CS 184 * Modeling the Evolution of Cognition

# Lecture Wk 4: Comparative Neuroanatomy

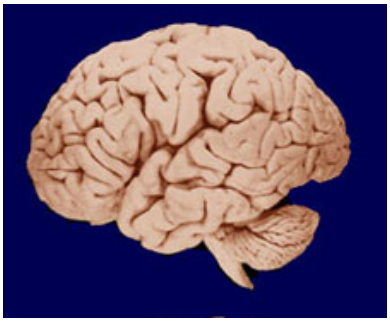
## Issues in Evolutionary Comparisons

- Anatomical comparisons & interpretation are **difficult and controversial!**

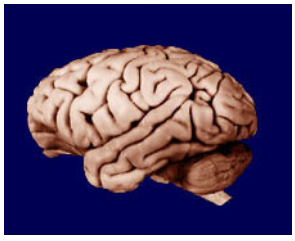
- **Fossil Record**
  - Archeological evidence generally based on **Endocasts** (inner surface of skull)
  - eg. **Area 10**: **Frontal Pole** (Anterior Frontal Lobe) Significantly larger in Humans than any Ape or Monkey
    - Diff not in cytoarchitectonics, but in **more space** available between cells for, especially, **cortico-cortico** connections
    - *Australopithecu africanus* (2.6 MYA, overlaps w/*H. habilis*) also shows larger Frontal Pole than Apes
    - Function still unclear- Poss involved in planning future actions, undertaking initiatives, solving analogies…
  - Can determine size & some surface structure but NOT **connectivity** (very critical to function!)
    - Connectivity patterns are some of the largest differences between human & nonhuman primates!

Comparing to Contemporary **Nonhuman Primate (NHP)** Brains
- Brains of many contemporary NHPs have probably also evolved in last 5 million years
- But the many commonalities across monkey, ape & human brains allow us to ID homologues
- Plus, diffs between monkey vs. ape-and-human, and human vs. ape-and-monkey, can be informative

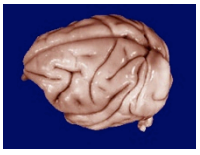
-**Scaling** = how size/shape changes as structure enlarges;
- Isometric Scaling = All parts get equally larger
  - Some argue expansion of human cortex is only what is expected, given overall enlargement of brain
- Allometric Scaling = Some areas get larger, or smaller, than others
  - Many hominid theories propose particular functional areas are differentially larger, more connected
- Human brain evolution involved a combination of these two = "**Mosaic Evolution**"



*Human*



*Chimpanzee*



*Rhesus Monkey*

These three images are (roughly) to scale.

Absolute Size Matters! – **Humans largest** – 3.5 X Chimpanzee, 10 X Rhesus monkey
- Not just relative size, but absolute size matters in brains: More cells, more connections; more processing
  - Note more convolutions visible in cortex, indicate expansion of cortical sheet, requiring more folding
  - Plus, new emergent properties? When does sufficient quantity make a qualitative difference??
- During fetal devel, "Regulator Genes" control timing of switch from Symmetric to Asymmetric Division of Stem Cells
  - Sym = Stem cells produce identical daughter stem cells Asym = Produce one Stem Cell & one Neuron (or Glia)
  - Delay of this switch by about 10 days (in humans vs. chimps) >> millions more Neurons
- **White Matter** (myelinated connections between cells) Most pronounced differences between human & nonhuman
  - 66% of human brain volume; But particularly tricky to compare, since scales up faster than grey matter

## NOT just cortex changed – also significant changes in related **Subcortical Structures**

- **Basal Ganglia** which functions in skill learning, automatization of routines, initiating/satisfying task constraints
  - Allometrically expanded, esp in areas that connect with Thalamus & Frontal Cortex

- **Ventral Dentate Nucleus** of **Cerebellum** > Thalamus > Prefrontal and Posterior Parietal Cortex
  - Dentate is newest, deep nuclei in Cerebellum; Allometrically scaled in humans
    - Largely responsible for planning & execution of fine movement
  - Ventral Dentate Nucleus is even more significantly enlarged than other parts of Dentate
    - Receives from especially Premotor, sends to Ventrolateral & Mediodorsal Thalamus
    - This area is NON-motor, plays a role in "cognitive" and "visio-spatial" actitvity
      - Including attention, planning, executive function, rule-based learning

- **STS** (**Superior Temporal Sulcus**) responds to Biological motion, including of head, limb & body movements
  - Involved in MULTIPLE functional systems (see below)

# Human (Hominid?) Brain Specializations

Three major **functional systems** appear especially impacted during human brain evolution

## Limbic + Prefrontal System  Affect regulation & social interpretation

- All these interactions probably help mediate assessment of **emotions in others, empathy, theory of mind**
- **Area 13** – in **Orbito-Frontal Cortex**, **increased diversification** in area in Humans and Bonobos (compared to other apes)
  - Many inhibitory connections with Limbic System, for mediating emotional responses?
  - Esp well developed connections with **Amygdala**; Damage associated with **Autism/Theory of Mind** deficits
- **Lateral Amygdala** (Emotional Learning) is the nucleus of the amygdala that is most disproportionately large
  - Connections w/Prefrontal (Orbito- and Dorso-Medial Frontal) are involved in regulating, & recognizing, affect
- **Mediodorsal** (**MD**) Nucleus of **Thalamus** – allometrically scaled = much larger & more neurons than expected
  - Heavily connected with Prefrontal cortices, helps activate complex emotional reactions, decisions
  - Plays a major role in declarative/episodic memory, emotional narrative
- **Anterior Principal** (**AP**) Nucleus of **Thalamus** – allometrically scaled = many more neurons than expected
  - Connects Hippocampus to Cingulate (Limbic System, for +/- evaluation) & Prefrontal corticies
  - May enable encoding more info and sustaining attention to social stimuli
- **STS** - Human STS has expanded reciprocal connections with above
  - e.g. As monkey watches another's head/face turn toward/from it, activity sweeps across one area of STS
    - Probably also for discriminating/interpreting eye movement (direction of gaze), facial expression, gesture
- **Von Economo Neurons (VEN)** - Long unbranched for communicating between distant areas of the brain
  - Found in apes & humans (and few other large-brained mammals), but not monkeys
  - Found esp in **Anterior Cingulate** (part of Limbic System involved in Social Assessment, +/-) and **Frontal Insula** (between Amygdala and Prefrontal Cortex, Spontaneous emotion, Social connectedness)

## Broca's + Wernicke's Speech System

While much of Human cortex may be isometrically scaled up, one area clearly allometric is **Planum Temporale**

- Temporal lobe in/around Lateral Fissure, **asymmetrically larger in LEFT** hemispehre
- Slight asymmetry seen in apes over monkeys, exaggeratedly different in humans, associated w/recognizing calls
- In humans, called **Wernickes Area**, for Language comprehension - Lexicon

- Note Broca's Area, while larger than in NHPs, is isometrically scaled!  (Also see more on this area, below)
  - But, **Basal Forebrain** has **NEW** part, not present in any other primate, modulates **arousal** of **Broca's Area**

PLUS, More connections between this area of Temporal Lobe & Premotor Cortex than in apes

- **Arcuate Fasciculus**, which reciprocally connects Broca's and Wernicke's Areas, to engage in language interactions
  - Also includes connections to **STS** – esp for reading biological motion of face (for lip reading, facial expression)

## Mirror Cell System

In HUMANS, areas in this system are **larger, and more heavily connected**, altho clear homologues exits in NHPs

- These brain areas themselves are isometrically scaled, but connections are allometric
- i.e. **White Matter** (myelinated axons connecting areas) more developed between Frontal and Parietal in Humans than NHPs

Critical components of this system include…

In Parietal Cortex…

- **Caudal Intra-Parietal (CIP)** = Active when distinguish shape/location of object
- **Anterior Intra-Parietal (AIP)** = Discriminate **Affordance**
  - i.e. How does shape/location of object afford grasping/manipulating

- In Premotor Cortex (Frontal Lobe)…
  - **Canonical Neurons** (e.g. in Premotor area: F5) = Active when monkey (or human) grasps an object
    - OR - when monkey (or human) sees an object that is graspable (i.e. that **"affords" grasping**)
    - This premotor area shapes hand appropriately to fit object individual is about to grasp
- Reciprocal connections reverberate activity between Parietal & Premotor Cortex
  - e.g. In humans and NHPs, Canonical & AIP co-activate when engage with affordances of objects
  - e.g. **Mirror Neuron System**" = Mirror Neurons found in both Parietal & Premotor Cortex
    - **Mirror Neurons** = Fire when individual reaches for/grasps object - OR – when it sees other do same
- **STS** also involved, re: biological motion of hands (recognizing how hand is moving - yours or others)
  - In addition to Prefrontal connections mentioned above, also connects with **Parietal** cortex
- Humans now show expanded **white--matter** connections between these areas of the Cortex

As discussed in ARBIB reading this week:

- **F5 (monkey premotor,** associated with hand/mouth) homologue with **Broca's area** (speech production)
  - We will discuss role in evolutionary relation between gesture & speech