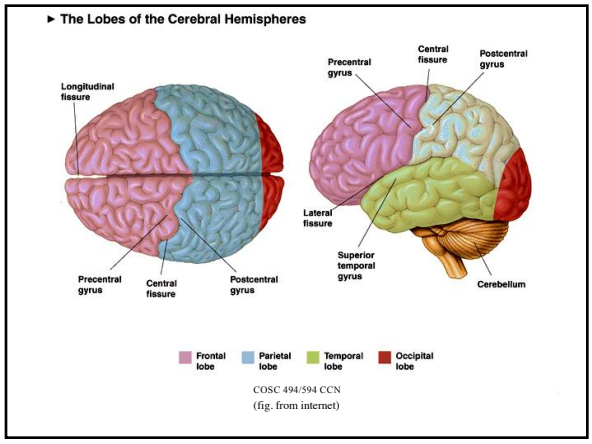
5. Brain Areas

Outline

A. Functional Anatomy of the Brain
B. Perception and Attention
C. Motor Control
D. Learning and Memory
E. Language
F. Executive Function

A. Functional Anatomy of the Brain

Comparing and Contrasting Major Brain Areas



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(fig. from internet)

Other (Subcortical) Areas

- Hippocampus: rapid learning
- Thalamus: sensory input, attention
- Amygdala: emotion, fear/desire
- Basal Ganglia: motor control, gating of PFC
- Cerebellum: coordinating movements
- Reward prediction system: dopamine release

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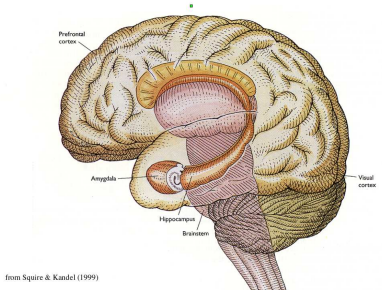
(slide < O'Reilly)

Subcortical Areas



from Squire & Kandel (1999)

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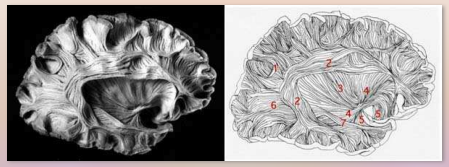
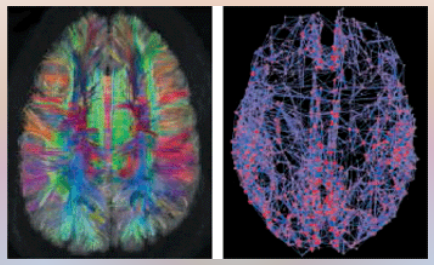
Left Hemisphere

Intercortical Connections



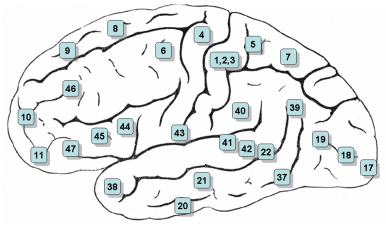
(1) Short arcuate bundles, (2) Superior longitudinal fasciculus,
(3) External capsule, (4) Inferior occipitofrontal fasciculus,
(5) Uncinate fasciculus, (6) Sagittal stratum,
(7) Inferior longitudinal fasciculus

Intercortical Connections (diffusion spectrum imaging)



G. Miller Science 330, 164 (2010) (2010)

Brodmann's Areas



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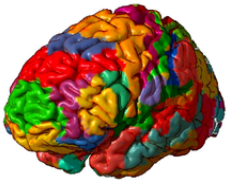
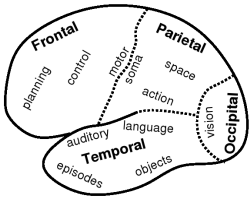
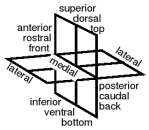
General Functions of Cortical Lobes





(how is this determined?)



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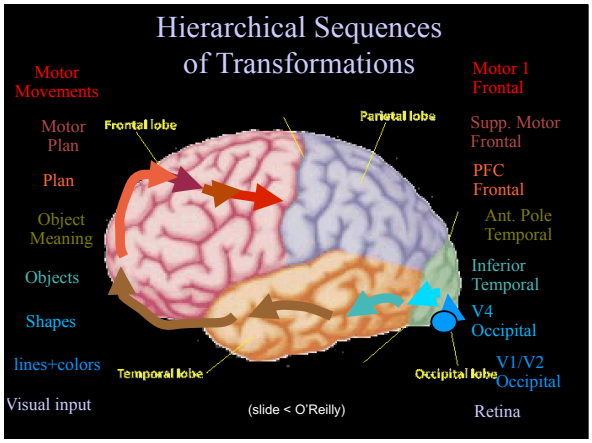
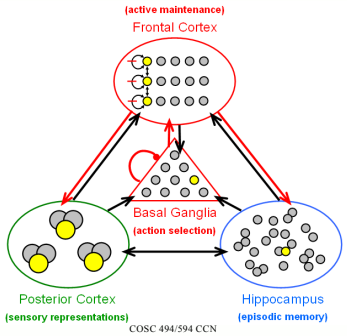
(slide < O'Reilly)

Hierarchical Sequences of Transformations



(slide < O'Reilly)

Tripartite Cognitive Architecture



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(slide < O'Reilly)

Large Scale Distributed Organizations

- Knowledge is distributed across multiple brain areas
- Multiple areas participate in representing a given thing (e.g., apple)
- Each area represents multiple things
- Same idea as distributed representation among units for individual items, but in this case across multiple areas/modalities, etc.

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(slide based on Frank)

Learning Across the Brain

	Learning Signal			Dynamics		
Area	Reward	Error	Self Org	Separator	Integrator	Attractor
Basal Ganglia	+++	−−−	−−−	++	−	−−−
Cerebellum	−−−	+++	−−−	+++	−−−	−−−
Hippocampus	+	+	+++	+++	−−−	+++
Neocortex	++	+++	++	−−−	+++	+++

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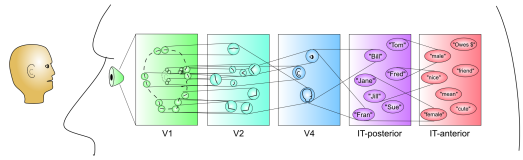
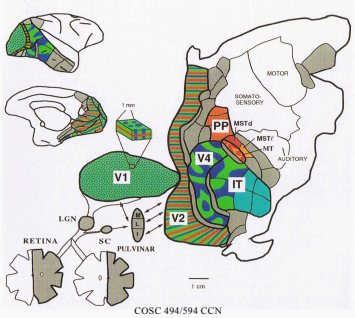
B. Perception and Attention

What versus Where

Hierarchy of Visual Detectors

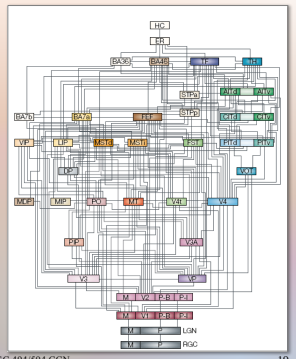


Macaque Visual System



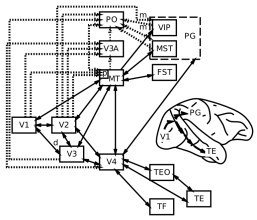
(fig. from Clark, *Being There*, 1997)

Hierarchy of Macaque Visual Areas



(fig. from Van Essen & al. 1992)

"What" vs. "Where" Pathways

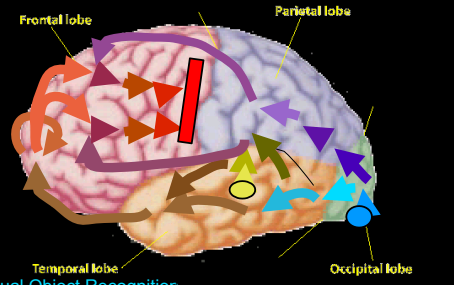


- "What" ignores differences in location, illumination, size, rotation
- "Where" emphasizes location, size, and ignores object identity

Multiple Interacting Pathways

Maintaining Abstract Information (plans, sensory info, etc) Movement

Spatial Processing
Touch



Visual Object Recognition
Audition Abstract Semantics

(slide < O'Reilly)

Early Vision

Principal Regions in "What" Pathway

- V1: Primary Visual Cortex
  - encodes image in terms of oriented edges
- V2: Secondary Visual Cortex
  - encodes in terms of intersections & junctions
- V4
  - more complex features over wider range of locations
- PIT: Posterior Inferotemporal (IT) Cortex
  - location & size invariant object recognition
  - includes FFA (fusiform face area)
- AIT: Anterior IT Cortex
  - abstract/semantic visual information

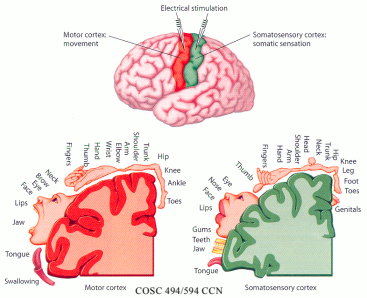
C. Motor Control

Parietal and Motor Cortex Interacting with Basal Ganglia and Cerebellum

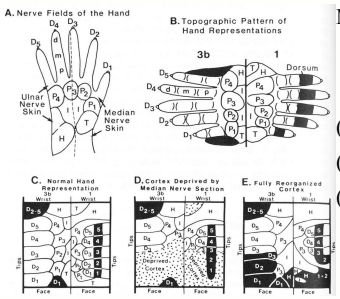
Motor Control

- Motor cortex (frontal to parietal)
  - high-level metrical processing of sensory information,
  - integrating multiple modalities and translating between different reference
  - arrives at a range of possible responses to the current sensory environment
- Basal ganglia
  - action selection: receives sensory inputs and potential responses being "considered" in frontal cortex; triggers disinhibitory signal enabling best action
  - action selection is shaped by reinforcement learning driven by dopamine signal
  - amygdala plays key role in driving these dopamine signals in response to sensory cues associated with reward and punishment
- Cerebellum
  - uses error-driven learning to acquire high-resolution metrical maps between sensory inputs and motor outputs

Somatosensory & Motor Homunculi



Reorganization of Cortex



- Median nerve sectioned to show fluidity of cortical organization
- (C) before
- (D) immediately after
- (E) several months later

(fig. < McClelland & al, *Par. Distr. Proc.* II)

D. Learning and Memory

Temporal Cortex and the Hippocampus

Computational Trade-offs in Learning & Memory

- Computational objectives that are mutually incompatible and thus cannot be achieved by a single brain system
- Learning must be slow to capture statistical structure (averaging)
- But you have to be able to learn rapidly too
- Tradeoff solved by two systems:
  - cortex learns slowly
  - hippocampus learns rapidly
- Third system: active memory (prefrontal cortex) ≈ fastest (immediately accessible)

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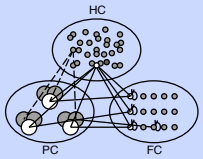
(slide < Frank)

Tripartite Functional Organization



PC = posterior perceptual cortex: *slow integrative learning*

HC = hippocampus and related structures: *rapid memorization*

FC = prefrontal cortex: *active maintenance ("working memory")*

Defined by set of functional *trade-offs*.

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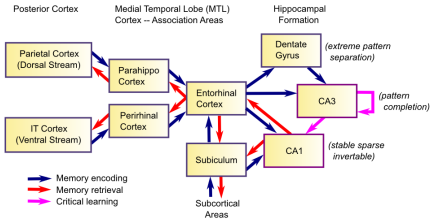
(slide < Frank)

Hippocampal Memory Formation



extremely sparse representations ⇒ pattern separation

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E. Language

Language

- Involves many of the foregoing functions
  - perception, memory, executive function, motor control
- Models (ch. 9) will address:
  - small scale model of reading, incorporating orthographic, phonological, and semantic aspects
  - regular behavior without rules
  - self-organization of semantic representations
  - interaction of syntax and semantics

F. Executive Function

Prefrontal Cortex and Basal Ganglia

Executive Function

- Builds on motor control functions of frontal cortex (FC) and basal ganglia (BG)
- Areas of FC oriented to
  - "what" vs. "how" processing
  - "hot" emotional vs. "cold" cognitive processing
- Prefrontal cortex (PFC) control over posterior cortex
- PFC and BG interact to implement dynamically gated working memory system

Ventral vs. Dorsal Organization of PFC