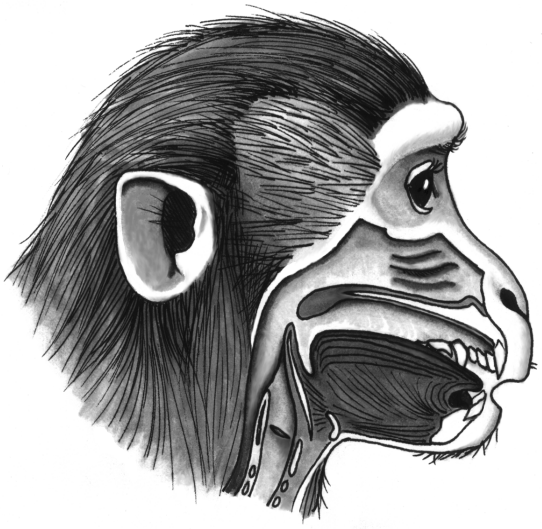
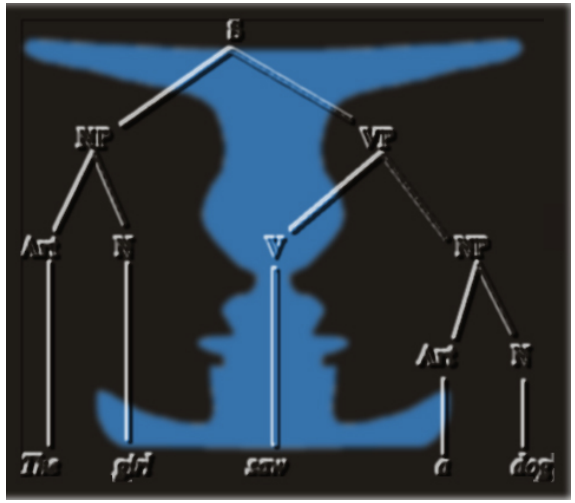
Evolving Human Language: Cognition Plus Communication

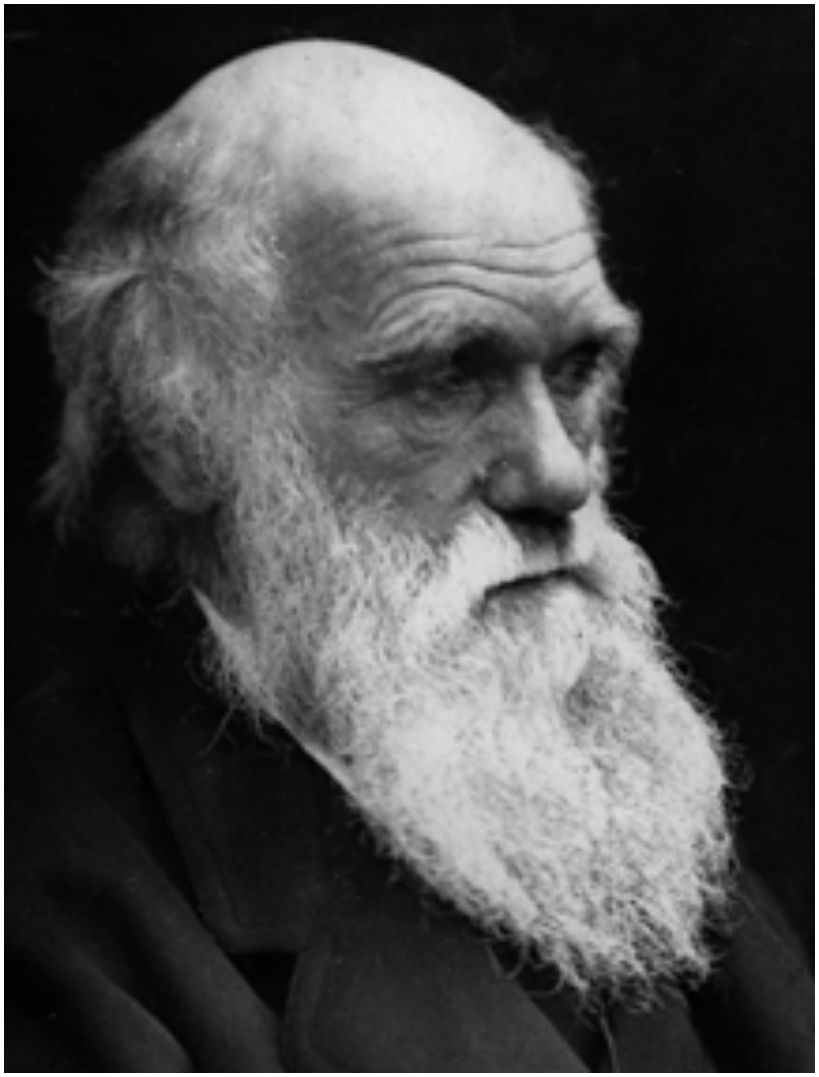
Tecumseh Fitch - University of Vienna

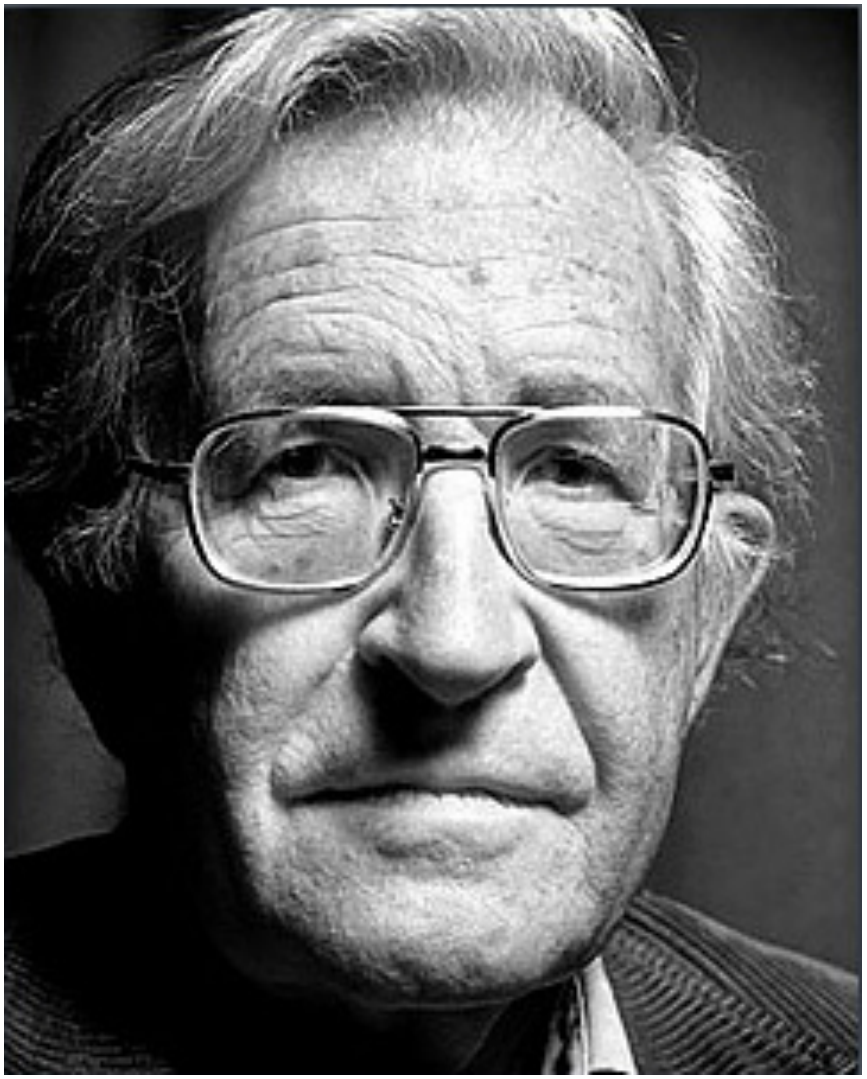
COGBIO
Department of Cognitive Biology



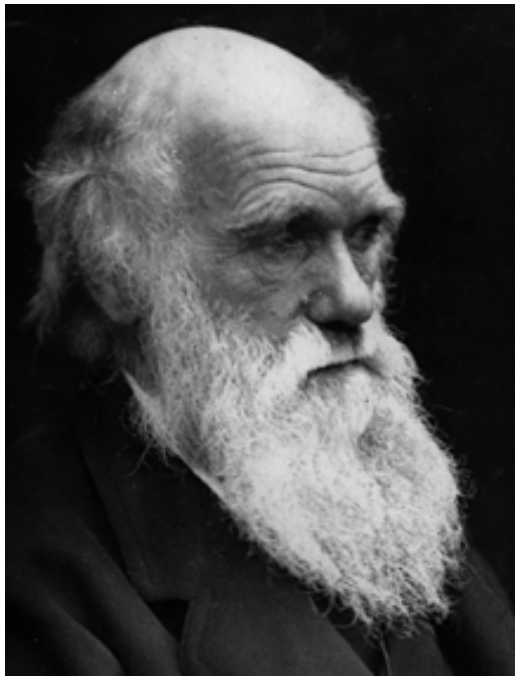


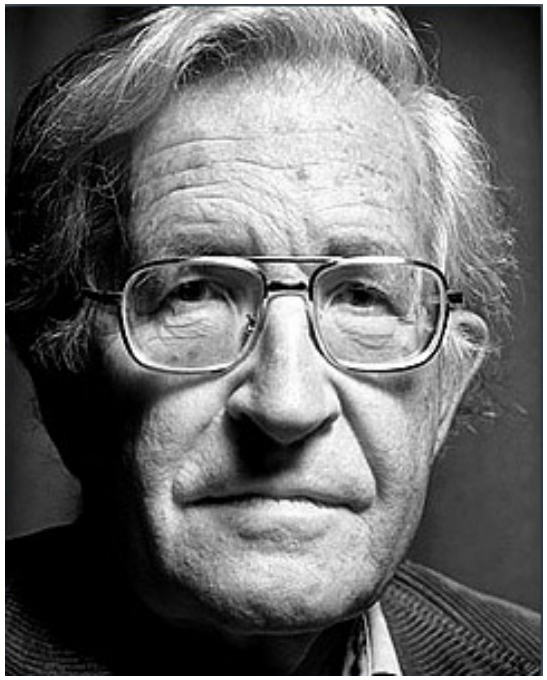
Traditional Opposition: Linguistics vs Evolution





Today: Bridges between Disciplines





Marc Hauser, Noam Chomsky, Tecumseh Fitch : The Language Faculty: What is it, who has it, and how did it evolve? *Science* 2002, 298:1569-1579.

Fitch, Hauser, Chomsky : The Evolution of the Language Faculty. *Cognition* 2005, 97:179-210.

Fitch : *The Evolution of Language*. Cambridge: Cambridge University Press; 2010.

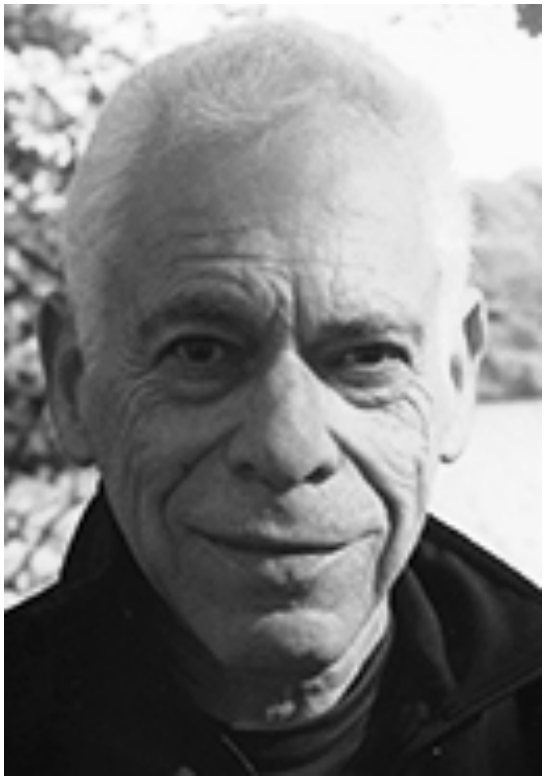
Rumi’s Parable of the Elephant

The Key to Language is…

Tomasello

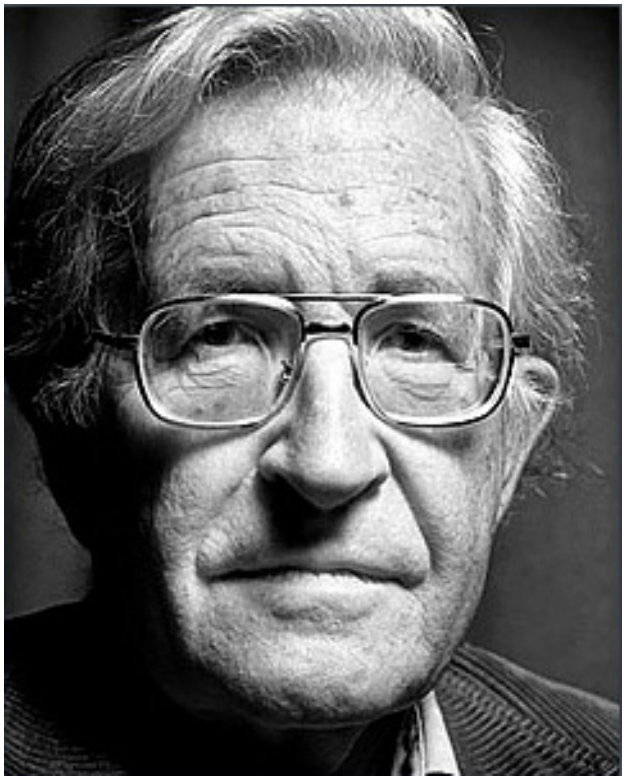
Shared Intentionality

Lieberman



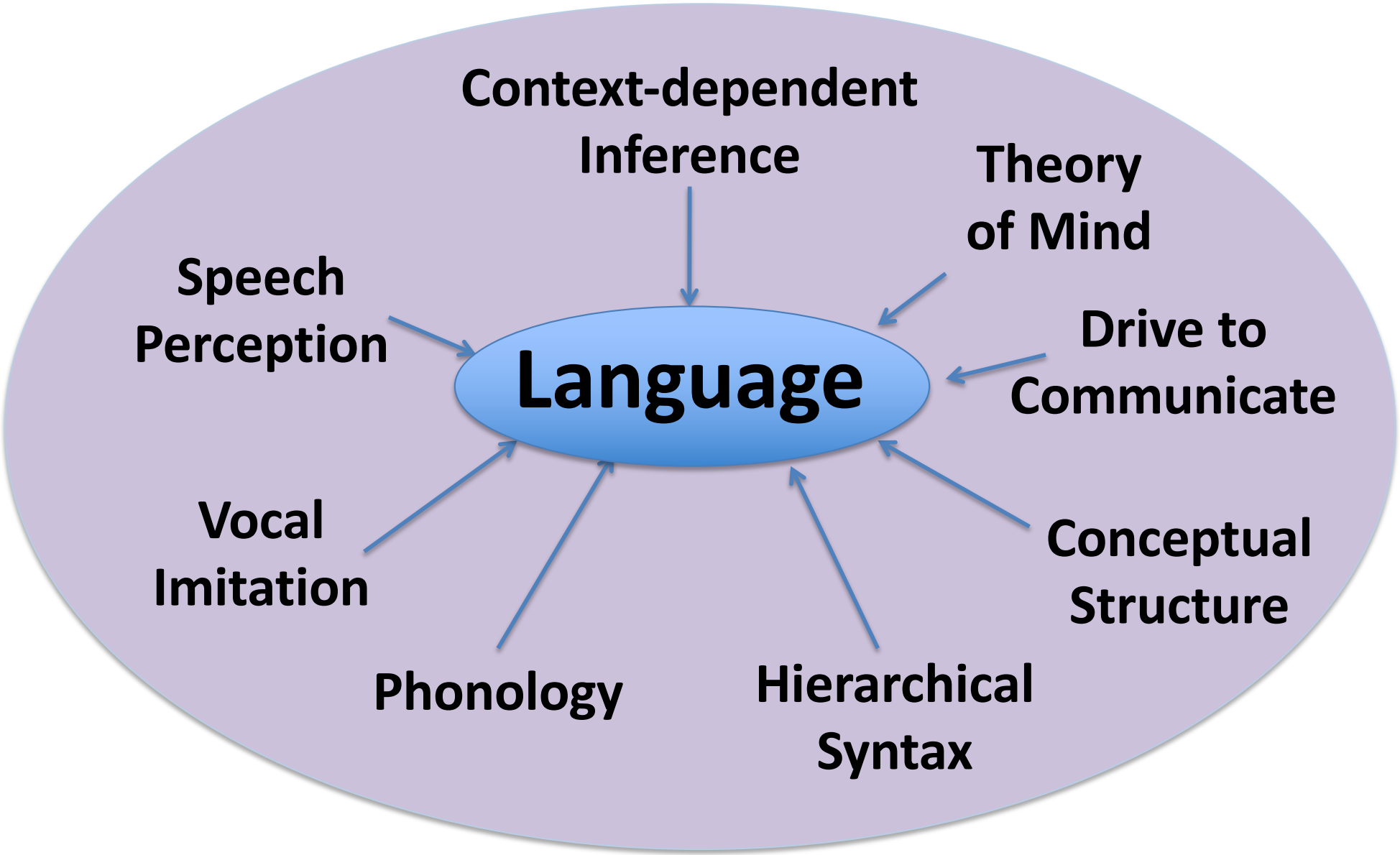
Speech

Chomsky

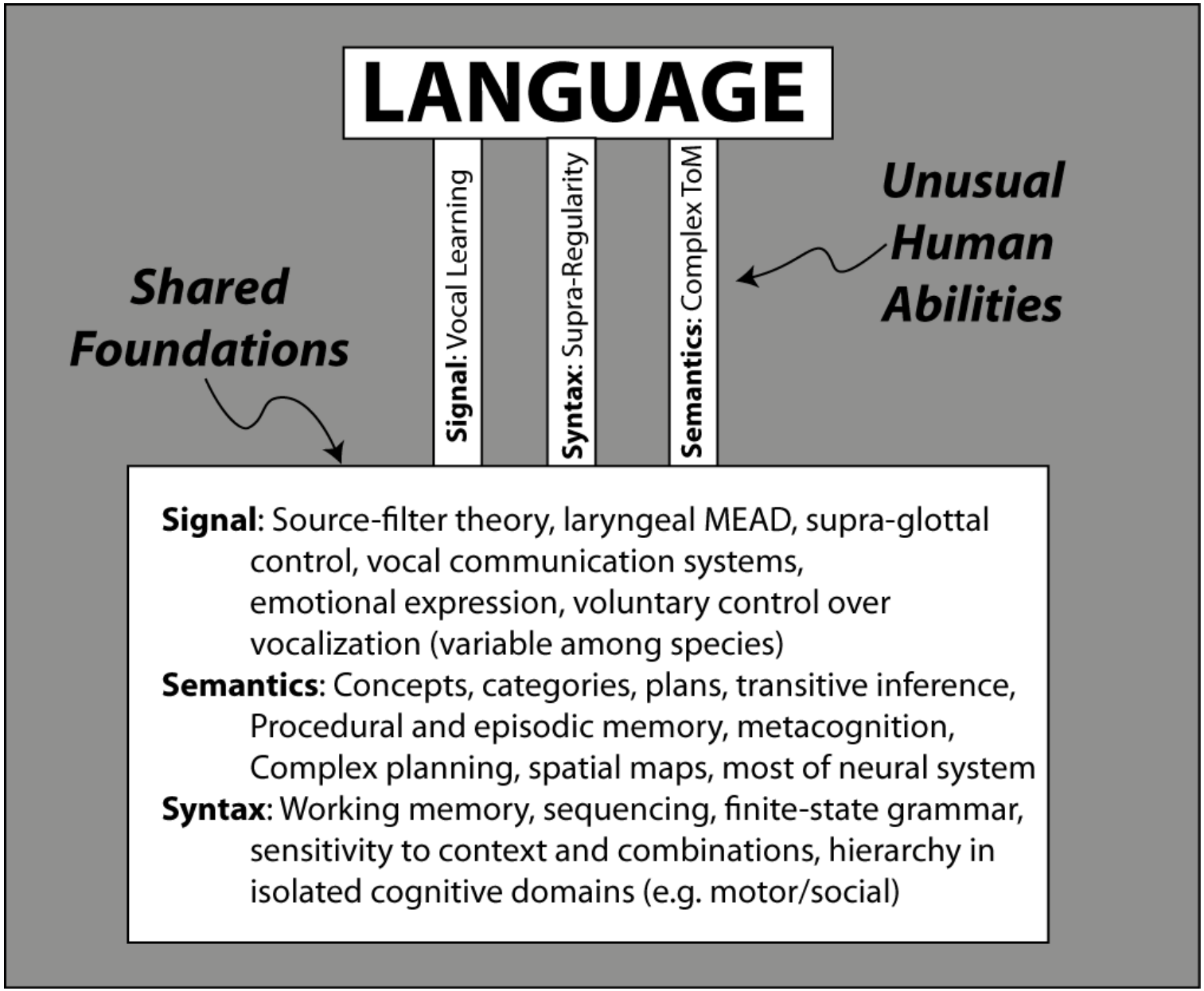


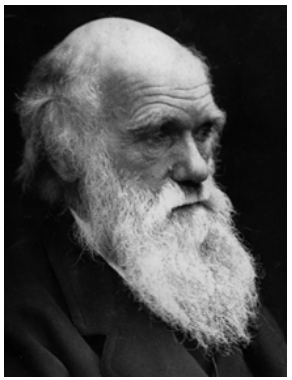
Merge

Modern Multi-Component View

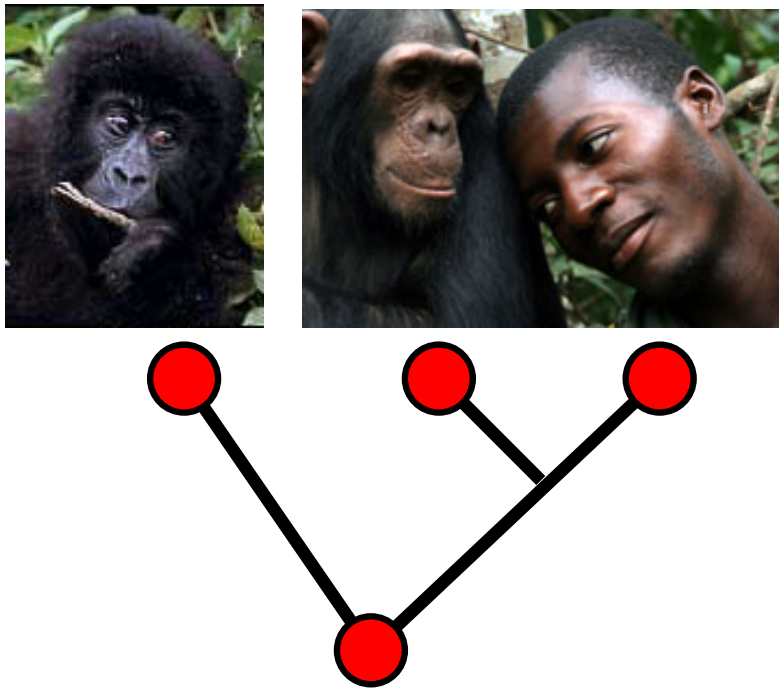


Broadly Shared Biological Foundations

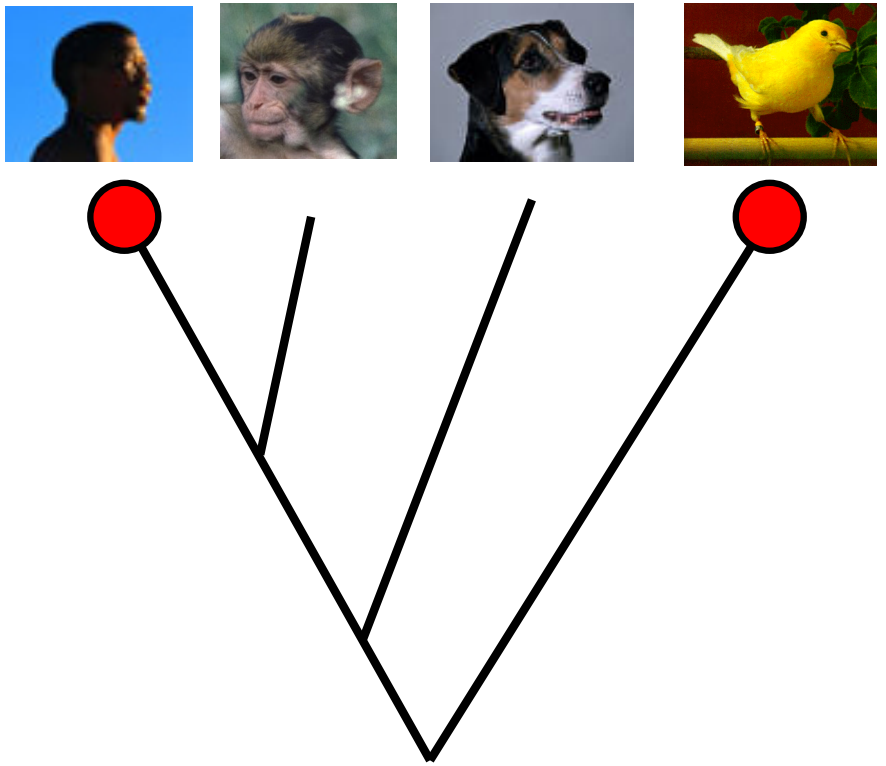




The Comparative Method: Homology and Analogy



<u>Homology</u> - Descended From Common Ancestor



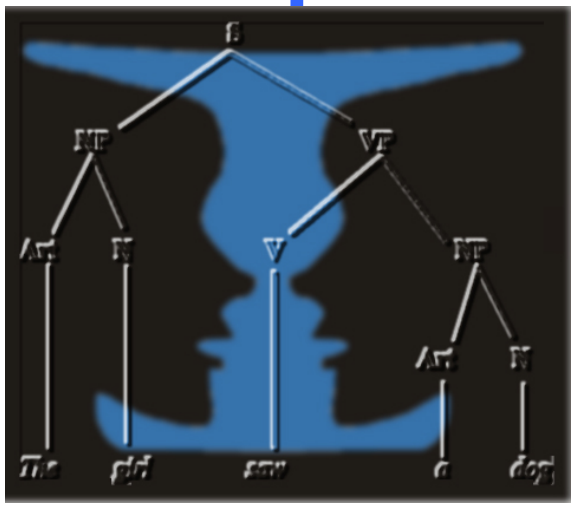
<u>Convergence</u> - Separate, Parallel Evolution

Faculty of Language - *Derived* components

(relative to chimpanzees) – not necessarily "unique"

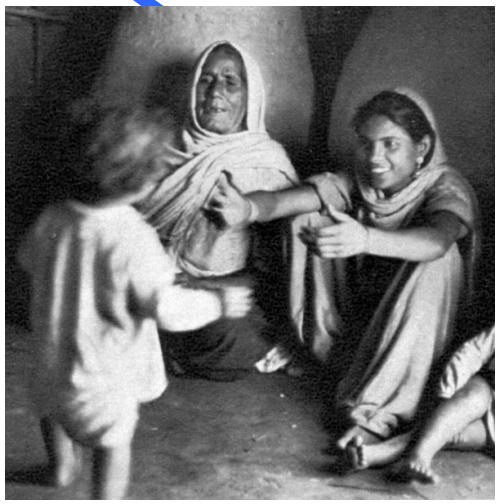
"Signal"

(Complex Signals: Vocal Control & Learning)



"Syntax"

(Compositional, Hierarchical, Processing)



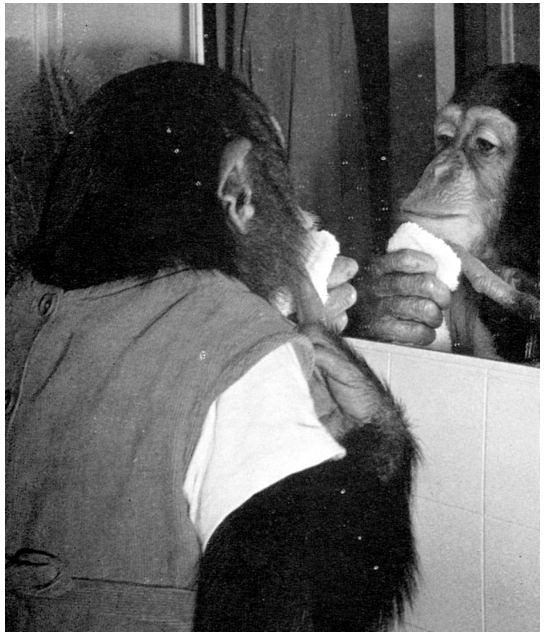
"Semantics"

(Intent to Communicate, Pragmatics)

Outline of Today's Talk

- Part 1: **Speech** – Neural connectivity, not vocal anatomy.
- Part 2: What's special about **Syntax?** The **Dendrophilia Hypothesis.**
- Part 3: Derived from *what*? Cognition *versus* Communication as sources of precursors

Core Fact: Apes cannot imitate speech



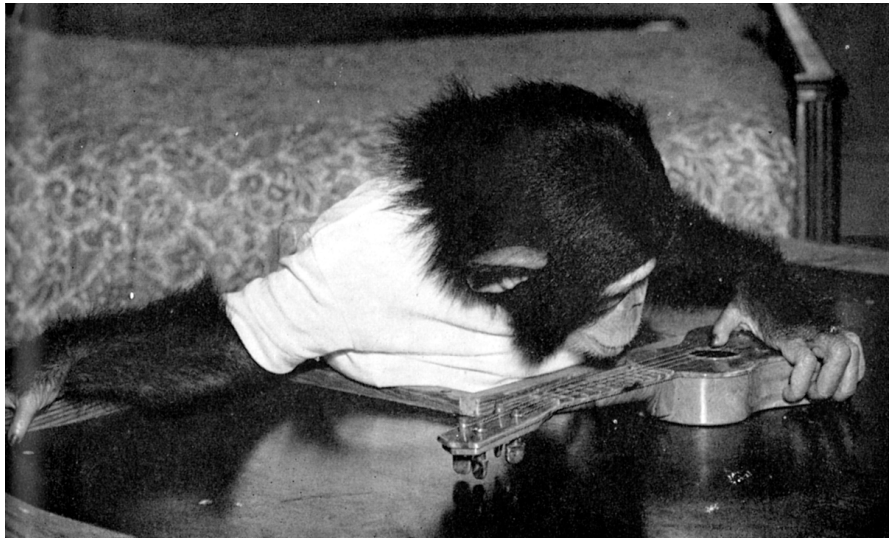
Furness, 1916

Yerkes, 1929

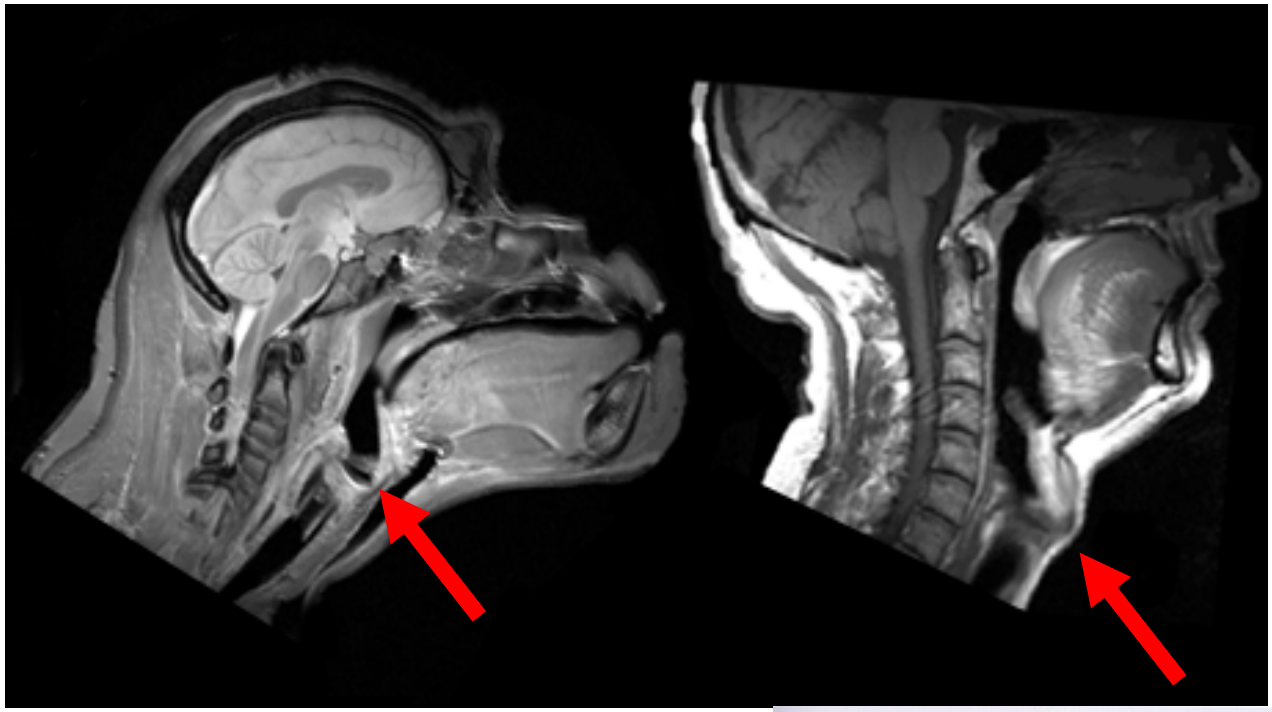
Hayes, 1951

Kellog, 1968

Gardner, 1969



Why Can Humans, but not Apes, Speak?
Two Traditional Hypotheses



Philip Lieberman et al. 1969; 1972

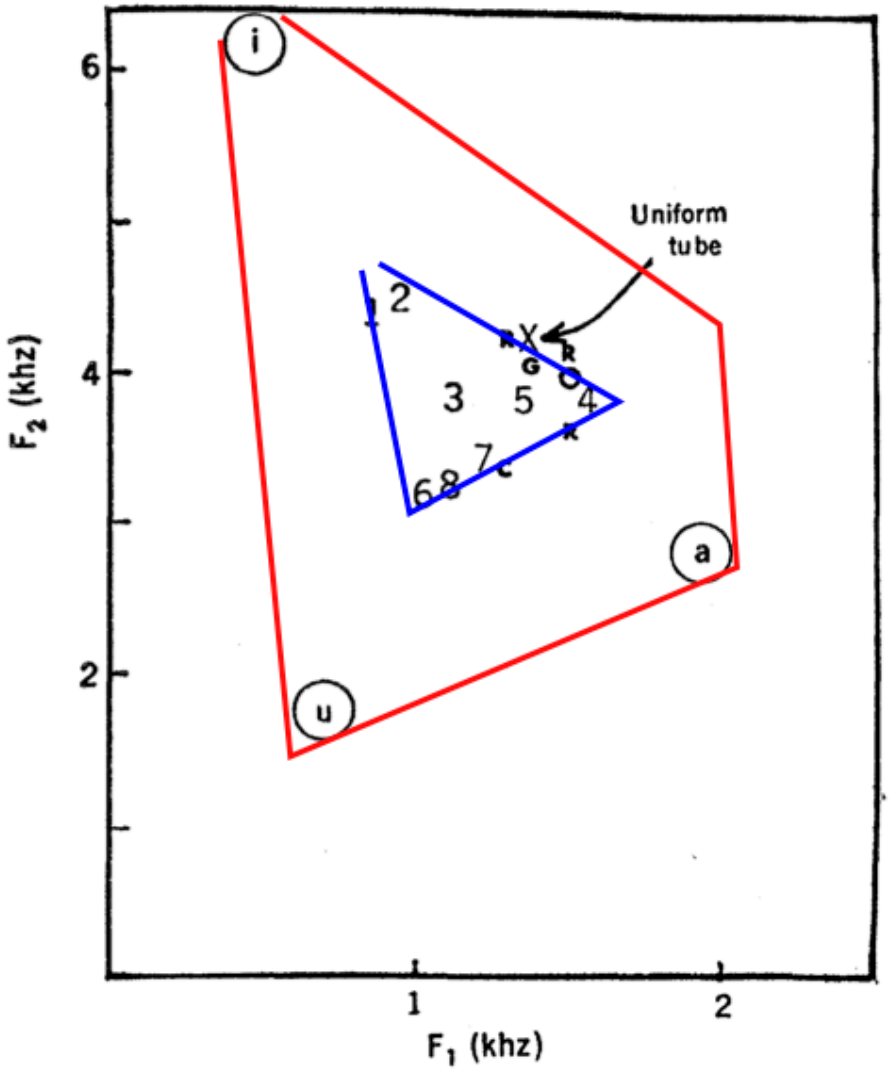
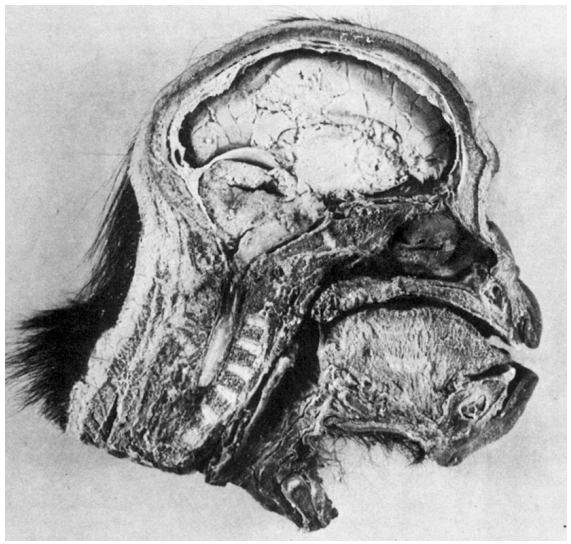
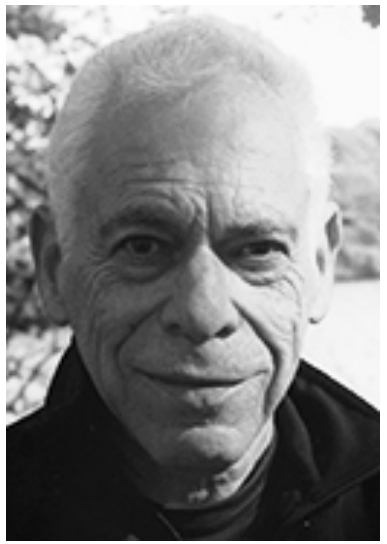
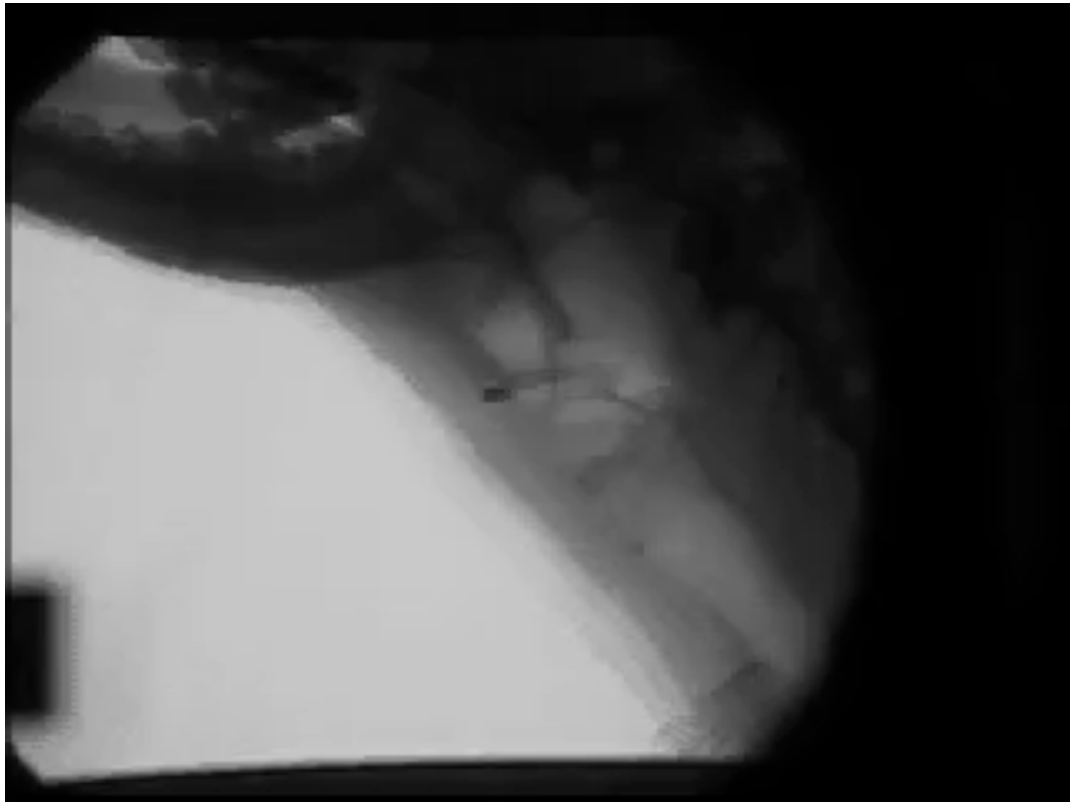


Fig. 2. Vowel "space" of simulated monkey vocal tract relative to human vowel space and natural ape and monkey cries

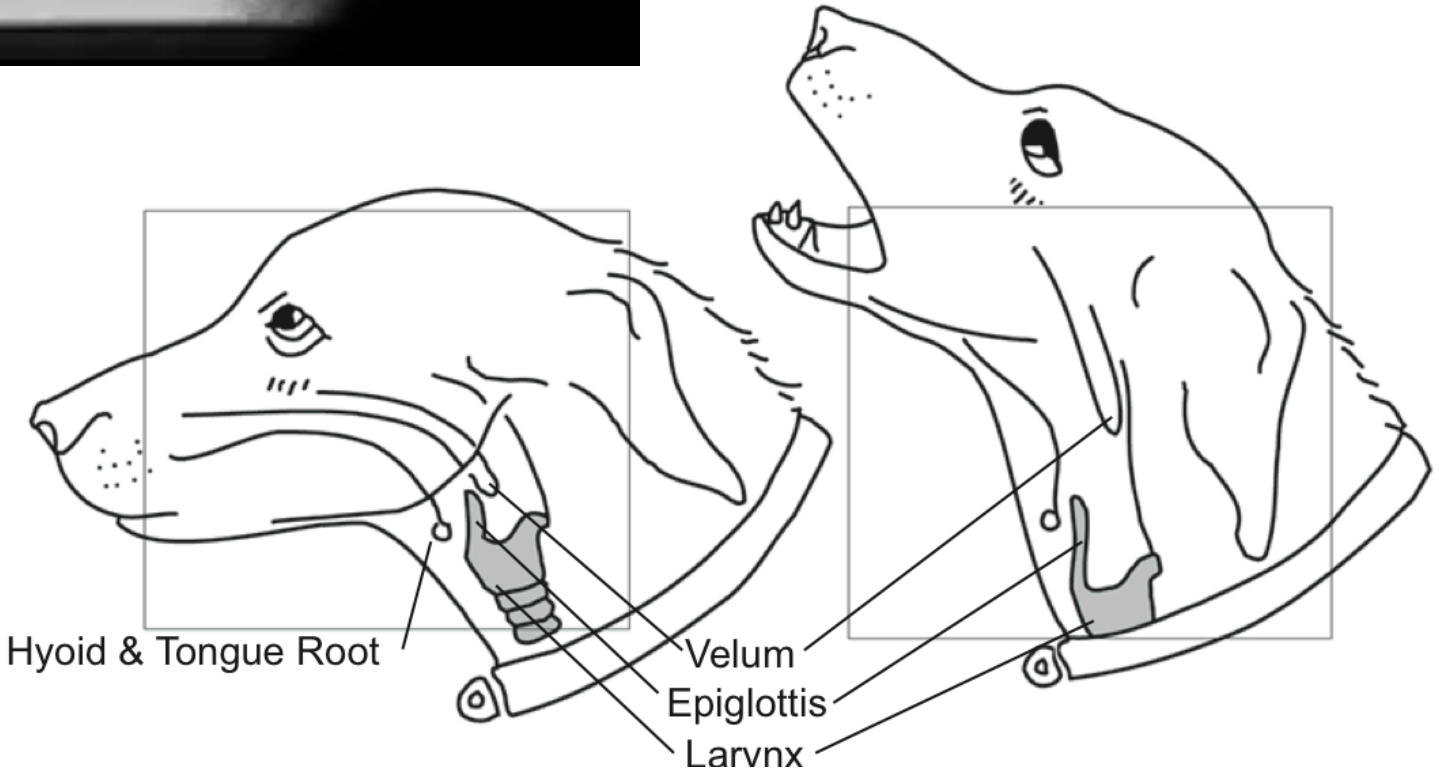




'The acoustic "vowel space" of a rhesus monkey is quite restricted… these animals thus lack the output mechanism necessary for production of human speech'

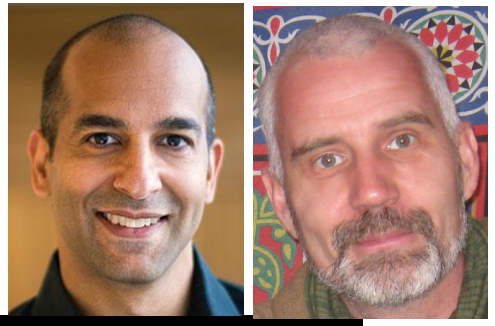


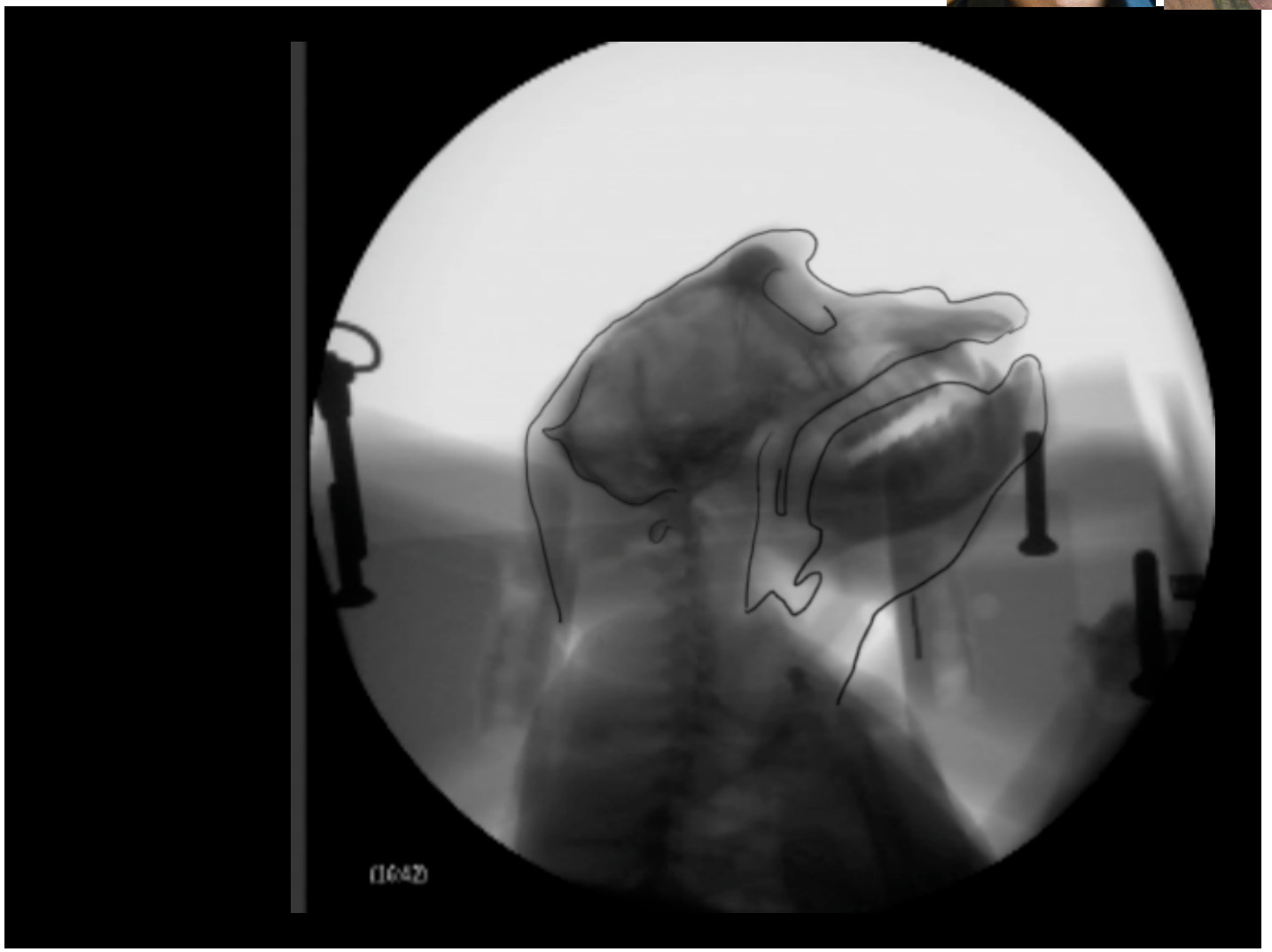
Larynx Lowers Dynamically in *All* Mammals studied. Dog Example:



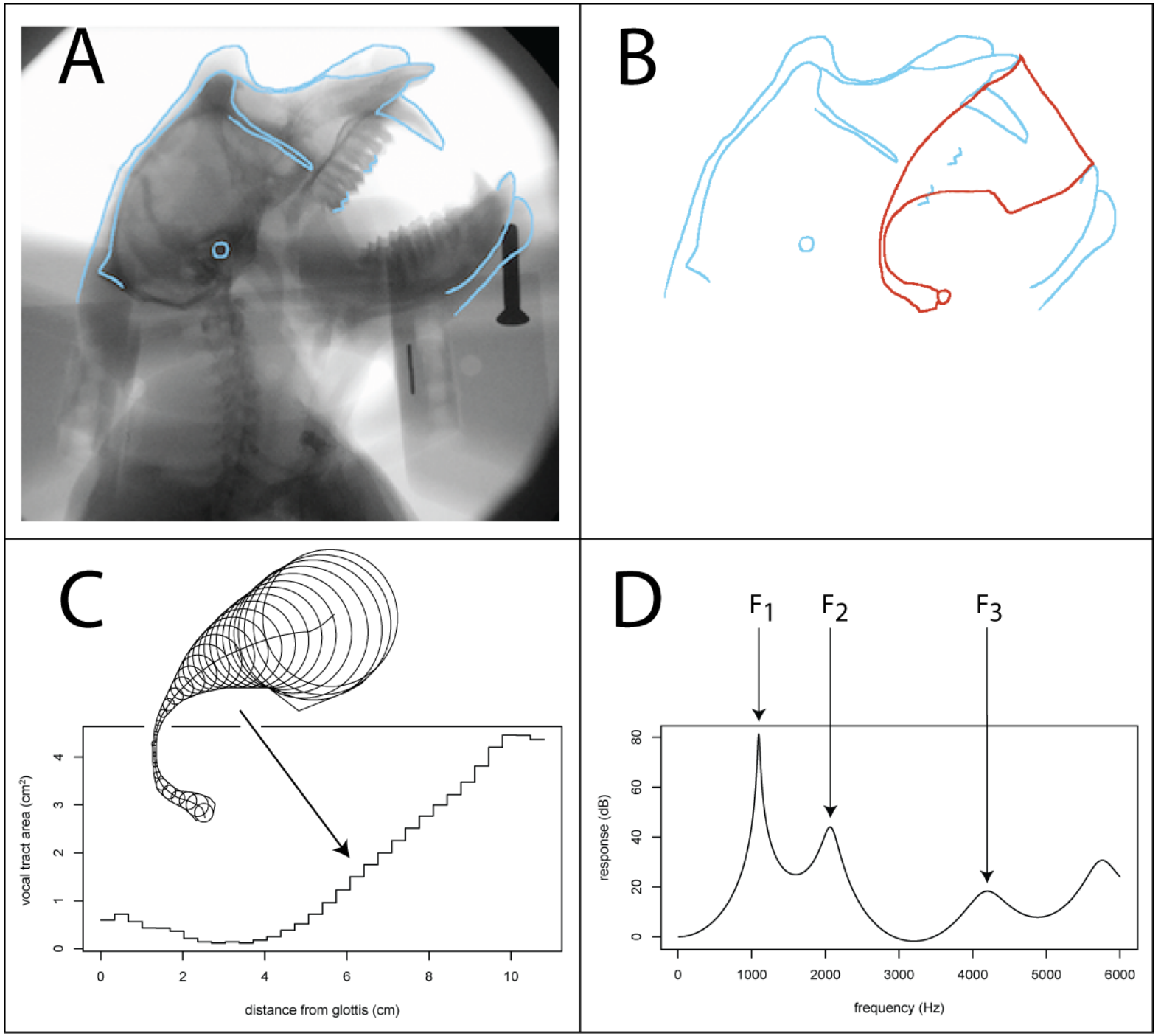
Fitch 2000
Phonetica

New Macaque Data: Vocal Tract Flexibility

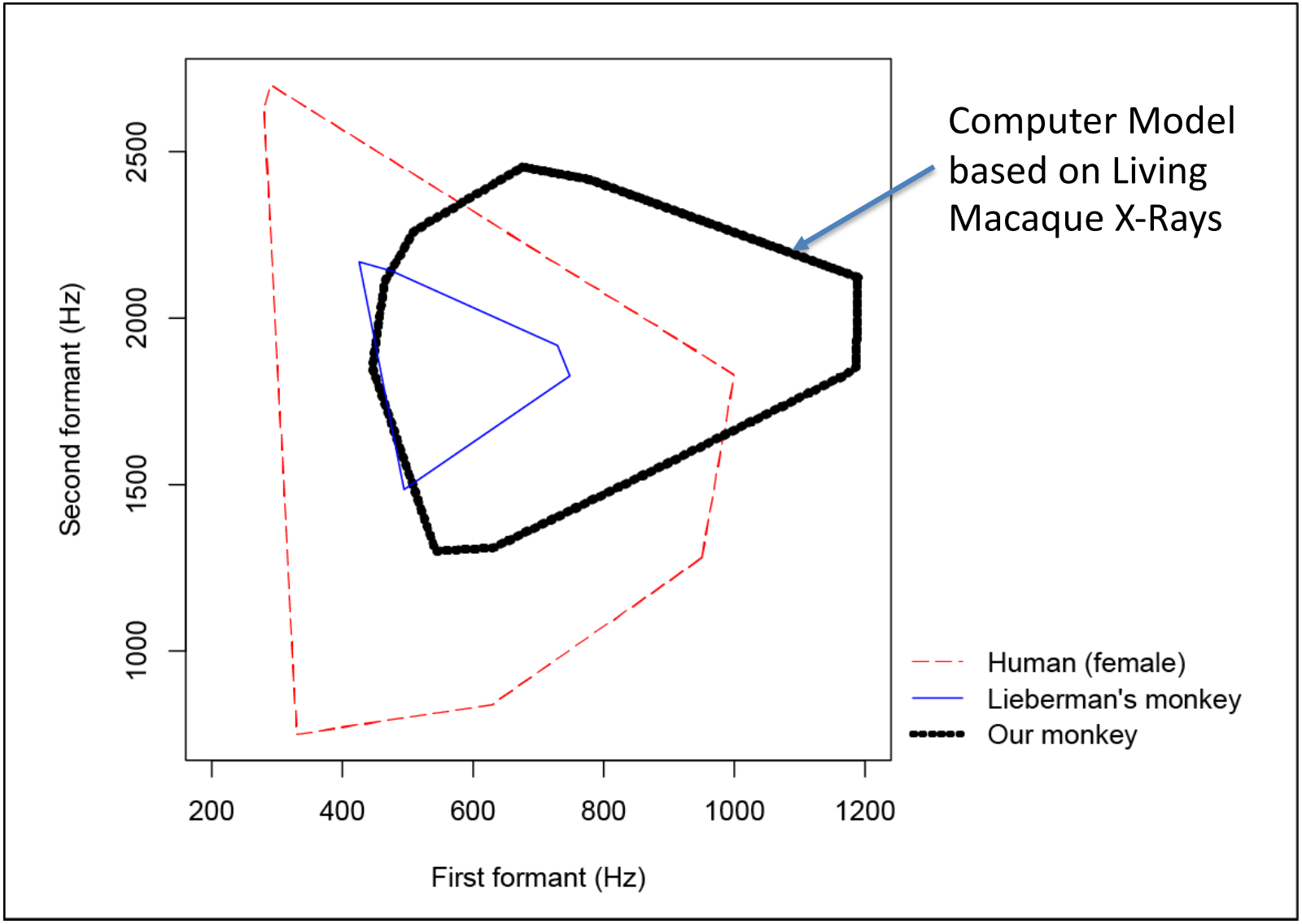




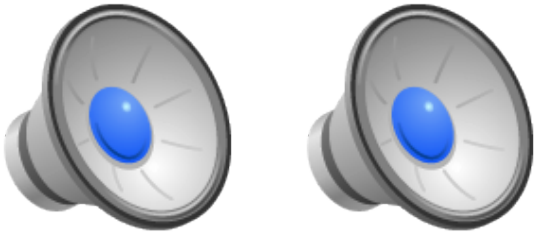
Fitch, Mathur, de Boer, Ghazanfar 2016 *Science Advances*



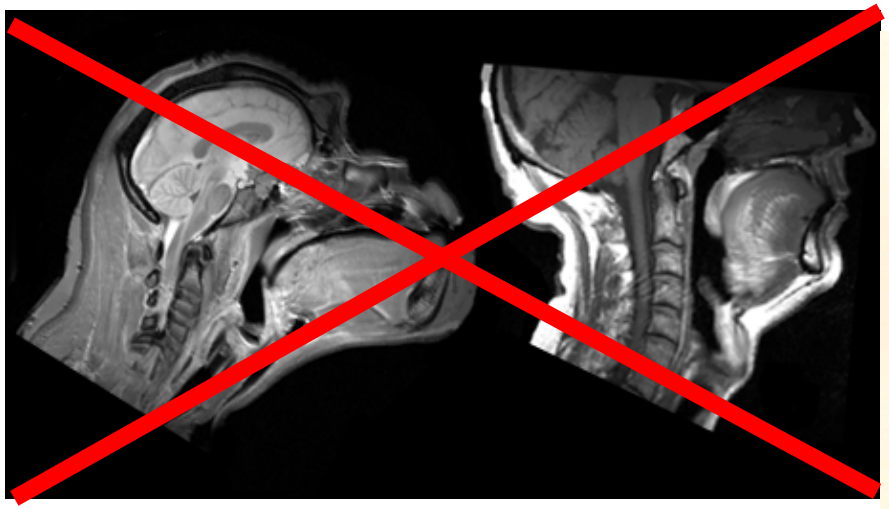
3 Male *Macaca fasicularis*: a variety of behaviors including feeding, lip smacks and vocs



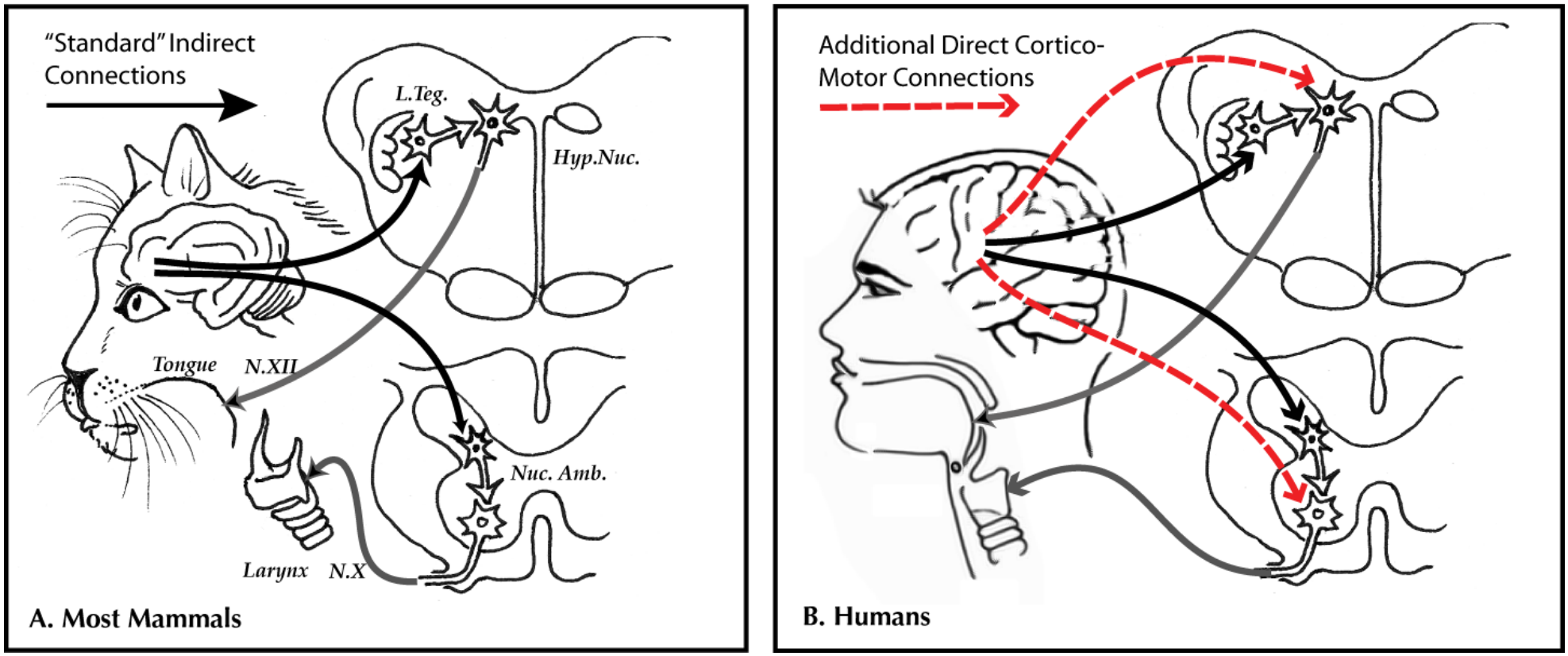
Fitch, Mathur, de Boer, Ghazanfar
2016 *Science Advances*



Key Differential Components of Spoken Language are **Neural** Mechanisms. But What?



The Direct Connections Hypothesis

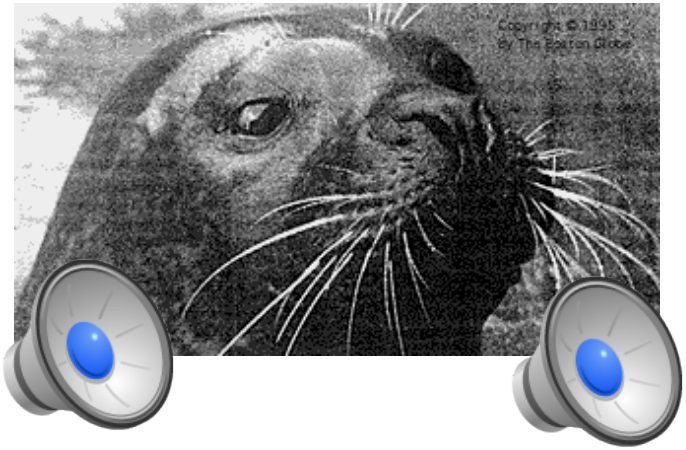


Kuypers 1958; Jürgens 1990;1995; Fitch 2010

Based on humans only… how to test this hypothesis?

Many Non-primate Animals *Can* Learn to Reproduce Speech:

Italian-Speaking Mynah Bird



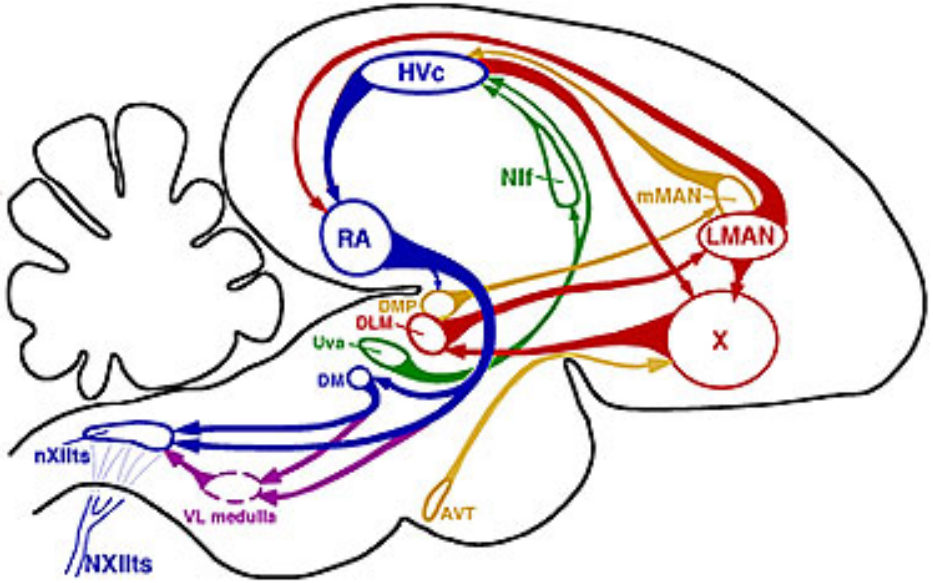
Hoover, a talking seal

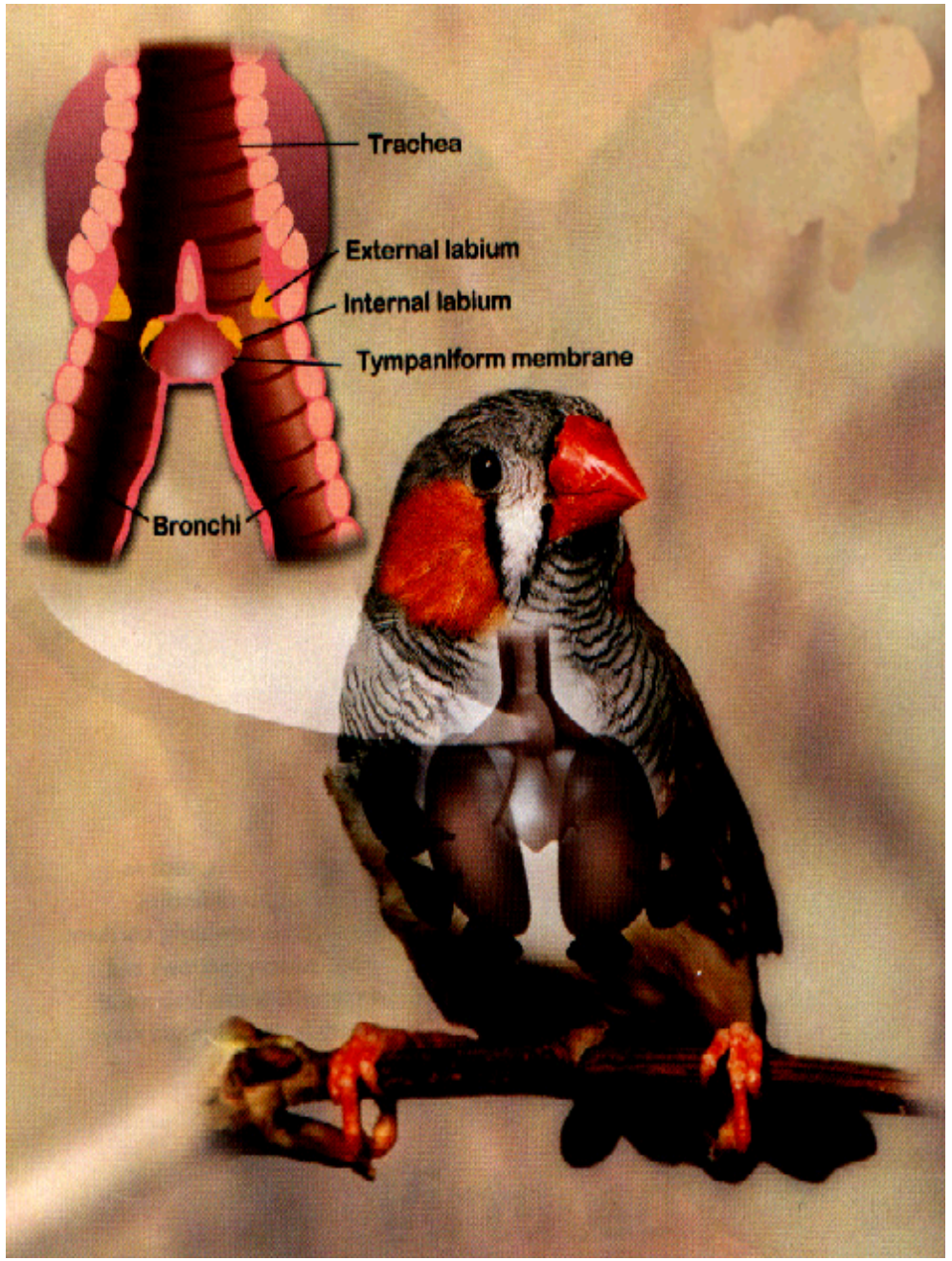
Testing DC Hypothesis: Vocal Learning has Convergently Evolved Multiple Times

Humans, Songbirds, Parrots, Hummingbirds,

Cetaceans, some seals and bats, elephants…

Direct connections exist in all three different avian vocal learning clades: **Prediction Upheld!**

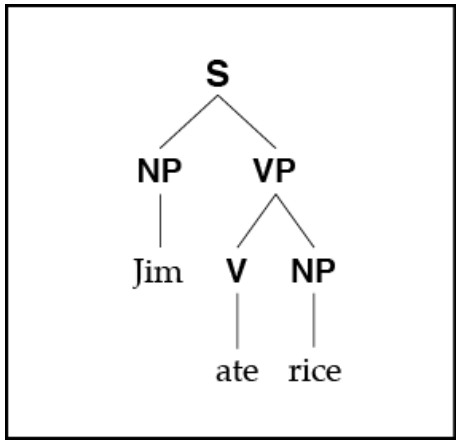


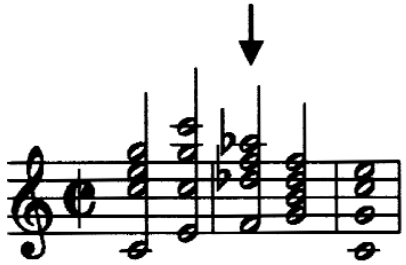


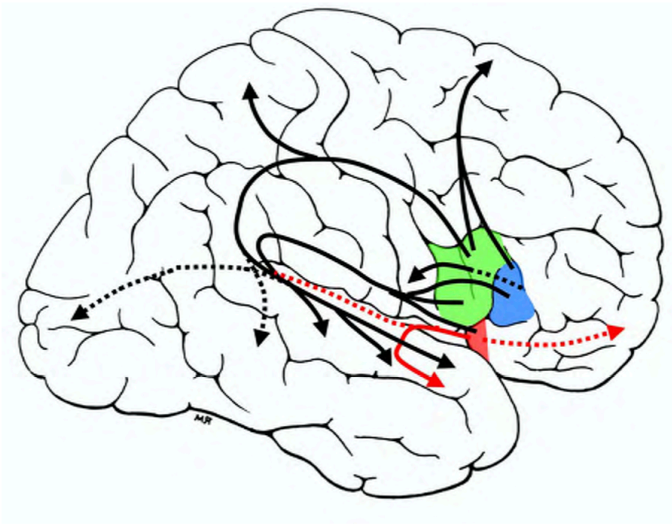
<u>Speech: Summary and Conclusions</u>:

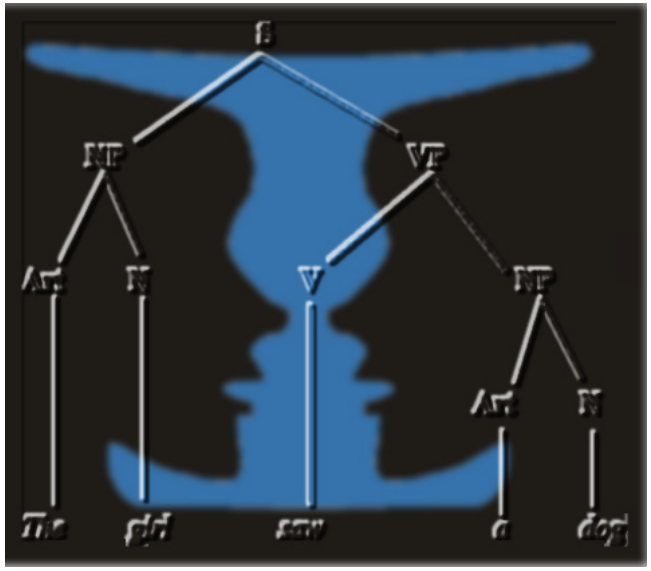
1. Comparative biological approach with living animals provides a powerful tool for generating and testing hypotheses
2. **Direct Connections** between cortex and motor neurons are needed for speech: a key derived component of spoken language

Part 2: Syntax



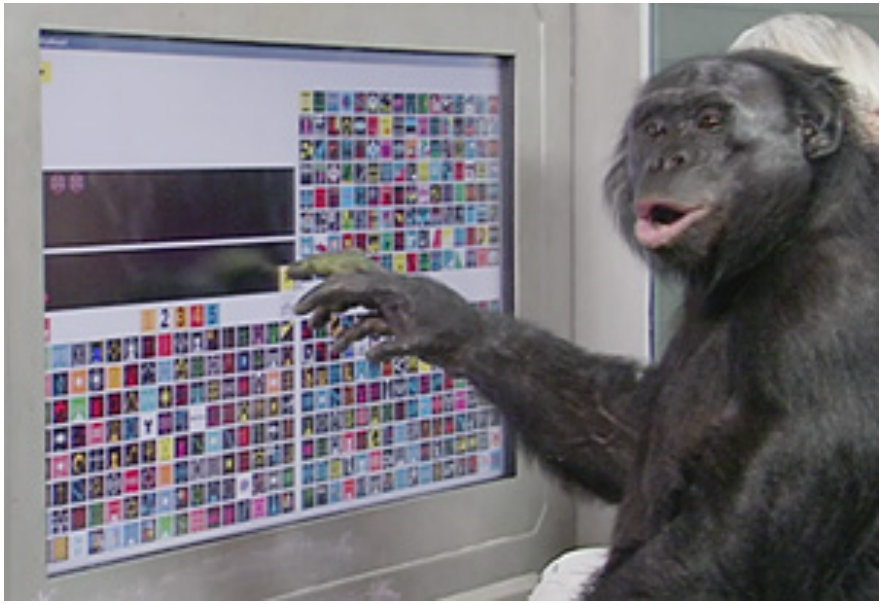






Sign Language Trained Apes: Better! But Learn Only Simple Syntax

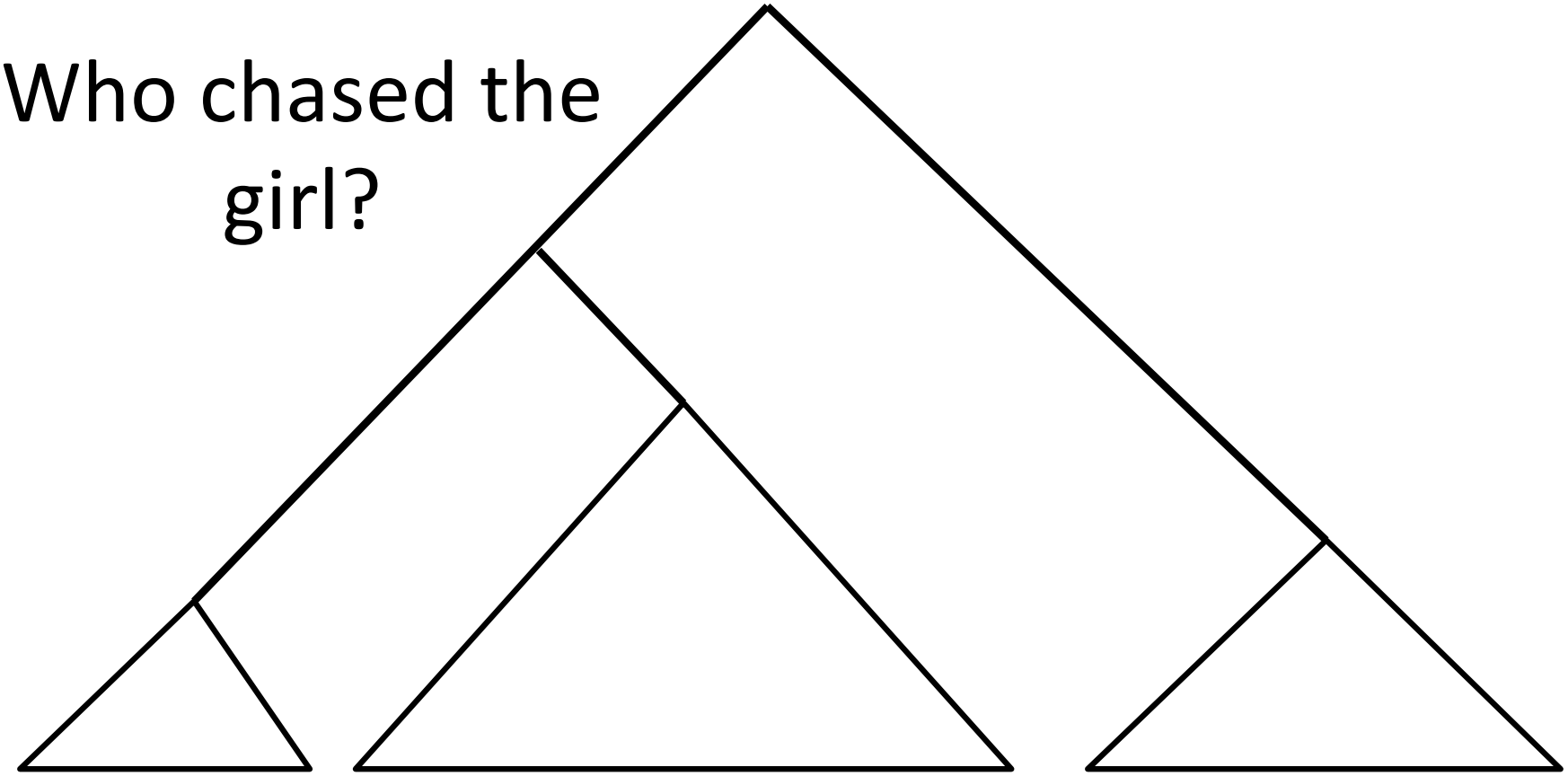
Washoe (chimpanzee)
Koko (gorilla)
Nim (chimpanzee)
Kanzi (bonobo



Savage-Rumbaugh et al (1993) Kanzi

Hierarchy in Human Language a Key Feature: Structure Dependence

Who chased the girl?

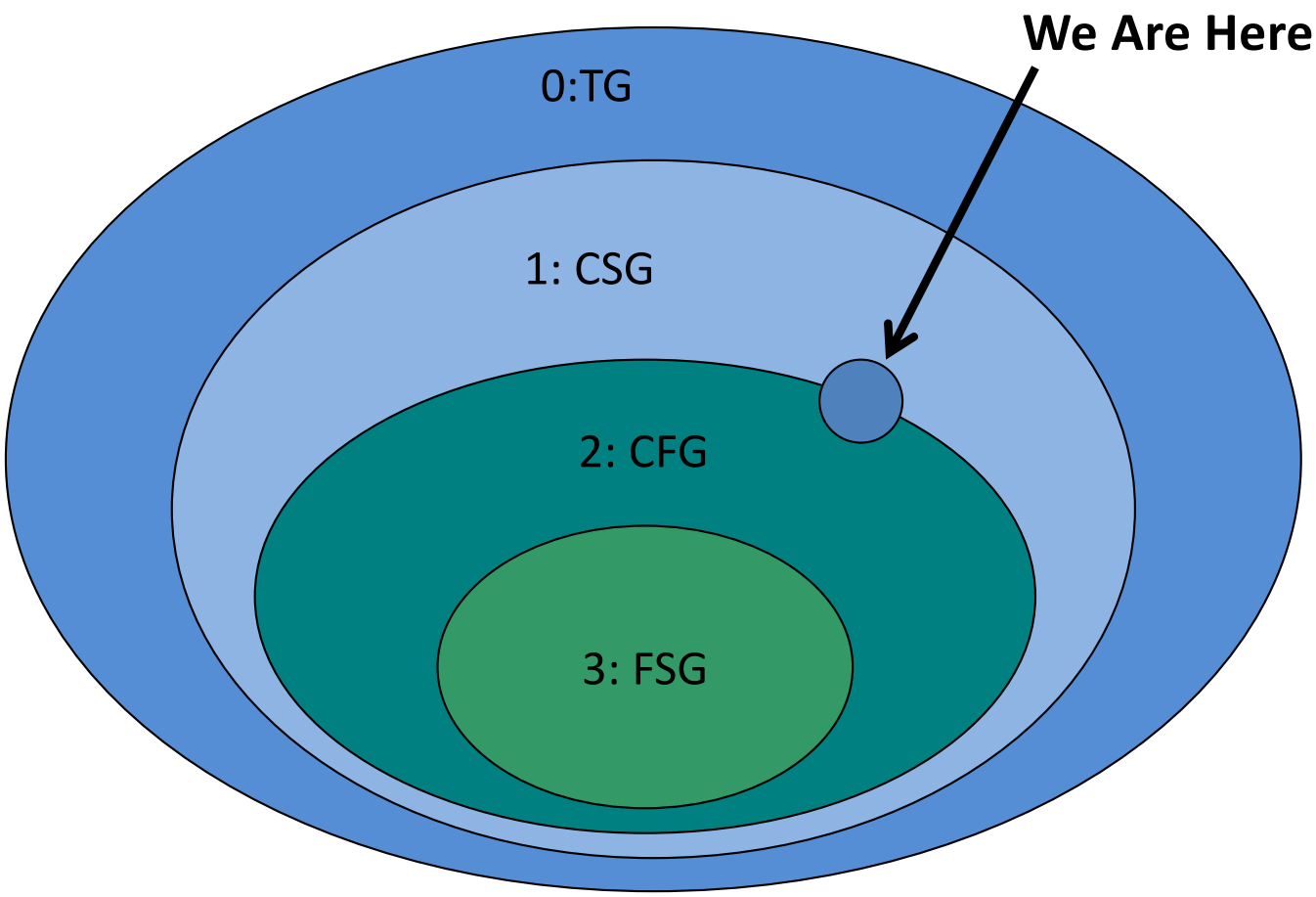


The boy who kicked the dog chased the girl.

The Formal Language Hierarchy
("Chomsky Hierarchy")

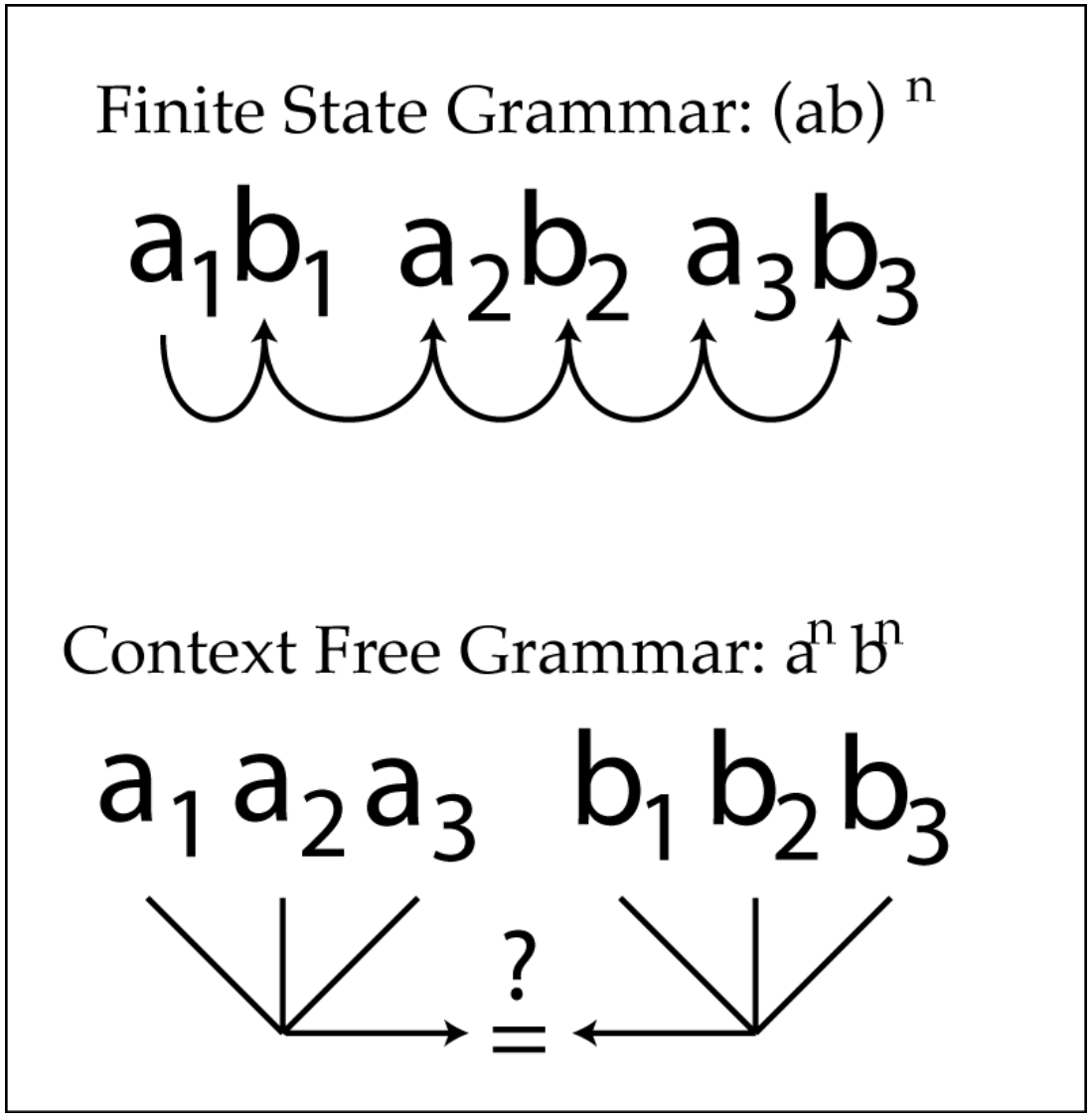
Turing

Chomsky



Nested Sets of Increasingly Powerful Rule Systems or "Grammars" (Chomsky 1957)

Two grammars – Simple pattern generating algorithms



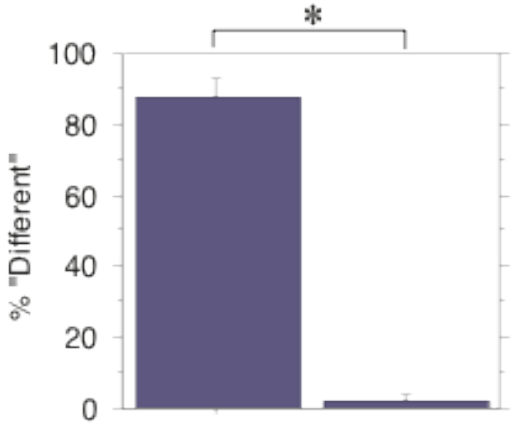
Sequential Rule
(Finite State Grammar)

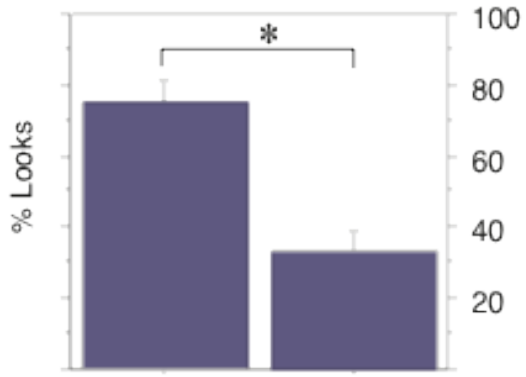
Hierarchical Rule
(Context Free Grammar)

Cotton-top Tamarin Results

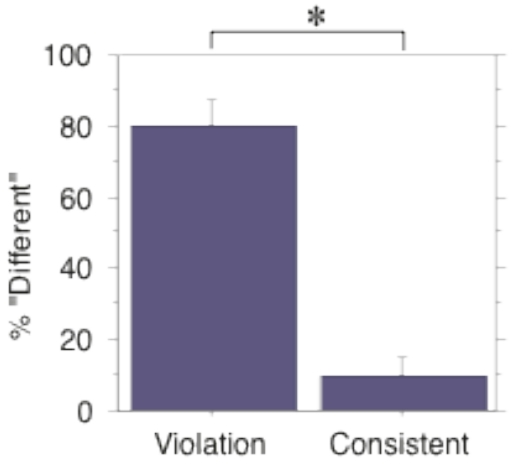
Humans

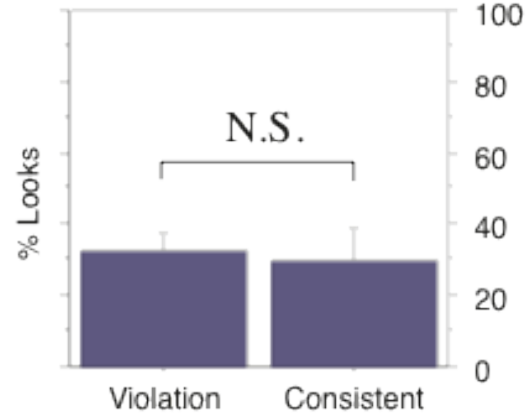
Monkeys





Sequential Rule
(Finite State Grammar)



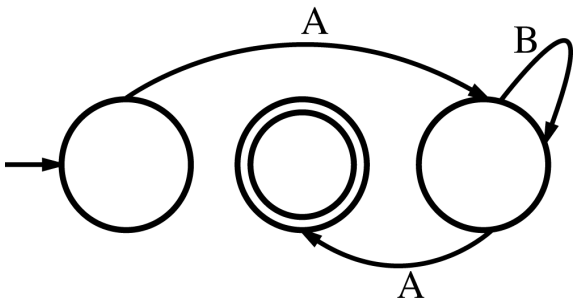


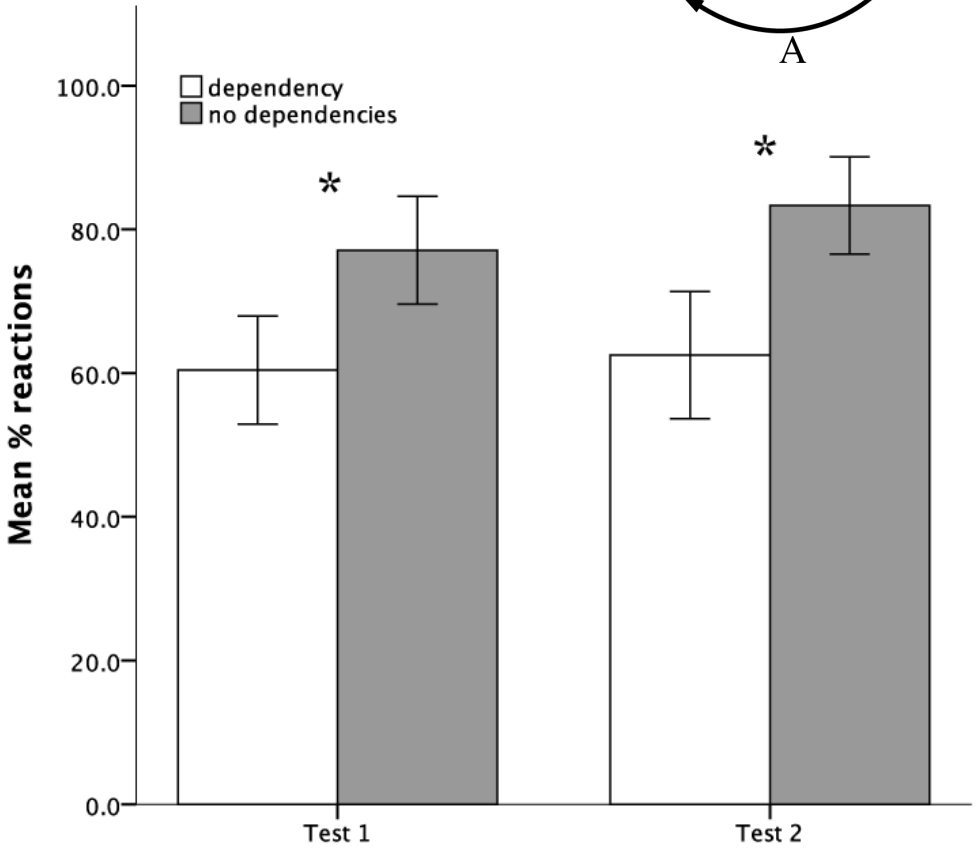
Hierarchical Rule
(Context Free Grammar)

Fitch & Hauser (2004) Science

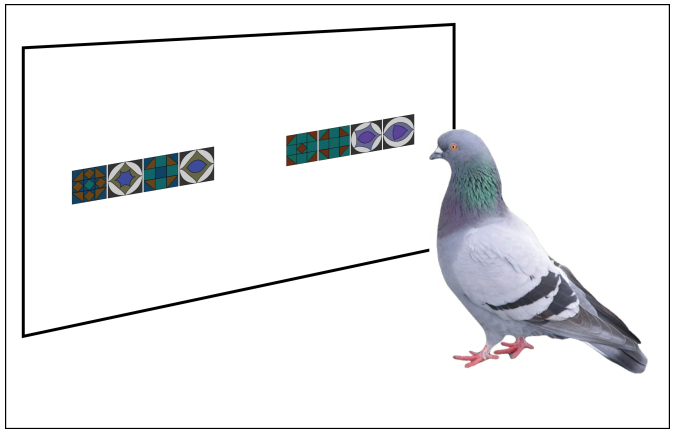
Another Regular Grammar of Interest:

AB*A



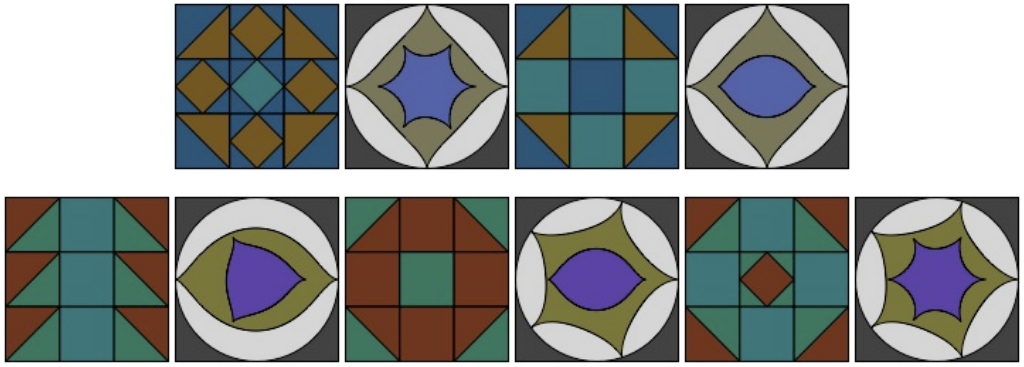


Andrea Ravignani et al 2013: Biology Letters 9(6) – Squirrel monkeys (tones)
Ruth Sonnweber et al 2015: Animal Cognition 18(3) – Chimpanzees (visual)
Stephan Reber et al (in review: Evo Hum Behav) – Marmosets (tones)

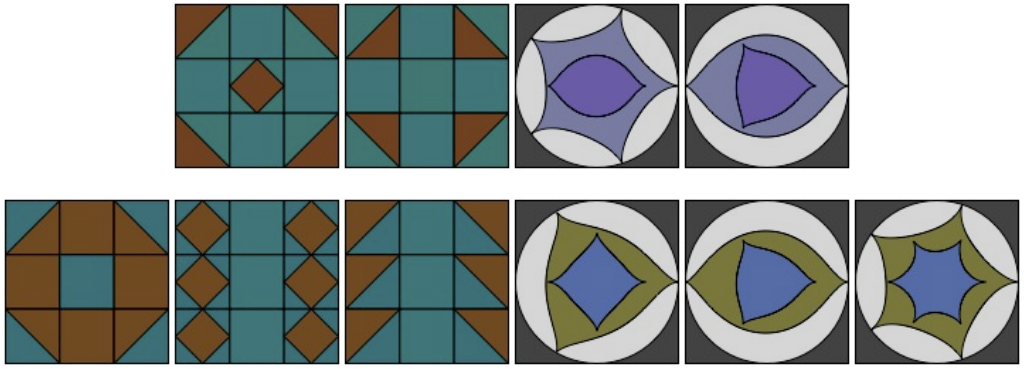


Artificial Grammar Learning: Birds

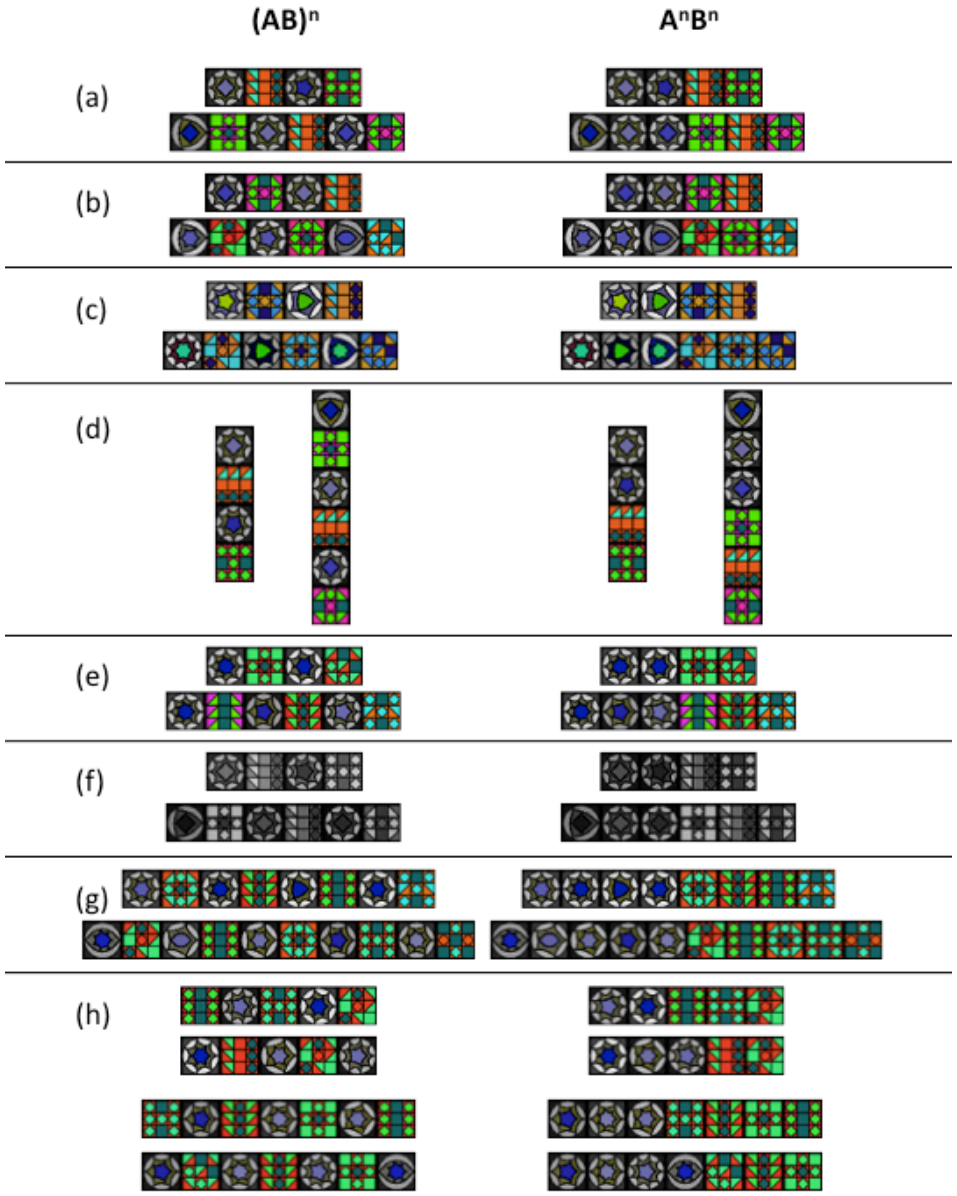
Nine Stobbe,
Ulrike Aust,
Gesche Westphal-Fitch



$(AB)^n$



A^nB^n

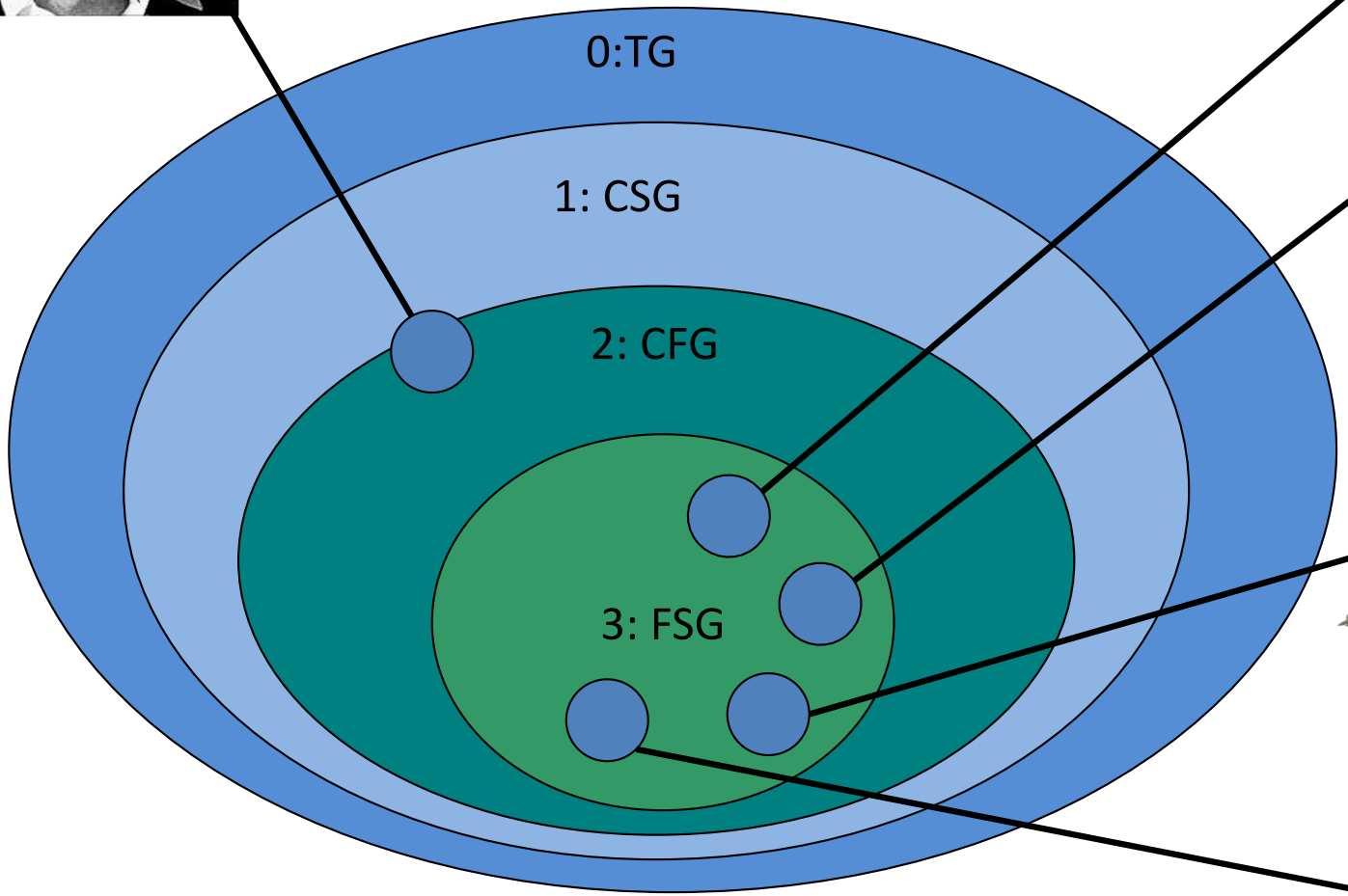


Keas

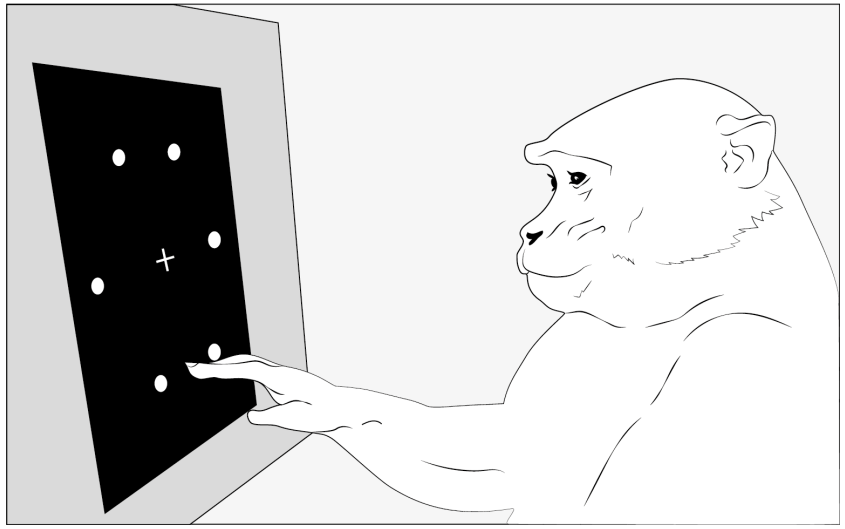
Successfully make many generalizations…

But fail to acquire **hierarchical grammar**

Artificial Grammar Learning in Animals: State of the Art 2017

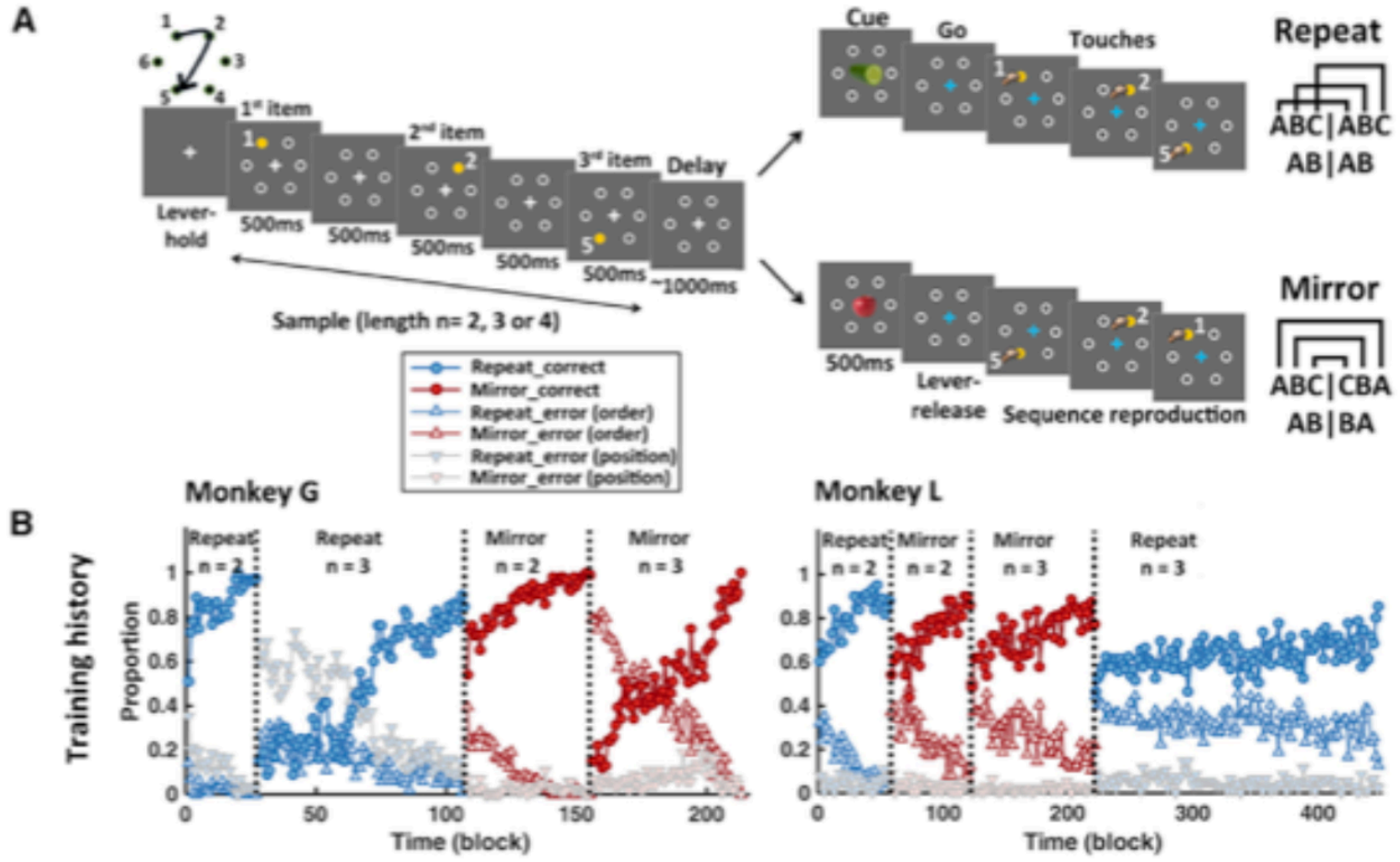


Reviews: Fitch & Friederici 2012 Phil Trans B 367: 1933; Wilson et al 2013 J. Neurosci 33:18825; Sonnweber et al 2015 Animal Cognition 18: 733

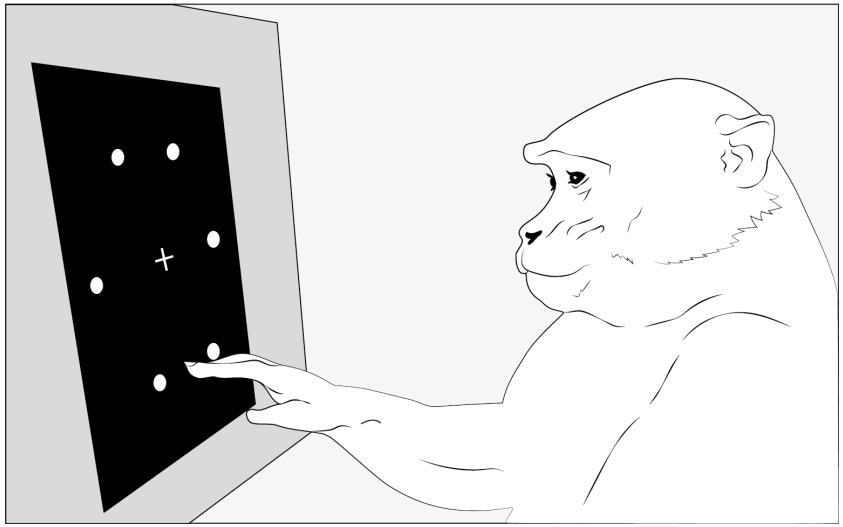


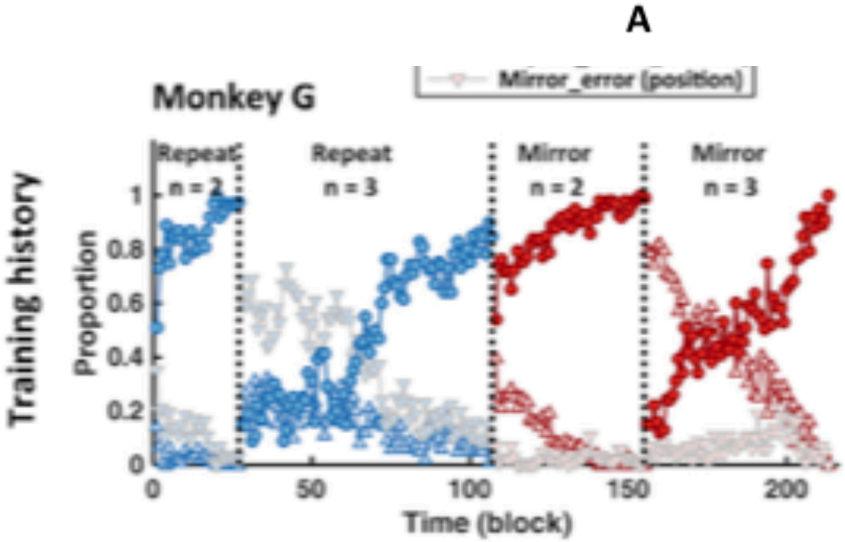
New Macaque Data – Wang Lab Paris

Jiang et al 2018: Current Biology: “Production of supra-regular sequences by macaque monkeys:

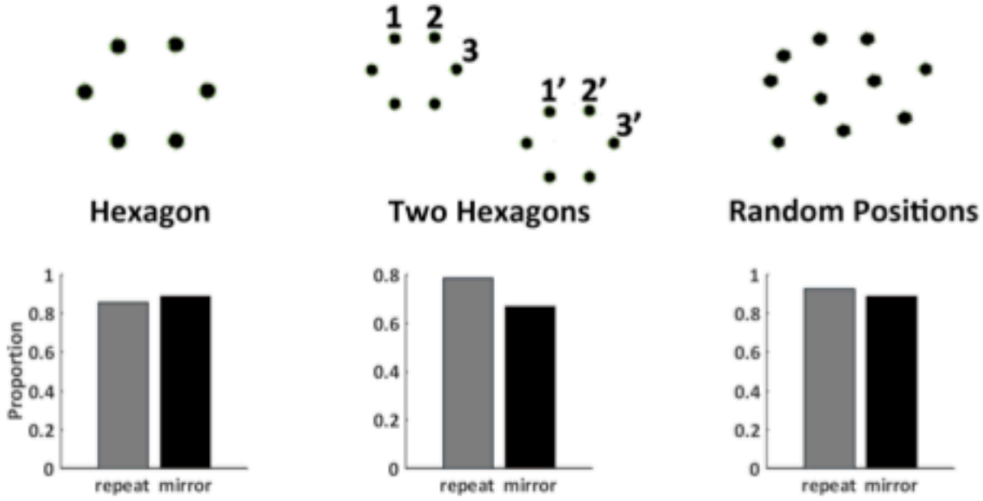


Comparing Macaques to Pre-Schoolers

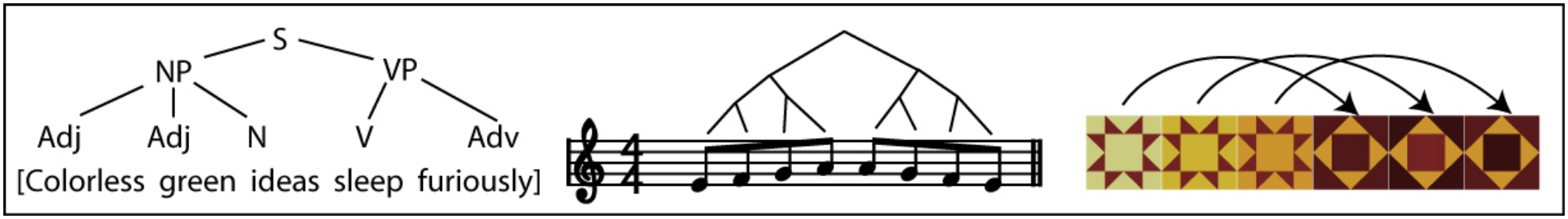




Monkeys: 1 Block is 800 trials, so 80K-160K trials to criterion.



Preschoolers: success after 5 demonstrations: fast and easy!



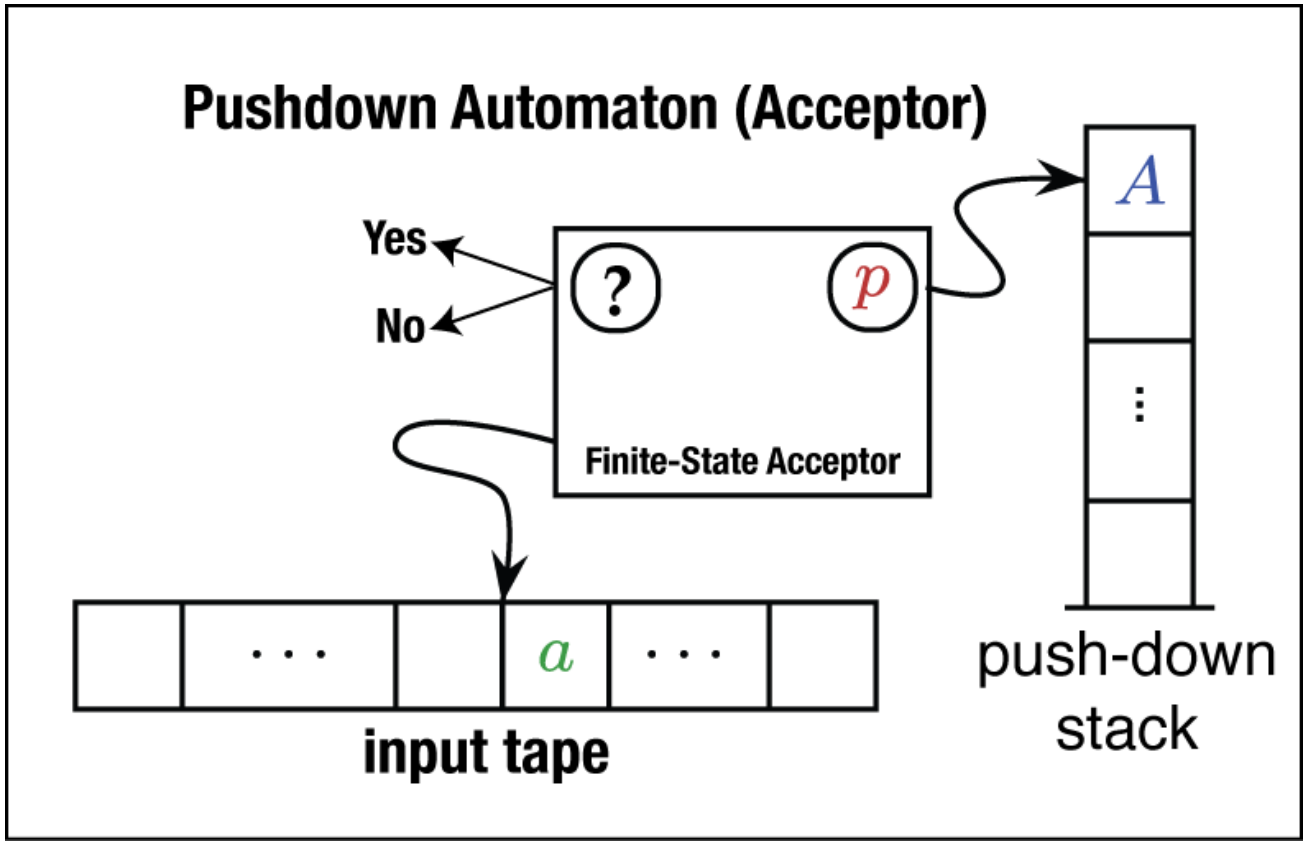
The Dendrophilia Hypothesis

Cognitive Hypothesis:

Humans have a species-typical, **multi-domain**, ability and propensity to infer tree-formed, hierarchical structures from data;

Requires supra-regularity.

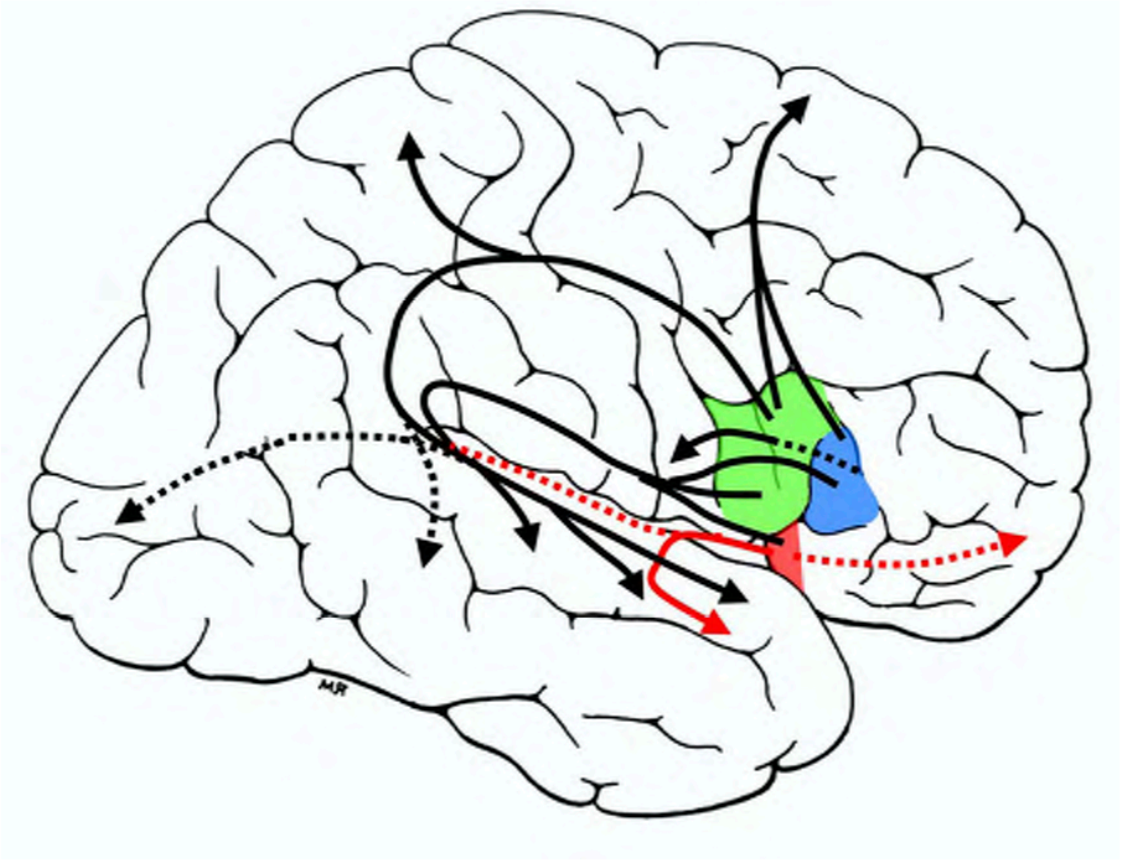
Computation of Hierarchy: Requires Auxiliary "Working" Memory

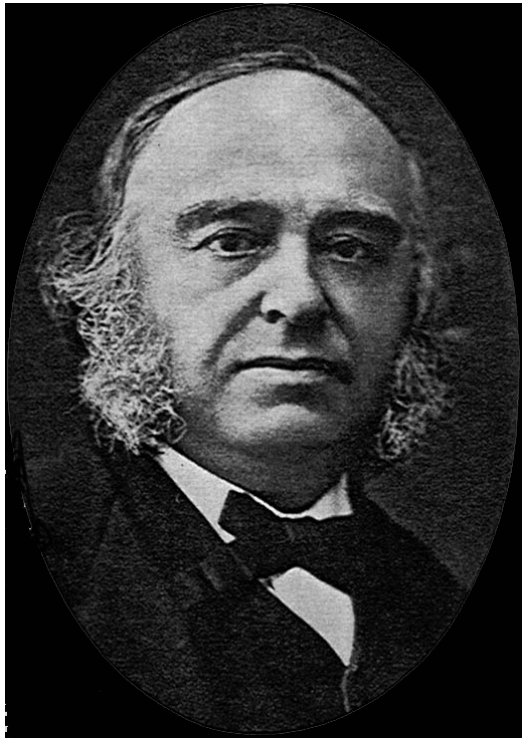


Push-Down Automaton: A finite-state machine with an additional memory system, termed a "**stack**"

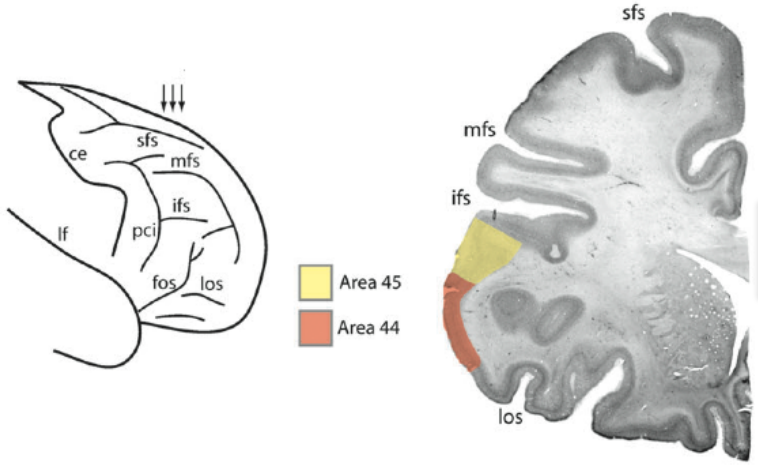
Neuro-Computational Hypothesis: Broca's Area supports Supra-Regularity

Broca's area provides a domain-general auxiliary memory (roughly equivalent to a "stack") for other brain regions





Natalie Schenker: Broca's Area (BA44/45) is the **most expanded human cortical region known**, relative to chimpanzees

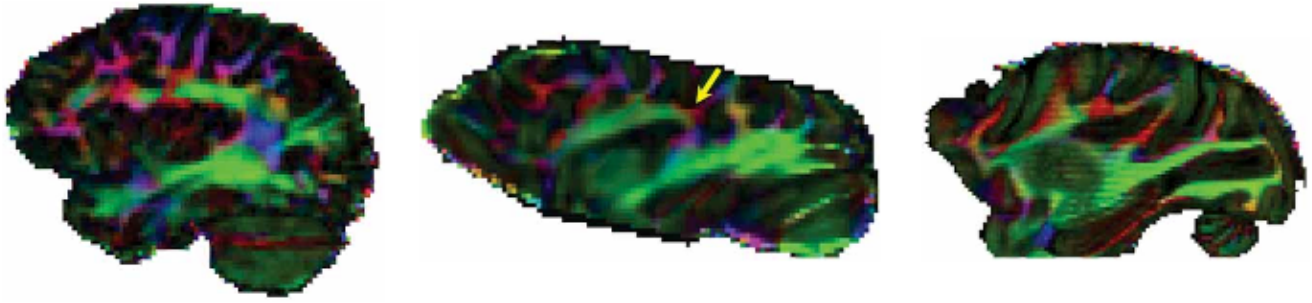


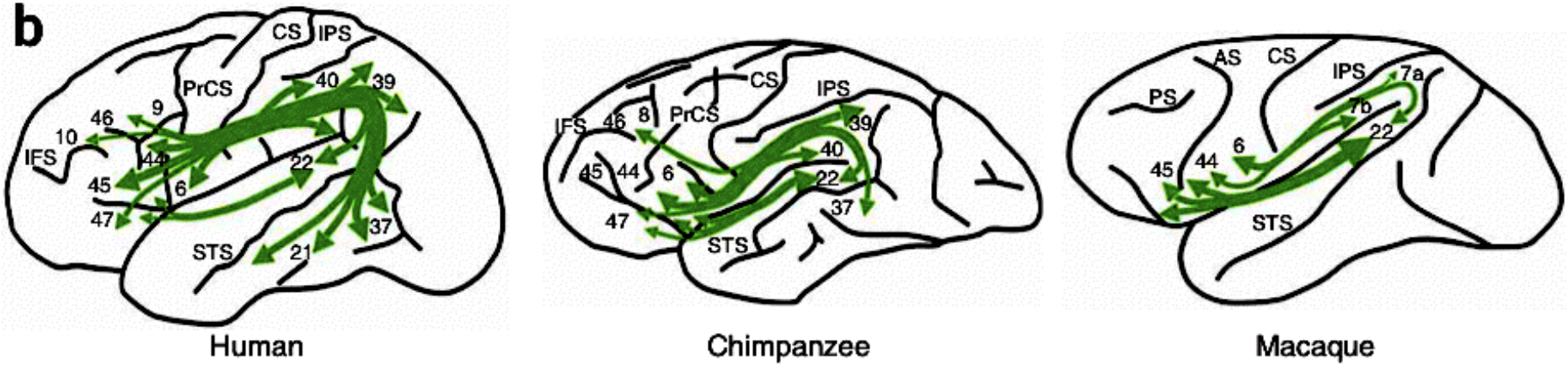
Rank ordered fold difference between brain structure volumes in humans and chimpanzees

Structure	Human versus chimpanzee fold difference	Data source
Brain	3.6	Chimpanzee (n = 12)—the present study; human (n = 10)—Uylings et al. (2006)
Neocortical gray	4.0	Chimpanzee (n = 6) and human (n = 6)—Rilling and Insel (1999)
Frontal cortex	4.6	Chimpanzee (n = 6) and human (n = 10)—Semendeferi et al. (2002)
Area 44 left	6.6	Chimpanzee (n = 12)—the present study; human (n = 10)—Uylings et al. (2006)
Area 10 right	6.3	Chimpanzee (n = 1) and human (n = 1)—Semendeferi et al. (2001)
Area 45 left	6.0	Chimpanzee (n = 12)—the present study; human (n = 10)—Uylings et al. (2006)
Area 45 right	5.0	Chimpanzee (n = 12)—the present study; human (n = 10)—Uylings et al. (2006)
Area 44 right	4.1	Chimpanzee (n = 12)—the present study; human (n = 10)—Uylings et al. (2006)
Area V1 left	1.8	Chimpanzee (n = 7) and human (n = 10)—de Sousa (2008)
Area 13 right	1.4	Chimpanzee (n = 1) and human (n = 1)—Semendeferi et al. (1998)

Schenker et al (2010) Cerebral Cortex 20:730

Jim Rilling: Broca's underwent a significant increase in connectivity: Arcuate fasiculus

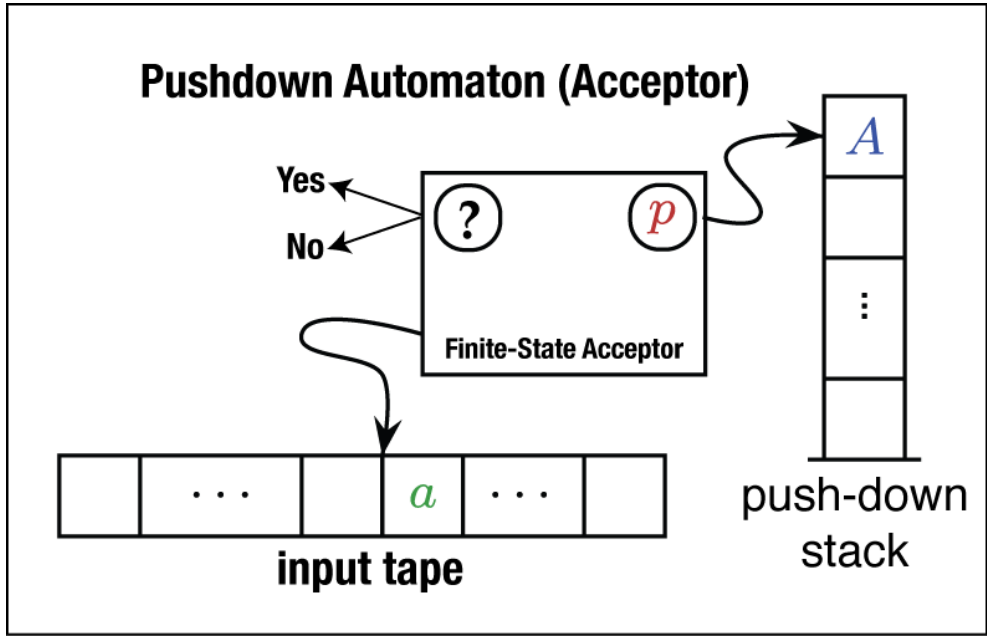


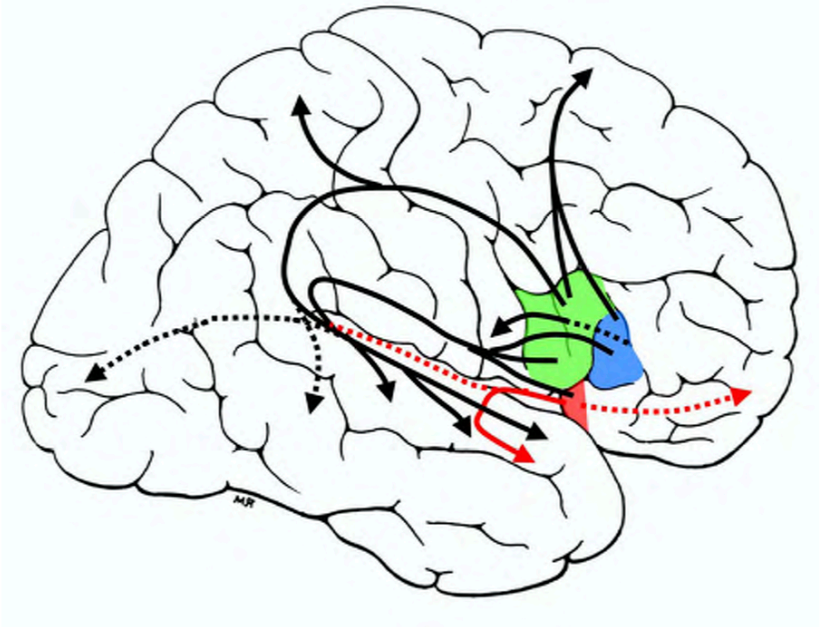


James Rilling et al 2008 Nature Neuroscience 11(4): 426-428

Hypothesis: Broca's & Supra-Regularity

Broca's provides a domain-general auxiliary working memory (roughly, a "stack") for other brain regions:
Greatly expanded in size and connectivity in humans.
Supports language (and other dendrophilic cognition)





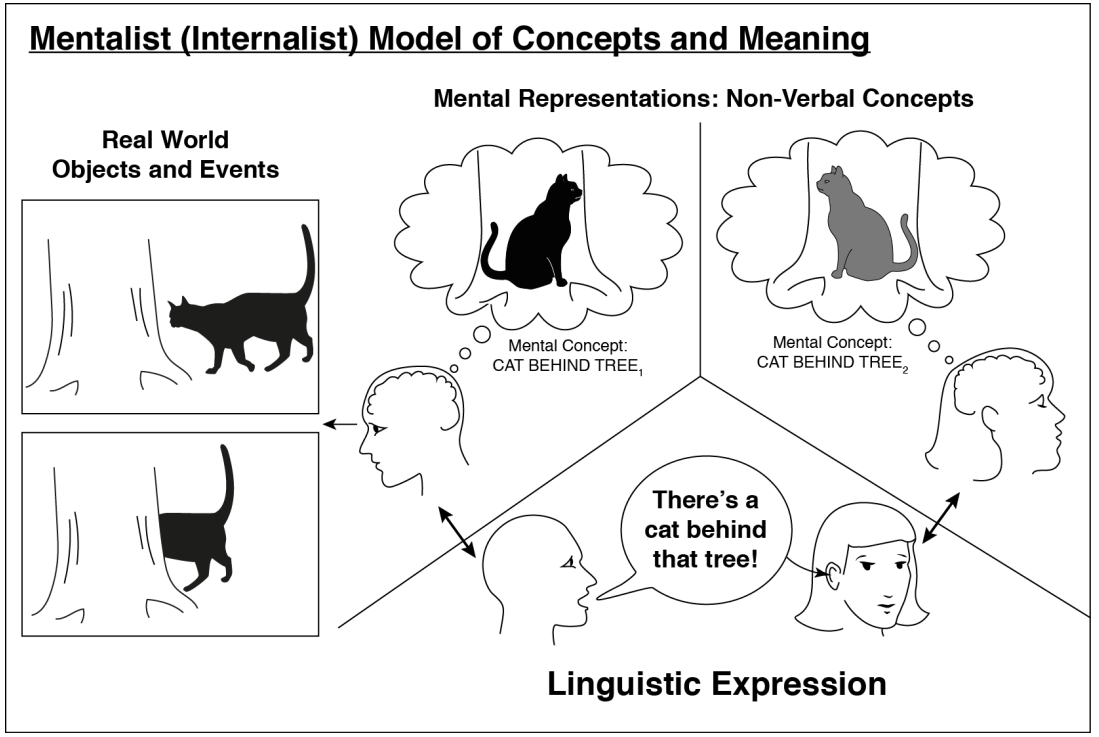
Syntax: Summary and Conclusions:

1. Comparative biology suggests that human syntax is quite unusual

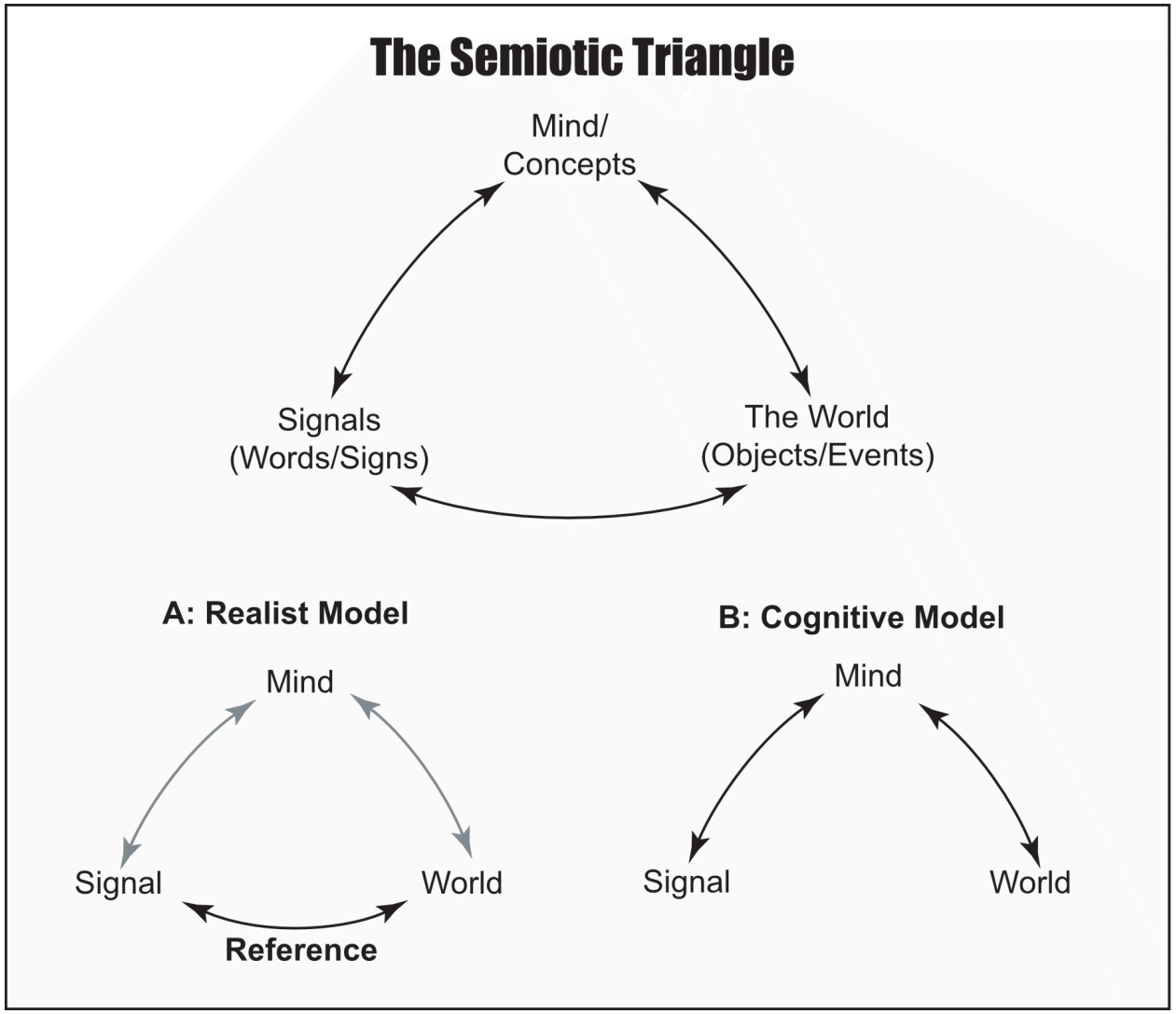
2. Humans have "**dendrophilia**": a propensity to interpret data in tree form

2. **Broca's area** expansion provides the neural basis for this: a key derived component of the FLD

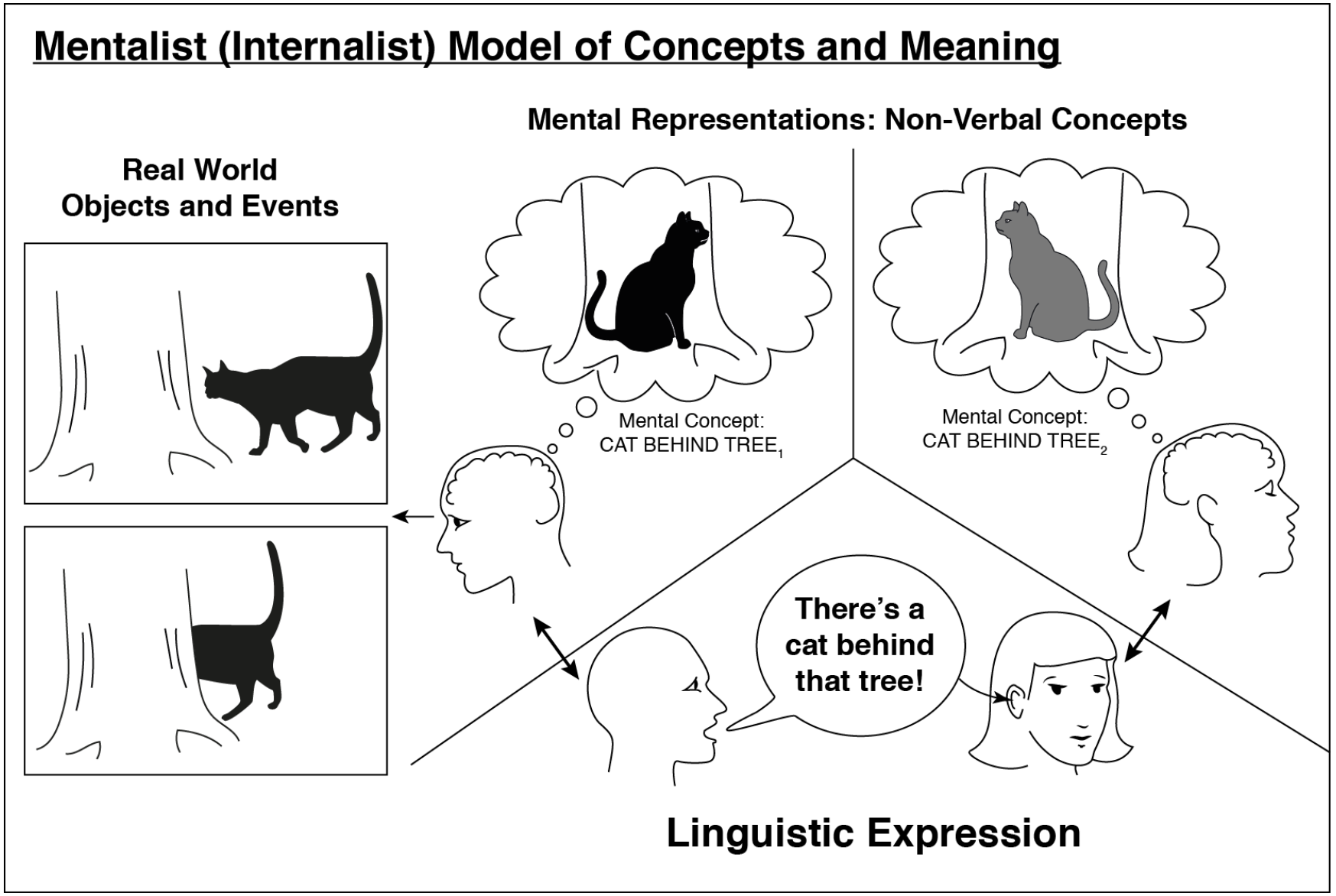
Part 3: Semantics



Different Models of Reference

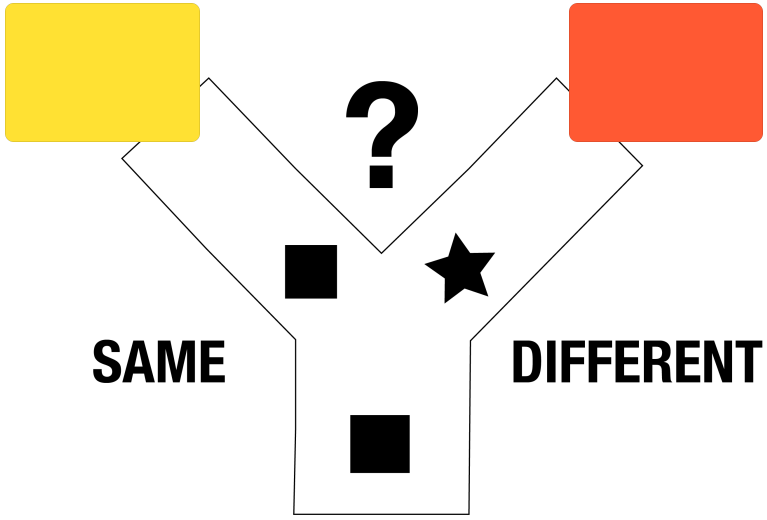


Words Refer to Thoughts, not Things!



Examples: **Vervet Alarm Calls**

Honeybee Dance Communication



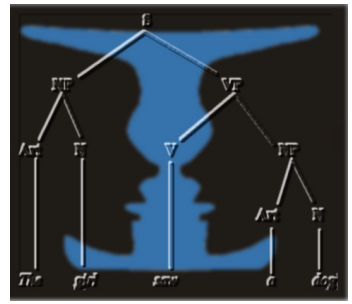
Semantics: Conclusions:

1. Animals communication systems are quite limited relative to their known cognitive abilities;
2. The appropriate precursors for many linguistic phenomena are likely found in animal **cognition** rather than animal communication.

3. Semantics: *Cognitive* Precursors

- Animals **know** (cognition) much more than they can **say** (communication)
- Therefore, the absence of, say, a vocalization "for" color does *not* imply that the species has no concept of color!
- Animal cognition research demonstrates a **rich conceptual world** in many species, suggesting that our semantic world builds upon a deep foundation

General Conclusions



- Study a **wide variety of vertebrates**
- **Determinants of speech are neural**, not vocal anatomy
- We are getting a clearer picture of what makes human **syntax** different from that available to animals.
- Humans appear to be unusually interested in, and gifted at processing, tree-like structure: we have **dendrophilia.** Broca's area is the computational core
- Much of our **semantic** apparatus preceded language and may be derived from conceptual tools already present in our nonhuman ancestors.

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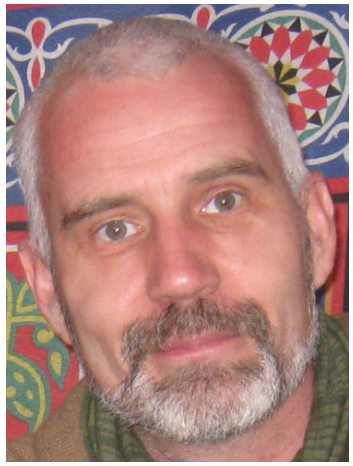











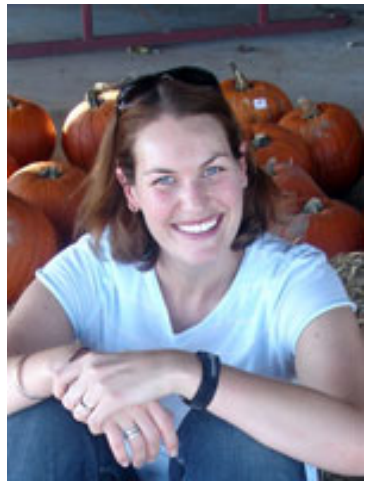

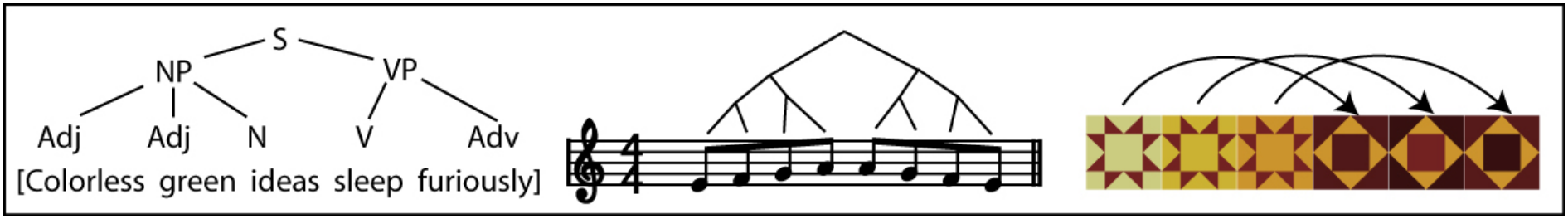

Thank You!

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