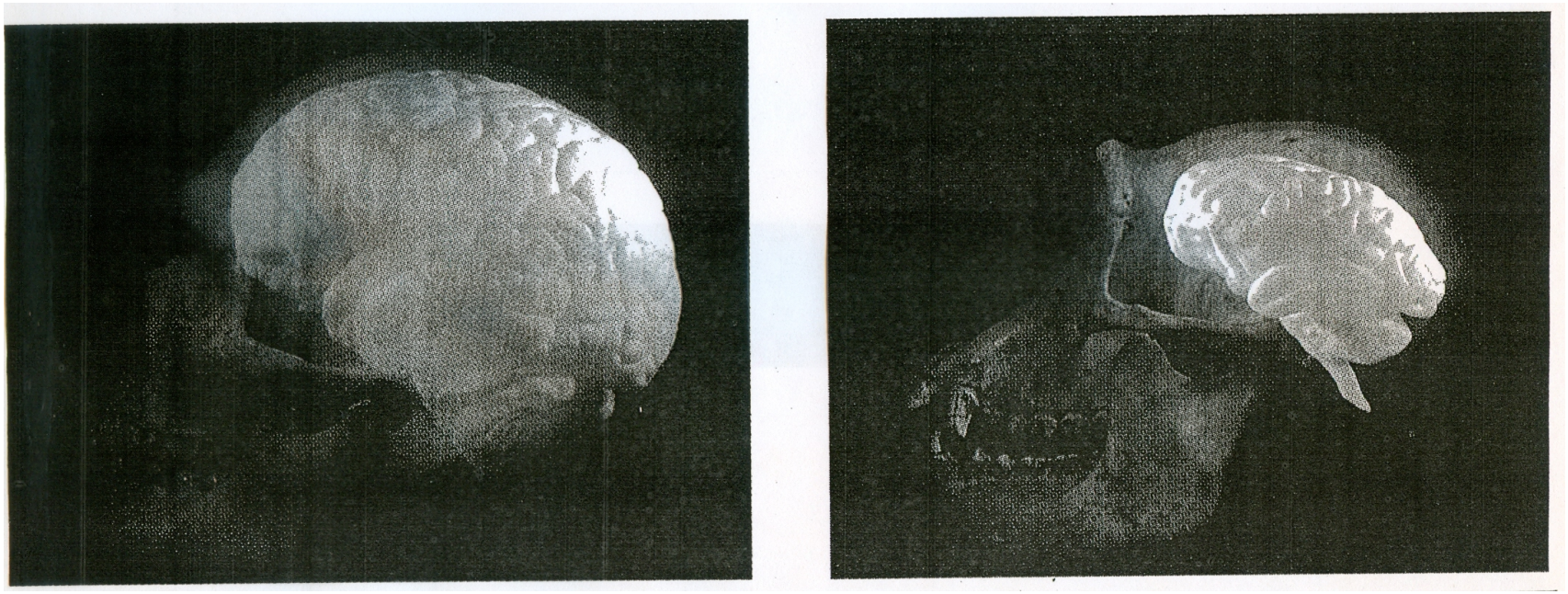
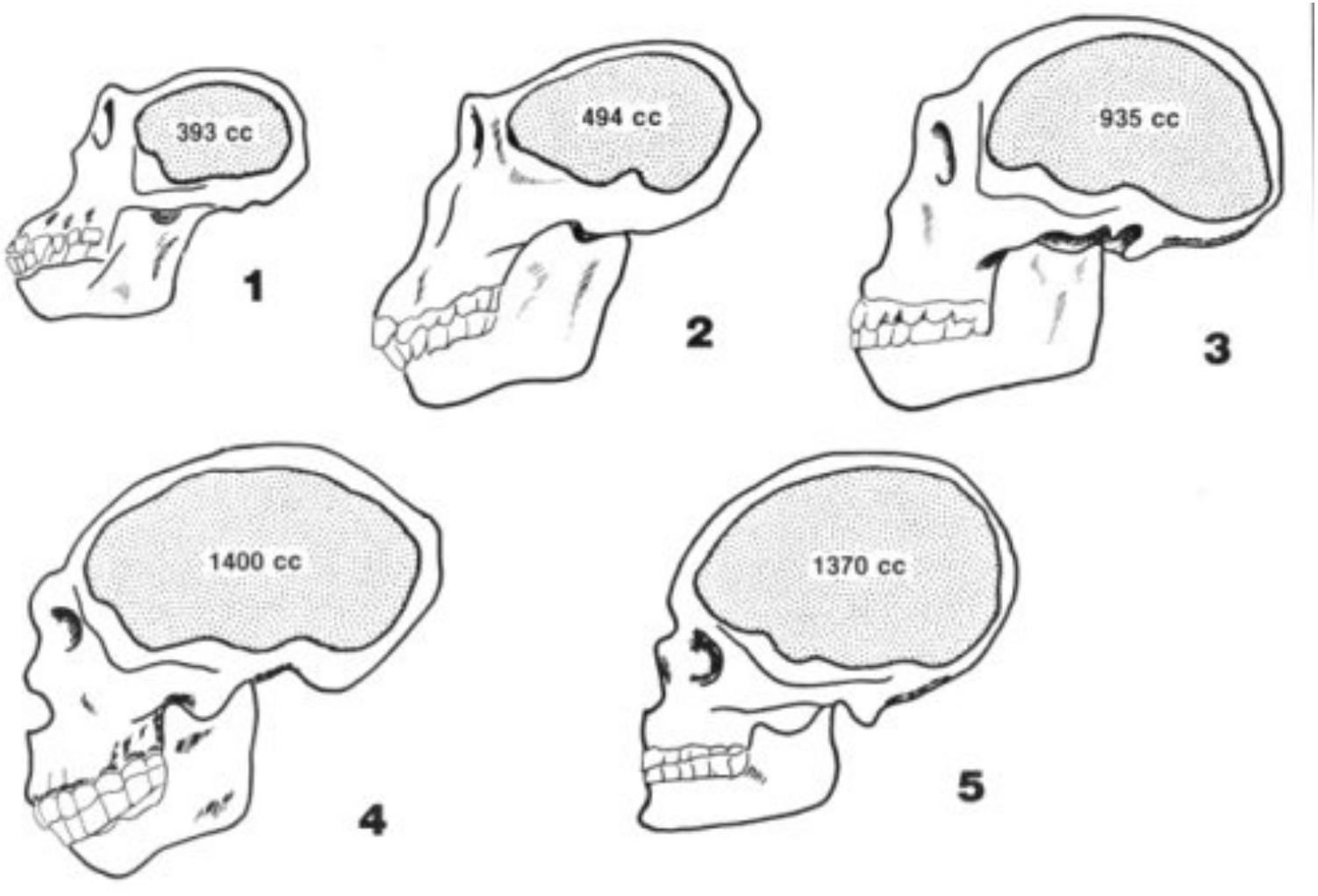
Comparative Neuroanatomy



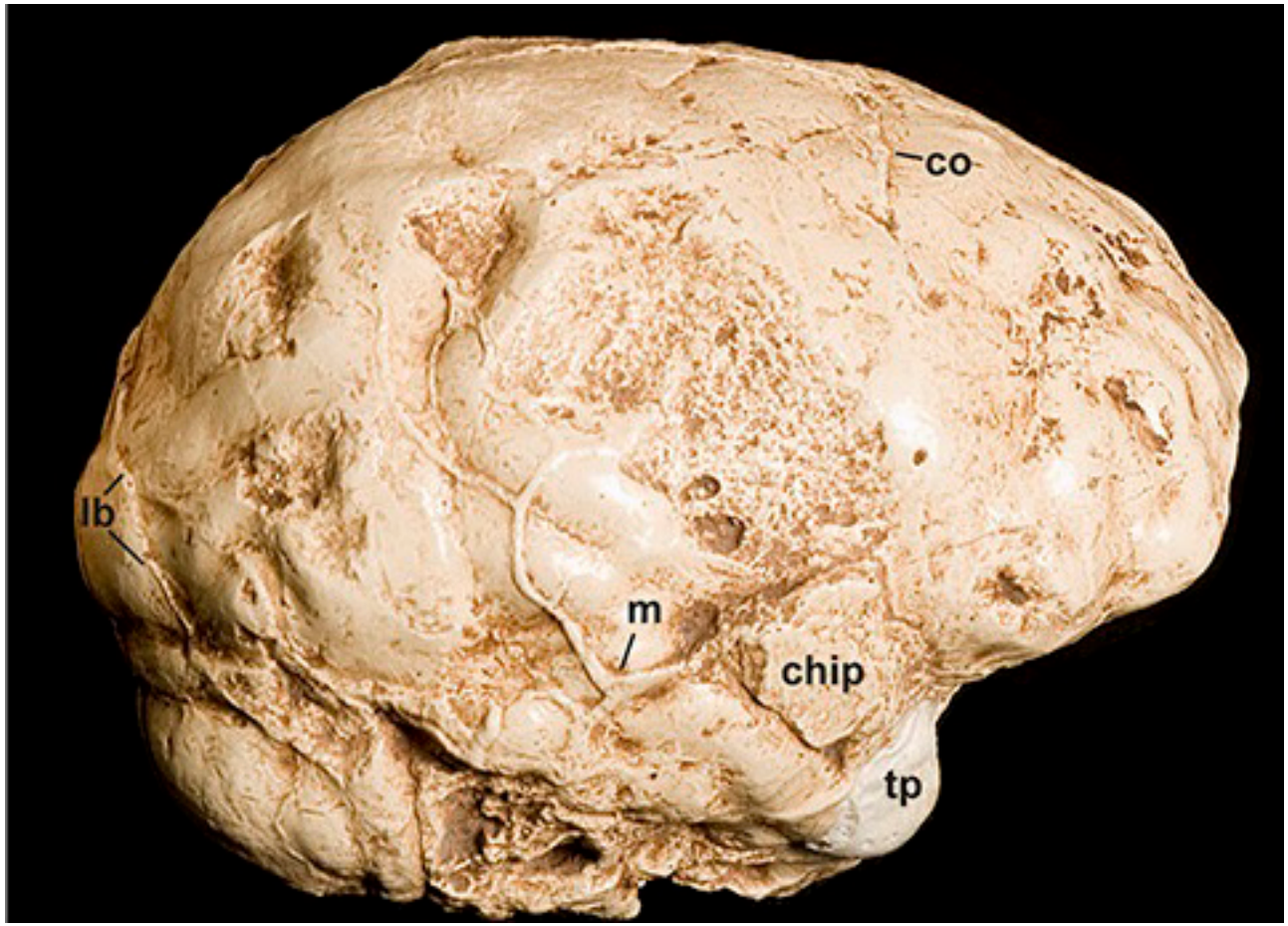
Homind Prehistory: Increasing Brain Size



Fossil Record: Endocasts

Endocast = A mold of the inner surface of the brain case

Can determine size and sometimes surface structure of brain, but NOT connectivity



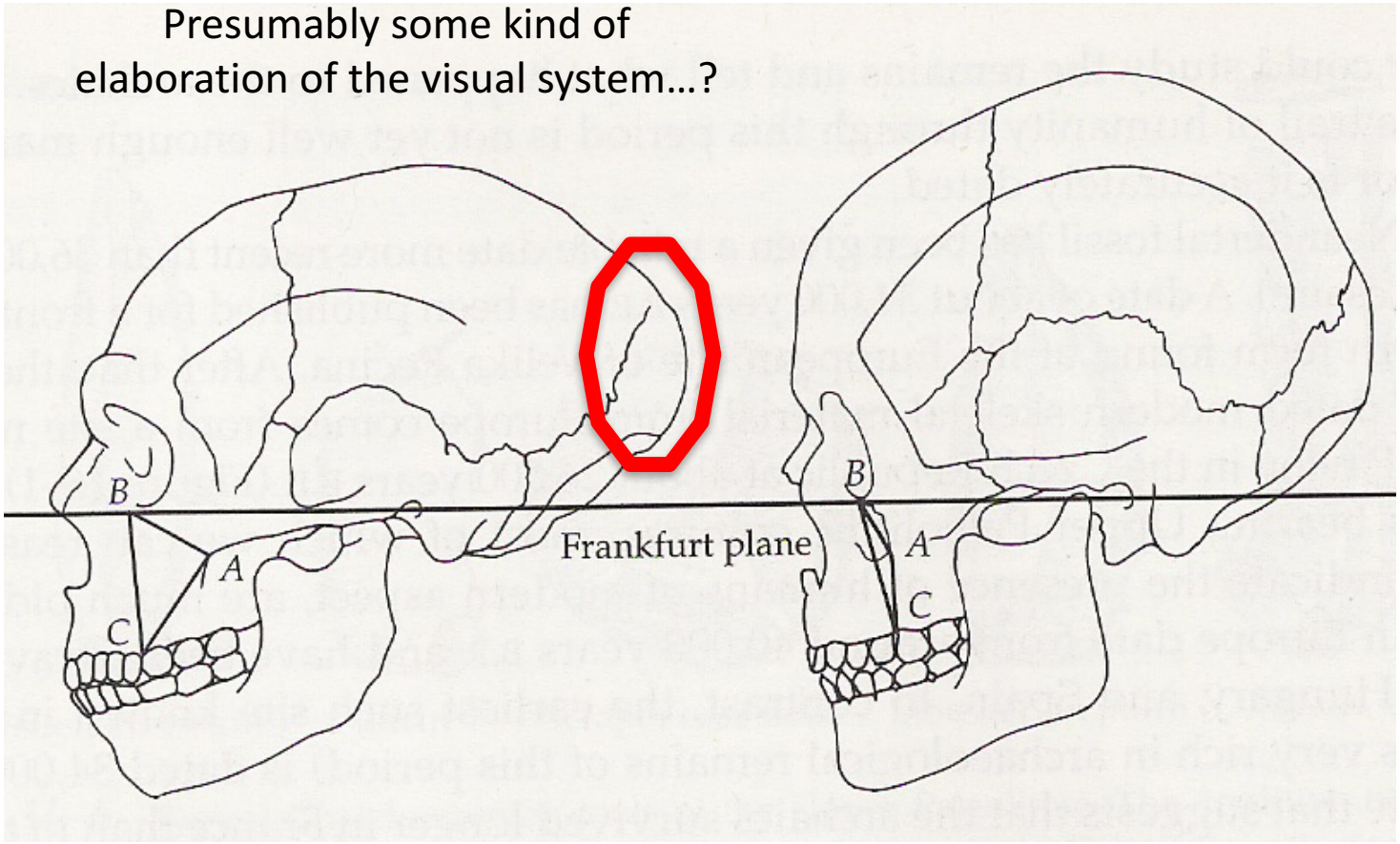
NOTE: Connectivity is often a principal difference between Human and NHP brains!

Fossil Record: Endocasts

Can learn *some* things about brain structure from them...

Occipital bun in ***Homo neanterthalensis***

Not found in *Homo sapiens*



Human Occipital lobe shows isometric scaling only

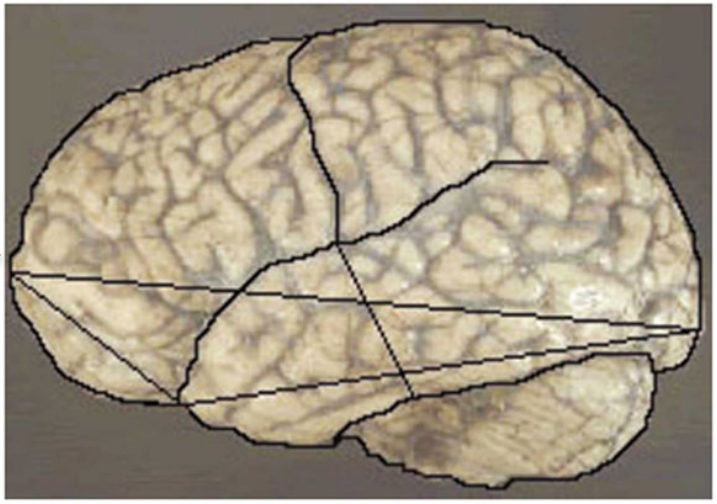
Frontal Pole (Area 10)

Area 10 allometrically larger because **more SPACE between cells**, mainly for cortico-cortico connections

Ventral View

Side View

In humans, pole is filled-out

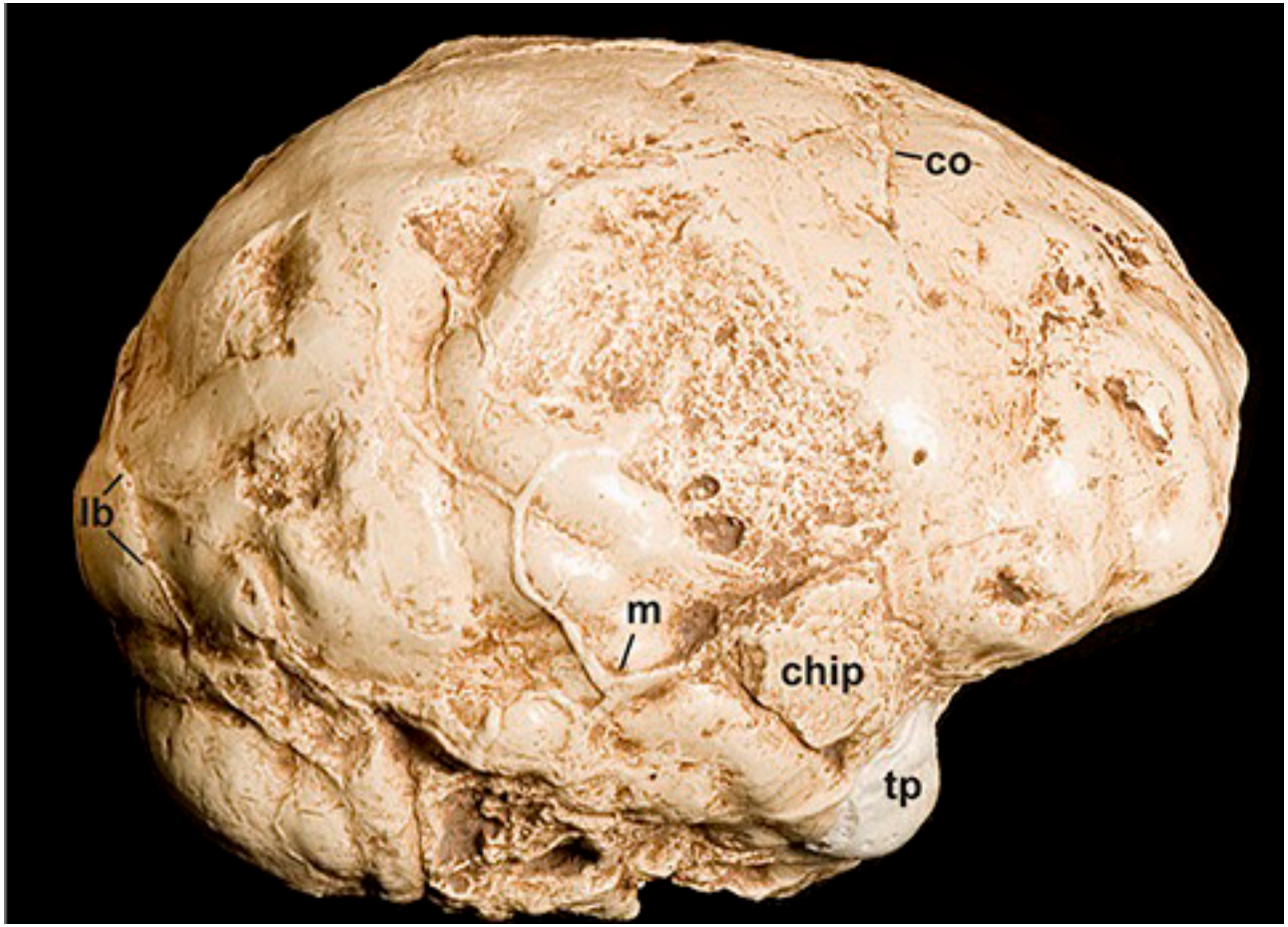


In chimps, pole is "pinched"

(Images not to scale – chimp brain significantly smaller than human)

Frontal Pole

Frontal Pole of *Australopithecus africanus* more like Human than like Ape!



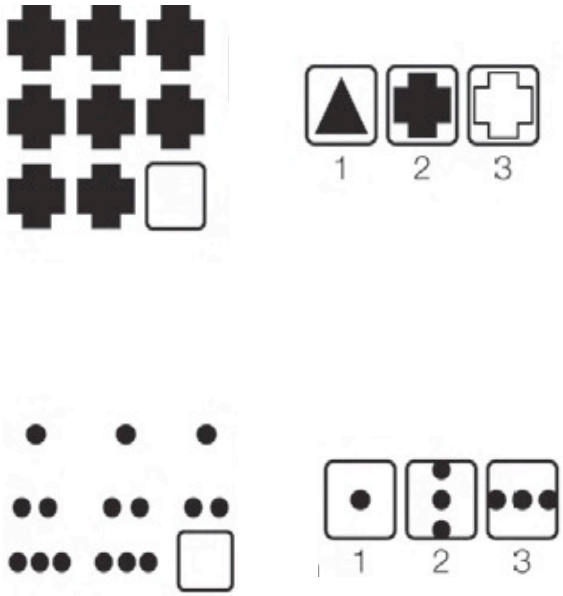
While brain roughly Ape-sized (~400 v. 360cc), Frontal Pole appears more "filled out".

A. africanus = **late** Australopithecine: 2.6 MYA vs. Lucy [*A. afarensis*] 3.4 MYA

(Just pre-dates *H. habilis* at 2.5MYA)

Role of “Frontal Pole” ?

Simple relational



Complex relational – Analogies

Associated with activation in **Parietal** lobe

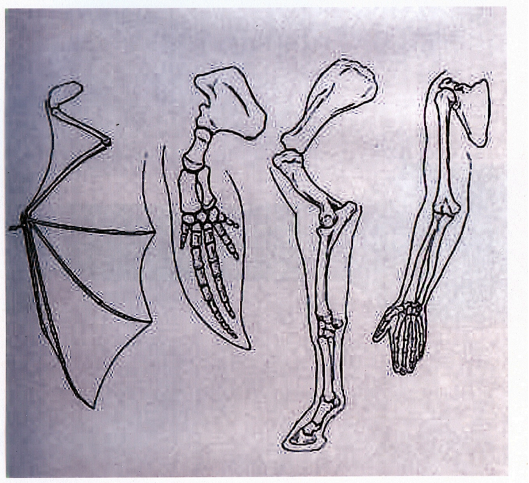
Associated with activation in **Parietal** lobe AND **Frontal Pole**

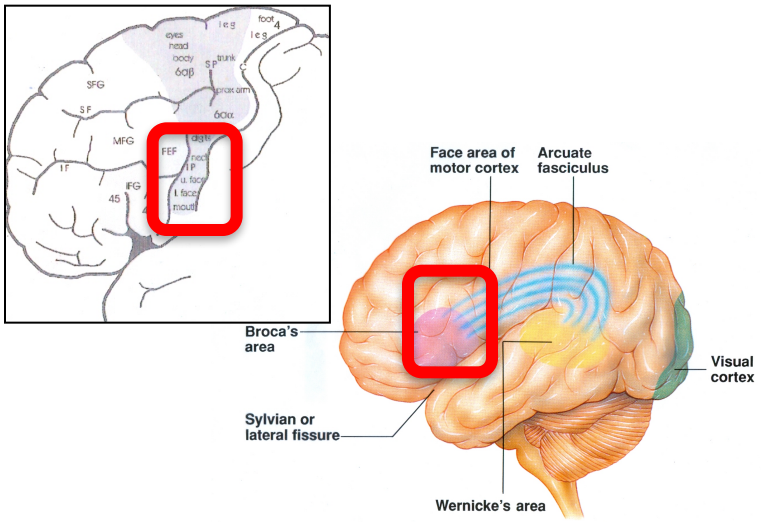
Ferrer, O’Hare & Bunge, 2009

Issues in Evolutionary Comparisons

- Comparisons with contemporary **Nonhuman Primates (NHPs)**
  - But note – NHP brains have also likely evolved in last 5 million years!

- Many commonalities allow us to identify homologues





- Informative differences between monkey VS ape-and-human,
  and between human VS ape-and-monkey
- BUT often controversial, differ with methods, etc!

Issues in Evolutionary Comparisons

- **Scaling** – how size/shape changes as structure enlarges
  - There are 2 types of scaling in human brain evolution

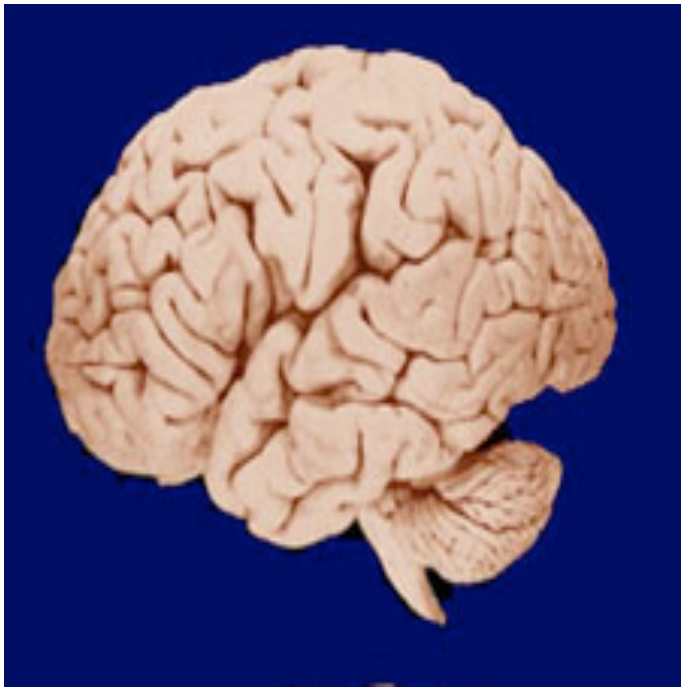
- Isometric scaling
  - All areas get equally larger

- Allometric scaling
  - Some areas get larger, or smaller, than others

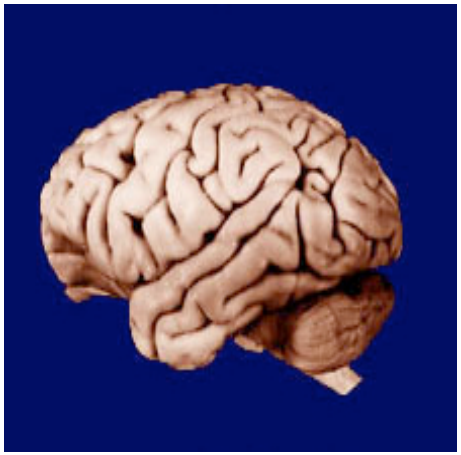
- **Mosaic Evolution**
  - Combination of above, as in Hominids
  - Both types can have cognitive effects

Absolute Size Matters

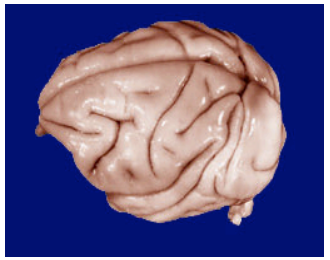
More cells, more connections, more processing



Human



Ape



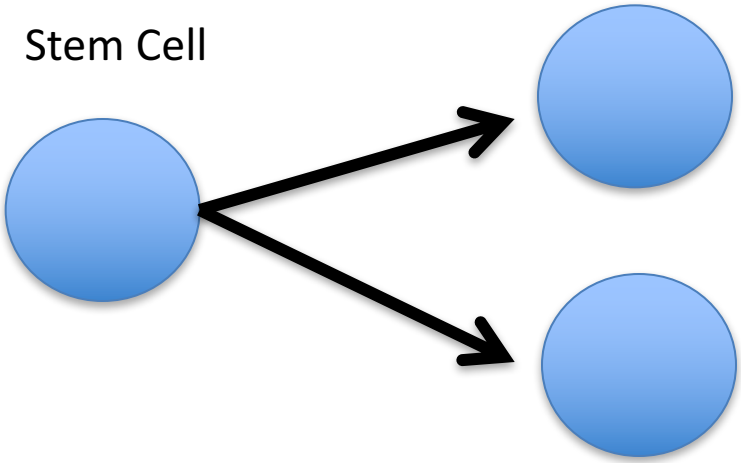
Monkey

Human = ~3.5X Chimpanzee, ~10X Rhesus monkey

Note additional **“Convolutions”** (folding) of cortex as size of cortical sheet expands

Brain Size: Development

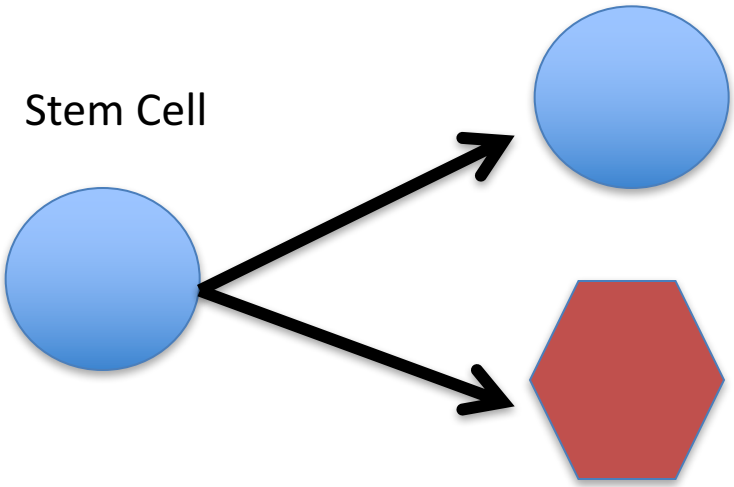
Symmetrical Division



Identical
"Daughter"
Stem Cells

Regulator Gene –
Controls timing of switch from
Symmetircal to
Asymmetrical Division

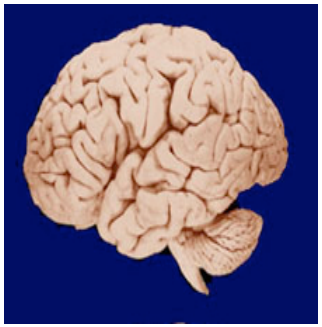
Asymmetrical Division



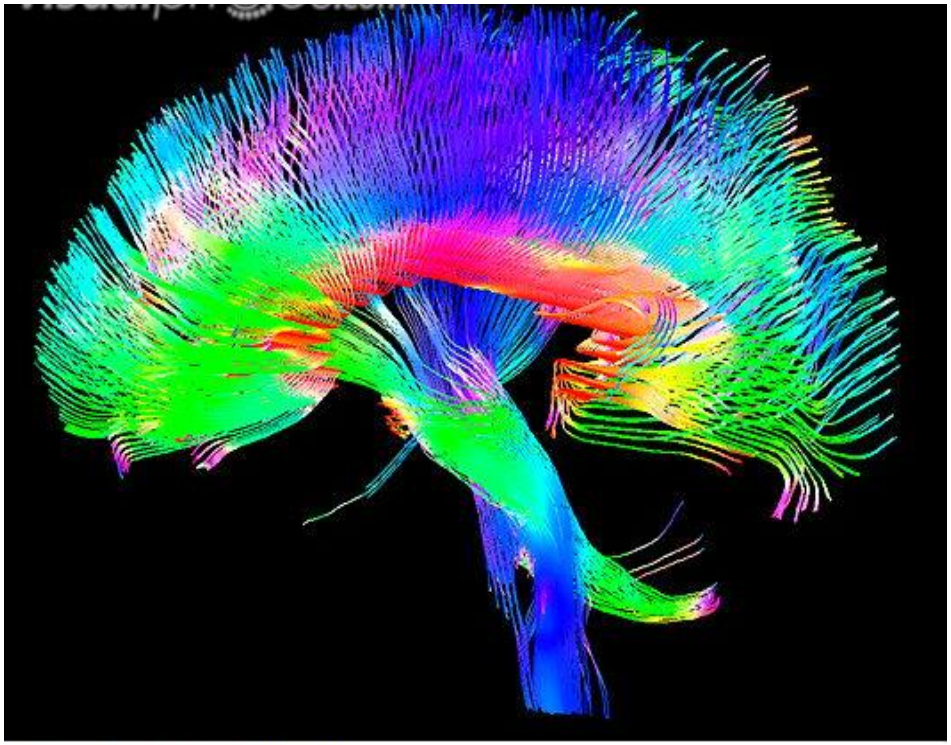
One Stem Cell

One Neuron
(or Glia)

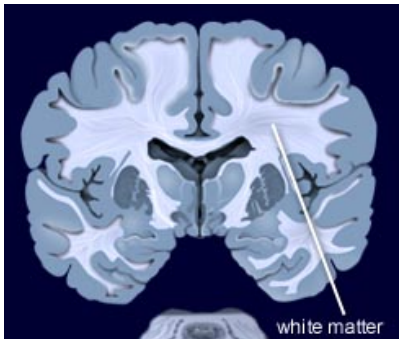
Switch delayed ~10 days
in humans vs. apes
>> millions more stem cells
to become neurons!



Expanded Connectivity



“White Matter”
= myelinated axons that
carry messages between neurons

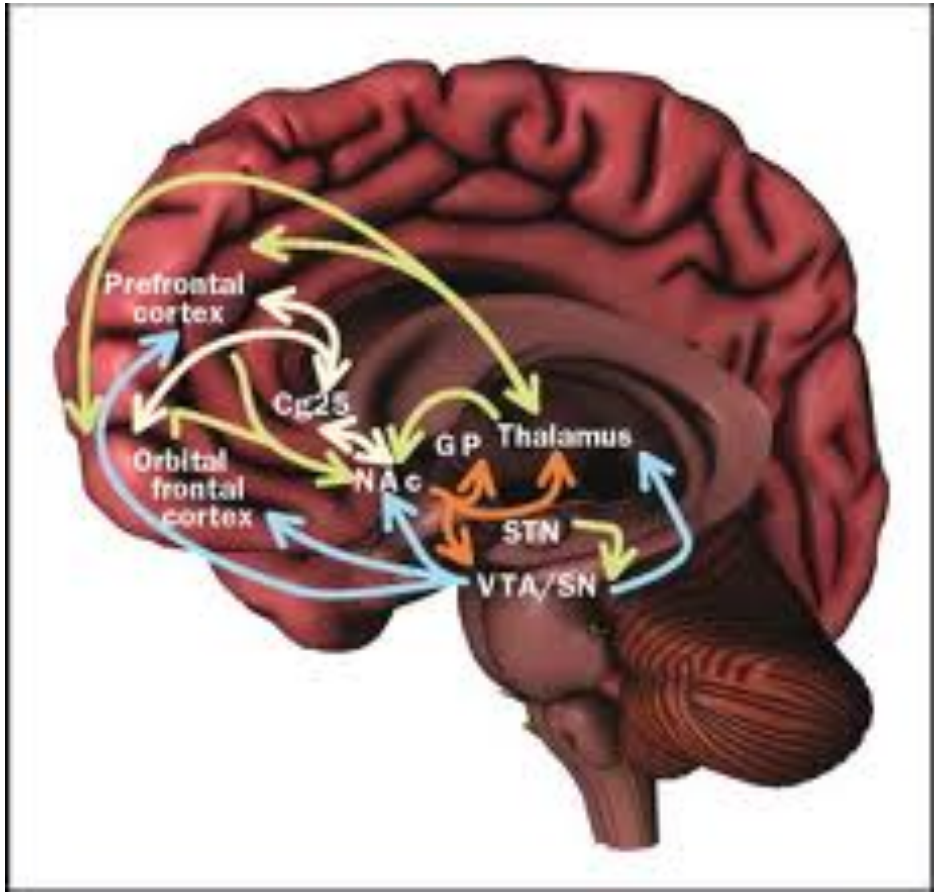


66% by volume of the human brain

Can be particularly difficult to compare,
since white matter scales-up faster than grey

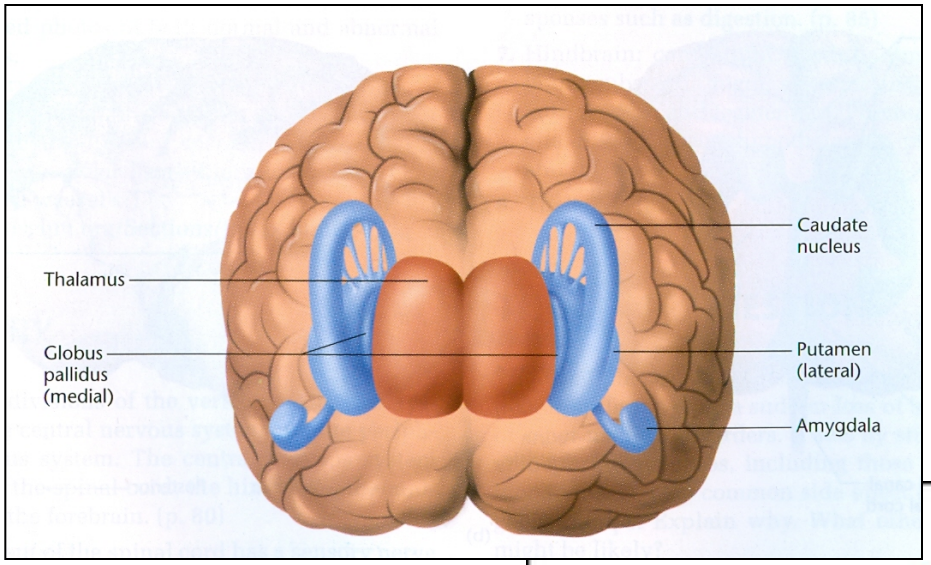
Some Allometrically-Scaled Areas Serve MULTIPLE Functions

e.g. Medial Dorsal Thalamus



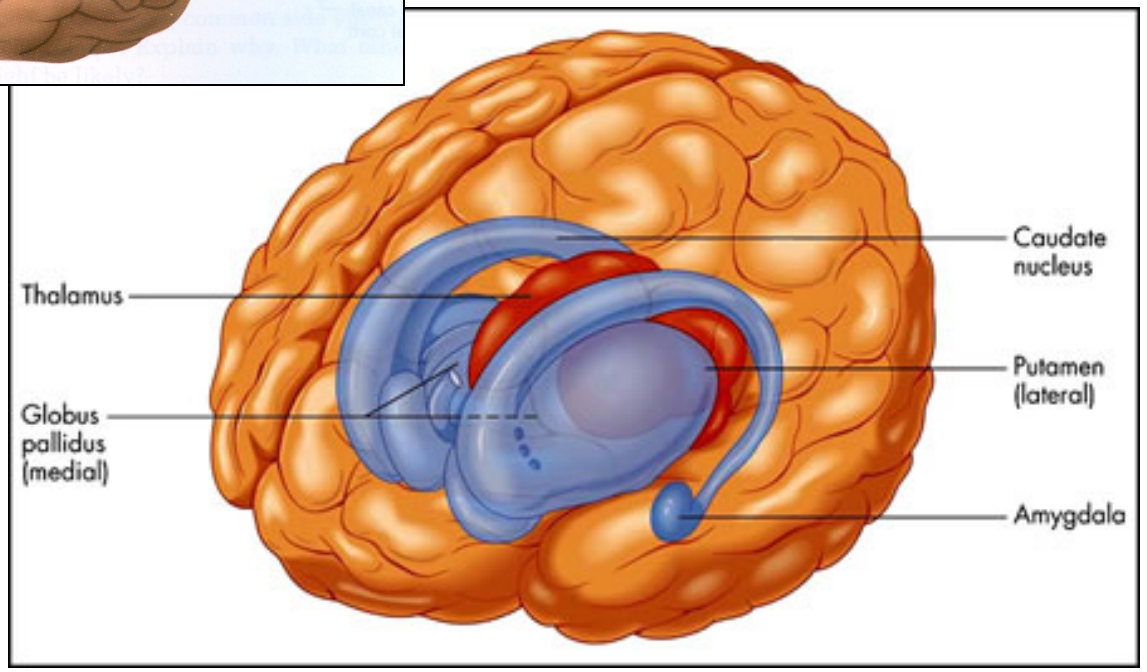
Plays a major role in <u>memory</u> functions as well as <u>reasoning</u>, <u>decision making</u>

Some Allometrically-Scaled Areas Serve MULTIPLE Functions



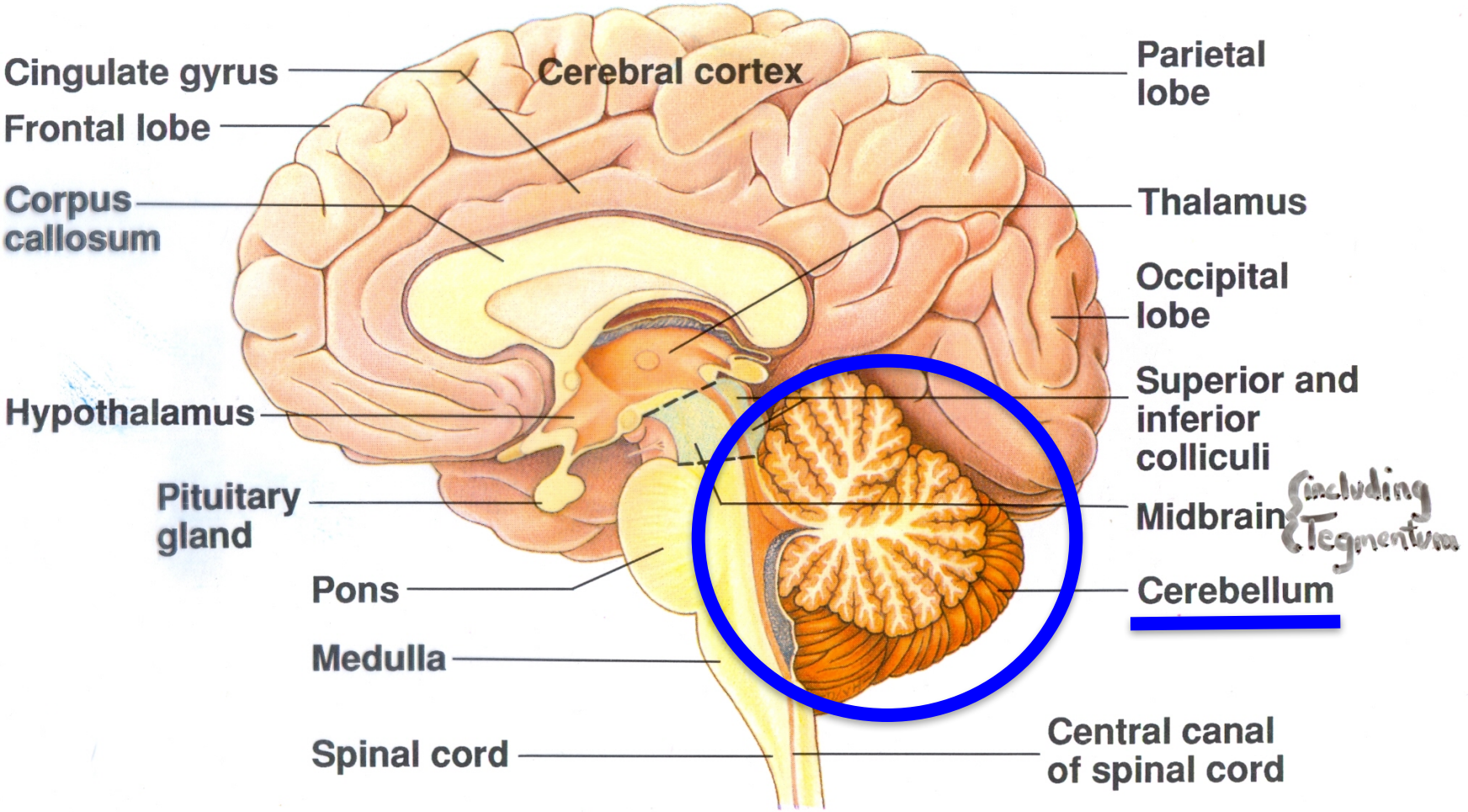
Basal Ganglia

e.g. Skill learning,
initiating/satisfying task constraints



Especially areas that connect with **Thalamus** and **Frontal Cortex**

Some Allometrically-Scaled Areas Serve MULTIPLE Functions



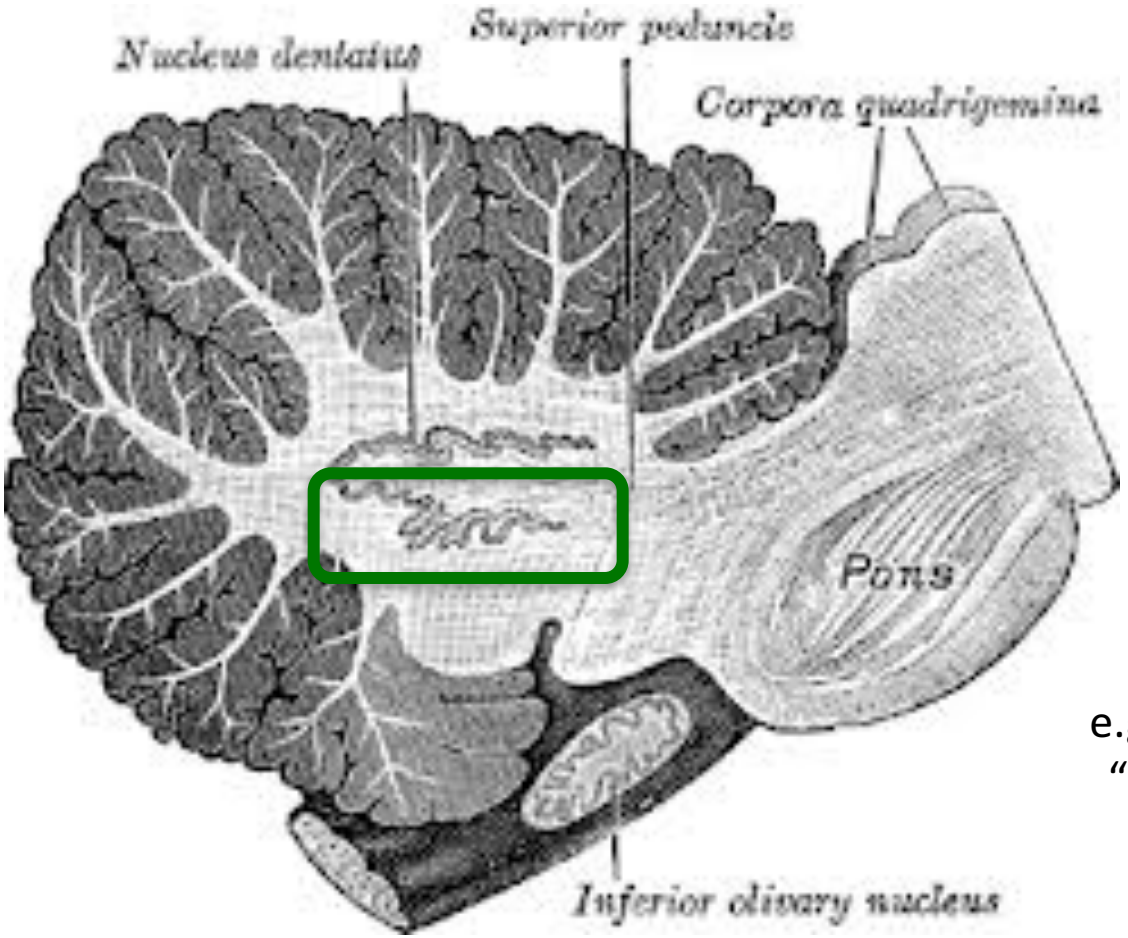
Some Allometrically-Scaled Areas Serve MULTIPLE Functions

Plan & Execute Fine Motor Control

e.g. For articulate speech, bimanual coordination, etc.

Dentate Nucleus

Some Allometrically-Scaled Areas Serve MULTIPLE Functions



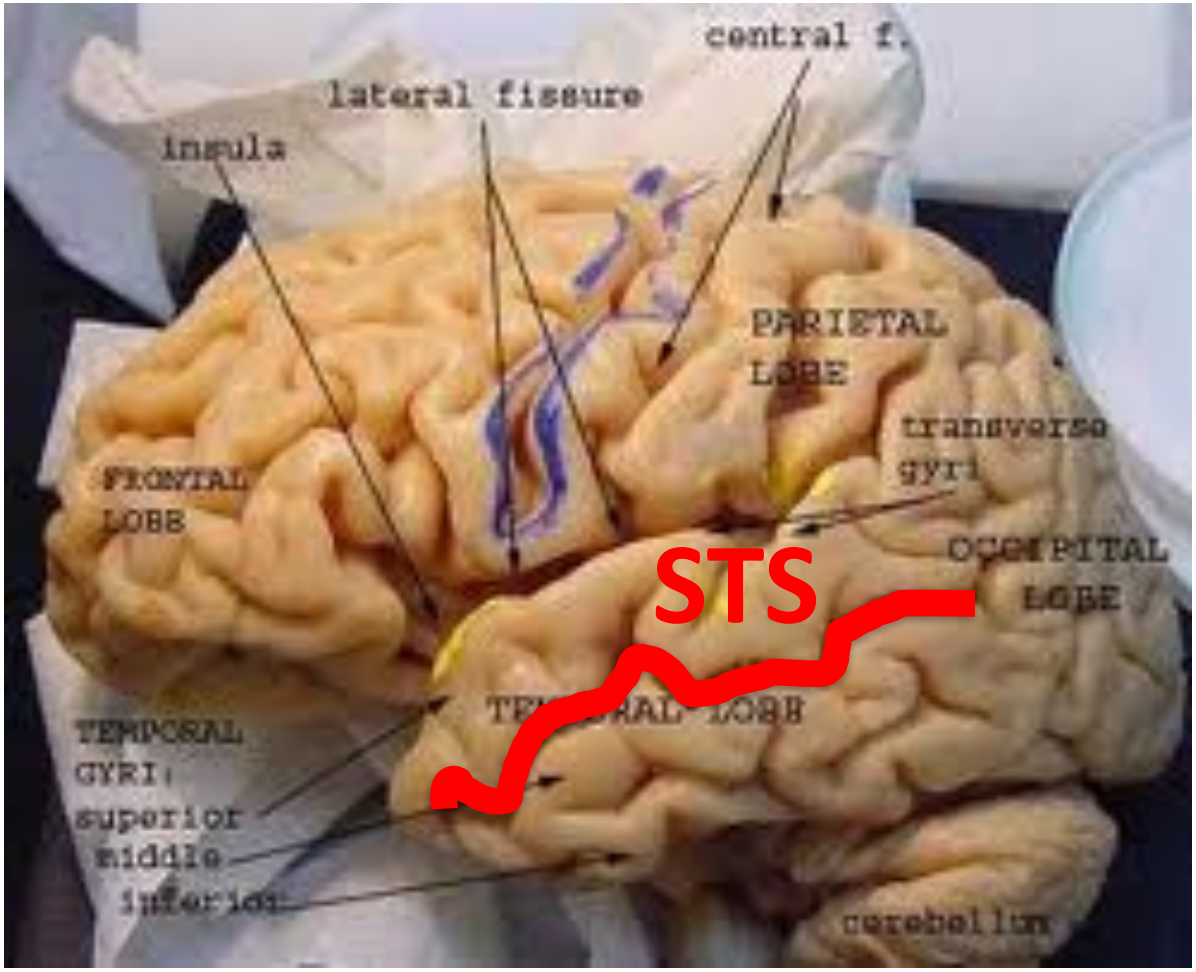
"NON-Motor"!

e.g. For "cognitive" and "visio-spatial" activity, etc.

Ventral Dentate Nucleus

Some Isometrically-Scaled Structures Play a Major Role in Otherwise Allometrically-Scaled Systems

e.g. **Superior Temporal Sulcus (STS)**



"Biological Motion"

Detect & interpret common patterns of movement

e.g. Gesture, Facial expression, Shifting direction of gaze, etc.

Plays a role in MULTIPLE functional systems.

Functional Systems

Socialization –
The Limbic-Prefrontal System

Limbic System – Emotion & Motivation

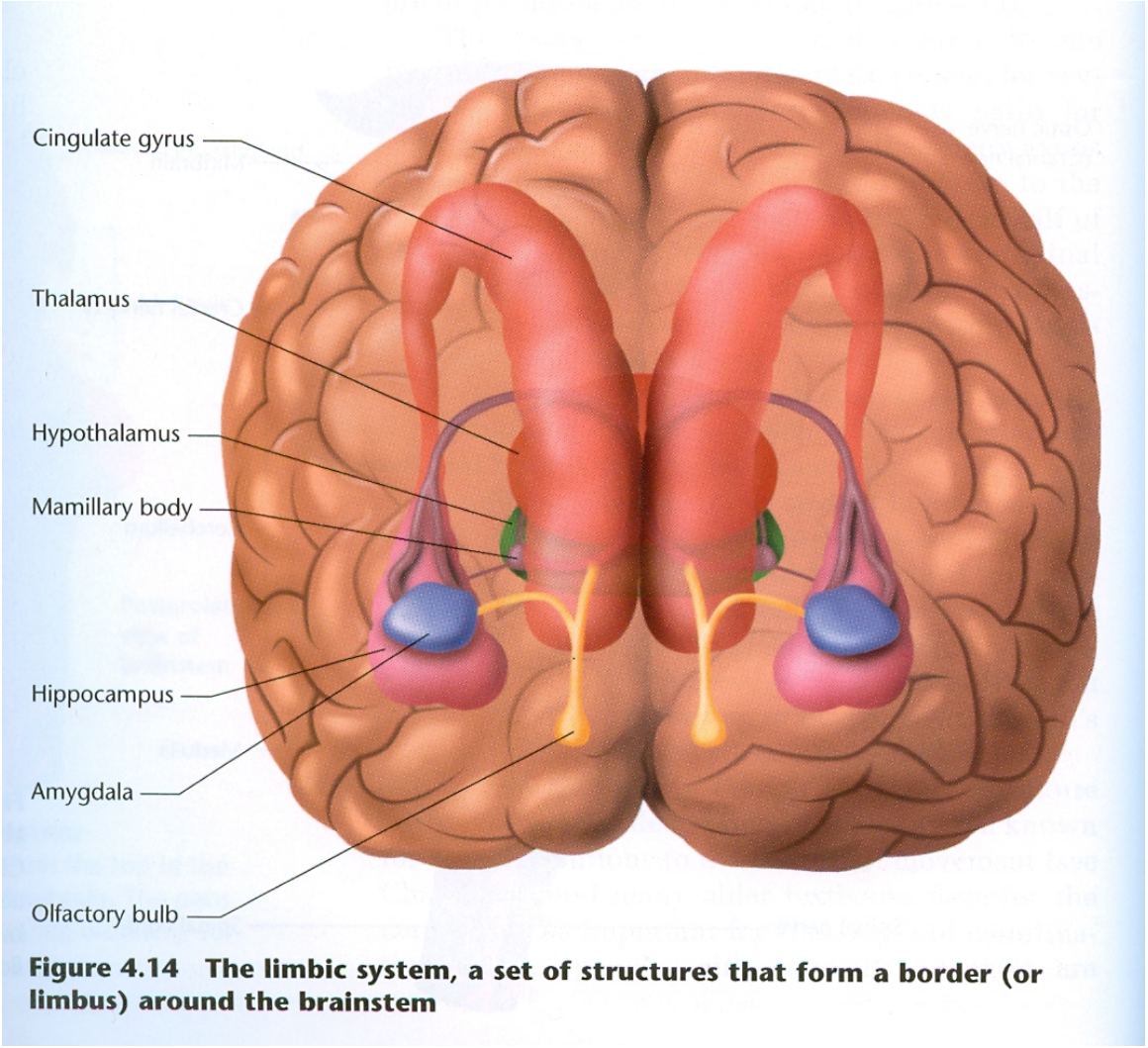
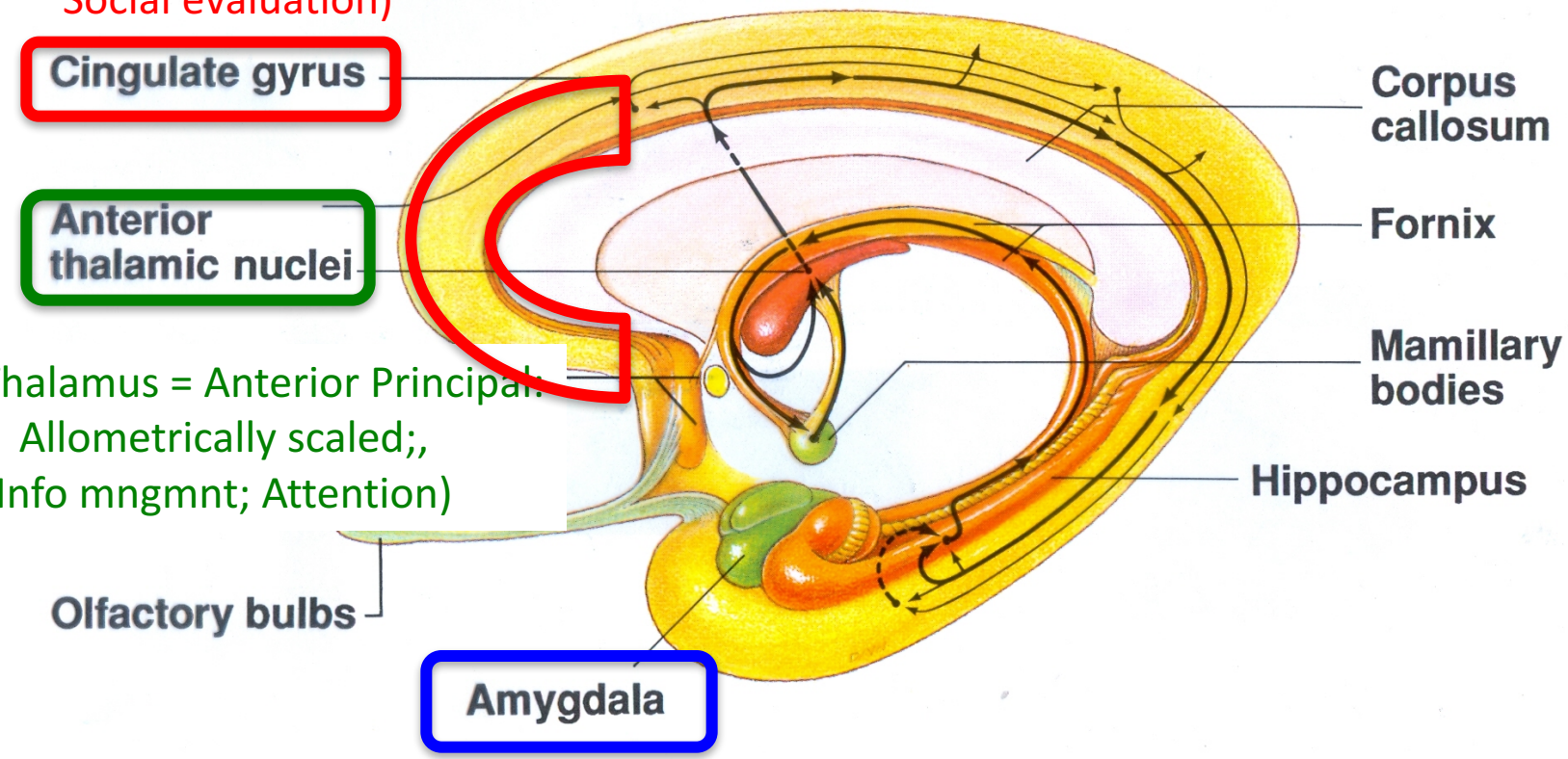


Figure 4.14 The limbic system, a set of structures that form a border (or limbus) around the brainstem

Limbic System – Emotion & Motivation

(ACC = Anterior Cingulate Cortex:
Isometrially scaled,
Social evaluation)



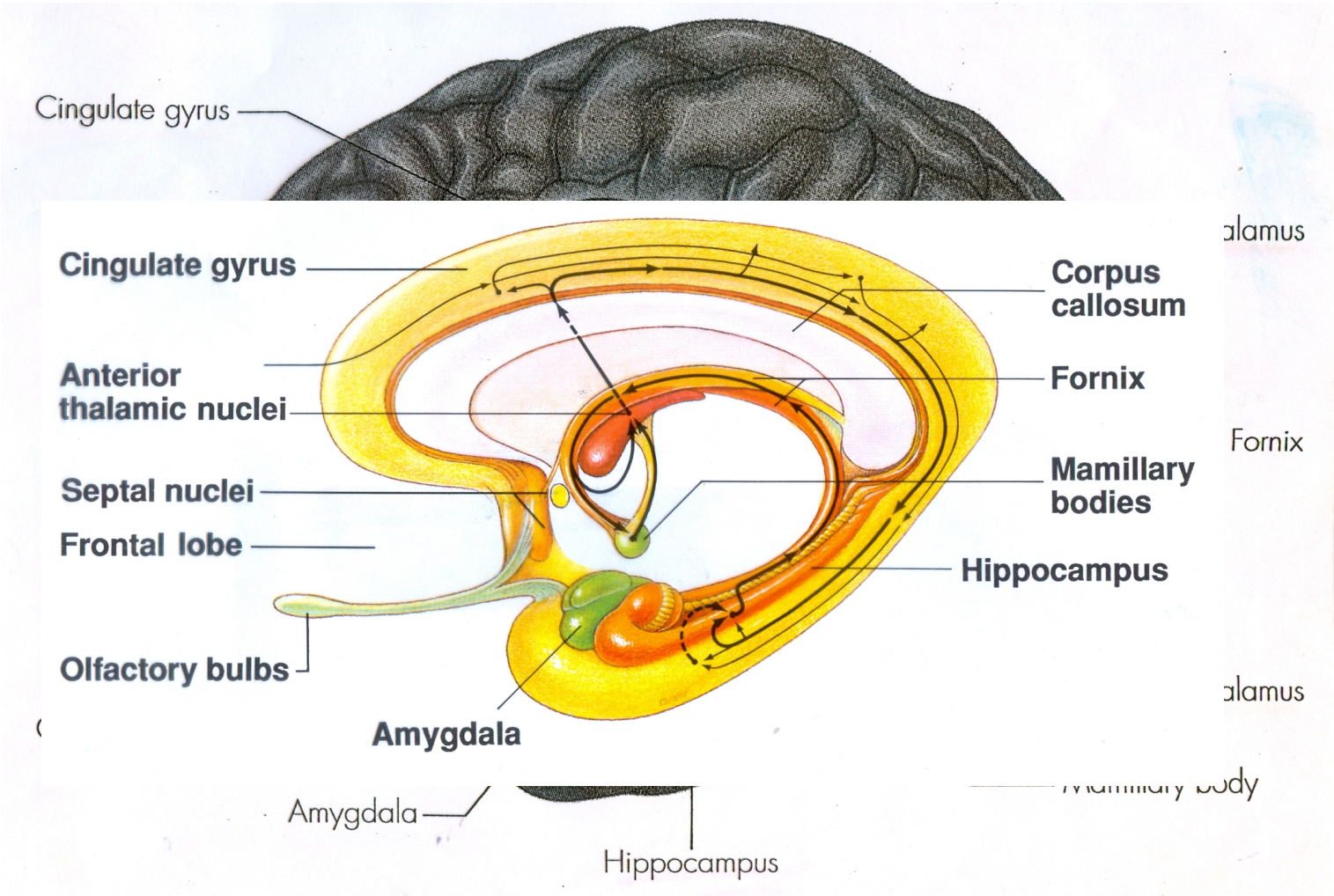
(AP Thalamus = Anterior Principal:
Allometrically scaled;,
Info mngmnt; Attention)

(Especially LATERAL Amygdala:
Emotional learning)

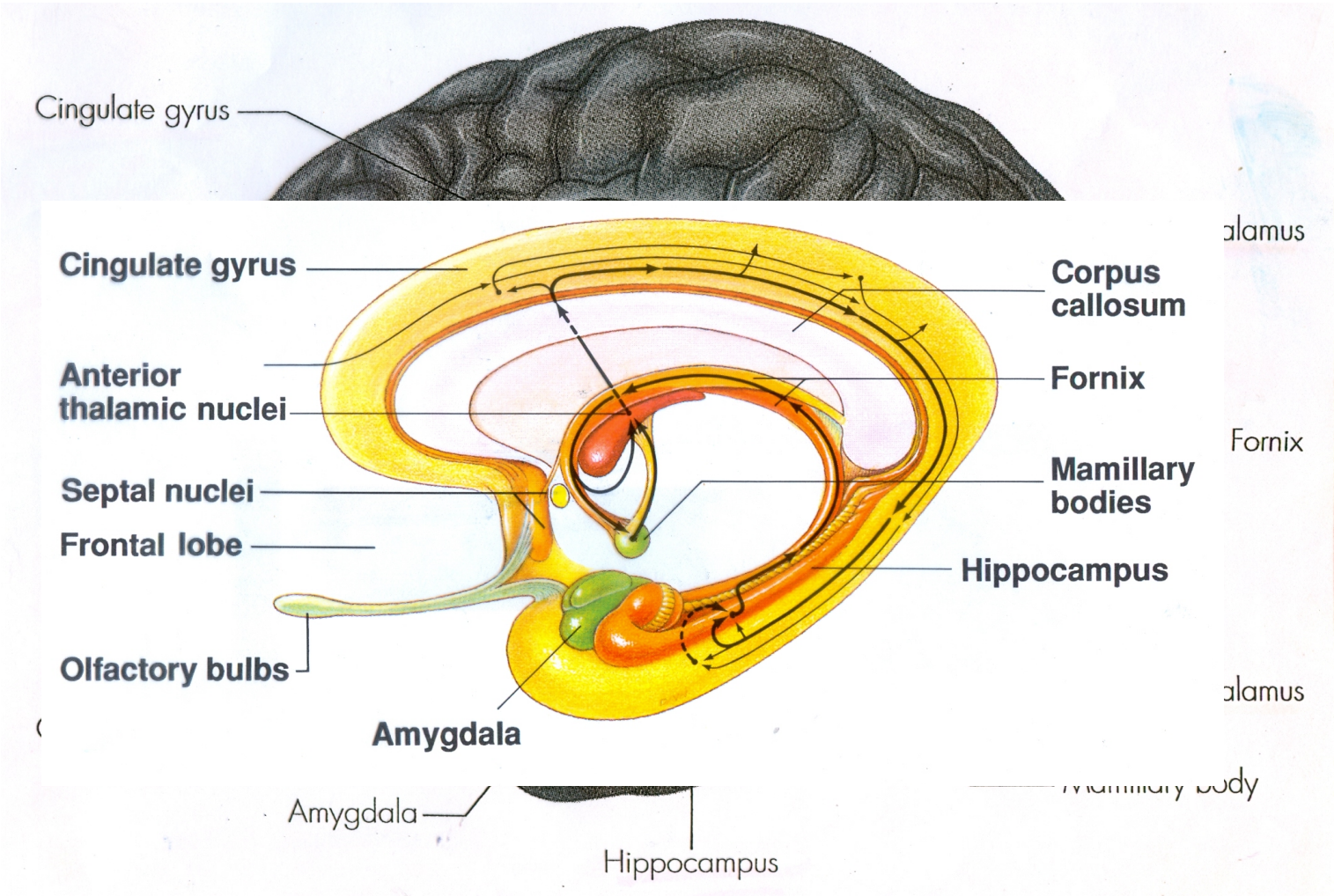
Limbic system

Based on McLean, 1949

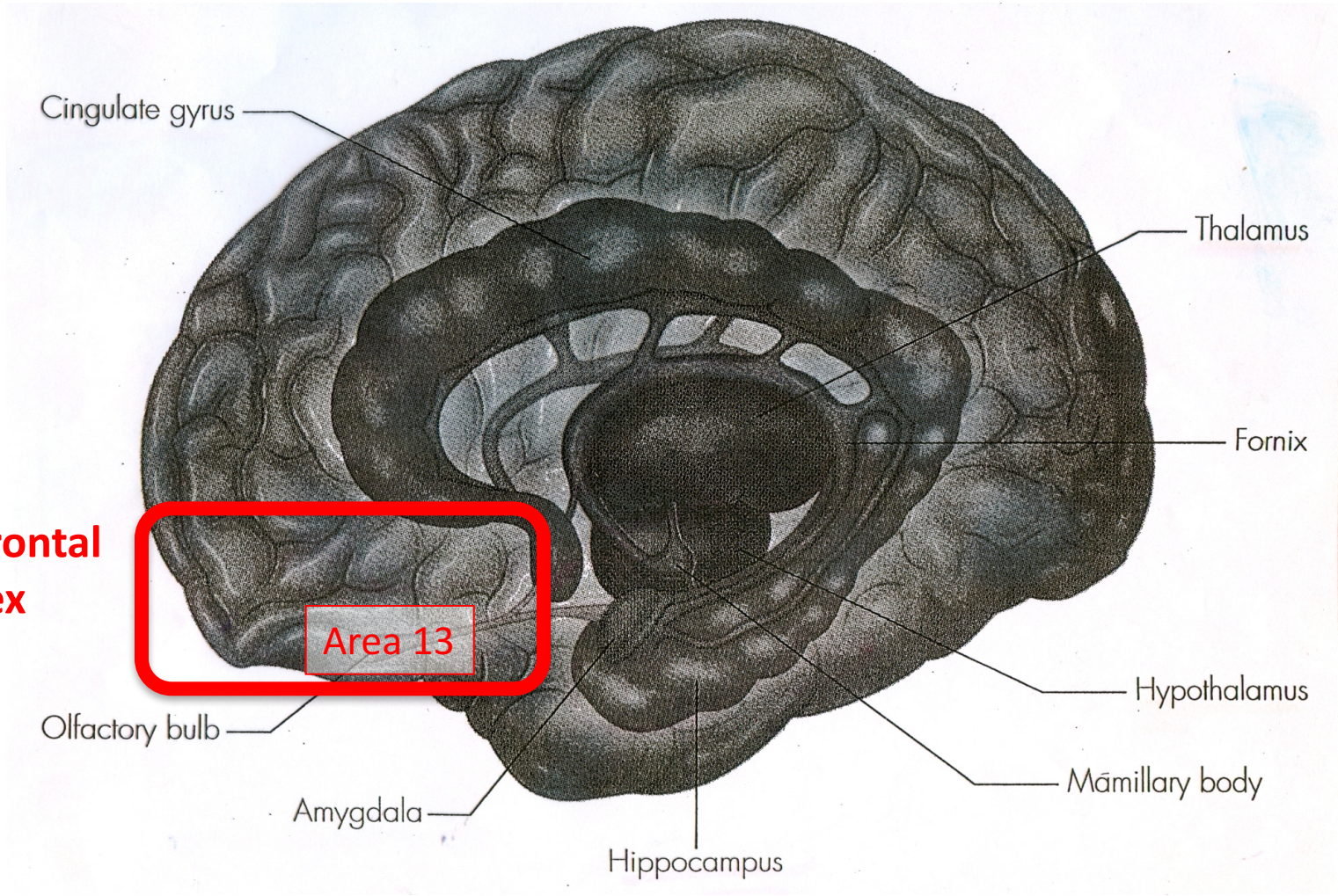
Limbic System – Emotion & Motivation



Limbic System – Emotion & Motivation



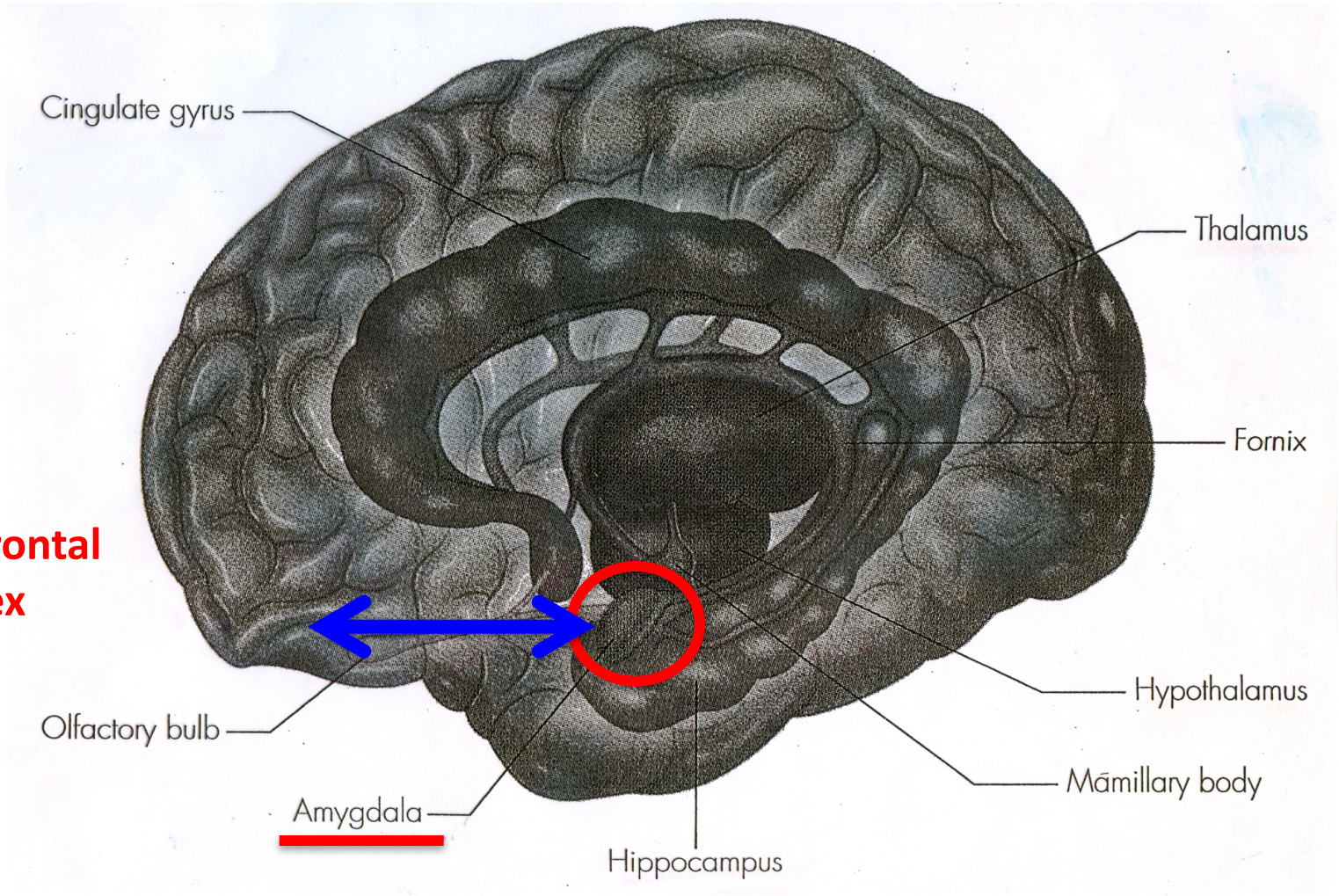
Limbic + Prefrontal System



Area 13 – Mostly inhibitory connections with Amygdala & other Limbic

Humans show increased <u>differentiation</u> compared to NHPs

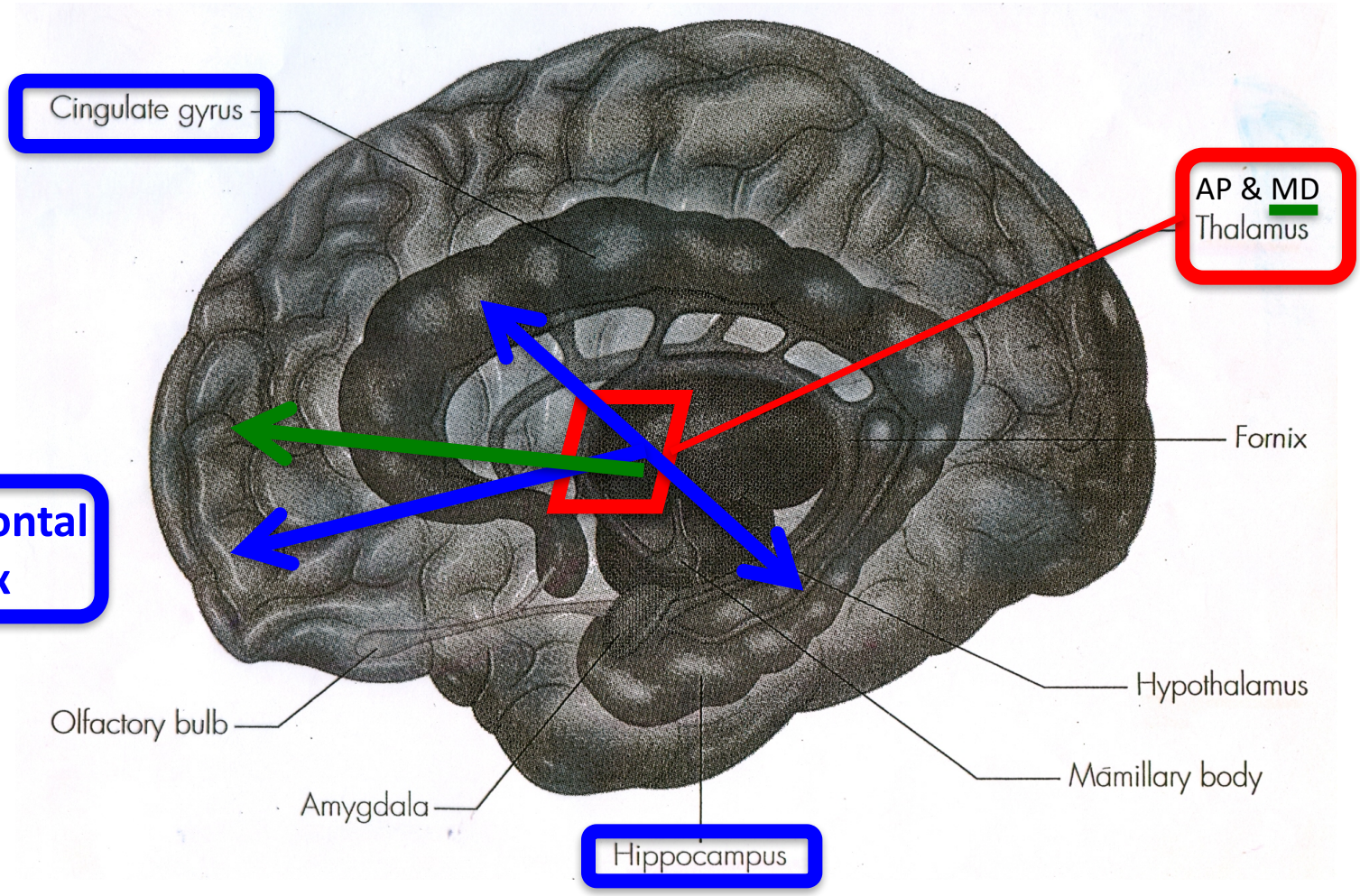
Limbic + Prefrontal System



Lateral Amygdala (Emotional Learning) allometrically scaled

Plus greater reciprocal interactions w/Prefrontal for recognizing & evaluating affect

Limbic + Prefrontal System

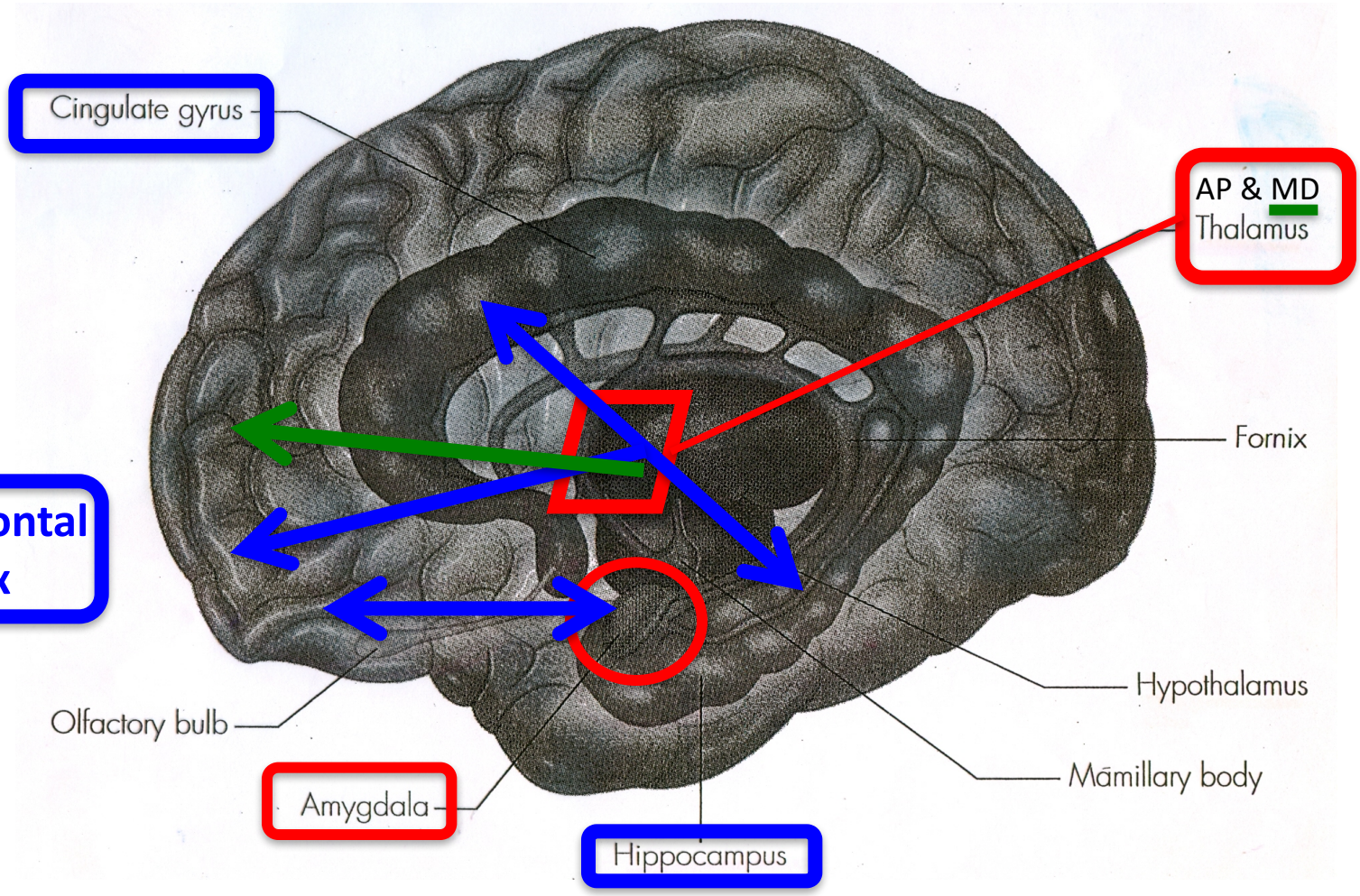


Anterior Principal & Medio-Dorsal Nuclei of Thalamus are allometrically scaled

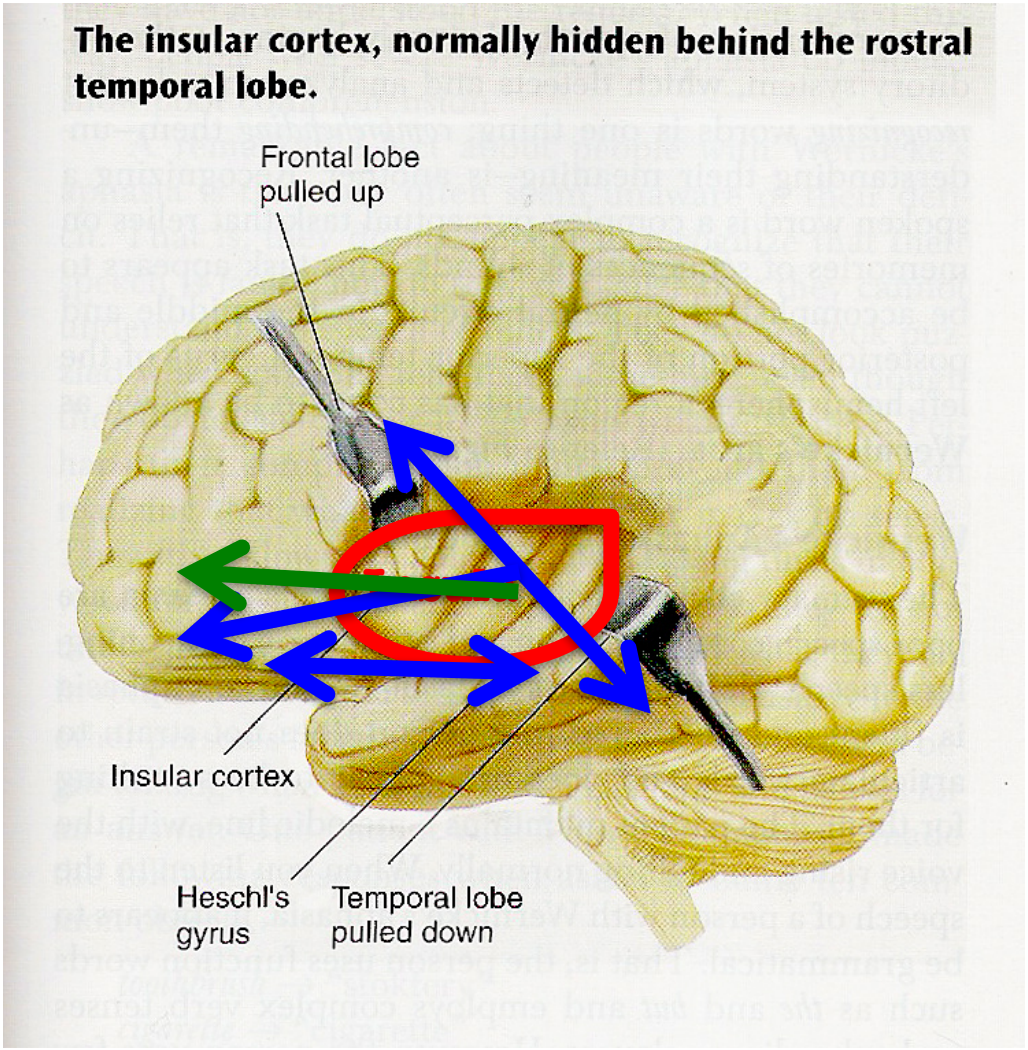
AP connects Prefrontal, Hippocampus & Cingulate for sustained attention to social stimuli

MD connects mainly to Prefrontal for episodic memory, emotional narrative, etc.

Limbic + Prefrontal System



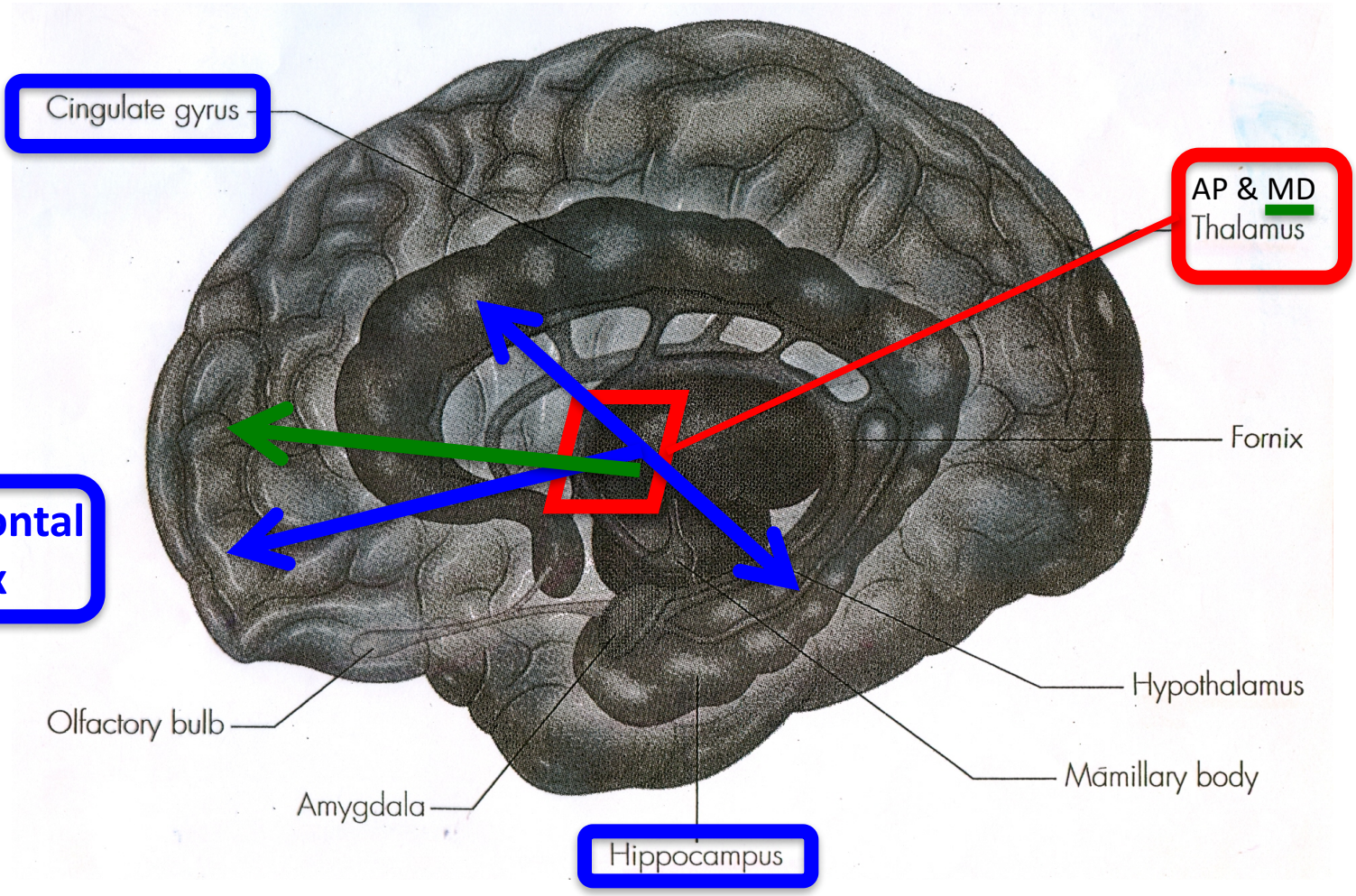
Limbic & Prefrontal System



Note, these connections to/from prefrontal cortex pass through **Anterior Insula**

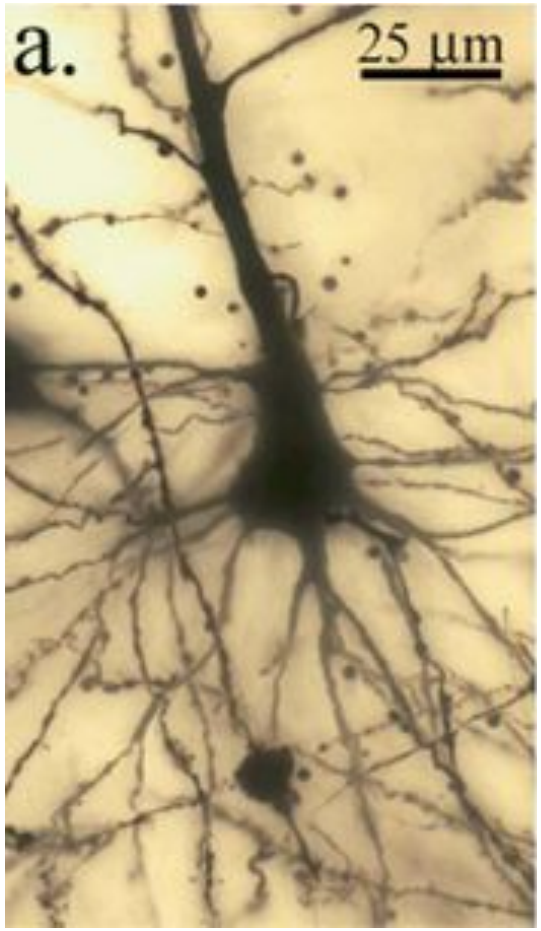
Implicated in spontaneous emotion, social “connectedness”, empathy

Limbic + Prefrontal System



Many of these connections especially involve **Von Economo** Cells

Von Economo Cells



Typical Pyramidal Cell

Von Economo
or “Spindle” Cell

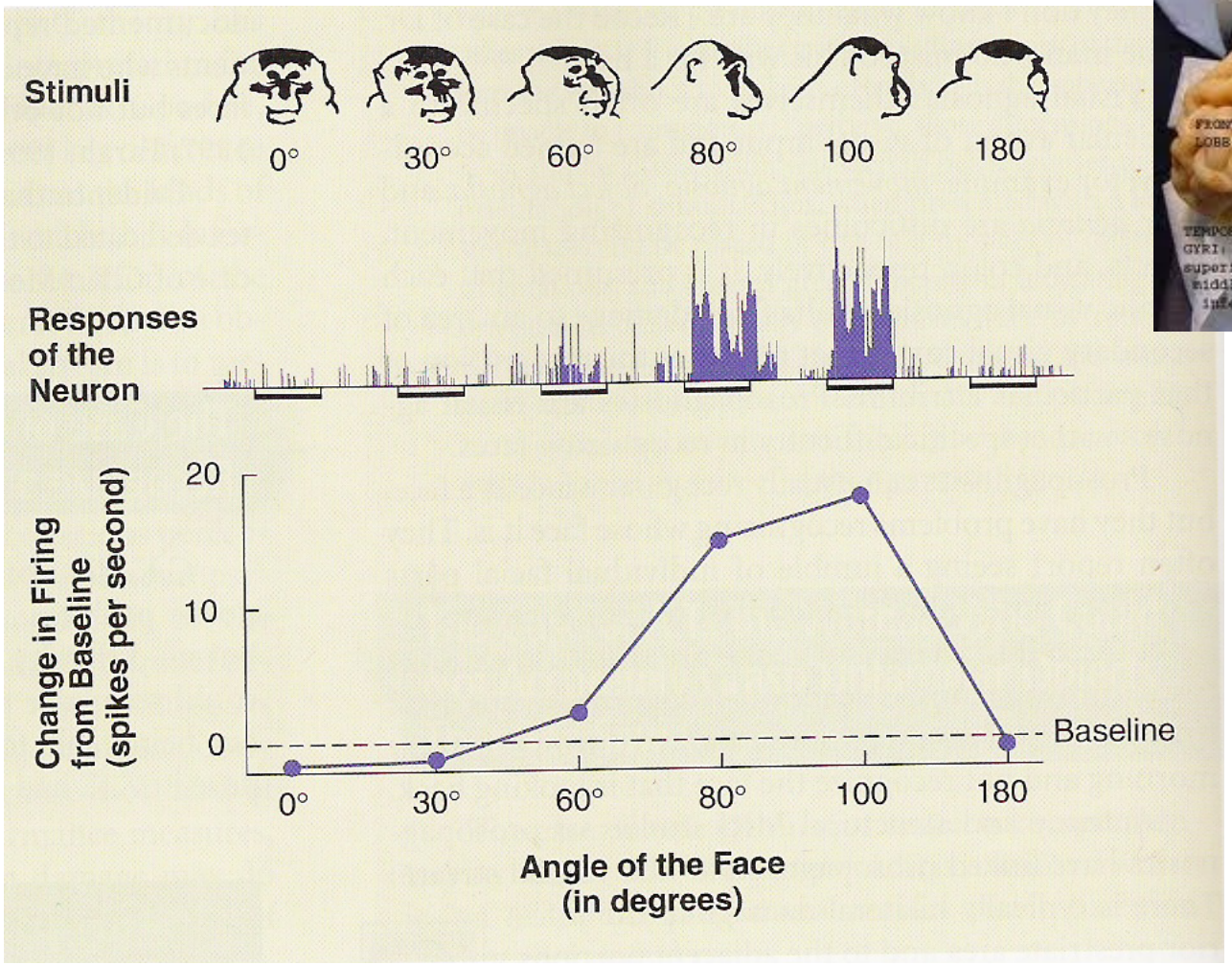
For “long distance”
Communication in large brains

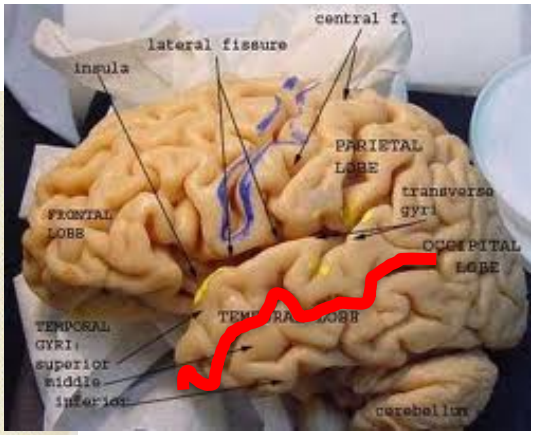
Found in Humans & Apes
(not monkeys)

Found especially in
Anterior Cingulate
and **Frontal Insula**

Limbic & Prefrontal System

STS - Superior Temporal Sulcus





Anterior STS – active when see face of another turning to/from subject

Limbic & Prefrontal System

STS - Superior Temporal Sulcus

Other parts of STS active in interpreting facial expression

Limbic & Prefrontal System

STS - Superior Temporal Sulcus

Other parts of STS active in interpreting facial expression

STS also responds to direction of eye gaze

Limbic & Prefrontal System

Hominids evolved special sensitivity to eye gaze

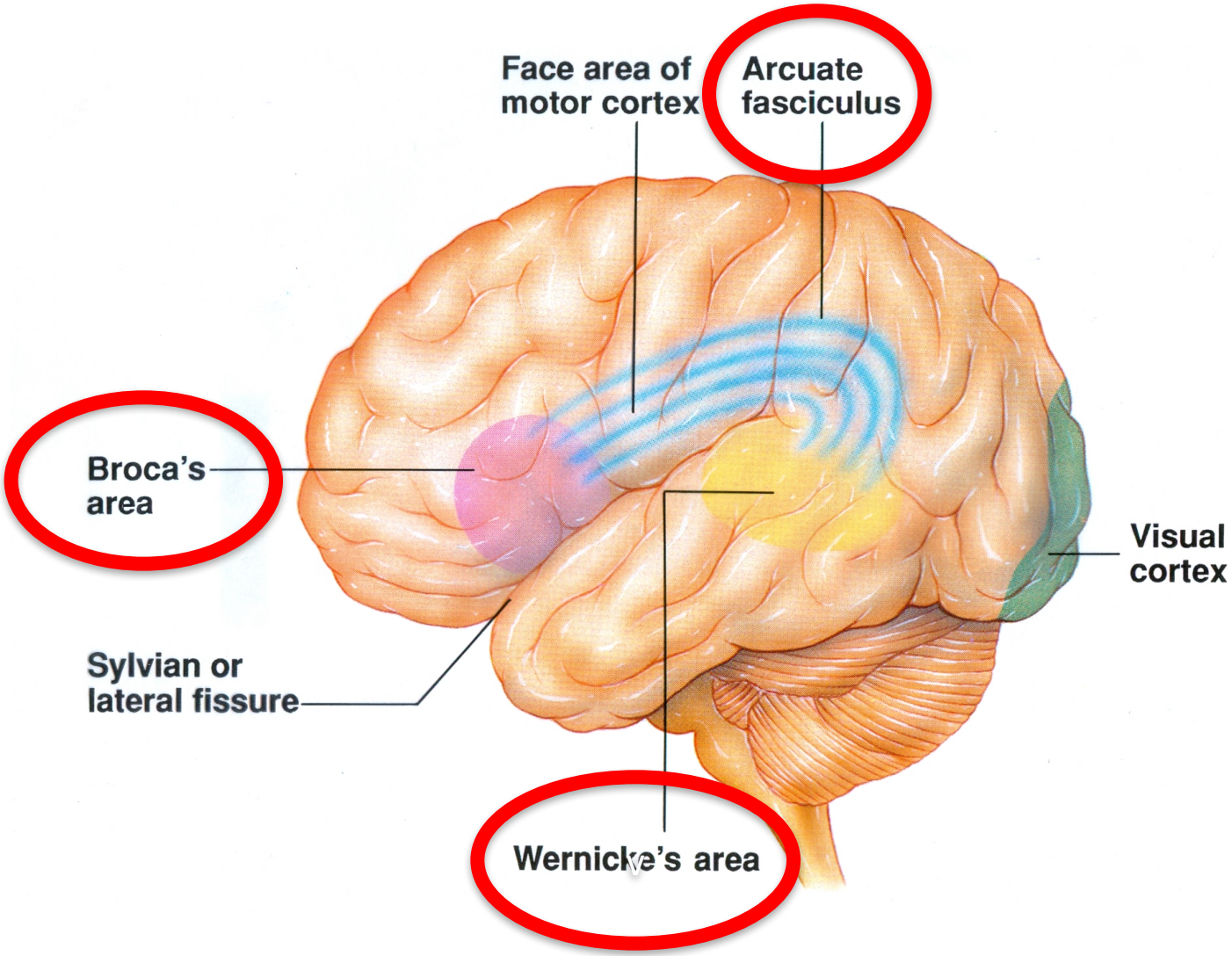
Accompanied (at some point) by anatomical loss of pigmentation in sclera

All of the above parts of Limbic-Prefrontal system play a role in "Empathy" and "Theory of Mind"

Broca's – Wernicke's System

SPEECH

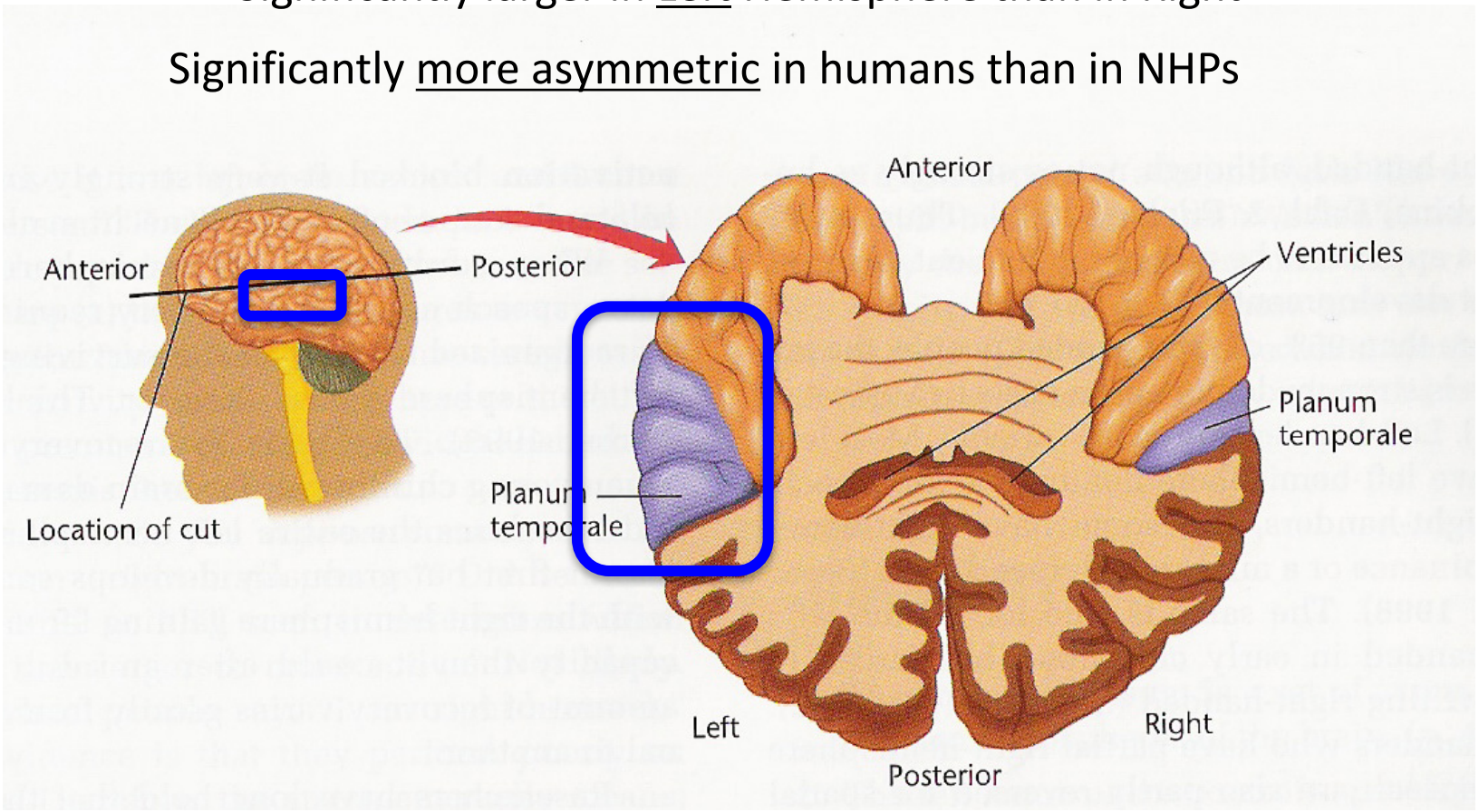
Broca & Wernicke System for Speech



Asymmetry of *Planum Temporale*
"Wernicke's Area" in Humans

Significantly larger in Left Hemisphere than in Right

Significantly more asymmetric in humans than in NHPs

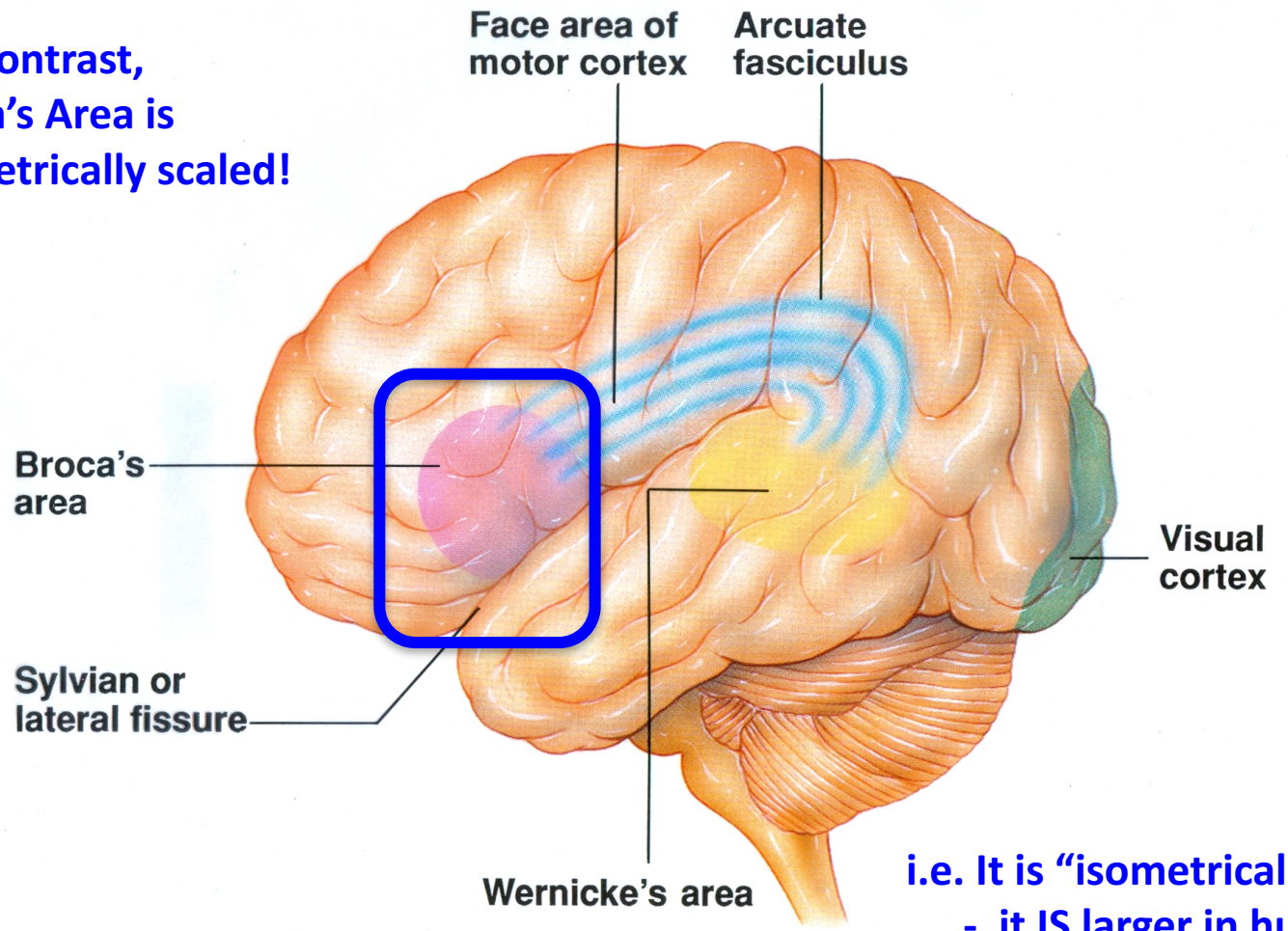


Slightly more asymmetric in Apes than in Monkeys

Involved in call recognition in NHPs

Broca & Wernicke System for Speech

In contrast,
Broca's Area is
NOT allometrically scaled!



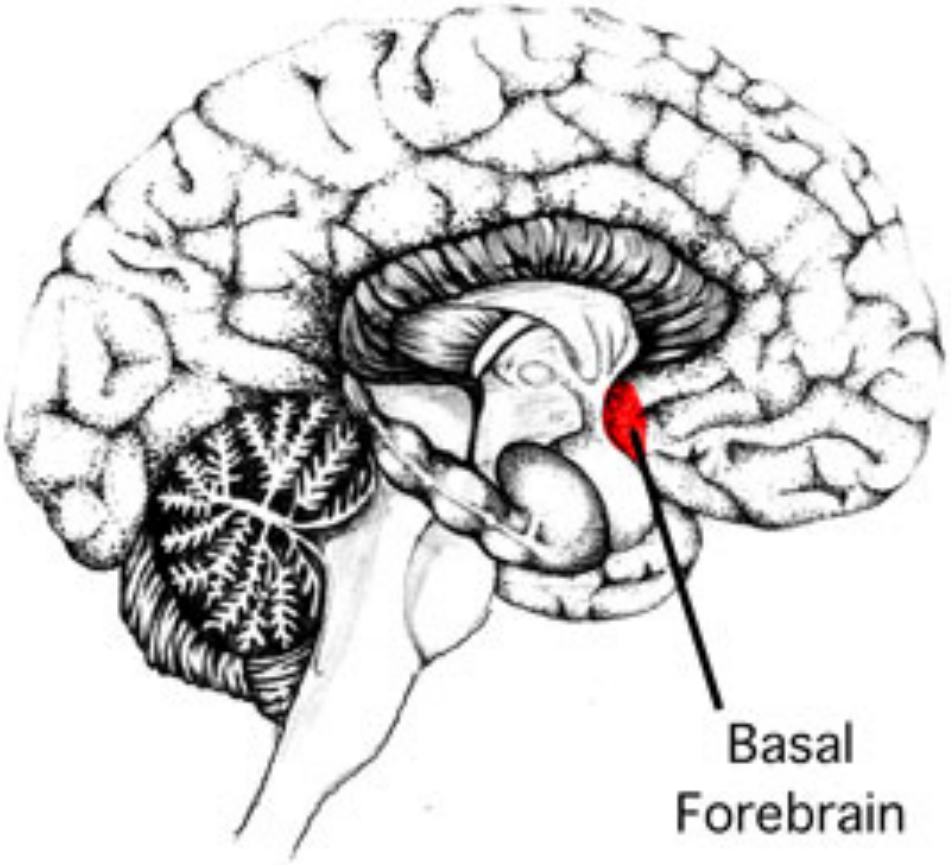
i.e. It is "isometrically" scaled
- it IS larger in humans,
but has expanded only as much
as overall brain has

“New” division of Basal Forebrain in Humans
>> Arouses Broca’s Area

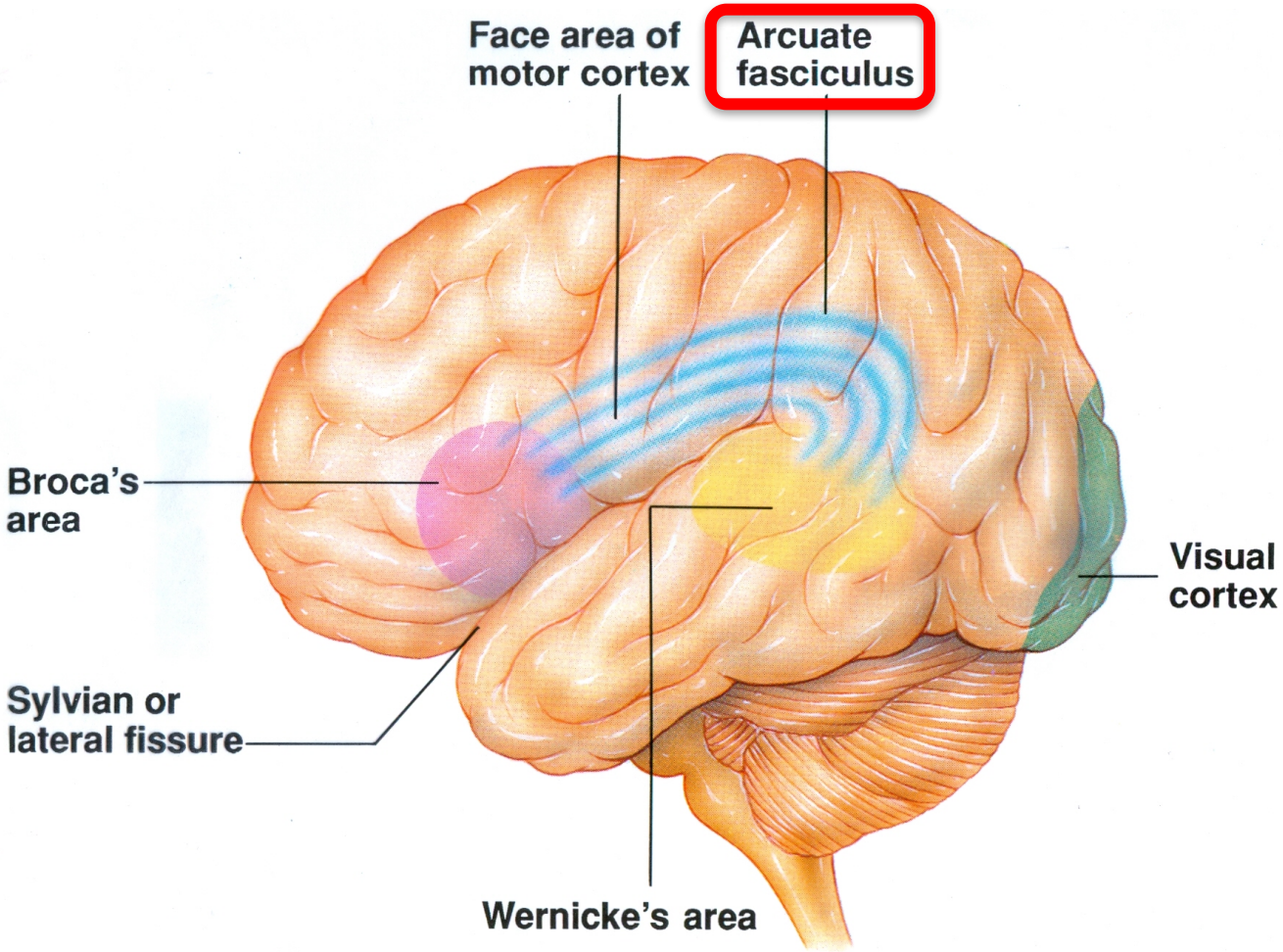
This substructure of Basal Forebrain
one of the few “new” areas
in the human brain

i.e. No obvious homologue
in the Basal Forebrains of NHPs

Specifically for sustaining
arousal of Broca’s Area



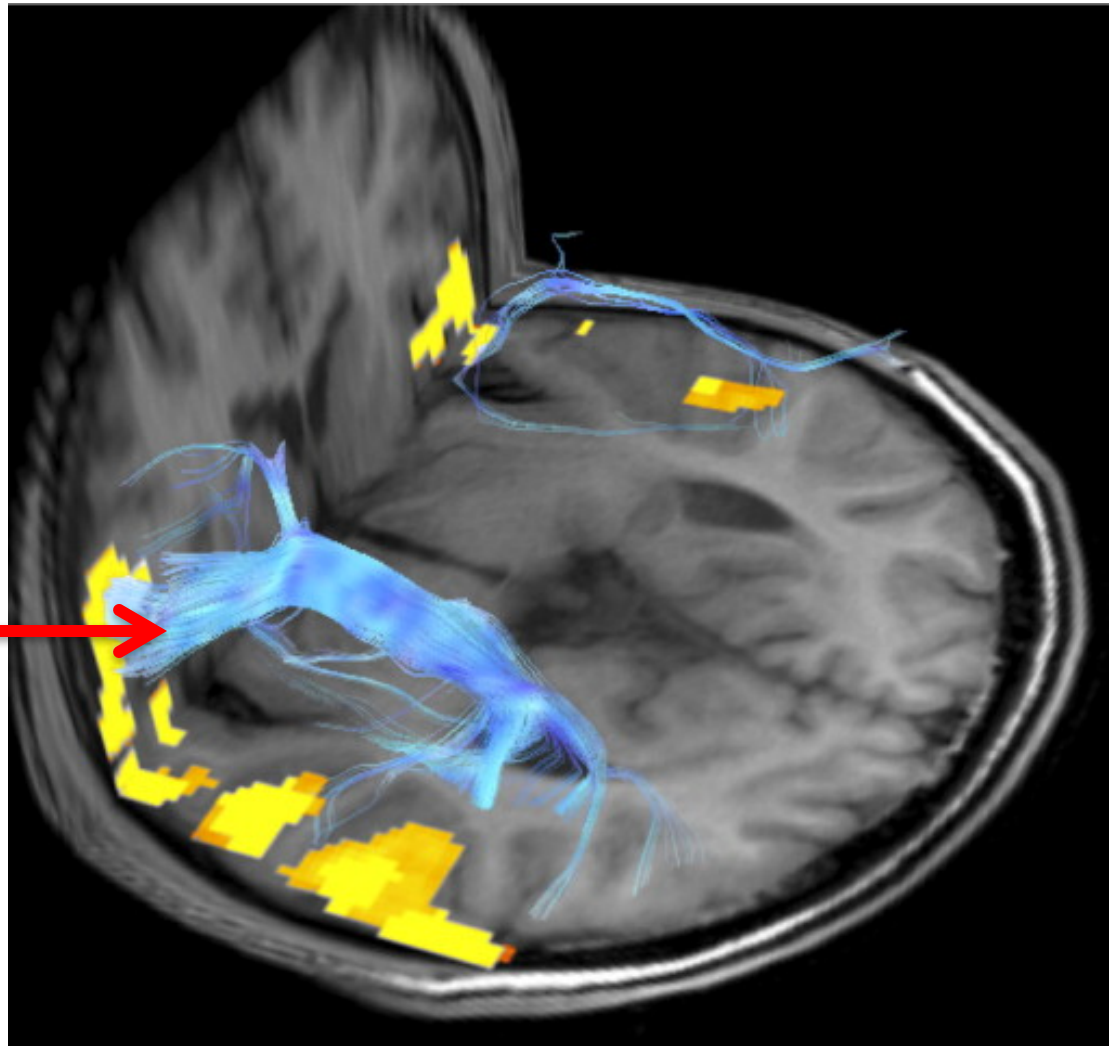
Broca & Wernicke System for Speech



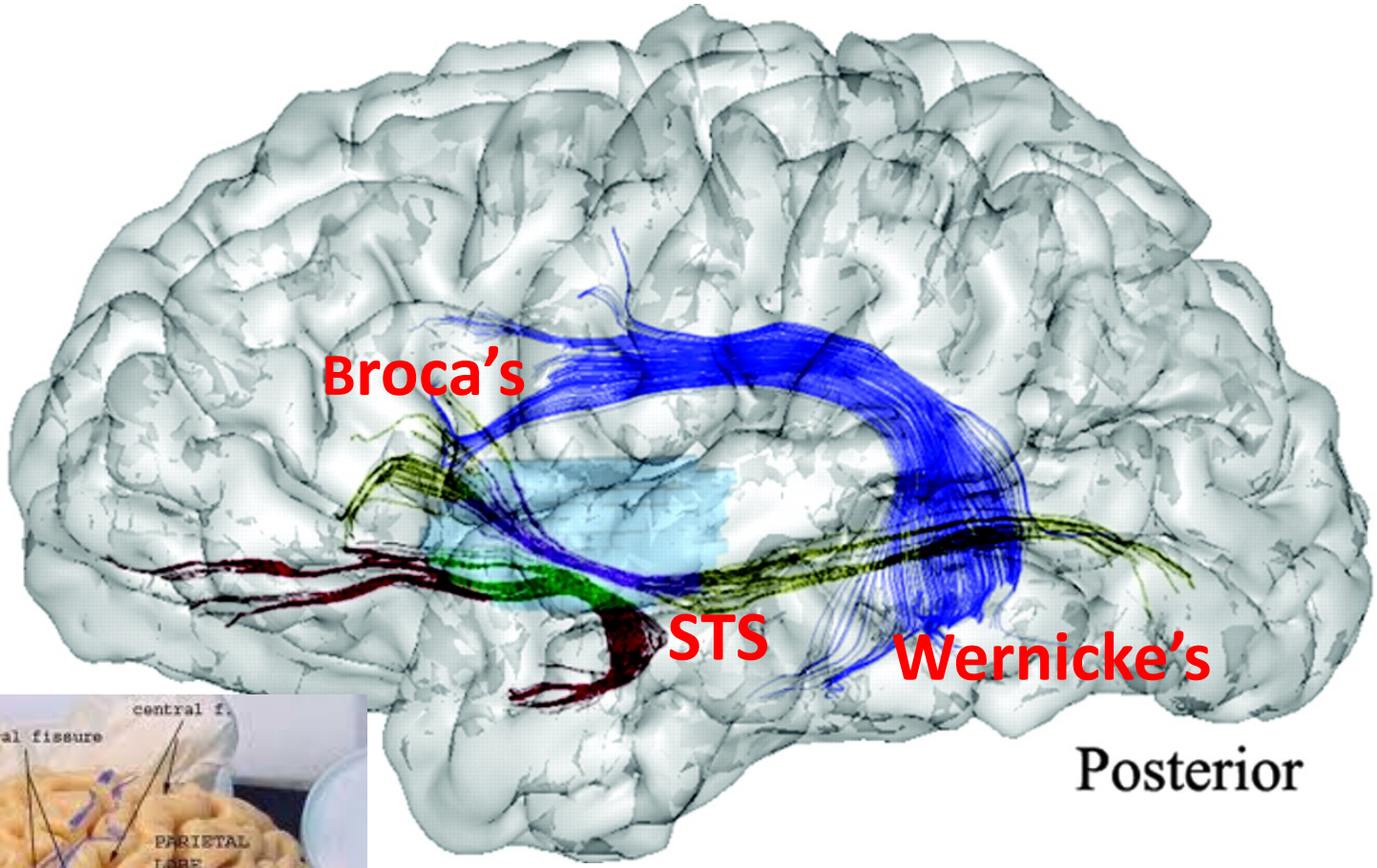
Broca & Wernicke System for Speech

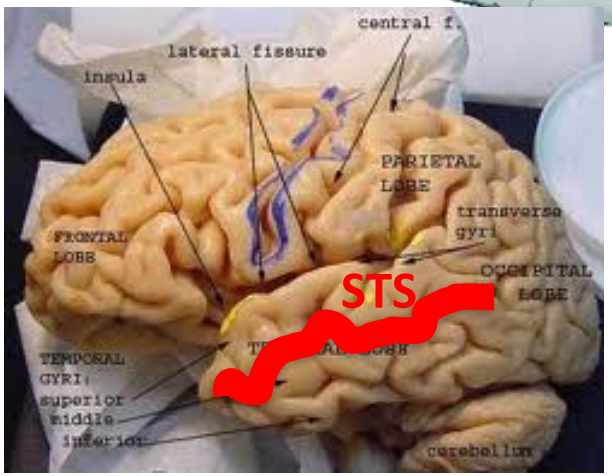
Arcuate Fasciculus - Significantly larger in Humans than NHPs

Arcuate in Left Hemisphere



Arcuate Fasciculus





Note also connects to **STS**

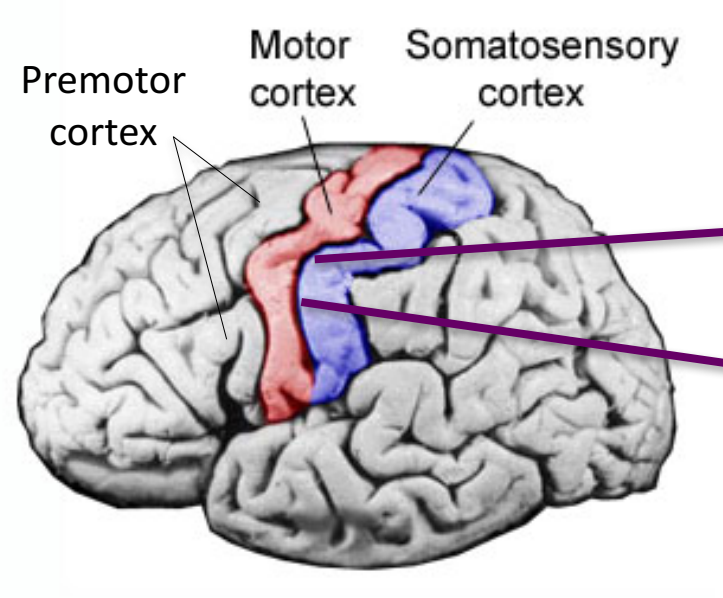
- Biological motion, e.g. of face, mouth, hands

Involved in Lip Reading, Facial Expression, and Gesture

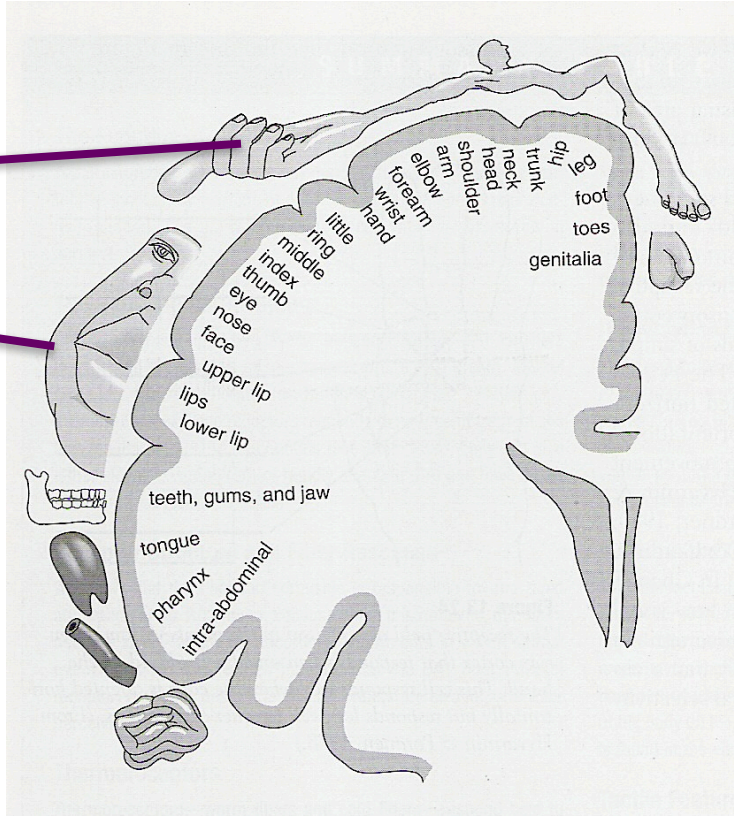
Socialization of Hand-Eye Coordination

The Mirror Cell System

Hand-Eye-Mouth Coordination



Map of body along Motor and Somatosensory gyri



Sensory & motor representations of Hand & Mouth are <u>adjacent</u> in brain

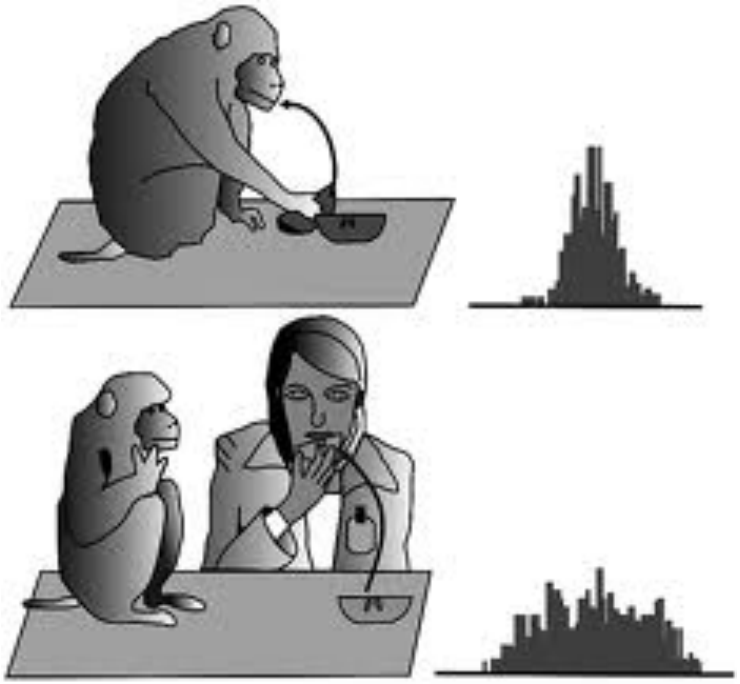
Influence each others' development and activation

Mirror Cell System

"Mirror Cells" respond when subject sees/feels self performing familiar act

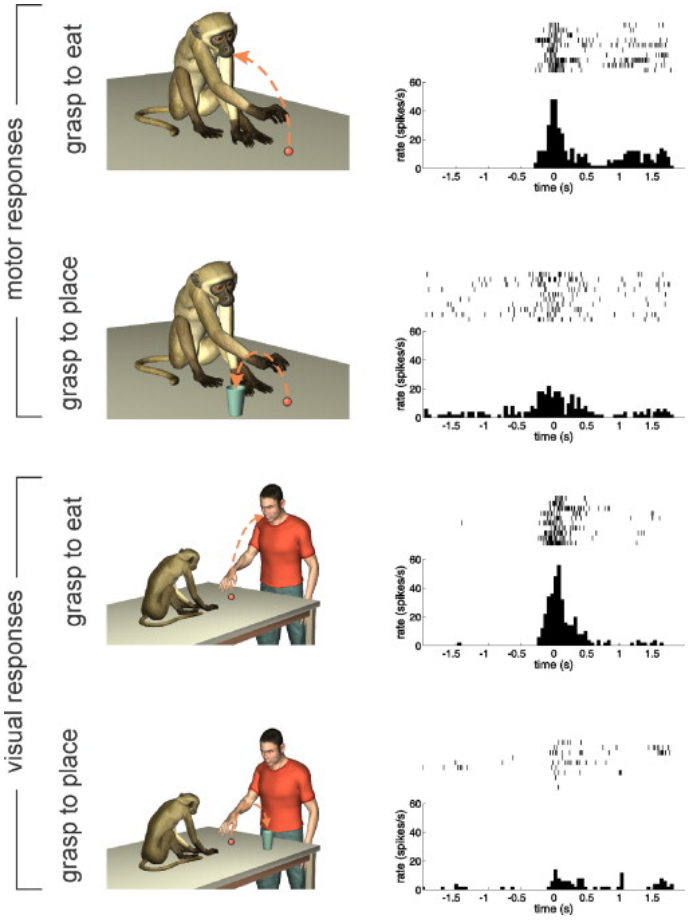
Mirror Cell System

"Mirror Cells" respond when subject sees/feels self performing familiar act



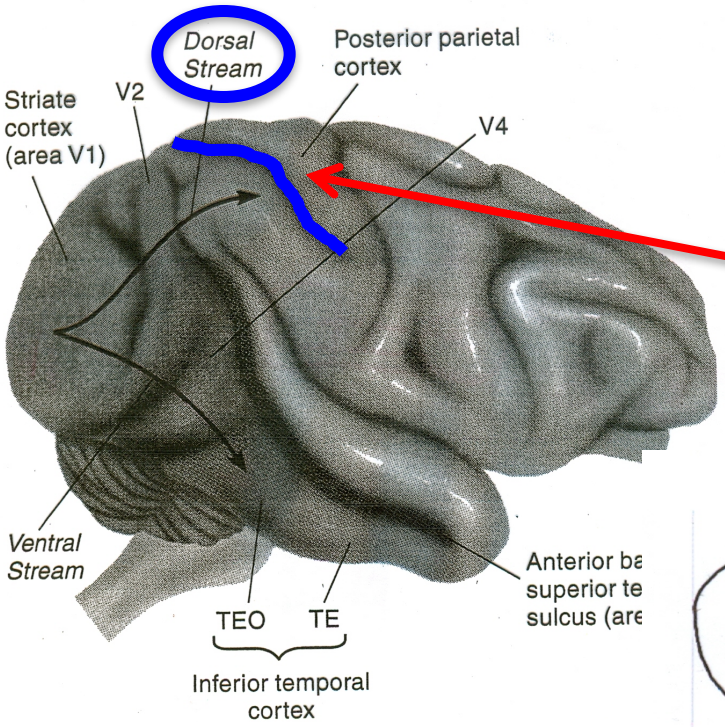
Same cells respond when subject sees another perform that act

Some specialized for "**Hand-Eye-Mouth Coordination**".



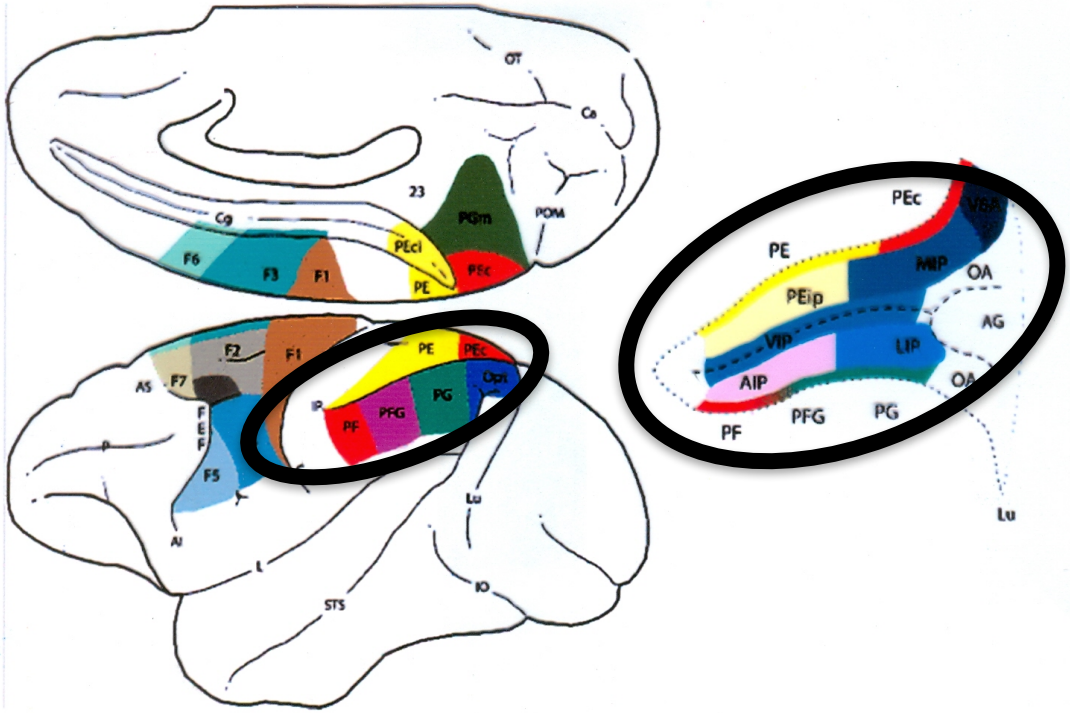
Mirror Cell System

"Where/How" Visual Pathway



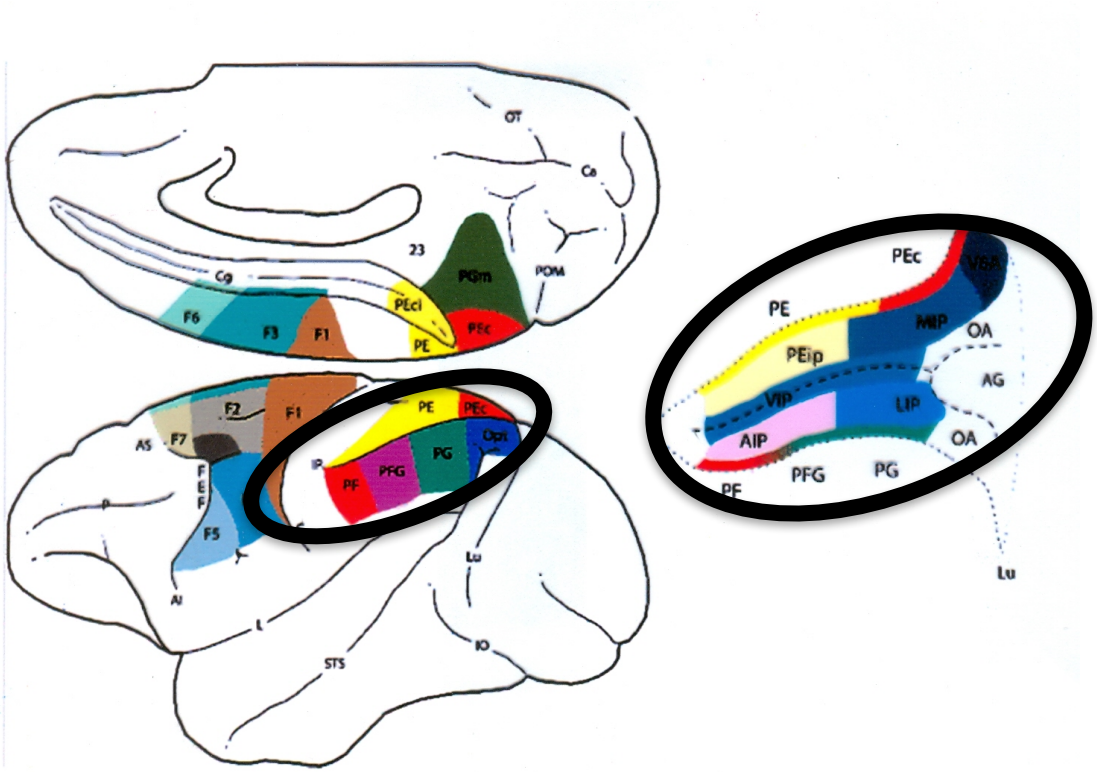
Parietal Lobe

Intra-Parietal Sulcus



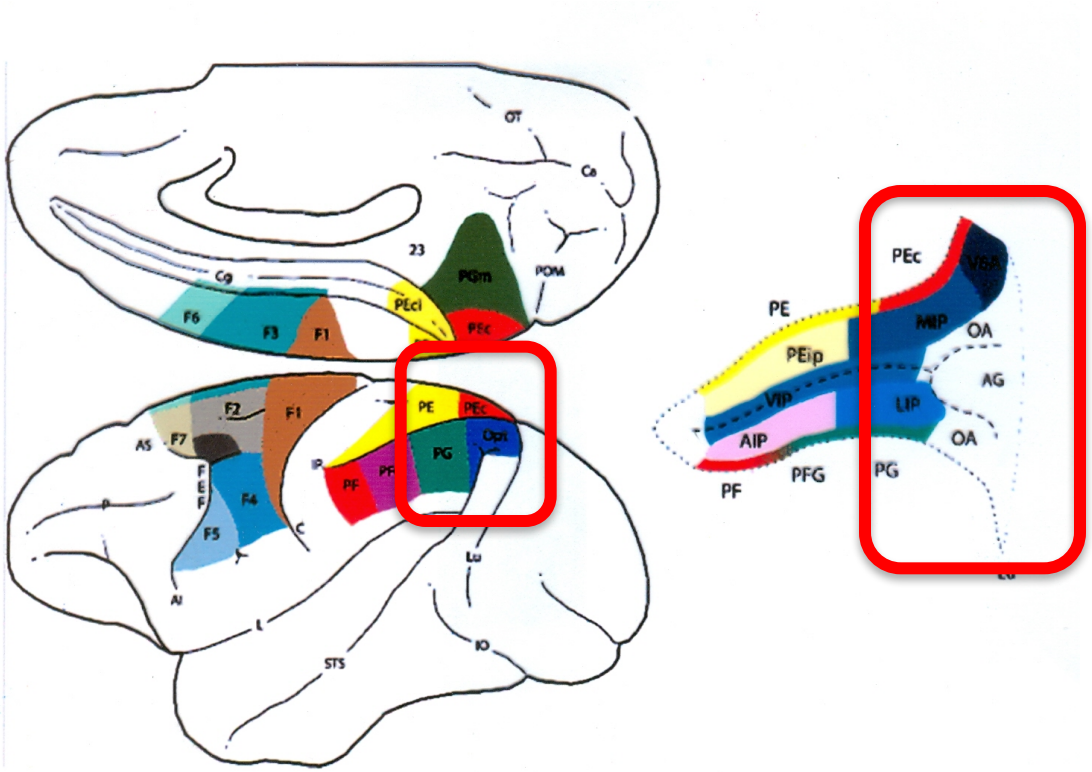
Mirror Cell System

Parietal Lobe



Mirror Cell System

Parietal Lobe



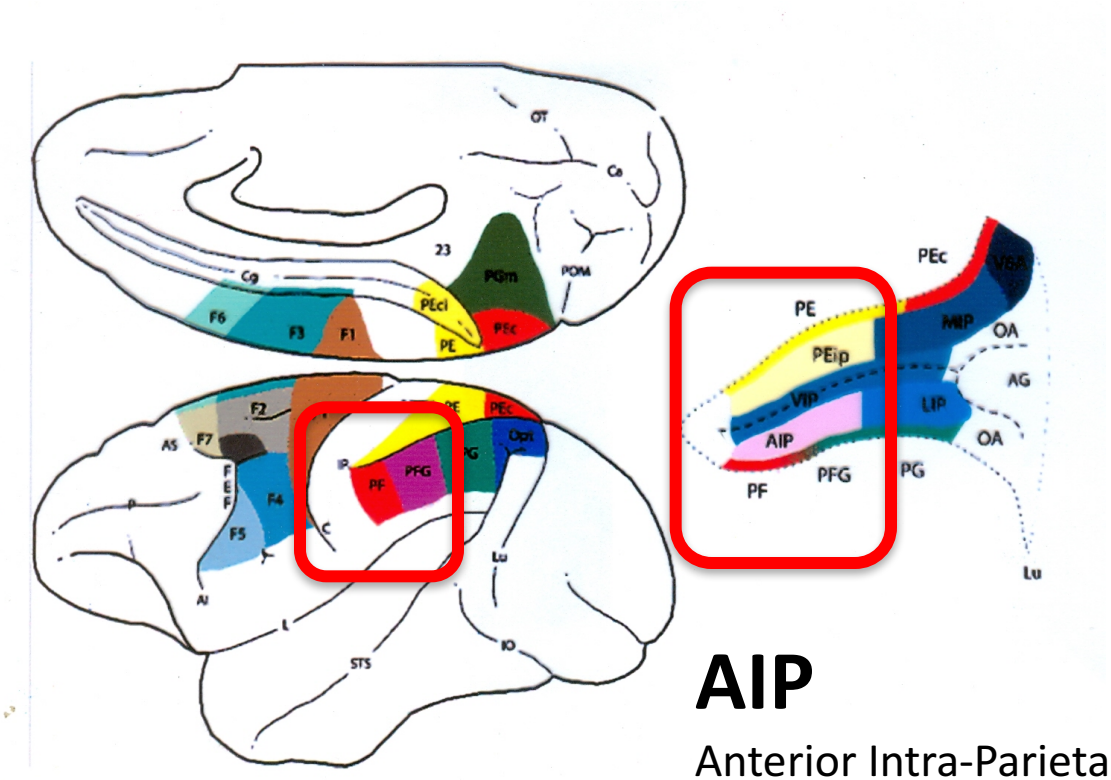
CIP

Caudal Intra-Parietal

= Object <u>shape & location</u>

Mirror Cell System

Parietal Lobe



AIP

Anterior Intra-Parietal
= Object affordances

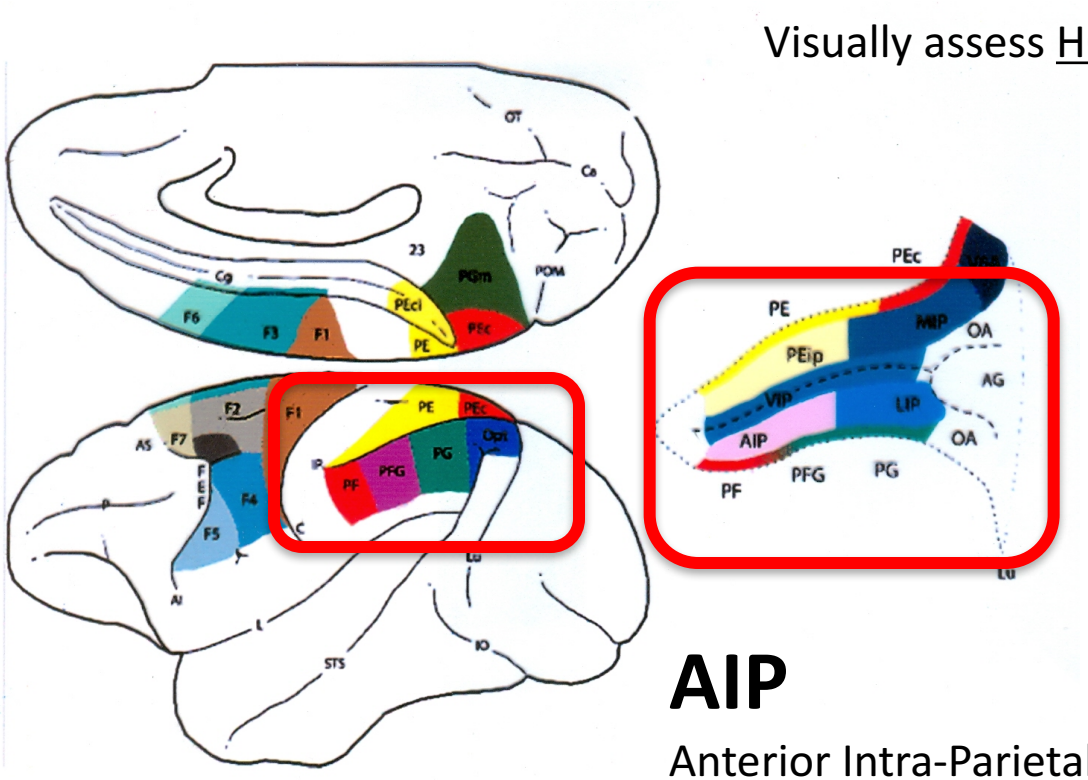
CIP

Caudal Intra-Parietal
= Object shape & location

Mirror Cell System

Parietal Lobe

Visually assess HOW to interact w/things



CIP

Caudal Intra-Parietal

= Object shape & location

AIP

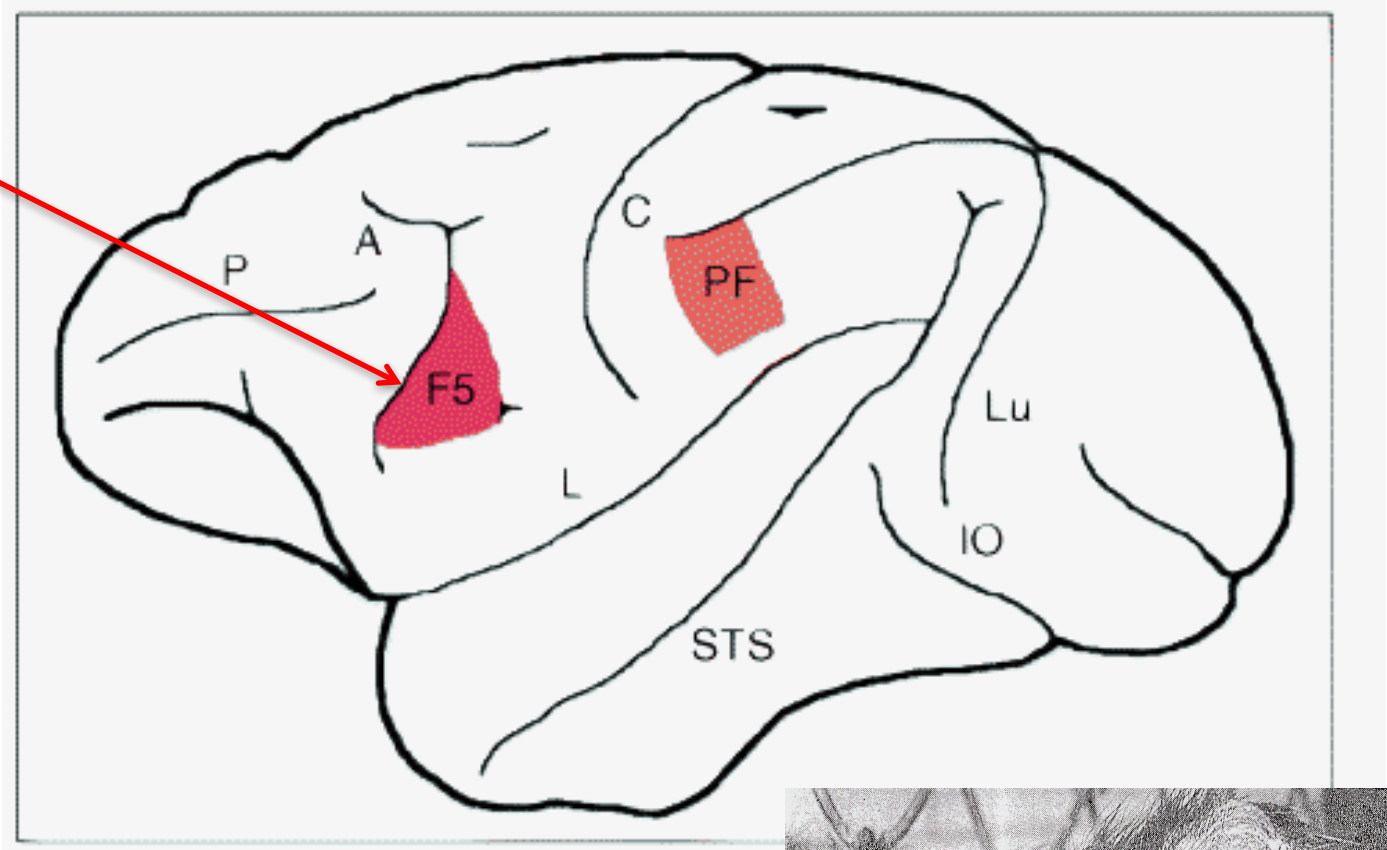
Anterior Intra-Parietal

= Object affordances

Mirror Cell System

Pre-Motor Cortex

Includes
Canonical
Neurons

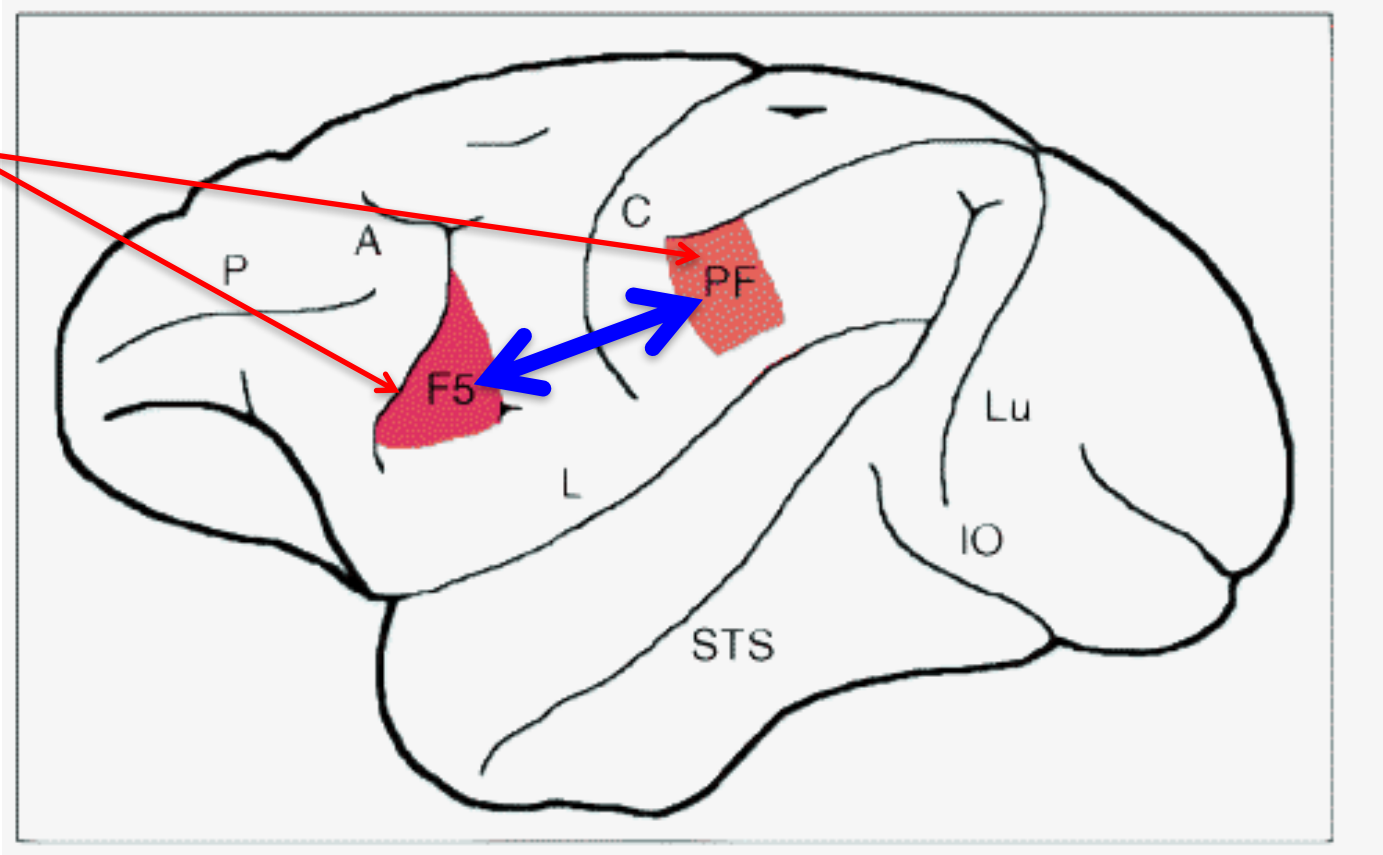


Canonical Neurons active when **grasp** or when see an object that is **graspable**

Mirror Cell System

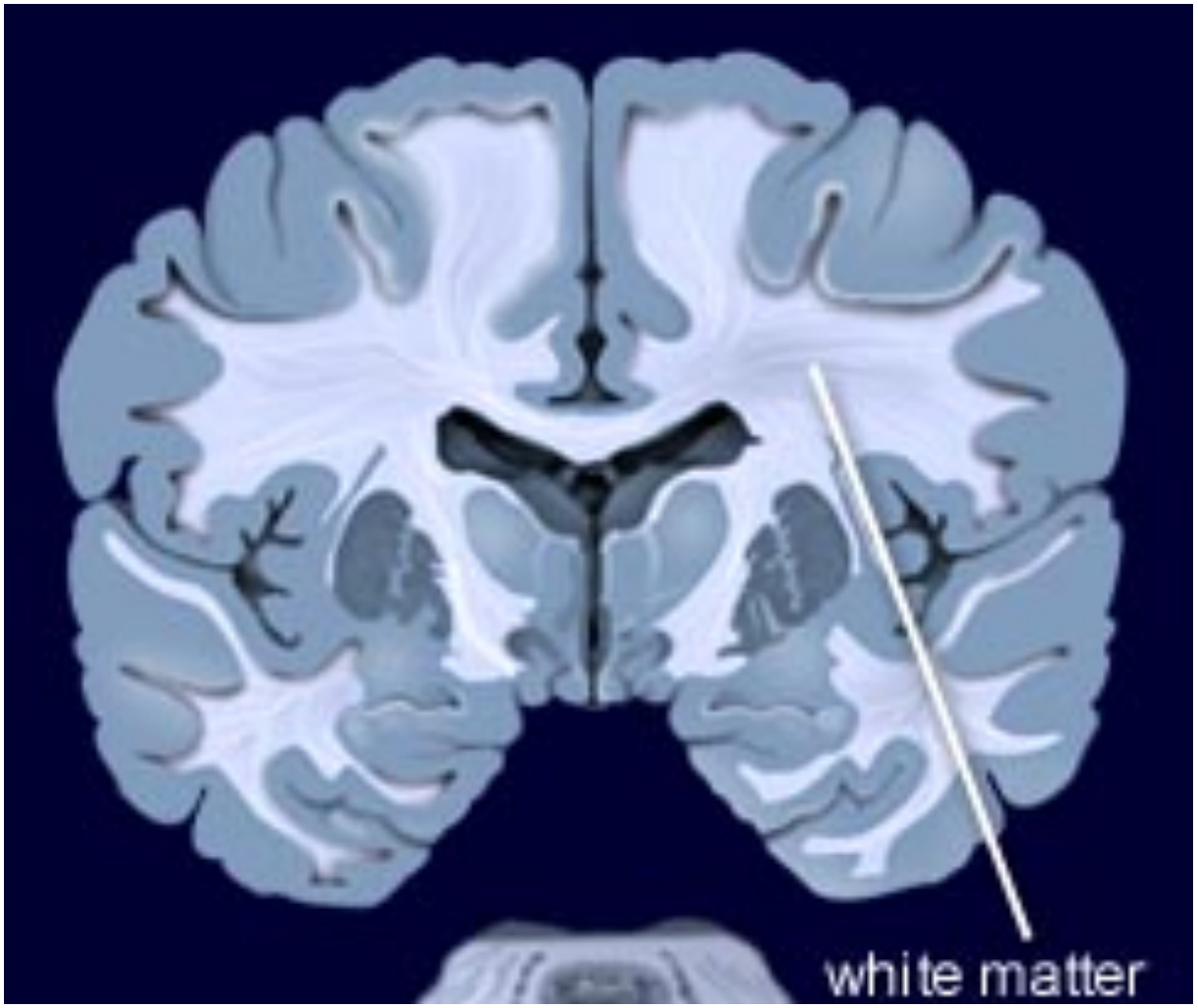
Pre-Motor Cortex

Mirror Neurons - in Frontal & Parietal



Reciprocal Connections between Mirror Neurons in Pre-Motor and Parietal

Mirror Cell System

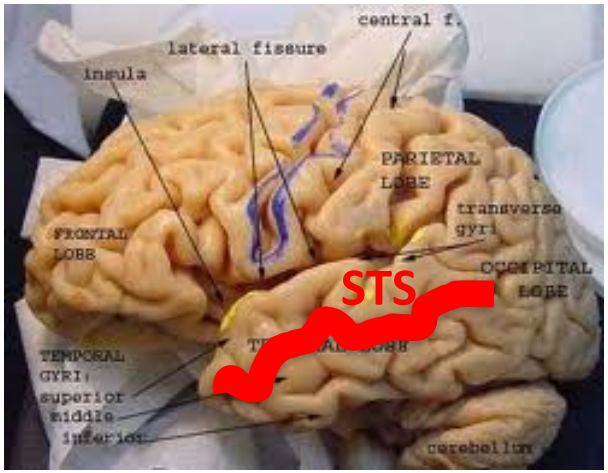


Above Pre-Motor & Parietal
areas are
LARGER in Humans,
but isometically scaled

It is the
White Matter
connections between
these areas that is
the most
allometrically
scaled.

Mirror Cell System

STS – for <u>hands and face</u> – also implicated here



Additional White Matter connections between STS & Mirror System

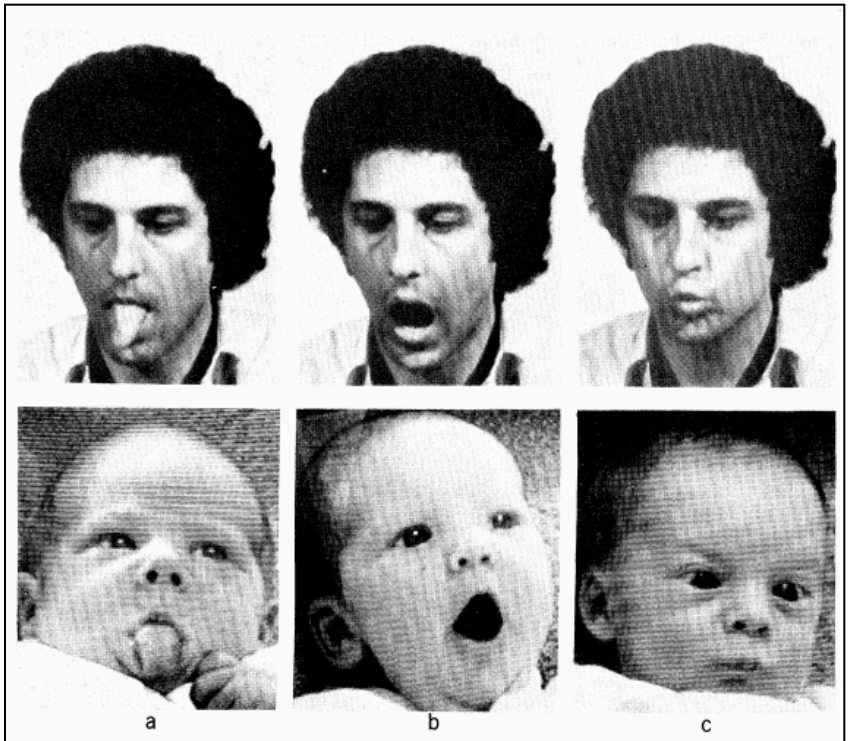


Fig. 1. Sample photographs from videotape recordings of 2- to 3-week-old infants imitating (a) tongue protrusion, (b) mouth opening, and (c) lip protrusion demonstrated by an adult experimenter.

Mirror Cell System
probably plays a role in
Imitation
and
Observational Learning