Ch 14. Evolutionary Perspective

Cognitive Neuroscience: The Biology of the Mind, 2nd Ed.,
M. S. Gazzaniga, R. B. Ivry, and G. R. Mangun, Norton, 2002.

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- Basic terminology and concepts used by comparative neuroanatomists
- Strategy that comparative neuroscientists use
- How evolutionary theory is important for understanding learning and cognition

The Historical Underpinning of Contemporary Evolutionary Neurobiology

The Historical Underpinning of Contemporary Evolutionary Neurobiology (1/3)

- A history of dogma regarding two major tenets of human design that shaped the direction of science in earlier times
  - Humans are the pinnacle of life or the center of the cosmos
    - Human brain is a unique amalgamation of evolutionary old areas and new areas.
  - Mind or soul is distinct from body
    - There is some unique aspect of human condition.

The Historical Underpinning of Contemporary Evolutionary Neurobiology (2/3)

- Neuroscience and cognitive science are beginning to incorporate the facts and theories of comparative anatomists and evolutionary biologists.
- Natural selection – important discovery
- Korbinian Brodmann(1909)
  - Cross-species comparisons of the cytoarchitecture of the cerebral cortex => common ancestor

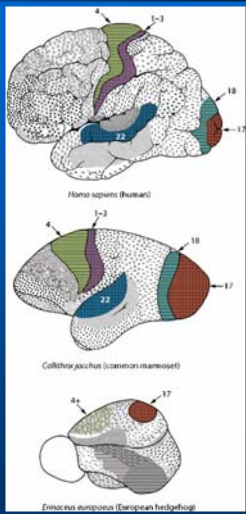

Figure 14.1 Cytoarchitectonic divisions of the human, marmoset, and hedgehog neocortex

The Historical Underpinning of Contemporary Evolutionary Neurobiology (3/3)

- Joseph Shaw Bolton, George Elliot Smith, and Constantin von Economo
  - Parceling the human cerebral cortex into separate division => established common view of the functional organization of the human brain
- James Watson, and Francis Crick..
  - Discovery of molecular structure of DNA
    - Life could be reduced to this very basic unit of organization.
- Konrad Lorenz, Niko Tinbergen, and Karl Von Frisch (1950~1970)
  - **Ethology and Neuroethology**
  - Fixed action pattern – 'egg-rolling response'
    - Once initiated, continues through to completion, independent of feedback.
  - Human behavior is excluded from explanations.
- E.O. Wilson (1970s)
  - Marriage between zoology and population biology => **"Sociobiology"**
  - Logical explanation of animal behavior seemed counter to natural selection
    - Highly social insects, such as ants
  - "It reproduce genes" – Wilson (1975) / The Selfish Gene
- Steven Pinker, Leda Cosmides, and John Tooby
  - **Evolutionary psychology**
  - They do not believe All behaviors are driven by genetic mechanism.
  - Brain have a set of rules that govern behavior. (adaptation)

Modern Evolutionary Neurobiology: Assumptions and Aims (1/3)

- Comparative Neuroscience
  - More brain centered and systems oriented
  - Appreciations of the fundamental role of genes in evolution, and the complex interaction between genes and the environment in the construction of the nervous system
  - Began with Broadmann
    - Mammals have neocortical areas in common, despite very distant phylogenetic relationships.
  - Clinton Woolsey subdivided the neocortex into functional subdivisions in a variety of mammals.

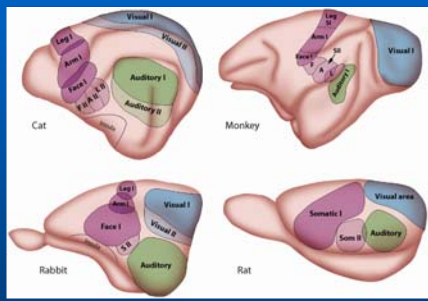

Figure 14.2 Functional subdivisions of the noecortex

Modern Evolutionary Neurobiology: Assumptions and Aims (2/3)

- Cross-species comparisons of neural structures
  - Charles Judson Herrick
  - A slight increase in the connectivity of homologous structures could effectively increase the processing capacity of the brain exponentially.
- Association areas
  - Almost all of the neocortex is sensory and motor in nature.
  - Complex brains evolve not by simply expanding association cortex, but by increasing the number of sensory and motor areas and the interconnections between them.
- Underlying assumption
  - All behavior in all animals is generated by the nervous system.
  - Brains evolve, and therefore behaviors evolve.
  - We can understand the process of the evolution of the brain and the behavior it generates **by examining** the products of the process, **the products of the process being extant (existing) animals**.

Modern Evolutionary Neurobiology: Assumptions and Aims (3/3)

- Bullock – aims of comparative neuroscience
  - Roots: Evolutionary history of the brain and behavior
    - How are brains similar and different?
    - What has evolution produced?
  - Rules: Mechanisms that give rise to changes in the nervous system
    - Are there constraints under which evolving nervous systems develop?
  - Relevance: general principle from a particular animal to all animals

Modern Evolutionary Neurobiology: The Choice of Animals

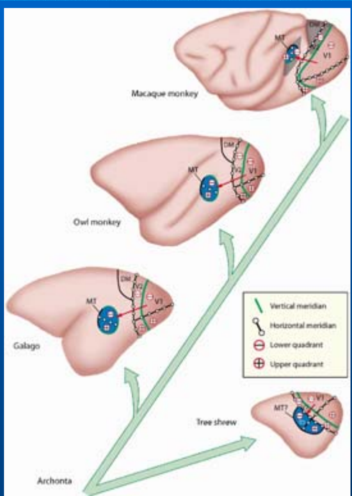

Fig 14.3. middle temporal visual area (MT)

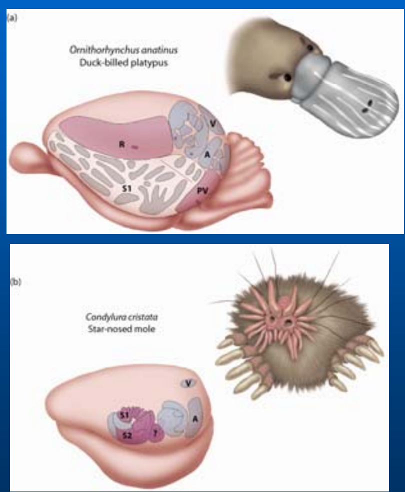

Fig 14.4. Rules of change for specialized peripheral structures and behavior

Basic terminology and concepts used by comparative neuroanatomists

First Principles (1/2)

- Natural Selection(3-observation of Darwin)
  - Individuals within a population vary
  - Some of this variation is heritable
  - Not all individuals within a population survive
- Phenotype & genotype
- Fitness & adaptation
- Exaptation
  - A structure that serves a particular function but then is co-opted for some other, very different function
- Genes & Alleles
- Chromosome
- Genetic specificity (1 function / 1 gene)
- Genetic pleiotropy (many functions / 1 gene)

First Principles (2/2)

- Epiphenomenon
  - A secondary symptom or effect, occurring with but not necessarily the cause or result of a phenomenon or event
  - Ex) Consciousness
    - selected for in evolution or epiphenomenon of the natural circuitry of a brain that evolved to solve complex sensory problems.
    - An epiphenomenon can become highly adaptive in a particular environment.
- Evolution works like a tinkerer – a tinkerer who uses everything at his disposal to produce some kind of workable object.
- Evolutionary Mechanism
  - Mutation & Recombination
  - Genetic flow & Genetic isolation

Strategy that comparative neuroscientists use

The Comparative Approach (1/3)

- Comparative neuroscientists
  - Works on animals other than humans in order to discover the basic principles of neural organization that can be applied to humans
- Why?
  - Indirect Methods (fMRI, PET), Limited behavior (MEG, EEG), Direct Methods are limited to human
  - We must rely on studies of other animals.
- Homology
  - A structure, behavior, or gene that has been retained from a common ancestor
  - Not necessarily have the same function (Exaptation allowed)
- Derived trait
  - Specialized and limited to a particular group or species.
- Plesiomorphic trait
  - A general feature of some group or lineage.
- Homoplasy
  - Structures that look the same but do not necessarily have a common ancestry.
    - The wing of a bat and the wing of a fly

The Comparative Approach (2/3)

- Convergent evolution
  - Similarities can arise independently in different lineage
  - A sign of the limited and rigid rules by which brains evolve
- Out-group comparison
  - To determine whether features of the brain are homologous, homoplaseous, or analogous
  - Phylogenetic relationships among animals
    - Close sister groups of a species are examined to determine if they possess the structure in question.

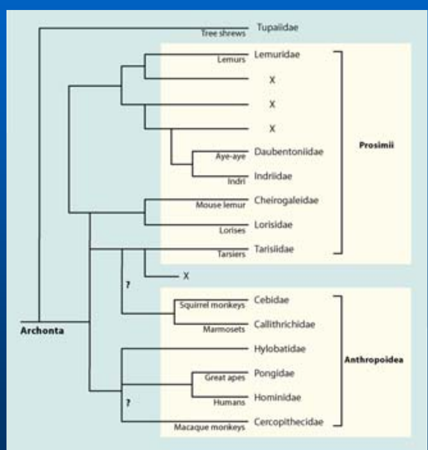

Fig 14.7. A diagram of the phylogenetic relationships between extant primates

The Comparative Approach (3/3)

- Principle of parsimony
  - The best hypothesis => The fewest transformation

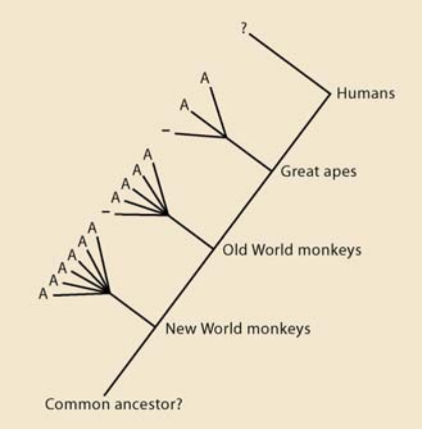

Fig 14.8. An example of how an out-group analysis can be used to make inferences about the unknown condition

The Scale of Nature Revisited

- Evolutions is linear or simply additive.
- “Higher-order” brain areas are simply added on to “lower animal” brains.

- Counterexamples
  - Prefrontal Cortex (echidna vs. human)
  - Broca’s area – added area vs. specialized (derived) area

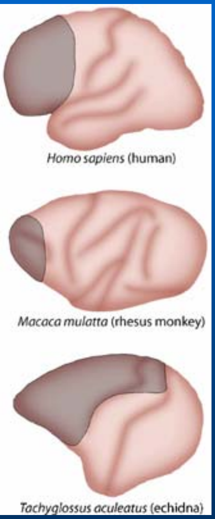

Fig 14.9. The location and extent of “prefrontal” cortex (gray) in three different species.

How evolutionary theory is important for understanding learning and cognition

Adaptation and the Brain

- Adaptation of human brains
  - Adapted 100,000 years ago.
  - Human irrationality: Framing effect
    - When the treatment is framed in a positive manner, people tend to choose sure bets;
    - In a negative manner, people tend to choose more probabilistic options.
  - Our behaviors are adapted for a simpler life.
  - Proximate factors VS Ultimate factors
    - Whiteness of Bones and Calcium

Adaptations at Multiple Brain Level (1/2)

- David Marr
  - First articulated the true problems associated with understanding how vision must works.
  - Trying to understand perception by studying only neurons is like trying to understand bird flight by studying only feathers.
    - We have to understand aerodynamics.
  - Three levels of description for any information-processing device
    - Devices are designed to solve problem.
    - They solve problems by virtue of their structure.
    - When one knows what problem it was designed to solve and why it was designed for that problem and not another one explain a device's structure.

Adaptations at Multiple Brain Level (2/2)

- Visual scene analyzing device
  - The evolutionary function of vision: scene analysis (Marr)
    - Two-dimensional visual array -> real-world conditions
  - Three discovery of researchers
    - Scene analysis is far more complicated than had been imagined.
    - Vision of human apprehends more information than any artifact.
    - Our evolved visual system must have a cognitive, built-in component.

Sexual Selection / Evolution & Physiology

- Sexual selection
  - Differences in behavior and body between male & female
    - Maximum Reproductivity
  - Spatial ability
    - Male > Female, Polygamy > monogamy
    - Hippocampus is crucial to spatial memory tasks.
- Evolution & Physiology
  - Predator & Prey: Coevolution & balanced coexistence

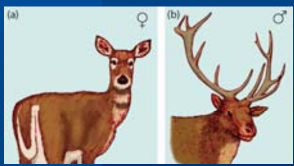

Fig 14.11. The typical morphology of a female doe and that of a polygamous male elk

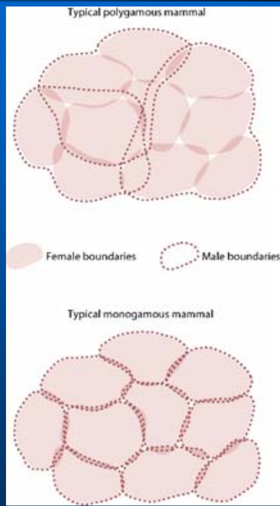

Fig 14.12. Typical home-range patterns for polygamous versus monogamous mammals

Adaptive Specialization and Learning Mechanism

- SR (Stimulus response) psychology
  - A general-purpose capacity in the brain acquires information during any and all kinds of learning tasks.
  - Associationism
  - Right reinforcement contingencies / Right brain state -> Learning proceed
- Randy Gallistel (1995)
  - Many learning mechanisms specialized for solving problem
    - Migratory thrushes must learn the center of rotation of the night sky when they are mere nestlings.
  - Nonassociative learning
  - Problem specific learning mechanism
  - Commonalities of learning mechanisms
    - Basic instruction set
    - Storing and retrieving the values of variables

Evolutionary Insights into Human Brain Organization (1/2)

- Large size = Higher level brain
  - A major assumption being challenged
  - More neurons and more cortical columns
  - Added on structure
- Comparative neurobiology
  - Unique capacities do not rely on cell number
  - Specialized circuitry / adaptation
    - Split brain research
  - The cortical area within a species contains variable proportions of morphologically and neurochemically defined cell type.

Evolutionary Insights into Human Brain Organization (2/2)

- Human brain
  - Human brains are larger because they have more devices for solving problem.
  - The variation seen in human's capacity to solve problem will not vary with brain size. (no correlation)
  - Big brain may be a by-product of other process for establishing the uniqueness of each specie's nervous system. (Specialized circuits)

Summary

- Complex capacities like language and social behavior are not constructs that arise out of brain simply because it is bigger than a chimpanzee`s brain.
  - These capacities reflect specialized devices that natural selection built into our brains through blind trial and error.
- If the variations created by mutations produce a slightly unique state of affairs that helps our brains make better decisions, the new capacities will survive.
- Trying to deduce similar features of brain organization and unique features is difficult. Therefore, the strategy comparative neuroscientists use is crucial.
  - Bullock proposed three main aims for comparative neuroscience.
    - Roots, rules, and relevance.
- A multitude of commonalities connect all species and lend strength to much of biological research.

Key Terms

adaptation	exaptation	homology	plesiomorphic
alleles	fitness	homoplasy	principle of parsimony
chromosome	genes	mutation	recombination
comparative neuroscience	genetic pleiotropy	natural selection	sociobiology
convergent evolution	genetic specificity	neuroethology	traits
ethology	genotype	out-group comparison	
evolutionary psychology	heritable	phenotype	

Thought Questions

1. A hypothetical cortical area, DF, has been newly discovered in macaque monkeys. The investigators who first described it hypothesize that it is involved in tactile object discrimination and propose that it might be present in humans as well. How can they test this hypothesis without performing experiments using fMRI or PET?
2. What are the three major aims of comparative neuroscience? Briefly explain each.
3. Why is the study of convergent evolution of brain structures or fields important?
4. An area MT has been described in humans. This region does not reside at the tip of the superior temporal sulcus as it does in all other primates that have been investigated. Further, the cortical architecture (how it looks in neural tissue that has been histologically processed) is quite different from that in other primates. Although it becomes active in response to moving stimuli, so do a number of other areas of human neocortex. Is this field homologous to the area MT described in other primates? Why or why not?
5. Should one look for a genetic explanation for all behaviors? Explain your answer.