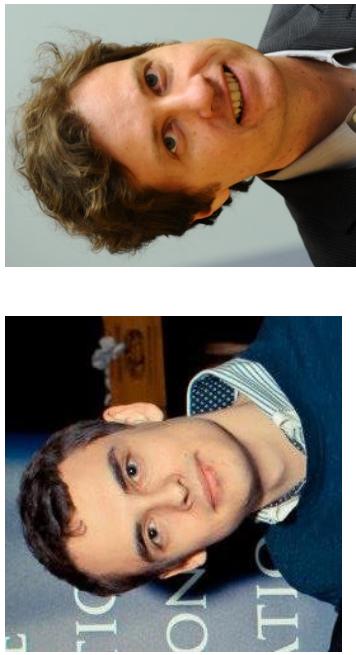


Welcome
to Lecture 12

Computation and the Brain

What happened last Wednesday

Great lectures by Dan Mitropolsky and Mike Collins



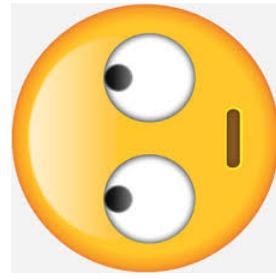
- Language is fascinating. Phonology (sounds), morphology (words), syntax (sentence structure), semantics (meaning), pragmatics (grounded meaning).
- Leaps in parsing technology: shift/reduce, dependencies, deep learning and LSTM's

Today: Language and Evolution (...and Computation)

- Some history and math of language
- Language and the Brain
- Evolution

Next week

- Development of the Brain



- Discussion of Consciousness

- Preliminary project presentations (please volunteer)

How did language come about?

- Some 3 MYBP the hominis group separated from the chimps
- *Habilis, floresiensis, neanderthalensis, heidelbergensis, denisovan, erectus, ergaster, sapiens*
- Only sapiens seems to have had language
- Evidence: lack of trappings of symbolic behavior such as figurative art
- 80 KYBP: first figurative art in Africa
- Did language come about the same time?

How language came about: the cons

- 1866: French Academy bans discussion of the origin of language
- “It is an irresistible question because it is about us. But this does not make it a scientific question. If there is no way to find out by science, then there is no way.” Noam Chomsky
- “If you don’t have a related species with a similar trait you have the problem of novelty.” Richard Lewontin
- Is human fascination with language an exercise in specism?
- **Pinker:** imagine elephants admiring their trunk...

How language came about: Speculation

- Was there a cognitive/neural Big Bang?
- Or gradual progress?
- Perhaps we had language (in some weak sense) far before 80 KYBP
- Maybe around 500 KYBP
- Homo sapiens
- Perhaps we gestured for a very long time
- C Corballis ‘The gestural origin of language’ Wiley 2010

What is needed for language?

- Is a prohibitively sophisticated muscular system in the mouth/face/tongue necessary?
- **(Or is it all in the Mind?)**
- When did we become capable of competent speech?
- Biologists seem to think that **many apes are ready...**
- MC Corballis thinks that we may have switched to speech long after we could have...
- Why was language of thought an **evolutionary advantage?**

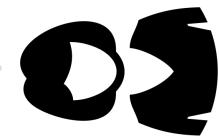
A tale of two island girls
and their mothers, grandmothers, etc.



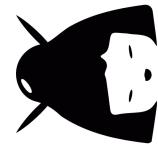
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English and Japanese are
separated by the changes
effected by about four
thousand mothers teaching
language to their children

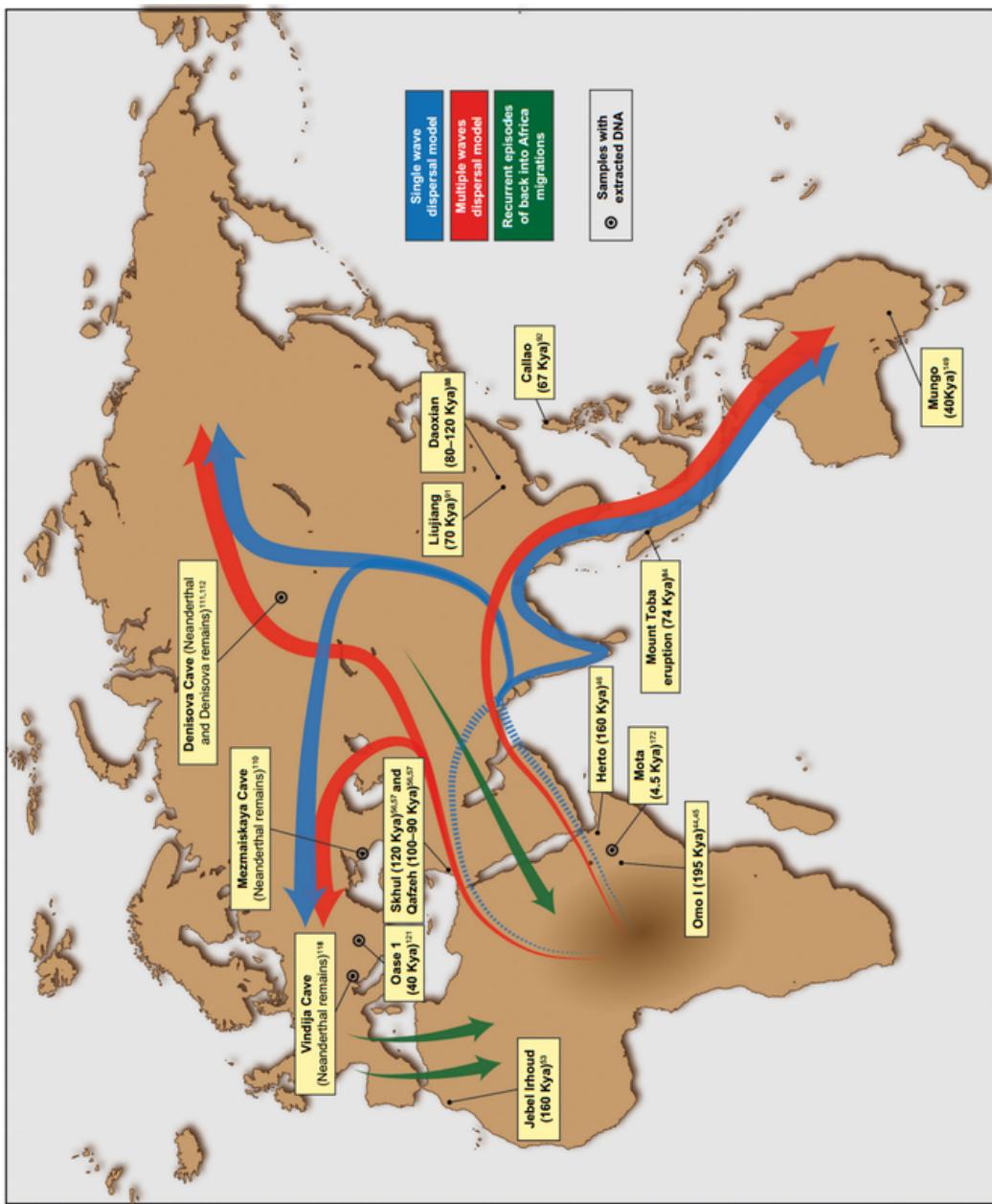


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Out of Africa

- 80 - 70 KYBP
- Europe: 40 KYBP
- Americas: 20 KYBP
- Arctic: 10 KYBP
- Polynesia: 2 KYBP
- Single migration?
• Or multiple?



A tale of two island girls
and their mothers, grandmothers, etc.

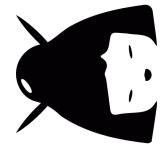
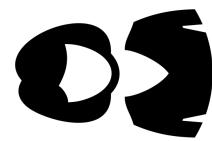


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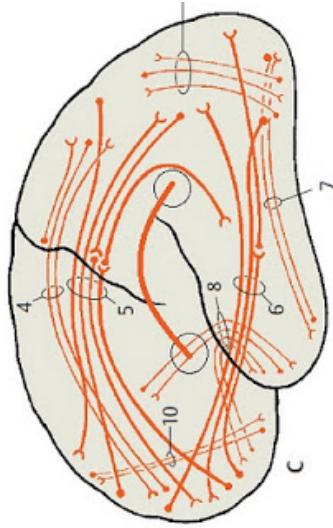
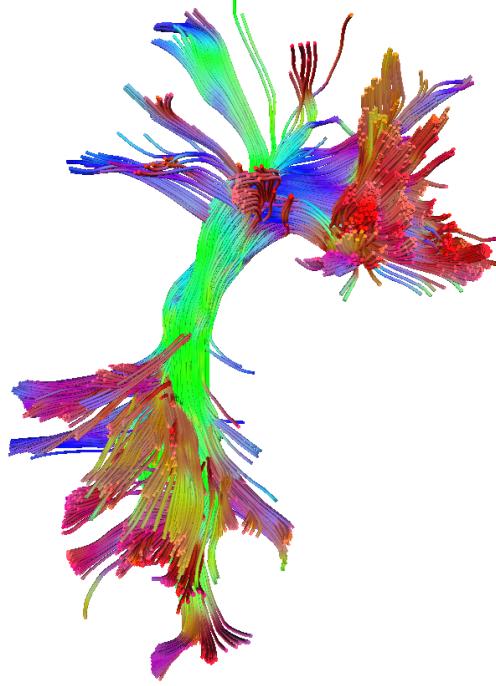
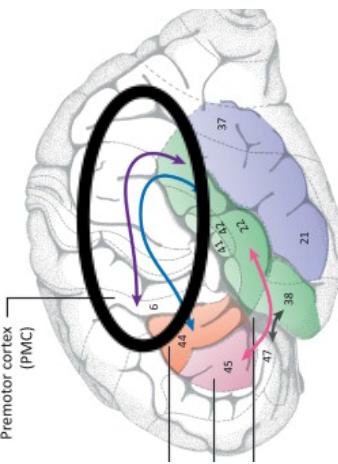
Btw, Tongan and Hawaiian
are only a few dozen
mothers apart...



Was there a neural Bing Bang?

- Our left and right hemispheres are anatomically asymmetric
- Seems to be specific to humans

- Main locus of asymmetry: the *arcuatum fasciculum*

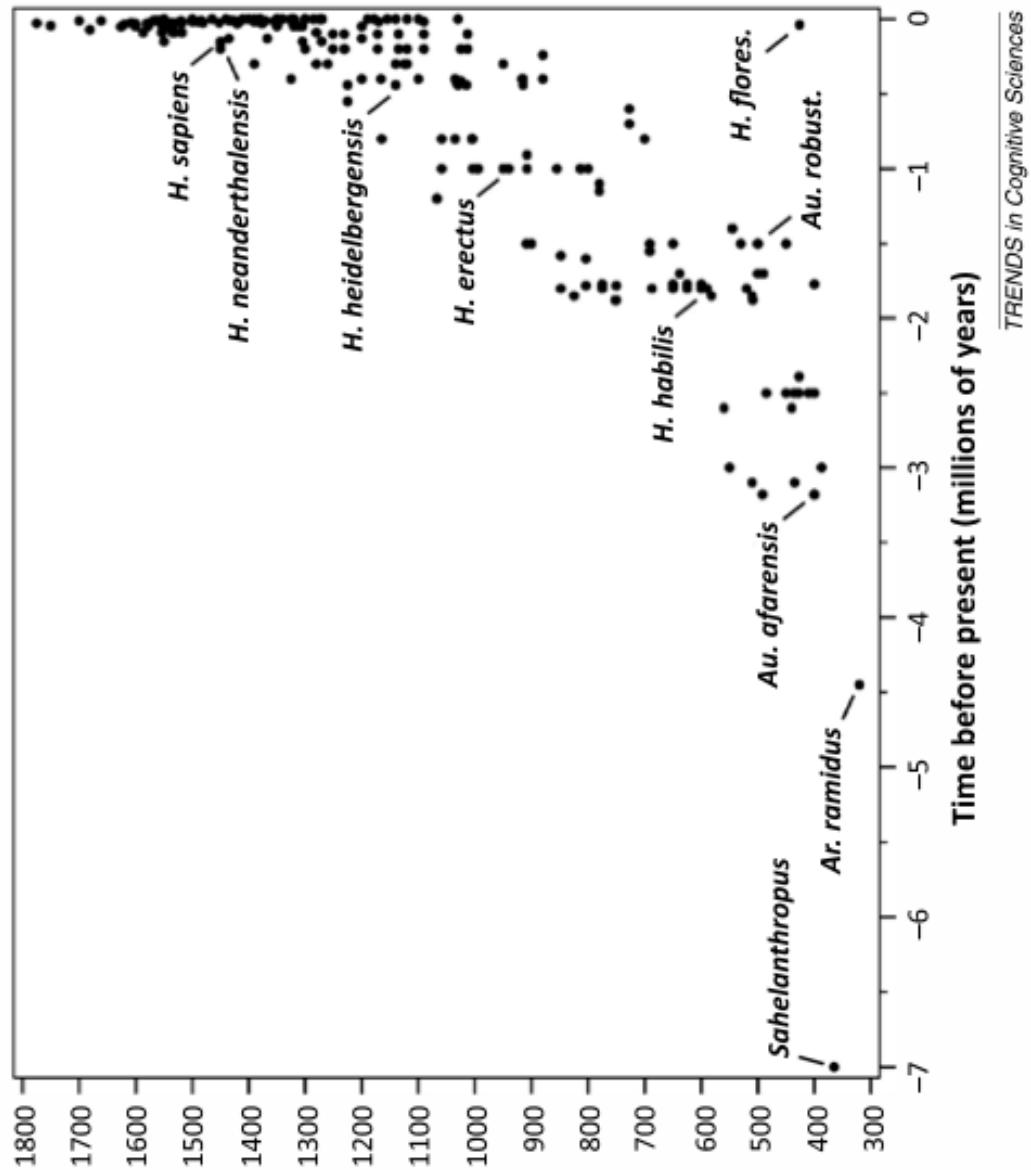


Was there a neural Bing Bang?

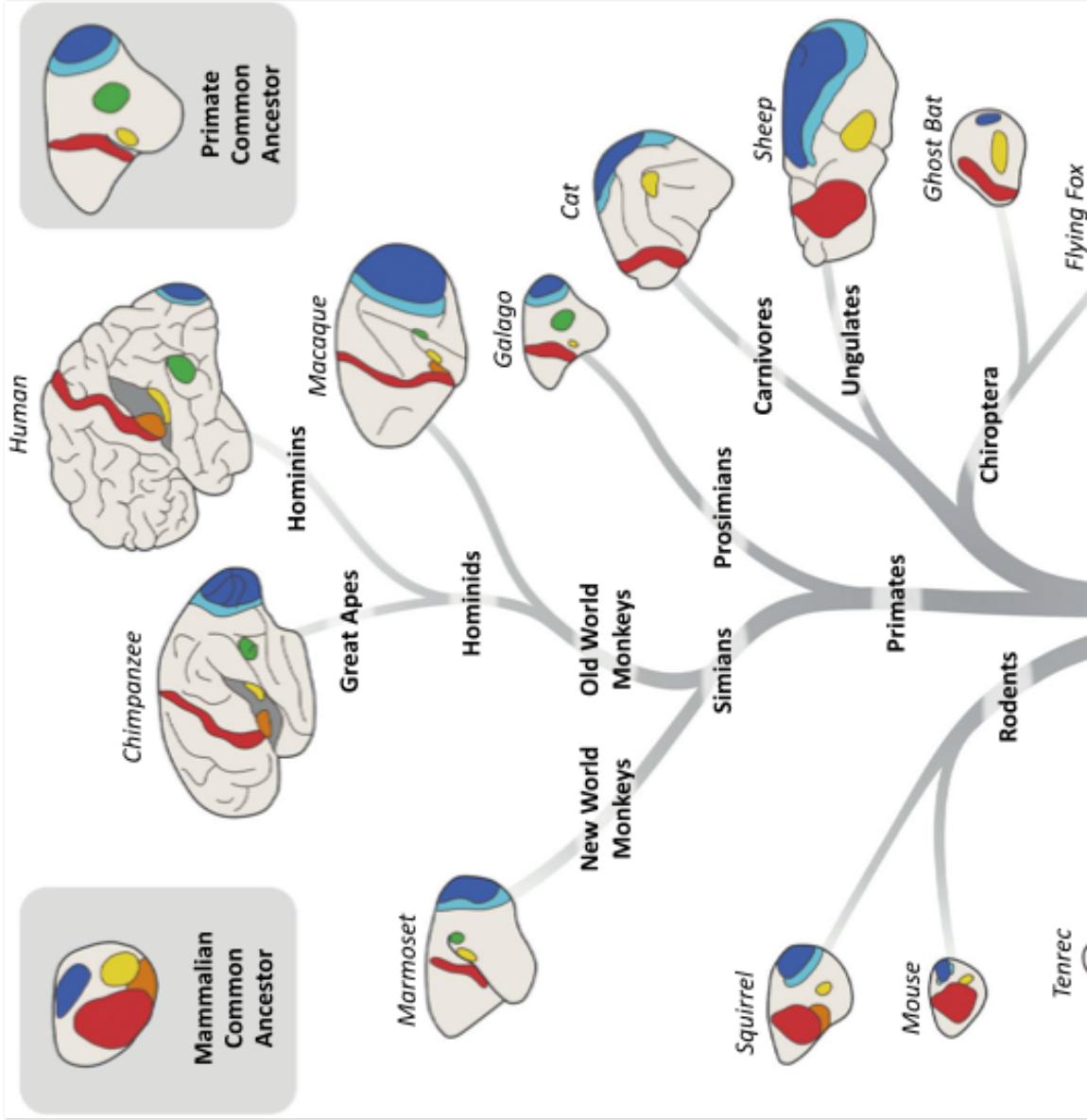
- Our left and write hemispheres are physiological asymmetric
- Main locus of asymmetry: the *arcuatum fasciculum*
- Left is dominant for 90% of right-handers, the opposite for *female* left-handers
- Degree of lateralization: 60% extreme, 20% mild, 20% almost none
- What happened since the chimp?

Brain size evolution [Buckner and Krienen, 2013]

EVOLUTION OF HOMININ BRAIN SIZE

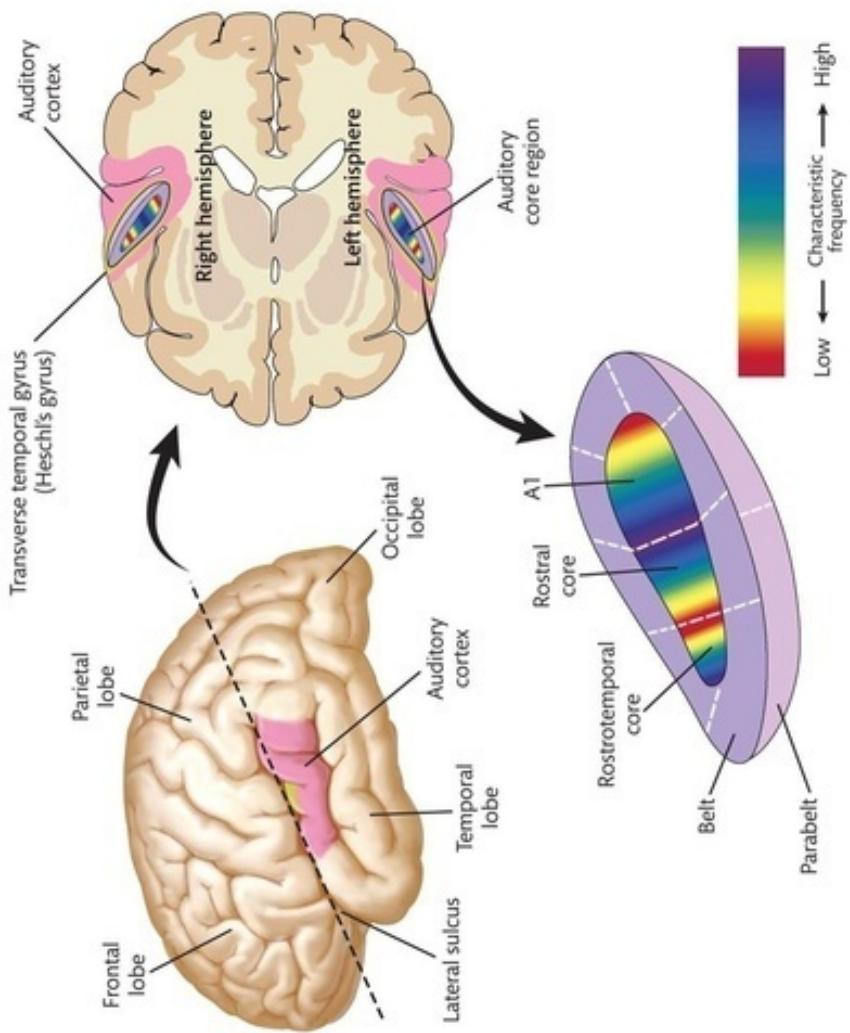


The rise of the association cortex



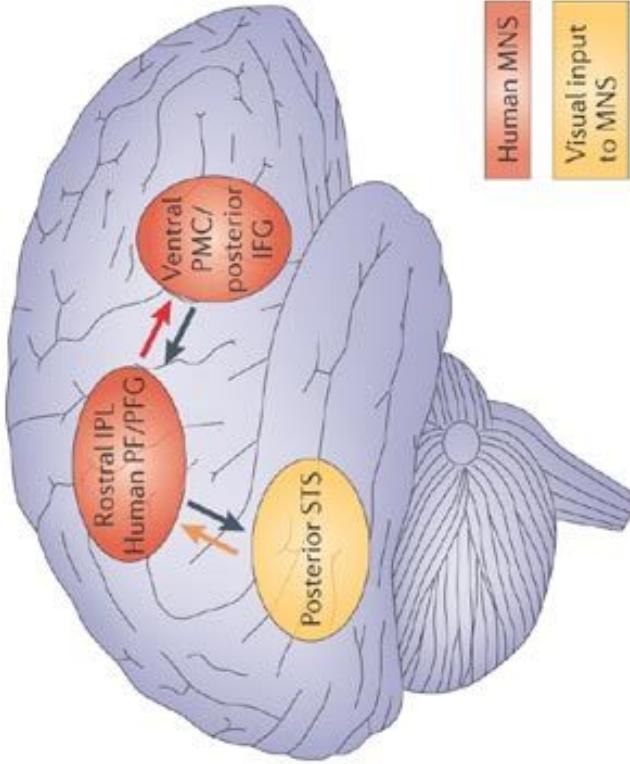
Btw: auditory cortex

- Near the ear
- A1, A2, belt, parabelt
- Still cochlea signal goes through thalamus (MGN)
- Specializes in frequencies
- Right: tonal, music
- Left: temporal aspects, **speech**



Incidentally: the mirror neural system

- Helps us understand the actions and intentions of others (and imitate)
- In humans and primates
 - (and a little in **songbirds**...)
- Seems closely related to language (look where it sits...)
- Cf: Corballis, Lakoff

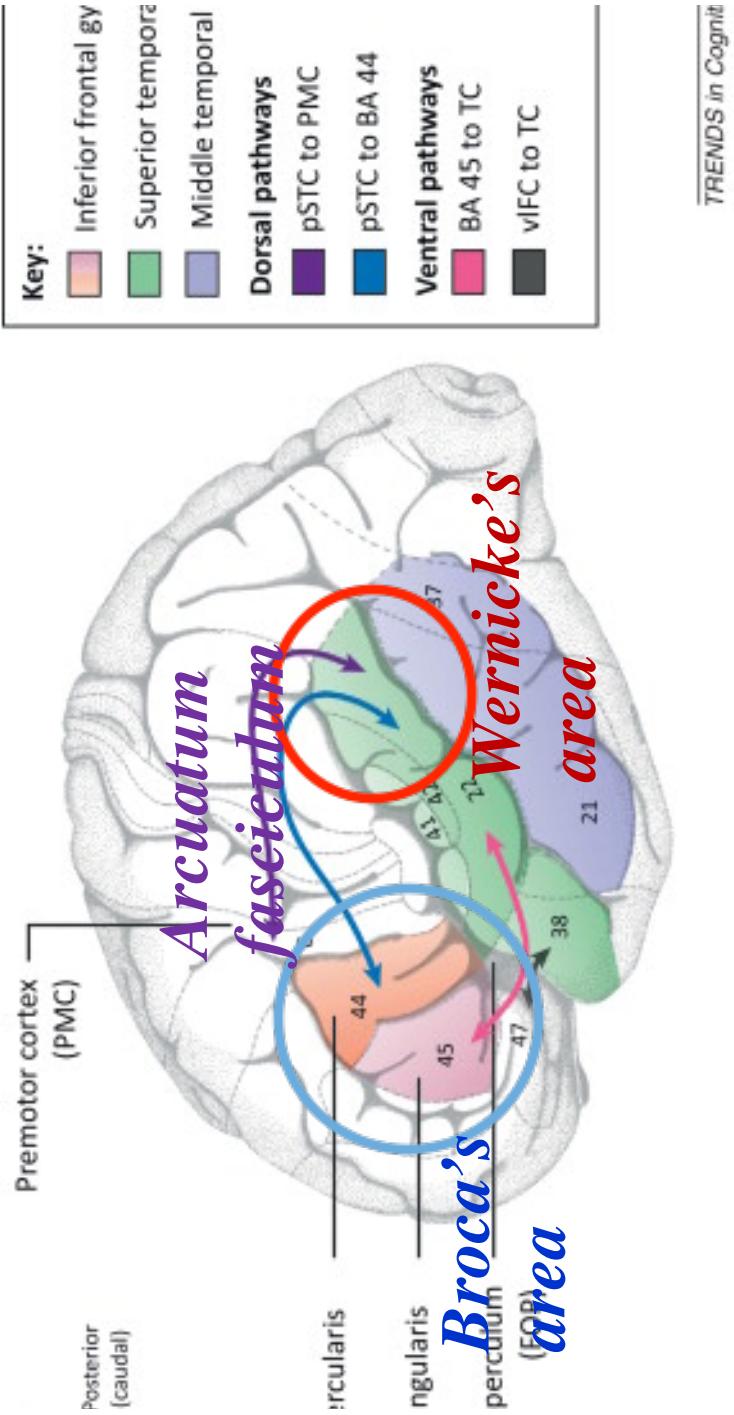


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Language and the Brain: history

- 1830s: language must be in the left hemisphere
- 1870s: Broca (production), Wernicke (comprehension) pathologies

The Language hemisphere



Language and the Brain: history

- 1830s: language must be in the left hemisphere
- 1870s: Broca (production), Wernicke (comprehension)
- Revised in 1970s: Broca aphasia (syntax, grammar), Wernicke aphasia (word meaning and selection)

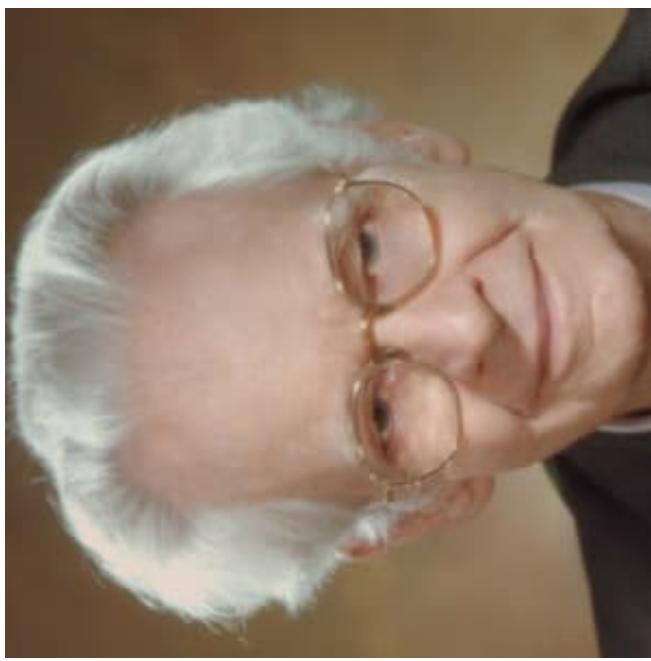
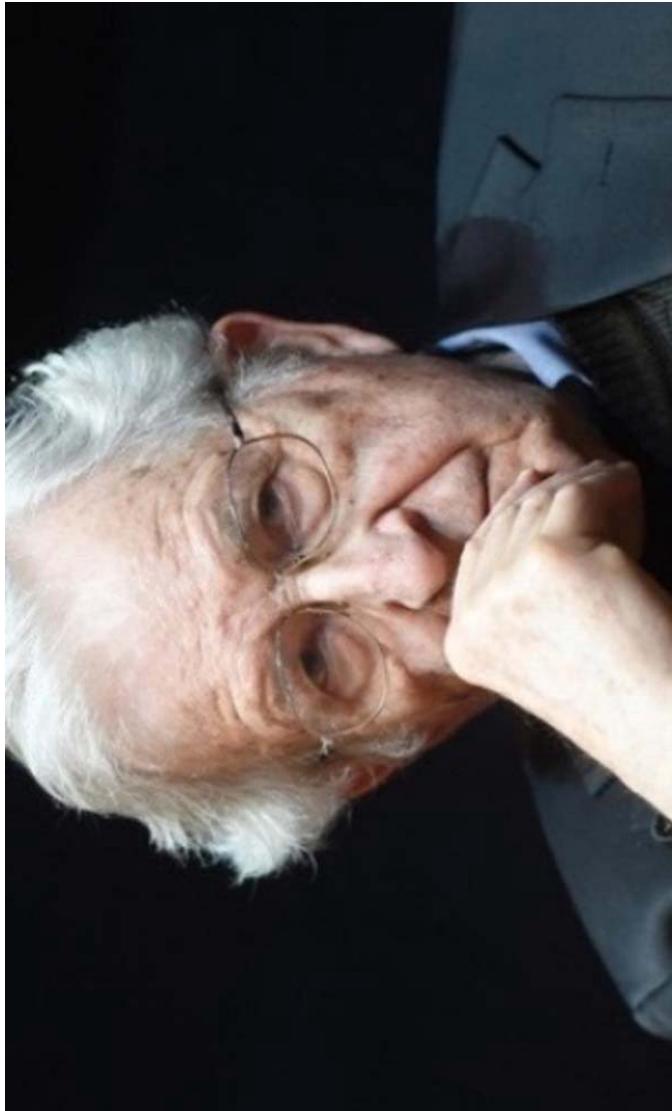
Broca aphasia

- poor or absent grammar
- difficulty forming complete sentences
- “Cup, me” instead of “I want the cup”
- more difficulty using verbs than nouns correctly
- difficulty repeating what has been said by others
- trouble with writing sentences, reading
- problems with full comprehension
- **difficulty following directions**
- frustration

Wernicke aphasia

- string words together to make sentences that don't make sense
- make up words that have no meaning
- unaware of the mistakes in their speech
- deliver words in a normal melodic line, even though the content may not make any sense
- articulate their words normally
- have difficulty repeating phrases
- add words when trying to repeat someone
- interrupt others and speak rapidly

Meanwhile in Cambridge, Mass., ca 1960:
The Skinner – Chomsky debate



The Skinner - Chomsky debate

- Or the **behaviorist** – **structuralist** debate
- Skinner believed, and showed by experiments, that behavior is the result of received reinforcements
- Influenced by the **tabula rasa** line of thought
- His 1958 book “Verbal behavior” went a bit too far
- Chomsky’s devastating critique is far better known and accepted than the book

Chomsky's theory

- Language is innate
- Enormous gap between stimulus and competence
- Grammar is innate and universal
- Children only have to tune it with “details”
- What makes us different: Recursion and infinity
- The **minimalist** program: all you need is **merge**

Grammar

$S \rightarrow A \ V \ P$ (agent, verb, patient)
 $A \rightarrow Alice \mid Bob \mid Chris \mid David$
 $V \rightarrow loves \mid hates \mid collects \mid enjoys$
 $P \rightarrow children \mid jewels \mid animals \mid toys$

The sentence generation algorithm:

Start with S

Keep replacing a symbol in the current string with rhs
of rule that has the symbol on lhs, until no such
possibility

Recursion and infinity

S → A V P

S → S and S

A → Alice | Bob | Chris | David

V → loves | hates | collects | enjoys

P → children | jewels | animals | toys

Recursion and infinity

S → A V P

S → A said that S

S → S and S

A → Alice | Bob | Chris | David

V → loves | hates | collects | enjoys

P → children | jewels | animals | toys

A propos recursion and infinity: the Pirahã controversy

- No number words, eg for “one”, “few” and “more”
- No color words
- Daniel Everett 2010:

“No recursion!”



Besides universality:
how about exclusivity?



The Chomsky hierarchy

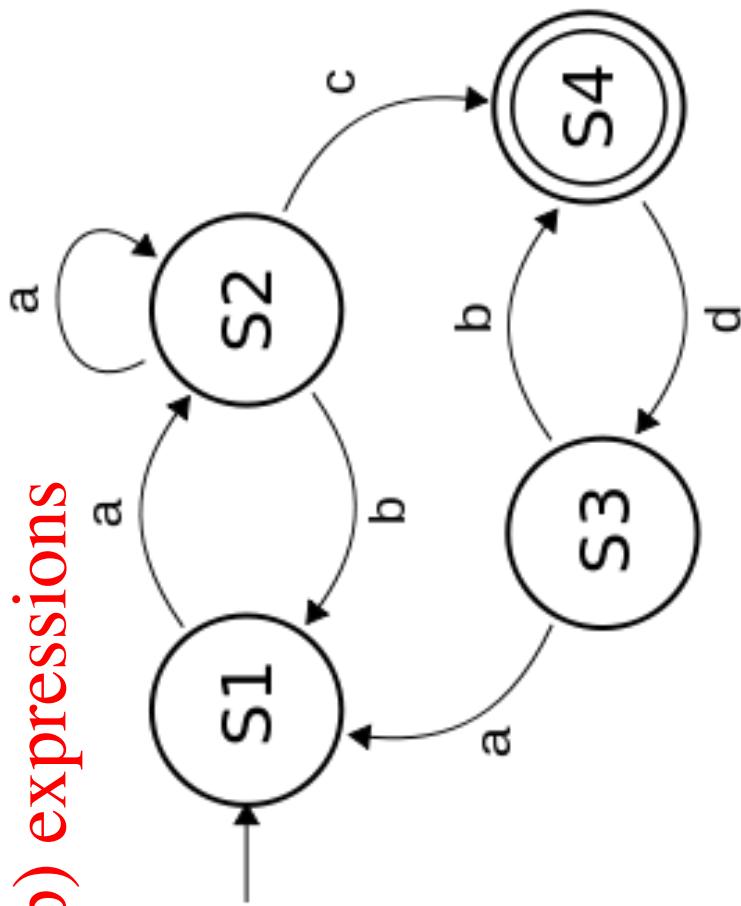
Four increasingly general kinds of (recursive, infinitary)
grammars

(**Assume only caps occur in lhs**)

1. Regular or right-linear: $A \rightarrow a \ b \ B$
2. Context-free: $S \rightarrow a \ B \ b \ S$
3. Context-sensitive: $SB \rightarrow S \alpha B \beta \ B \gamma \ B \delta \ B \epsilon \ B \ z$ (**rhs no shorter than lhs**)
4. General: $ScD \rightarrow Ba$

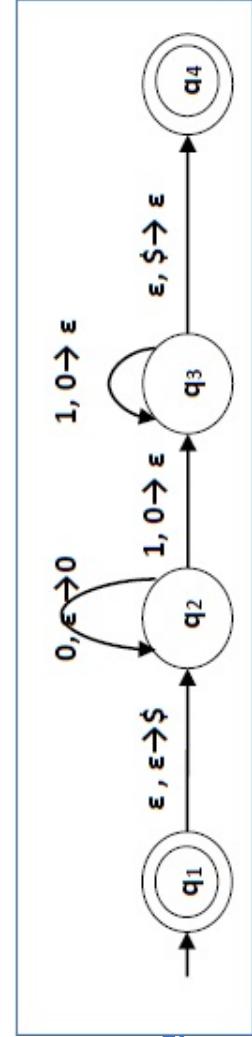
Grammar type hierarchy induces a machine/recognizer hierarchy

- Right linear grammars $A \rightarrow abB$ correspond to **finite state machines** or **regular (grep) expressions**
- One-way reading, finite states
- E.g., $(a+b)aa(bb+ab)^*$
- **But not $\{anbn : n \geq 0\}$**



The Chomsky hierarchy II

- Context-free (or phrase-structure) grammars $A \rightarrow bBA$ correspond to **nondeterministic pushdown automata**
- Finite states, one-way reading, but can also look at/modify the top of a stack
 - E.g. $\{anbn : n \geq 0\}$, palindromes, ...
 - **But not $\{ww : w \text{ a word}\}$,** or $\{anbn cn : n \geq 0\}$



PDA for $L = \{0^n 1^n \mid n \geq 0\}$

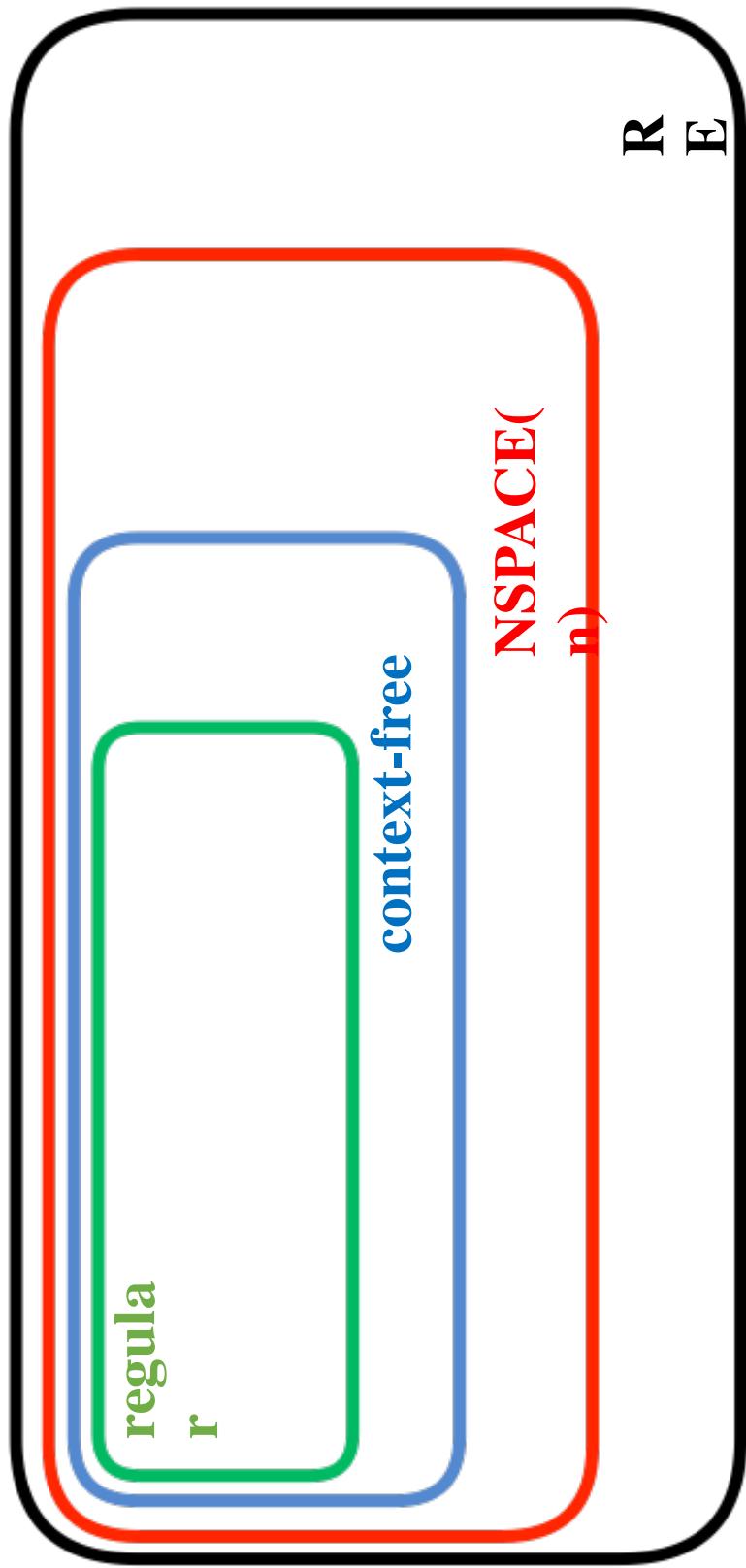
The Chomsky hierarchy III

- Context-sensitive (or non-shrinking) grammars
 $Ab \rightarrow bBab$ correspond to **nondeterministic Turing machines that run in linear space (LBAs)**
- E.g. $\{ww: w \text{ a word}\}, \{anbn cn : n \geq 0\}, \dots$
- **But not $\{M: M$ is (the description of) a Turing machine destined to halt $\}$**

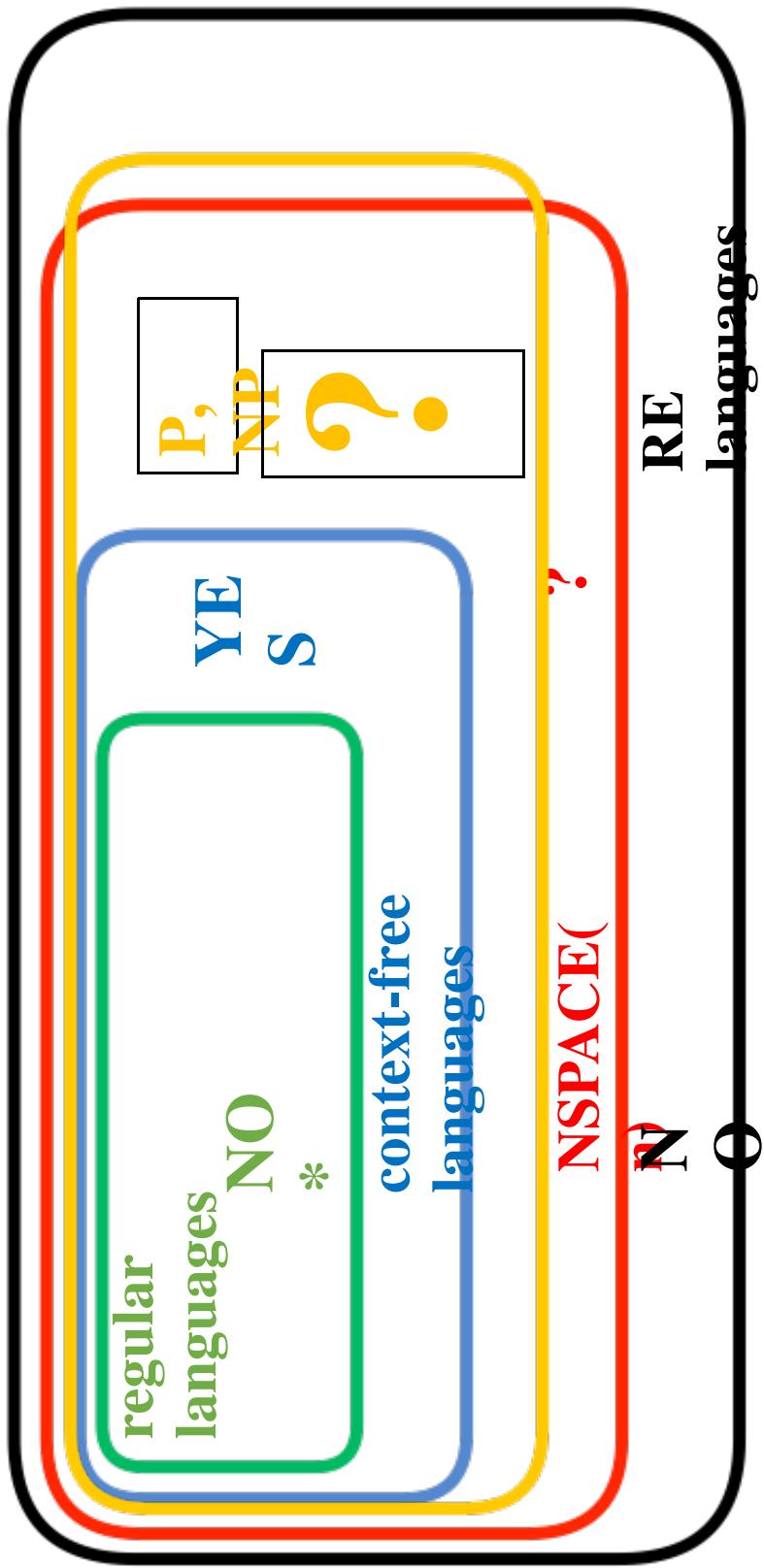
The Chomsky hierarchy IV

- Unrestricted grammars correspond to **Turing machines** that accept by halting
- All recursively enumerable (RE) languages: decision problems ‘‘solved’’ by Turing machines that reject by never halting...

The Chomsky hierarchy



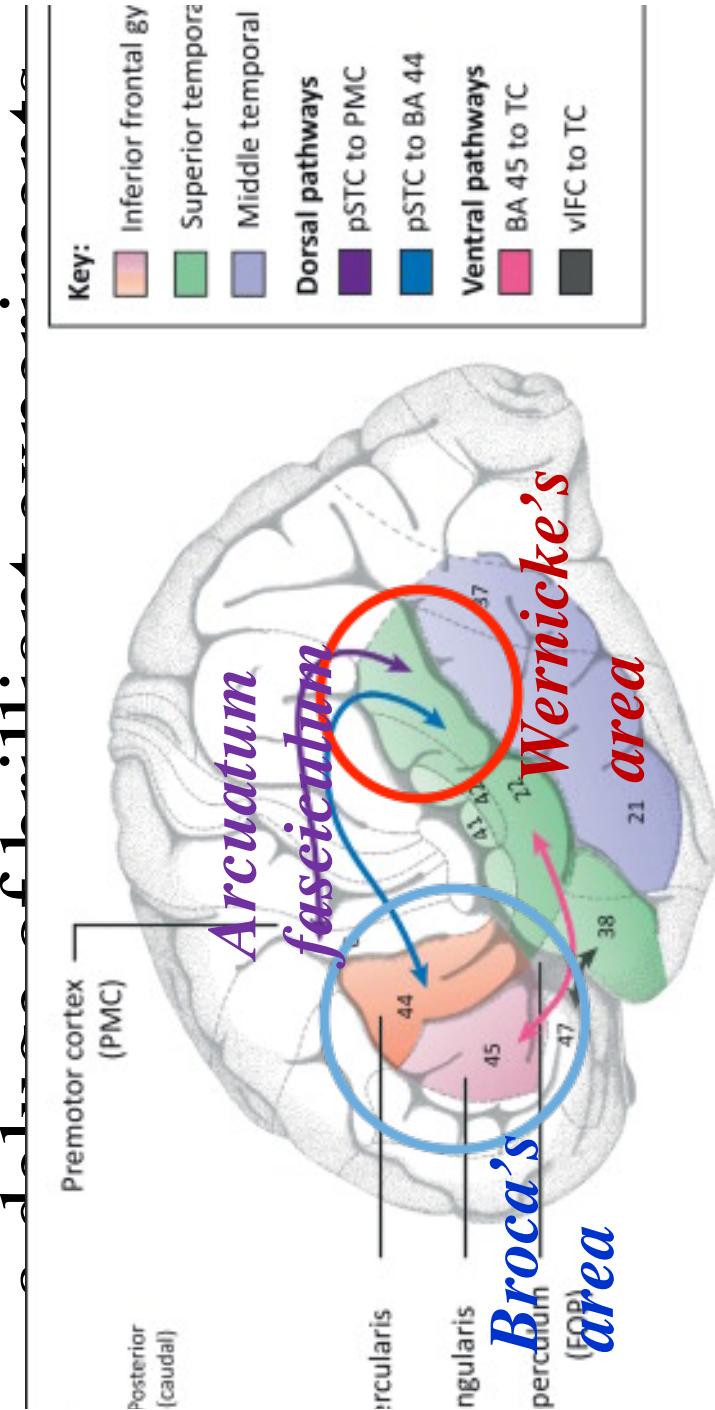
The Chomsky hierarchy: Nondeterminism makes a difference?



The Chomsky hierarchy

- Tremendous influence on CS
- Much of the research agenda in the 1960s TCS
- Helped us understand how to write compilers
- Trained us for the real problems to come

Meanwhile, in the language hemisphere:

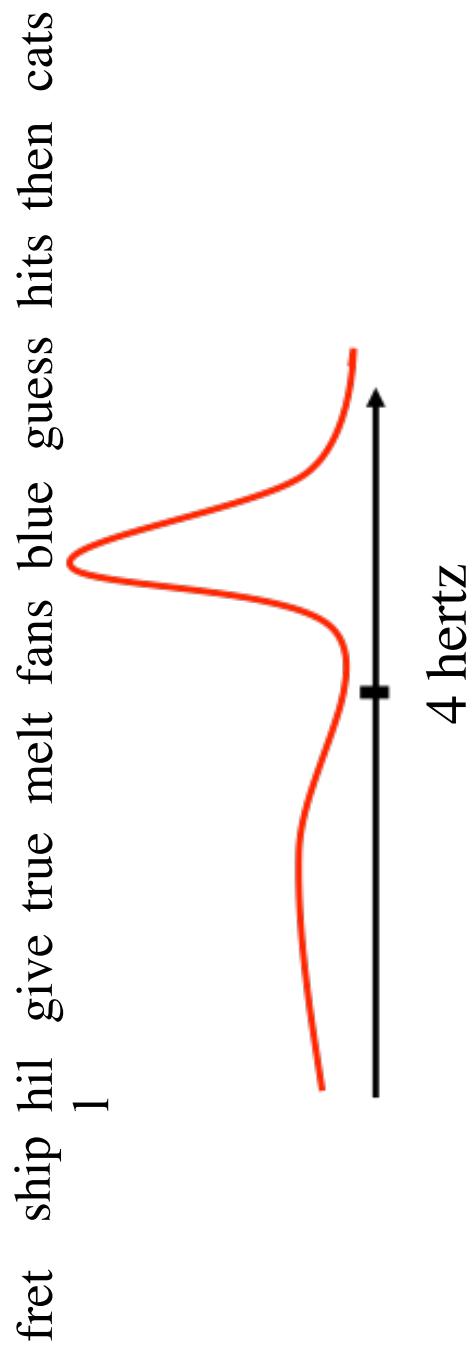


TRENDS in Cognit

....this text pulsates at four
Hertz, the rhythm of four
beats per second, and I
believe that you may find this
rhythm a bit familiar,
because it coincides with the
rhythm of speech, and I don't
mean my speech but speech
in general, by all speakers, in
all languages...

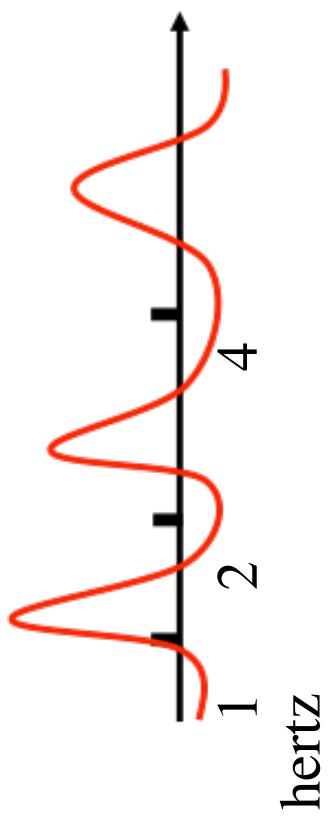
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The [Poeppe1 2016] experiment

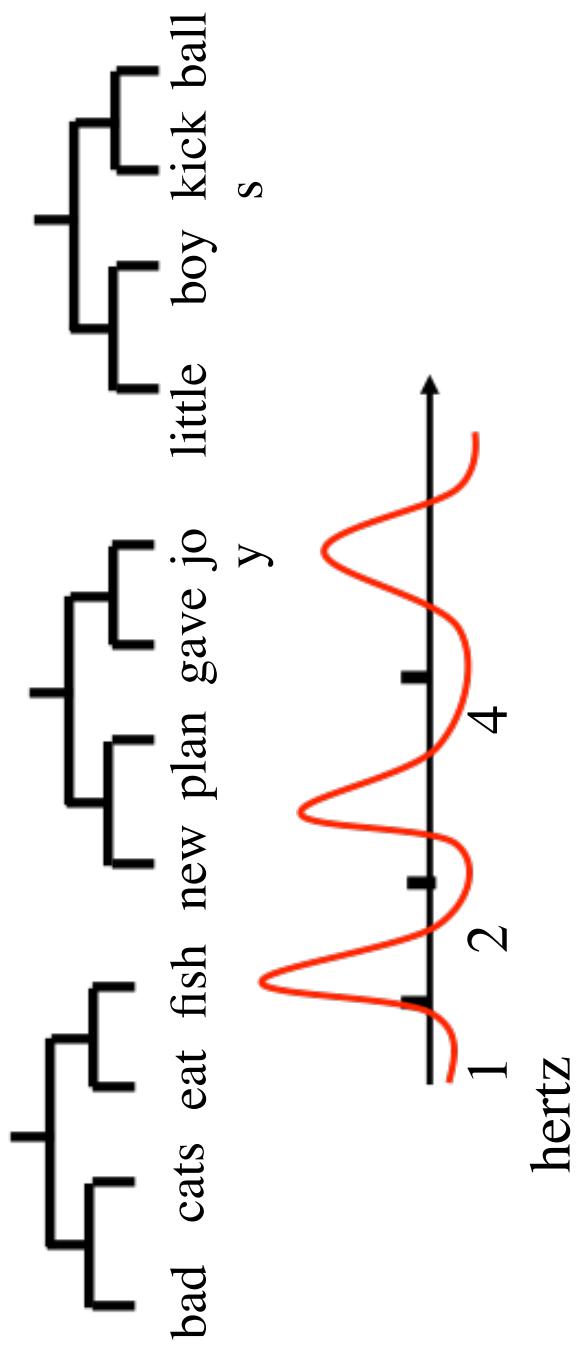


The [Poeppe1 2016] experiment, stage II

bad cats eat fish new plan gave jo
little boy kick ball
y s



My interpretation



[Frankland & Greene PNAS 2015]

“The ball hit the **truck**”

vs

“The **truck** hit the ball”

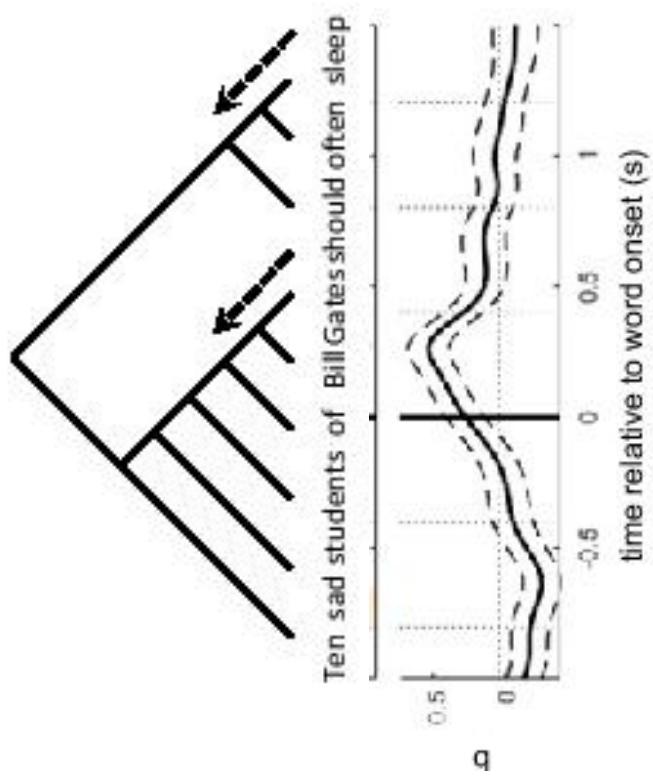
Different areas of the STG responded to “truck” in the two sentences [*Recall relations...*]

The first area also responded to
“The **truck** was hit by the ball”

But...

- By what mechanism can each tree-building step be carried out by a dozen or so spikes?
- $12 \sim \text{gamma} / \text{theta}$
- Recall our discussion of Projection and Merge of Assemblies

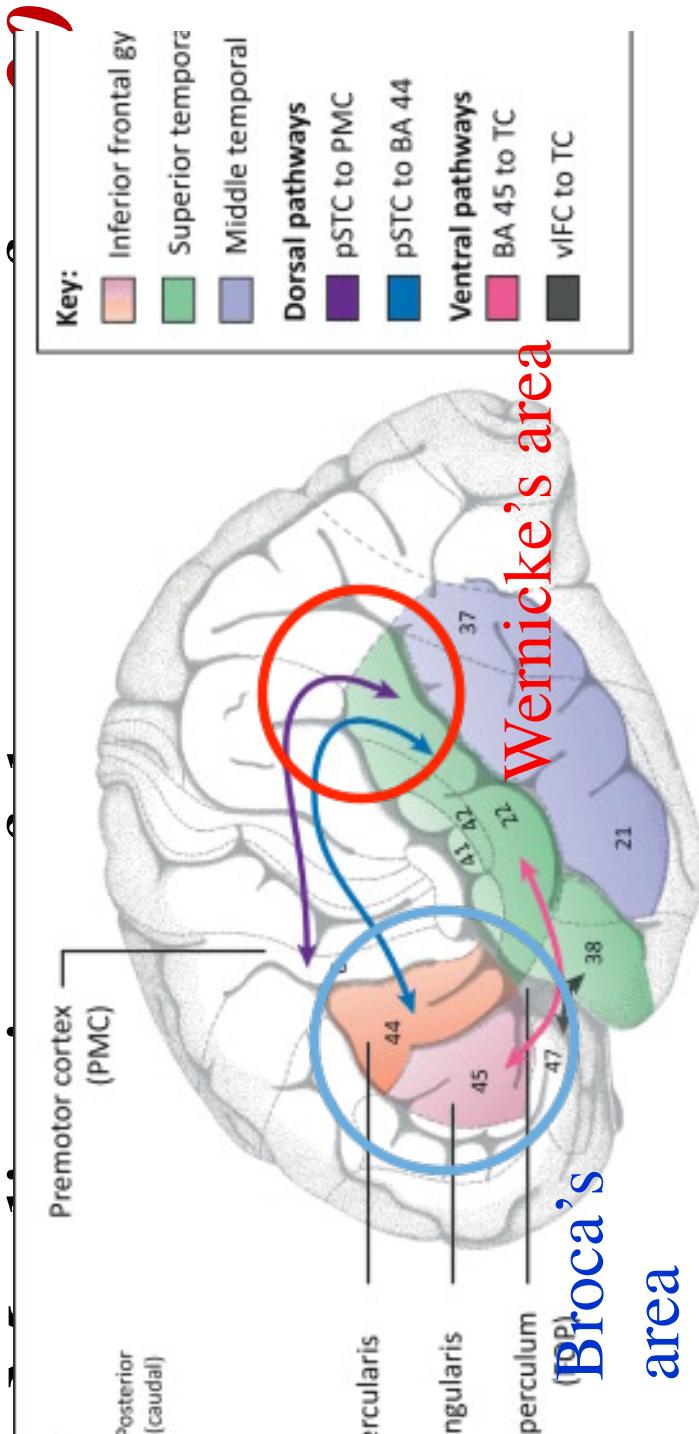
[Nelson...Dehaene, PNAS 2017]



Zaccarella & Friedericci “Merge in
the human Brain” *Front. Psych.*
2015

- The completion of phrases, and especially
of sentences, **lights up parts of Broca's
area**

[ZF 2010]: Neural pathways for syntax?

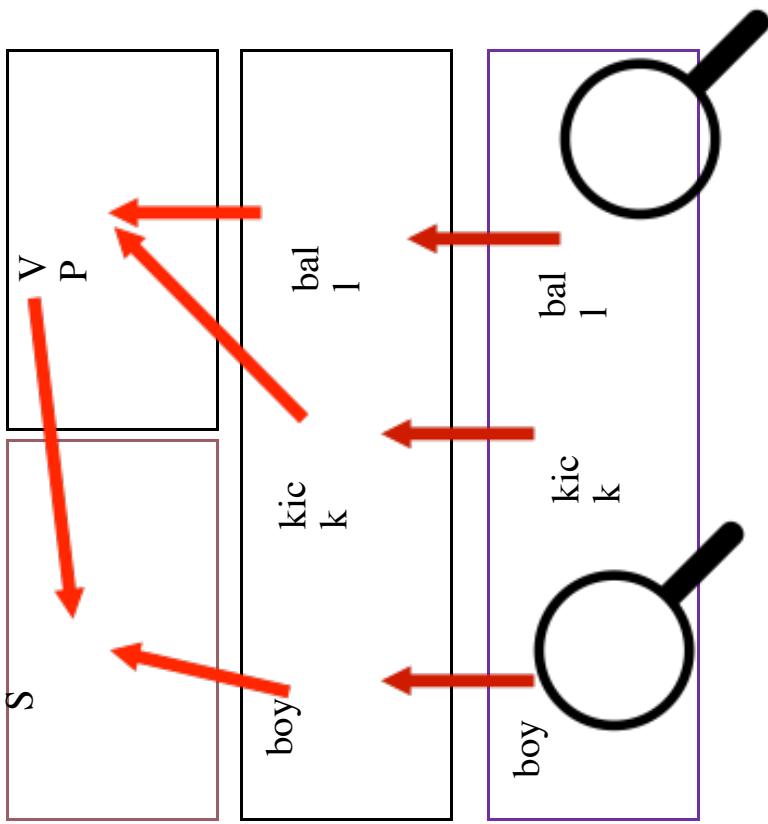


But what is the neural gadget
that does all this?

- Let us consider *assemblies of neurons*

- They seem to encode concepts, presumably also words
- They can be projected to other areas
- They associate/intersect to reflect affinity
- They can create trees by Merge

a brain architecture for syntax



Next: Evolution

(...and Computation, of course)

Evolution

Evolutionists flock
to Darwin-shaped
wall stain

(from **The Onion**)

