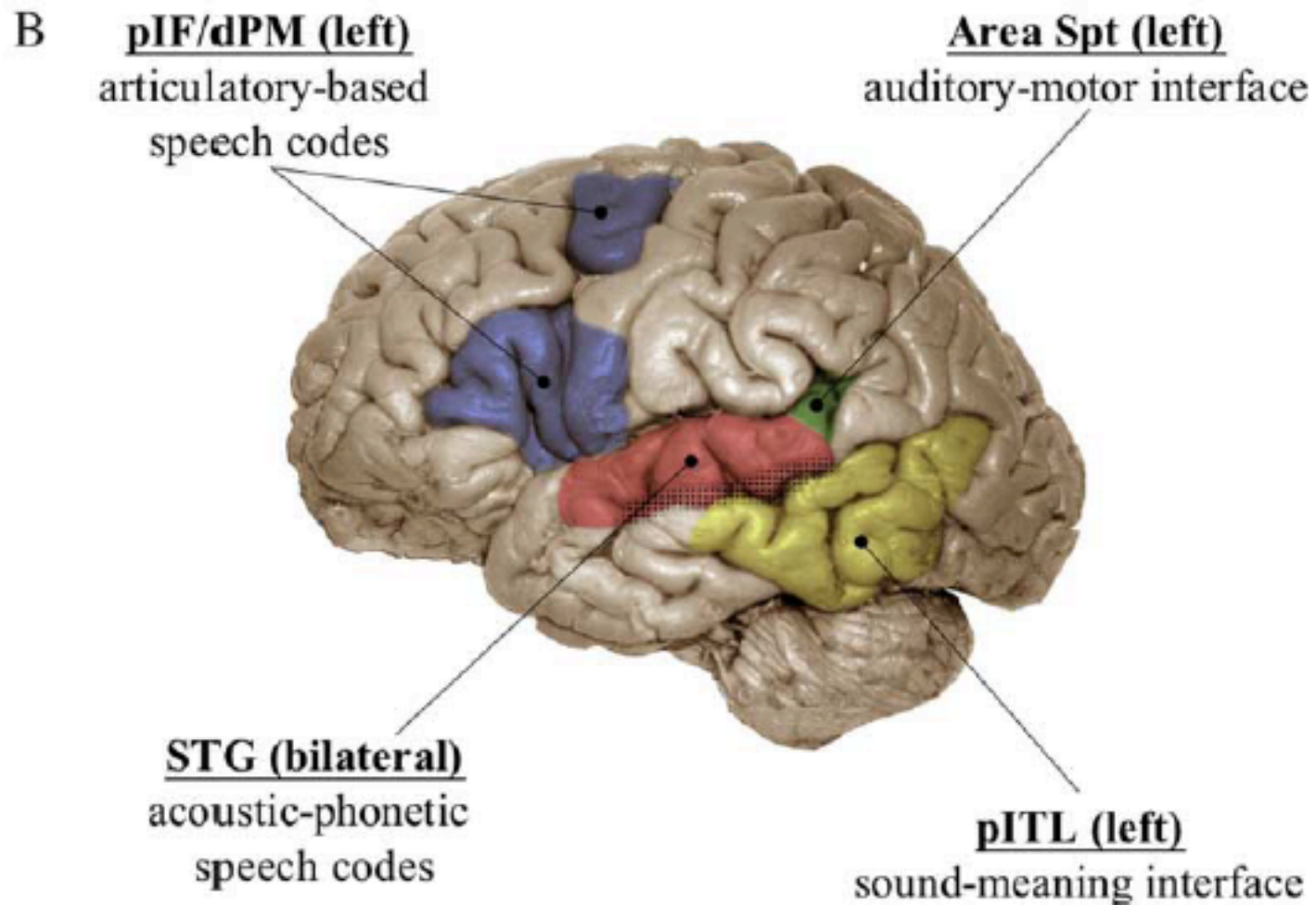
- *Rehearsal* of utterances, as well as their planning, inner try-out and monitoring, needs a feedback-loop that allows “self-generated patterns” of articulatory circuits to interact with auditory circuits. Descriptions of neural circuits (Hickok & Poeppel 2004) rendering such “motor-to auditory mappings” suggest that the respective *auditory-articulatory interface connects to an auditory-conceptual interface*.
- Such integration is a prerequisite of *verbal working-memory* in the sense of a relatively autonomous, actively “self-feeding” processor, apt to keep self-generated patterns resonating and circulating within our symbol-manipulating system.
- Recent experiments by Geva et al. (2011) indicate, moreover, that the neural processes operating inner speech are initiated in frontal regions before they involve posterior regions that “link speech production to speech comprehension.”

Hickok &  
Poeppl  
2004:71









# Relating Frankish's *linguistic mind* to Wittgenstein

- According to Frankish (p. 212), humans internalized their skills in interpersonal argument; on the level of mentality, where linguistic reasoning happens, they experience themselves as intentionally acting. And linguistic clauses or intonation units can be viewed as a special case of action units (Fenk-Oczlon and Fenk 2002).
- Should we, therefore, assume that the clausal structure of speech shapes inner speech – and thus even thought? Later Wittgenstein would deny at least this last step from linguistic structure to the structure of thought:
  - “Thought and intention are neither ‘articulated’ nor ‘non-articulated’” (Wittgenstein 2006: 185).
  - In Wittgenstein “a thought lacks duration” and hence can neither accompany a sentence nor occur in an accelerated form (Budd 1989: 144).
- But Wittgenstein could neither know empirical evidence for motor theories of speech perception (Liberman and Mattingly 1985) and cognition nor for a temporal segmentation (Schleidt and Kien 1997) of cognitive activities.

## Relating Frankish's *linguistic mind* to Wittgenstein

- Frankish considers that even language-based reasoning will be ***genuinely computational***. Post-Tractarian Wittgenstein also considers something beyond, prior and fundamental to language and thought. “This something is *grammar*”, asserts Moyal-Sharrock (2003: 131), referring to Wittgenstein’s *On Certainty*.
- Many of her explications of *grammar* fit with what is often addressed as “computational” – an indeed appropriate label for Wittgenstein’s definition of *meaning* in the *Investigations* (§43): “the meaning of a word is its use in the language”:
- Under this conception, say Manning and Schütze (1999), much of Statistical NLP (Natural Language Processing)-research “directly tackles questions of meaning.” (*Google Translate* relies, like the native speakers of one or more than one language, rather on statistical than explicitly rule-based analysis).

# Inner speech as continuous training of language processing and production

- Even more demanding than the detection of regularities is the integration of this enormous body of “computational” – non-personal, non-conscious, and in the essence statistical – knowledge of language into the production system, i.e., its ongoing proceduralization. Inner speech helps improving linguistic/rhetoric skills and keeping them on a personally high level. This preparation for fast and accurate interpretation and action in future situations comes by
  - (i) a facilitation of the access to, or retrieval from, implicitly learned, predictive statistical dependencies allowing for instance a fast and automatic check of an expression’s possible meaning(s) in a given context,
  - (ii) a more or less habitual training of those complex interactions between an auditory-motor interface and an auditory-conceptual interface operating our verbal working memory, and
  - (iii) a continual adjustment of programming devices to a huge and ever growing body of tacit or implicit, statistical/linguistic knowledge.

## Inner speech as continuous training of language processing and production

- In point (i) the focus is on the role of the hearer and in (iii) on that of the speaker. But this is anyhow a rather artificial distinction: Not only is the *speaker* always also listener of her own utterances, but also is the *hearer* a tentative and anticipative, though subvocal “co-speaker” of the utterances she is listening to.
- This view might well be extended to the special kind of inner speech that accompanies **reading**. Here its main function is the transformation of a visual code into the auditive-articulatory code of our verbal working memory; but the long-term training- and programming-effects mentioned above will be realized as well.

## To summarize:

- Inner speech prepares for future argumentation, and this kind of preparation is supported by its more general function of scaffolding the build-up of complex thought and arguments.
- In the present paper I wanted to draw attention to even more general but less obvious benefits of this “mental training”, i.e., the priming and fitness of highly developed, “genuinely computational” mechanisms operating language as a cognitive and communicative tool.

## References

- Bickerton, Derek 1995 *Language and Human Behavior*, Seattle: University of Washington Press.
- Budd, Malcolm 1989 *Wittgenstein's Philosophy of Psychology*, London: Routledge.
- Buzsáki, György 2006 *Rhythms of the Brain*, Oxford: Oxford University Press.
- Carruthers, Peter 2002 “The Cognitive Functions of Language”, *Behavioral and Brain Sciences* 25, 657-726.
- Fenk, August and Fenk-Oczlon, Gertraud 2006 “Within Sentence Distribution and Retention of Content Words and Function Words”, in: Peter Grzybek (ed.), *Contributions to the Science of Text and Language*, Dordrecht: Springer, 157-170.
- Fenk-Oczlon, Gertraud and Fenk, August 2002 “The Clausal Structure of Linguistic and Pre-linguistic Behavior”, in: Talmy Givón and Bertram F. Malle (eds.), *The Evolution of Language out of Pre-Language*, Amsterdam: John Benjamins, 215-229.
- Fenk-Oczlon, Gertraud and Fenk, August 2009-2010 “Some Parallels between Language and Music from a Cognitive and Evolutionary Perspective”, *Musicae Scientiae*, special issue, 201-226.



- Frankish, Keith 2010 “Evolving the Linguistic Mind”, *Linguistic and Philosophical Investigations* 9, 206-214.
- Geva et al. 2011 “The Neural Correlates of Inner Speech Defined by Voxel-based Lesion–symptom Mapping”, *Brain* 134, 3071-3082.
- Guerrero, Maria C.M. de 2005 *Inner Speech - L2: Thinking Words in a Second Language*, New York: Springer.
- Hickok, Gregory et al. 2003 “Auditory-Motor Interaction Revealed by fMRI: Speech, Music, and Working Memory in Area Spt”, *Journal of Cognitive Neuroscience* 15, 673-682.
- Hickok, Gregory and Poeppel, David 2004 “Dorsal and Ventral Streams: a Framework for Understanding Aspects of the Functional Anatomy of Language”, *Cognition* 92, 67-99.
- Holenstein, Elmar 1980 *Von der Hintergehbakeit der Sprache*, Frankfurt am Main: Suhrkamp.
- Lieberman, Alvin M. and Mattingly, Ignatius G. 1985 “The Motor Theory of Speech Perception Revised”, *Cognition* 21, 1-36.
- Manning, Christopher D. and Schütze, Hinrich 1999 *Foundations of Statistical Natural Language Processing*, Cambridge, MA: The MIT Press.

- Mitterer, Josef 1992 *Das Jenseits der Philosophie: wider das dualistische Erkenntnisprinzip*, Wien: Passagen-Verlag.
- Moyal-Sharrock, Danièle 2003 “Logic in Action: Wittgenstein’s *Logical Pragmatism* and the Impotence of Scepticism”, *Philosophical Investigations* 26, 125-148.
- Peirce, Charles S. 1976 [1904] “Καινὰ στο ἰχθῆα”, in: Carolyn Eisele (ed.), *The New Elements of Mathematics* 4, Atlantic Highlands, NJ: Humanities Press, 236-263.
- Peirce, Charles S. 1931 CP 1.339, in: Charles Hartshorne and Paul Weiss (eds.) *Collected Papers of Charles Sanders Peirce*, Vol.1, Cambridge, MA: Harvard University Press.
- Rogalewski, Andreas et al. 2004 “Prosody as an Intermediary Evolutionary Stage between a Manual Communication System and a Fully Developed Language Faculty”, *Behavioral and Brain Sciences* 27, 521-522.
- Saffran, Jenny R. 2001 “The Use of Predictive Dependencies in Language Learning”, *Journal of Memory and Language* 44, 493-515.
- Saffran, Jenny R. et al. 1996 “Statistical Learning by 8-month-old Infants”, *Science* 274, 1926-1928.
- Schleidt, Margret and Kien, Jenny 1997 “Segmentation in Behavior and what it Can Tell us about Brain Function”, *Human Nature* 8, 77-111.

- Vouloumanos, Athena and Werker, Janet F. 2009 “Infants’ Learning of Novel Words in a Stochastic Environment”, *Developmental Psychology* 45, 1611-1617.
- Tenenbaum, Joshua et al. 2011 “How to Grow a Mind: Statistics, Structure, and Abstraction”, *Science* 331, 1279-1285.
- Wilson, Edward O. 1975 *Sociobiology. The New Synthesis*, Cambridge, MA: Harvard University Press.
- Wittgenstein, Ludwig 2006 [1953][1933] *Philosophical Investigations*, Malden (MA): Blackwell Publishing.



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# **Language evolution requires and reinforces inferential machinery**

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# Overview

- An increasingly complex language requires and stimulates developments of neurocognitive mechanisms that in turn allow further progress in language. This framework – **reference needs inference, reference “feeds” inference** – suggests a general principle explaining the fast evolution of our capabilities to use and acquire complex languages.
- **Aim:** Here we shall put that framework more precisely with regard to the perceptual/cognitive mechanisms involved and the succession of their involvement in the course of language-evolution.
- **Method:** This attempt requires a lot of “uncertain conjectures” from partial and indirect information, thus suggesting a use of the “probabilistic approach” and its “top-down or ‘function-first’ strategy” (Griffiths et al. 2010).

# Overview

- Starting point is the inferential, pattern-extracting machinery in general **(i)**
- It requires especially in the auditory mode an efficient sensory memory because of the principally transitory character of acoustical input **(ii)**
- A system integrating the respective perceptual circuits with articulatory circuits is able to keep (intended) utterances resonating for various purposes **(iii)**

# Method

- In their plead for a top-down/function-first strategy in cognitive modeling, Griffiths et al. (2010) refer to Marr's (1982) **three levels**:
  - **(a) Computation**: What is the goal of computation and the logic of the strategy by which it can be carried out?
  - **(b) Representation and algorithm**: What is the representation for the input and output, and what the algorithm for the transformation?
  - **(c) Hardware**: How can the representation and algorithm be realized physically?
- One of Griffiths' arguments for a top-down strategy starting with level **(a)** in the analysis of human cognition: We are far from understanding level **(c)**, i.e., "how rich knowledge can be implemented in neural circuits."



# Method

- In our case, the object to be modeled is the neurocognitive machinery that is required for the development, acquisition and use of complex natural languages.
- Since language acquisition itself follows a top-down or hypothesis-driven strategy requiring a lot of “uncertain conjectures” from partial and indirect information, the use of a probabilistic top-down approach in this field is “reflexive” in the sense (of Giere 1985) that it has “itself as an instance”.

## (i) Inferential machinery in general

- Our perceptual/cognitive system appears to make inferences that “go far beyond the data available” (Tenenbaum et al. 2011)
- It is not purely data-driven but is incessantly generating top-down processes, i.e. “hypothesis-testing”. This picture connects with neurobiological descriptions:
  - Buzsáki (2006): “‘Representation’ of external reality is /.../ a continual adjustment of the brain’s self-generated patterns by outside influences”.
  - Ringach (2009): “ongoing cortical activity represents a continuous top-down prediction/expectation signal that interacts with incoming input to generate an updated representation of the world”.

## (i) Inferential machinery in general

- Continuous interactions between expectation and input also explain the effects of **learning by doing**, e.g. through an efficient anticipatory allocation of visual attention (Collins and Barnes 2009).
- The respective anticipations are vital and allow for instance (faster) pattern recognition.
- Anticipation plays a **multiple role** in experience
  - as a precondition for efficient learning,
  - as an essential aim
  - and criterion of success of the learning process.
- Cognitive progress, in this sense, is done by a continuous projection of more or less fitting hypotheses onto the process under consideration (“use of redundancy”) and continuous modifications induced by discrepancies between the expected and the observed – to the effect that the predictability of events and the efficiency of the analysis increase.

## **(i) Inferential machinery in general**

- Such an inferential machinery is required for anticipating events and for “anticipating” what the other would already know or understand or intend, i.e. for efficient “mind-reading” (Fenk & Fenk-Oczlon 2007)
- Social intelligence, incl. a “theory of mind”, obviously plays a very general role in the evolution of communication systems (Fitch et al. 2010). But which facets of intelligence are, in addition and more specifically, required for the development of human language?

## (ii) Inferential machinery in language development

- Pattern recognition, as a central function of inferential machinery and statistical inference, is inevitable for the identification of utterances at any complexity level (phonological, morphological, syntactical). For instance:
- “Sensitivity to frequency with which different sounds follow each other in speech” helps us to break the speech record up into words (Zacks & Hasher 2002)

## (ii) Inferential machinery in language development

- Saffran et al. (1996) could demonstrate such a separation of words already in 8-month-old infants and characterize that “as resulting from innately biased statistical learning mechanisms”. (A functionalist interpretation of an innate *Language Acquisition Device*?)
- Powerful statistical learning and pattern recognition also show in the acquisition of rudimentary phrase structure (Saffran 2001) and in the detection of word-referent relations (Vouloumanos & Werker 2009).

## (ii) Inferential machinery in language development

- The **detection of patterns** in the sound stream requires a selective “**echoic memory**”: The development of a predominantly verbal or “half-musical” (Jespersen 1922; Fenk-Oczlon & Fenk 2009) language – possibly from an alarm-system (Noble et al. 2010) using, for obvious reasons, the auditory channel – must have gone together with the development of a sensory memory retaining unprocessed clauses of increasing complexity and duration.
- But serial position effects in the recall of words from auditorily presented sentences (Fenk & Fenk-Oczlon 2006) seem to reflect, moreover, rehearsal processes:

### **(iii) Auditory-articulatory integration**

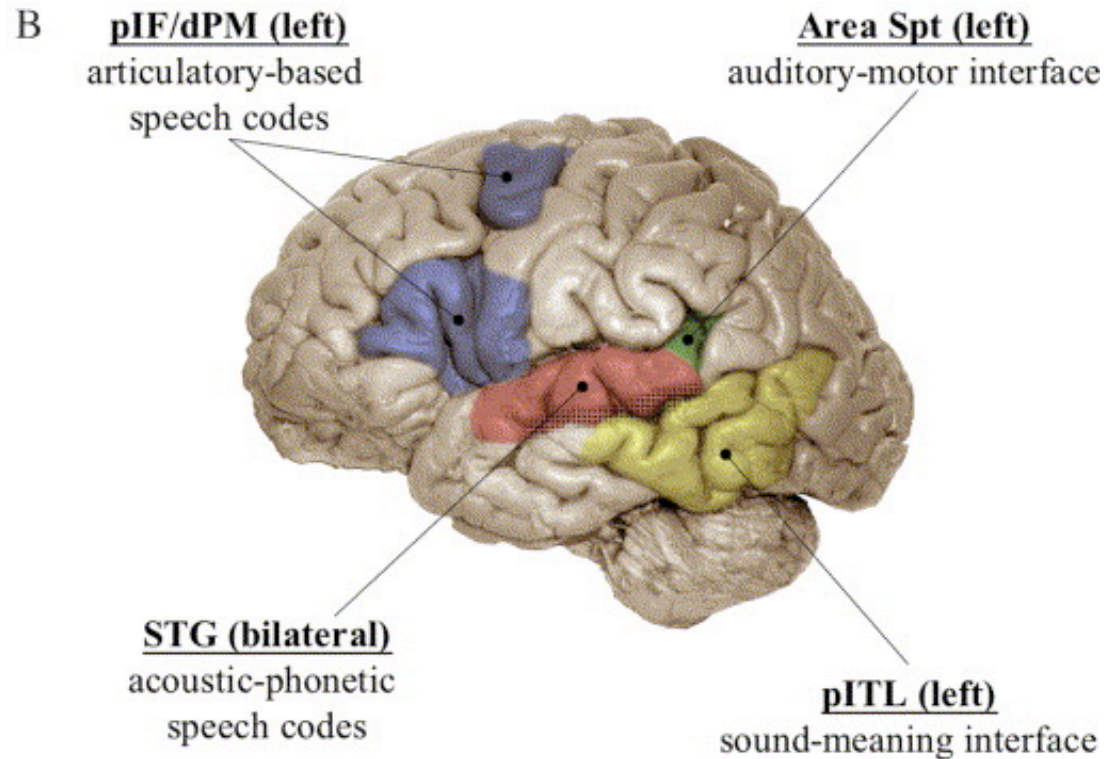
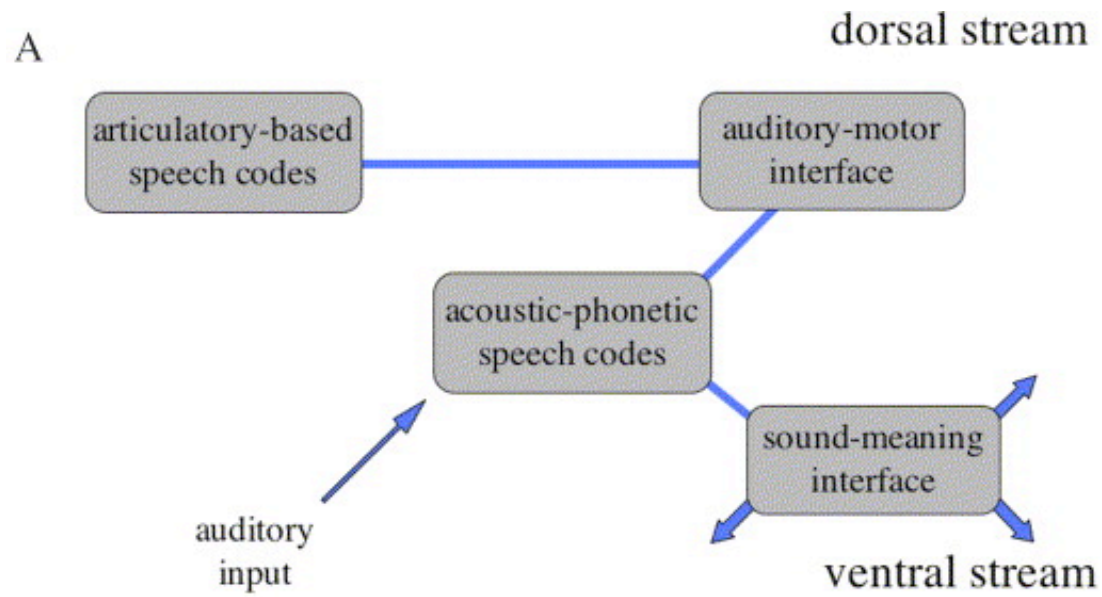
- Rehearsal as well as a monitoring of intended propositions needs a coupling that allows “self-generated patterns” of articulatory circuits to interact with auditory circuits (Hickok et al. 2003; Hickok & Poeppel 2004:89)
- Such a back-coupling is a prerequisite of a verbal working-memory.

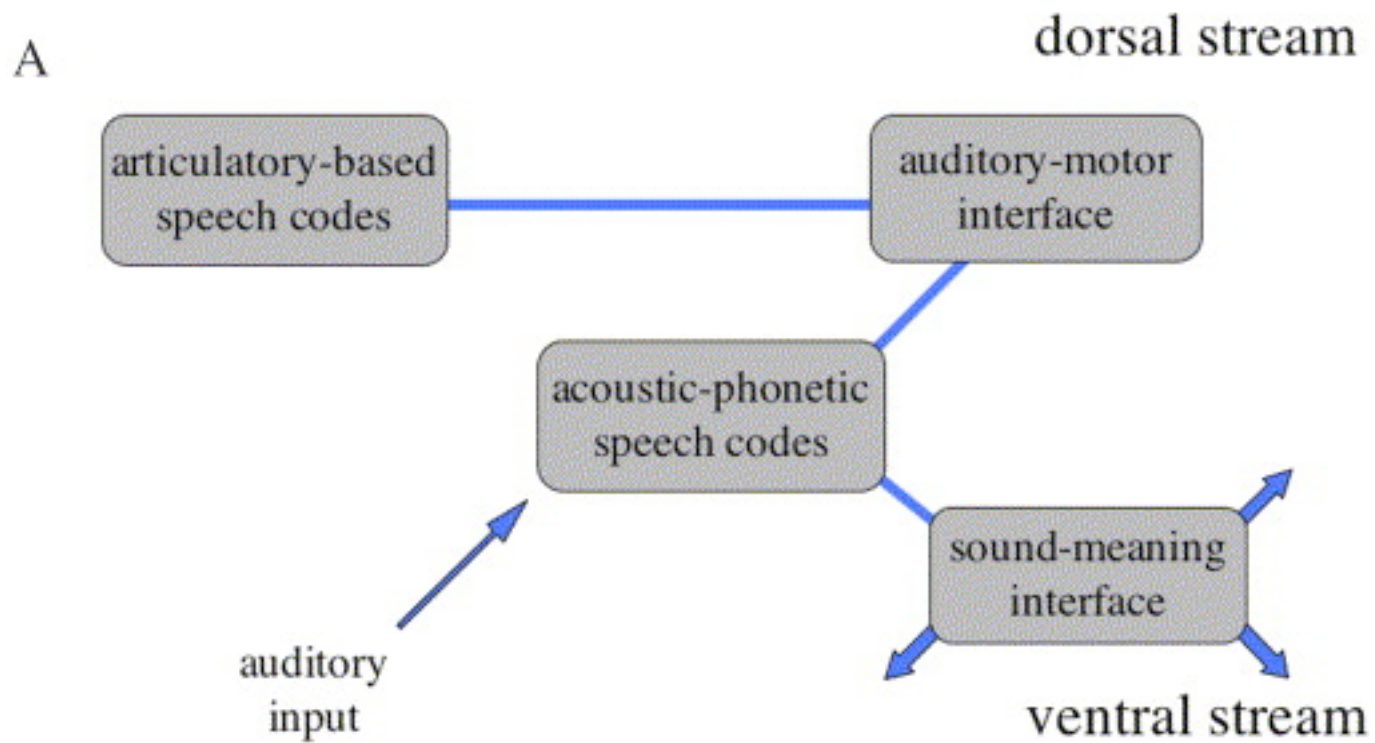


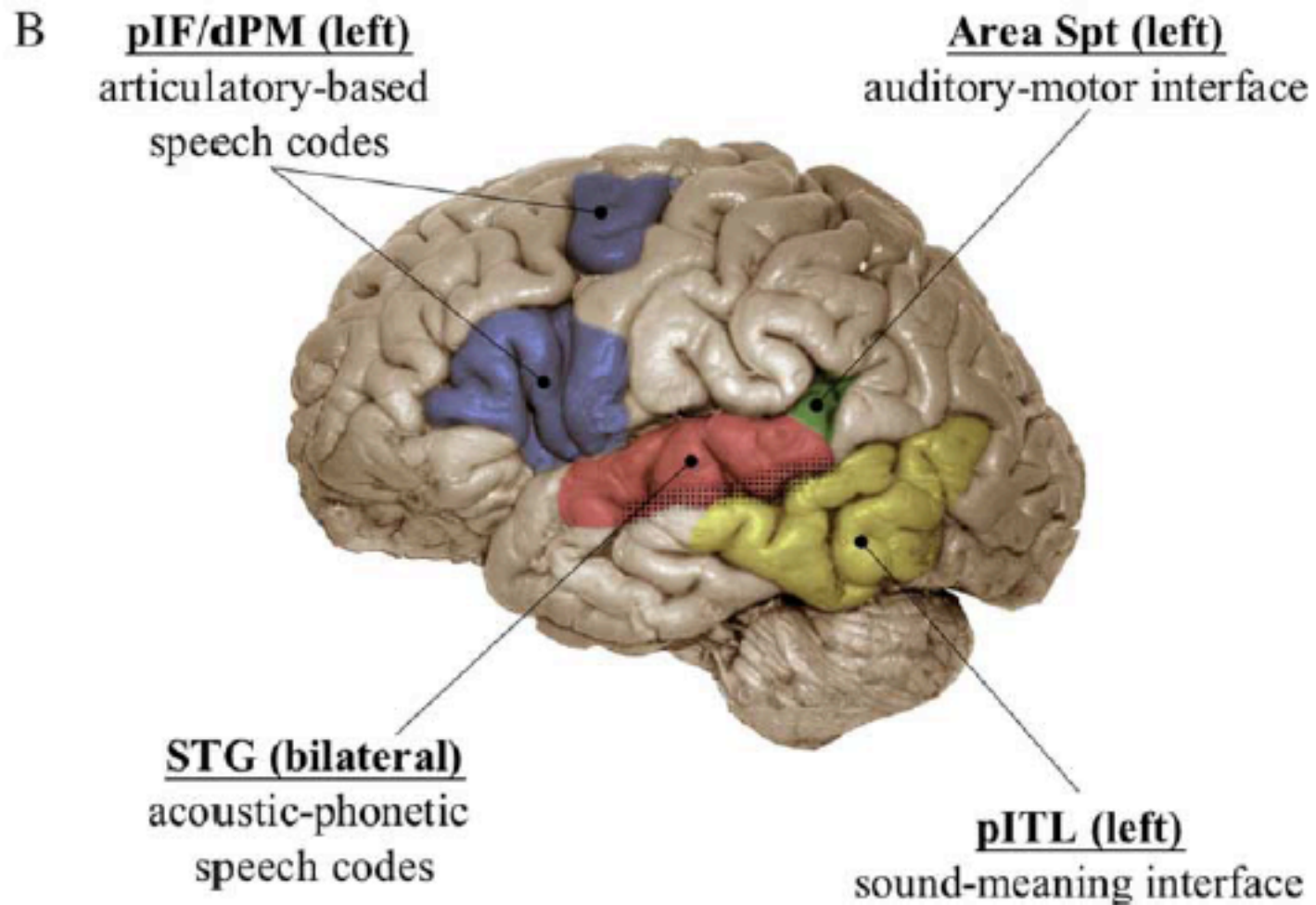
# Interfacing interfaces?

- Hickok & Poeppel (2004) describe a connection of auditory-related cortices with
  - (a) “motor representation via projections to temporal-parietal regions (the dorsal stream)”
  - (b) “conceptual representations via projections to portions of the temporal lobe (the ventral stream)”
- This would mean that our auditory-articulatory interface (a) interfaces, via auditory-related cortices, with an auditory-conceptual interface (b) - a prerequisite of, and maybe the origin of a relatively autonomous, “self-feeding” and symbol-manipulating system that is deeply involved in the human thought process.

Hickok &  
Poepfel  
2004:71







# Excursus: Why an auditive-articulatory code?

- Such a code is, other than a visual-gestural code, functional even without intervisibility (cf. alarm-calls). And the hands, the eyes, and thus also the “eye-hand dyad” remain free for other (visually guided) activities such as the flight through the branches and tool-making.
- Our “long-distance” senses are involved in the control of our own body’s activities. Probably a selective advantage: the specialisation of
  - an “eye-hand dyad”: eye-hand coordination to guide and control manual activities
  - an “ear-mouth dyad” for an auditory guidance and control of a predominantly articulatory communication

## Concluding remarks

- The old idea of a “ratiomorphic”, intuitive-statistical apparatus (Brunswik 1957; Gregory 1974) has, though criticized as just metaphorical (Gigerenzer & Murray 1987), proved to be very successful.
- Its basic principle, i.e. the comparison of top-down predictions with sensory input, is still reflected at several levels of language perception: cf. the revival of the Halle & Stevens’ analysis-by-synthesis model (Poehpel & Monahan 2011) and recent descriptions of related neural processes (Sohoglu et al. 2012).
- The more language-specific, the younger the respective mechanisms; inferential machinery, as the most general and fundamental mechanism from a computational view, is the oldest and is an ubiquitous trait at least in **neural** organisms.

# Concluding remarks

- Other recent hominoids will show the same mechanisms as humans – not only inferential machinery, but also echoic memory, auditory-motor integration, and even conceptual representation. But since the human brain seems to be a linearly scaled-up primate brain (Herculano-Houzel 2009), they will exhibit lower degrees of neural connectivity and of performance in each of the fields.
- To claim, however, “based on negative evidence” (de Waal & Ferrari 2010), that primates absolutely *lack* a certain cognitive ability, would be generally risky because of *the asymmetry in our opportunities to experience* (Fenk 2010): This is an asymmetry in favor of “positive” evidence; “negative” evidence would presuppose the possibility of a proof of the 0-hypothesis.

## Lower performance in other recent hominoids --

- on the one hand due to lower degrees of neural connectivity within and between the respective areas,
- on the other due to our language. That symbol system is, as soon as available, at any rate - or at least (Carruthers 2002) - a necessary scaffold for the build up of complex thoughts. Actually, it brings about much more: It penetrates and enhances all those mechanisms required for the acquisition and use of language. We are “wired” for language acquisition (cf. the results of Vouloumanos & Werker the Saffran group) – equipped with the necessary statistical calculators and programmed for their intensive training from the beginning of our individual life.
- This difference should be considered in the interpretation of (quasi-)experimental comparisons with children of other species.



## Selected References

- [1] Fenk-Oczlon, G. & Fenk, A. (2002) The clausal structure of linguistic and pre-linguistic behavior. In T. Givón & B.F. Malle (eds.) *The Evolution of Language out of Pre-Language*, 215-229. Amsterdam: John Benjamins
- [2] Fenk, A. & Fenk-Oczlon, G. (2007) Inference and reference in language evolution. In S. Vasniadou et al. (eds.) *Proceedings of EuroCogSci07*, 889. Hove: Lawrence Erlbaum Associates
- [3] Griffiths, T.L. et al. (2010) Probabilistic models of cognition: exploring representations and inductive biases. *Trends in Cognitive Science* 14, 357-364
- [4] Giere, R.N. (1985) Constructive realism. In P.M. Churchland & C.A. Hooker (eds.) *Images of Science*, 75-98. Chicago: The University of Chicago Press
- [5] Tenenbaum, J.B. et al. (2011) How to grow a mind: statistics, structure, and abstraction. *Science* 331, 1279-1285
- [6] Buzsáki, G. (2006) *Rhythms of the brain*. Oxford: Oxford University Press

- [7] Fenk, A. & Fenk, L.A. (2011) Wired for anticipation: an adaptive trait challenging philosophical justification? In C. Jaeger & W. Loeffler (eds.) Epistemology: Contexts, Values, Disagreement. Contributions of the 34<sup>th</sup> International Wittgenstein Symposium, 69-71. Kirchberg am Wechsel: The Austrian Ludwig Wittgenstein Society
- [8] Saffran, J.R. (2001) The use of predictive dependencies in language learning. *Journal of Memory and Language* 44, 493-515
- [9] Saffran, J.R. et al. (1996) Statistical learning by 8-month-old infants. *Science* 274, 1926-1928
- [10] Fenk-Oczlon, G. & Fenk, A. (2009) Some parallels between language and music from a cognitive and evolutionary perspective. *Musicae Scientiae*, Special Issue 2009-2010 "Music and Evolution", 201-226
- [11] Noble, J. et al. (2010) From monkey alarm calls to human language: how simulations can fill the gap. *Adaptive Behavior* 18, 66-82
- [12] Fenk, A. & Fenk-Oczlon, G. (2006) Within sentence distribution and retention of content words and function words. In P. Grzybek (ed.) *Contributions to the Science of Text and Language*, 157-170. Dordrecht: Springer

- [13] Hickok, G. et al. (2003) Auditory-motor interaction revealed by fMRI: Speech, music, and working memory in area Spt. *Journal of Cognitive Neuroscience* 15, 673-682
- [14] Hickok, G. & Poeppel, D. (2004) Dorsal and ventral streams: a framework for understanding aspects of the functional anatomy of language. *Cognition* 92, 67-99
- [15] Brunswik, E. (1957) Scope and aspects of the cognitive problem. In J. Bruner et al. (eds.) *Contemporary approaches to cognition*, 5-31. Cambridge: Harvard University Press
- [16] Gregory, R.L. (1974) *Concepts and mechanisms of perception*. New York: Scribner
- [17] Gigerenzer, G. & Murray, D.J. (1987) *Cognition as intuitive statistics*. Hillsdale, N.J.: Lawrence Erlbaum Associates
- [18] Deacon, T.W. (2010) A role for relaxed selection in the evolution of the language capacity. *PNAS* 107, 9000-9006
- [19] Poeppel, D. & Monahan, P.J. (2011) Feedforward and feedback in speech perception: Revisiting analysis by synthesis. *Language and Cognitive Processes* 26, 935-951
- [20] Sohoglu, E. et al. (2012) Predictive top-down integration of prior knowledge during speech perception. *The Journal of Neuroscience* 32, 8443-8453

# Open Questions

- Rather speculative: Since the development of efficient long-distance nerve tracts in the cerebrum is a matter of the size of that “new” brain, evolutionary age may also be indicated by cortical proximity: The short connections of primary to secondary, “associative” sensory areas should be older than dorsal stream, ventral stream, fasciculus arcuatus, etc.