Reduction III: Mechanistic Reduction

Mechanistic Explanation: A Review

- A mechanism is "a structure performing a function in virtue of its components parts, component operations, and their organization"
- An important part of mechanistic research is decomposing the mechanism--identifying its parts and determining what operations they perform
  - The emphasis on taking a mechanism apart into its parts and operations is reductionistic
    - Moreover, it is a process that can be iterated by decomposing the parts themselves to explain how they perform their operations
- But equally important to mechanistic research are
  - Recomposition--figuring out how the parts fit together so that the operations can work together to generate the phenomenon
  - Situating--relating the mechanism to the various factors in its environment that impact on its functioning

Similarities with Ruthless Reduction

- Like ruthless reduction, mechanism does not focus on laws but on parts of the system that are responsible for operations involved in generating the phenomenon
  - They are both therefore contrasted with theory-reduction accounts
- Both maintain that testing hypotheses often involves manipulating a part within the mechanism and observing an effect on the behavior of the whole
- Mechanistic reduction agrees with ruthless reduction that there are times when pursuing the explanatory process down to the molecular (or even the biophysical) level is appropriate
  - For mechanism the goal is not to go to the lowest level for its own sake but because it can answer questions about how the phenomena are produced

## Differences Between Mechanistic and Ruthless Reduction

- On the mechanistic account, explanation of a given phenomenon requires identifying the parts and operations that interact to produce the phenomenon
  - This requires discovering productive continuity between the operations of the different parts
- In many cases the entities identified by ruthless reduction in explaining cognitive activities such as learning are multiple levels below the parts and operations of the initial mechanism
  - They are not directly the parts of the mechanism that are, when properly organized, produce the phenomenon
  - Rather, they are parts of *another* mechanism that is responsible for one of the component operations of the first mechanism (or of some mechanism further down)
- On the mechanistic account, one can iterate the process of decomposition, but then one is treating the operation of the part as the phenomenon to be explained

The Important of Recomposition on the Mechanist's Account

- To understand the phenomenon, mechanistic explanation requires showing how the operations of the various parts can actually realize the function
  - Researchers need to show that carrying out the different operations suffices to realize the phenomenon
    - The often do this in computational models that specify each of the operations and their relations to others
  - End up with an account that exhibits productive continuity
- Ruthless reduction only seeks to show that the part in question does affect the phenomenon
  - It neither seeks to recompose the mechanism nor to identify the productive continuity between the operations of the parts
    - Accordingly, it can easily lead to over stating what the components identified actually contribute to the phenomenon

From LTP Back to the Whole Hippocampus

- To learn new memories, it is essential
  - To recognize when a stimulus is another instance of one that has already been learned
    - Requires recurrent connections so as to have a network with attractors
  - To learn to respond differently to a different stimulus, one must differentiate the new inputs from the previous ones
    - Requires sparse coding that separates the inputs
- Different parts of the hippocampus appear suited for these different tasks
  - The Dentate Gyrus provides sparse coding
  - The CA3 fields have large number of recurrent projections that generate attractors
- Rolls recomposed this network in a computational simulation and showed it would exhibit the desired behavior
  - This moves up from the molecules to the organized network in the hippocampus
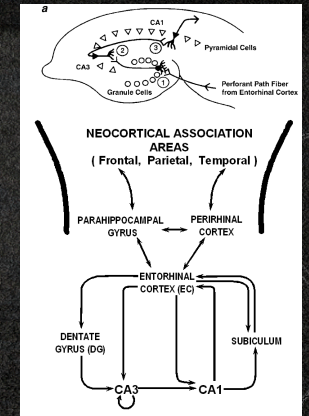
The Hippocampus Is Just Part of the Higher-Level Mechanism

- McGaugh showed that other structures, such as the amygdala are important for memory consolidation
  - Agonists to the β-Adrenergic receptor on the amygdala can enhance memory
  - Antagonists to the receptor block the ability of dexamethasone to enhance memory
- McGaugh concludes "It is clear from these findings that memory consolidation involves interactions *among neural systems*, as well as cellular changes within specific systems, and that amygdala is critical for modulating consolidation in other brain regions"

Extended Consolidation

- Hippocampal lesions produce both anterograde and extended retrograde amnesia extending back months to years before the lesion
- Most researchers assume that long-term memories are eventually encoded in a distributed fashion in the cortex
  - Extended training of cortex may contribute to development of memories that are not readily overwritten with the next event
- During parts of sleep without rapid eye movements (hence, non-REM sleep), new LTP is blocked but previous LTP is maintained
  - May figure in the gradual training of cortex
    - McNaughton and collaborators have shown synchronous firing during maze-learning and during non-REM sleep and suggest that the latter may be important for memory consolidation
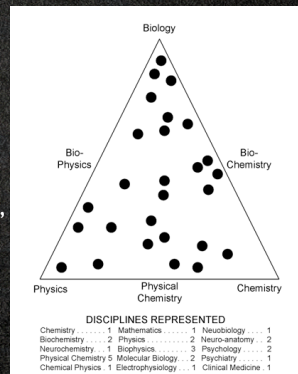
Memory Must Be Reconsolidated

- When a memory is recollected, it must be reconsolidated or it will be forgotten
- This phenomenon was discovered in the 1960s in the heyday of electroshock therapy
  - Electroshock administered in conjunction with a second foot shock 6 or 24 hours after an initial one eradicated the learning associated with the first shock
  - Similar effects produced by a protein synthesis inhibitor
- Also possible to enhance memory after recall with electrical stimulation of the mesencephalic reticular formation (same as effect if applied during learning episodes)
- Research on molecular mechanisms led to neglect of these findings but in the last decade they have again become the focus of research
  - Memories may be supprisingly labile after recall
- Mechanism of reconsolidation appears to be similar to that of consolidation, but to involve different brain regions--further expanding the network of brain regions involved in memory

The Scope of the Memory Consolidation Mechanism

- Much more is involved in memory consolidation than synthesis of new receptors in regions of the hippocampus
  - Network of neurons with different patterns of connectivity
  - Structures such as the amygdala, cortex, and whatever is required for reconsolidation
- Mechanistic research, which emphasizes recomposition of the mechanism, is geared towards finding these additional components whereas ruthless reduction is not

The Disciplinary Context of Neuroscience

- Bickle's claim about the dominant tendencies in neuroscience is correct--much of neuroscience is pursuing ruthless reduction
  - How did neuroscience come to have this
  - perspective?
- Schmitt's dream in the 1950s of *mental biophysics*: bring together pursuits such as solid-state physics, quantum chemistry, chemical physics, biochemistry, ultrastructure (electron microscopy and x-ray diffraction), molecular electronics, computer science, biomathematics, and literature research"
  - No role for classical neuroanatomy or neurophysiology, let alone psychology
- Subsequently, initiated the *Neurosciences Research Program,* which provided the basis for the Neurosciences Institute (now located on Torrey Pines mesa) and the Society for Neuroscience

DISCIPLINES REPRESENTED

Chemistry 1	Mathematics 1	Neubiology 1
Biochemistry 2	Physics 2	Neuro-anatomy . . 2
Neurochemistry . . . 1	Biophysics 3	Psychology 2
Physical Chemistry 5	Molecular Biology . . . 2	Psychiatry 1
Chemical Physics . 1	Electrophysiology . . . 1	Clinical Medicine . 1

Contrast Molecular and Systems-level Neuroscience

- The research on vision in the primate brain developed by recording from individual neurons,
  - The focus was not on the intracellular processes but on identifying the operations of different cells and identifying the pathways between cells that led to recognition of objects and coordination of action
- Recall Van Essen and Gallant: "These explorations involve mainly physiological and behavioral techniques that are quite different from the cellular and molecular techniques most familiar to this journal's readership. Nonetheless, we hope that a review of recent progress in understanding visual cortex will interest a broad spectrum of neuroscientists who share the ultimate objective of attaining a continuum of explanations of brain function, from the most molecular to the most cognitive levels

Behavioral Neuroscience

- An outgrowth of physiological psychology:
  - Traditionally, physiological psychology emphasized certain approaches and techniques, particularly lesions, electrical stimulation, and electrophysiological recording. Study of the biological bases of behavior is now much broader and includes genetic factors, hormonal influences, neurotransmitter and chemical factors, neuroanatomical substrates, effects of drugs, developmental processes, and environmental factors, in addition to more traditional approaches. All these variables act ultimately through the nervous system . . . The contemporary meaning of the term 'behavioral neuroscience' is almost as broad as 'behavior' itself. Behavioral neuroscience is the field concerned with the biological substrates of behavior. Judging by its current rate of development, behavioral neuroscience could well become a dominant field of science in the future (Thompson, 1983, p. 3).

Newcomer: Cognitive Neuroscience

- Early attempts to bring neuroscientists within the scope of cognitive science failed, but in the 1980s some researches in both psychology and neuroscience saw the potential for mutually profitable dialogue (coevolution)
- One of the Sloan Foundation's grants for Cognitive Science went to create a Cognitive Neuroscience Institute established by Michael Gazzaniga. He then
  - helped leverage a ten-year investment in cognitive neuroscience by the McDonnell Foundation and the Pew Charitable Trust
  - Established the *Journal of Cognitive Neuroscience*
 - Established the Cognitive Neuroscience Society

New Trend: Network Theorizing

- Neuroscience, like many other areas of biology, is increasingly recognizing that the systems they are dealing with involve networks of many components interacting with each other in a multitude of ways
- Turn to graph theory to represent the diverse parts/operations and the ways they impinge on each other.
- Two levels of analysis:
 - Sub-graphs
  - Global-network
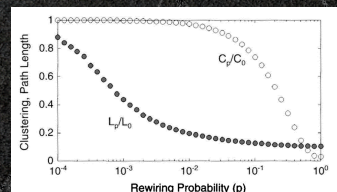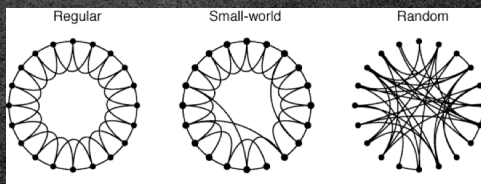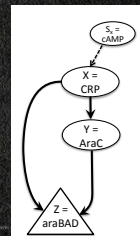
The Connectome Project

- In 2005 Sporns, Tononi, and Kotter advanced the proposal to identify the human connectome: graph representations of the structural connectivity in the human brain
- Multiple spatial scales from individual neurons to brain regions
- Macro-scale based on structural and diffusion tensor MRI
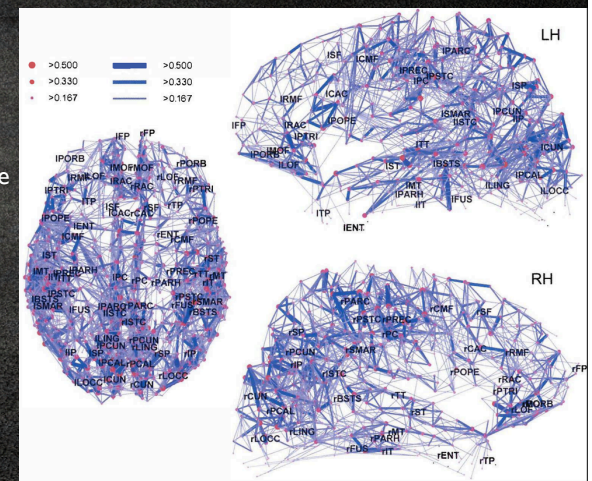
Default Mode Network

- In the 1990s Marc Raichle and his collaborators began to identify a number of brain regions in which blood-flow (BOLD signal) decreased in task conditions
  - Precuneus/posterior cingulate cortex, medial frontal cortex, lateral parietal cortex, etc.
- In the same decade researchers discovered very slow oscillations in the BOLD signal (< .1 Hz)
  - These were often synchronized across brain regions
- Raichle and his collaborators found that the regions less active in task conditions oscillated in synchrony with each other and out of phase with other areas
  - Named the Default Mode Network
  - Contrasted with other networks active in specific task conditions (attention, vision, etc.)

Fox et al, 2005
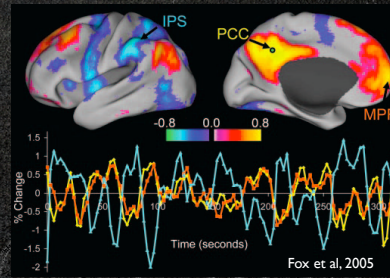
Relating Structural and Functional Maps

- The structural techniques being applied to create the human connectome and functional techniques used to identify the Default Mode Network and others both generate networks that can be analyzed in graph theory terms
- These maps are highly correlated, indicating that the structural networks may be the basis for functional processing in the brain
- Both techniques reveal small-world organization with hubs
- There is increasing evidence that such organization can facilitate sustained complex dynamical behavior
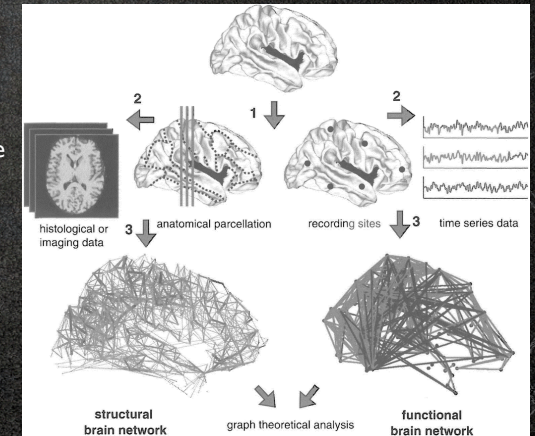
Rethinking Neural Processing

- Traditional view in research on biological mechanisms, including the brain--the mechanism was in the same default state until it was activated by a stimulus
  - All one needed to know was how it responded to a stimulus
- Emerging view--the mechanism is constantly engaged in dynamical behavior that is directed by processes internal to it
  - Stimuli perturb the ongoing dynamical behavior
  - But the ongoing dynamics affects how the mechanism will respond to stimuli
- Mechanistic reduction needs to be supplemented with dynamical analysis--dynamic mechanistic explanation

Fontanini and Katz