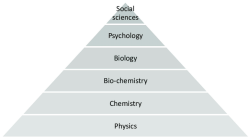
Explanation in Neuroscience 3 Levels and Reduction

Reductionism

- A commonly advanced criticism of the neurosciences is that it is reductionistic
  - It attempts to explain behavior and cognition in terms of chemistry and physics
- Thereby it treats people as *just collection*s of cellular, molecular, chemical, or physical processes
  - What humans do, what they think, etc., is all due to low-level material processes

What Are Levels?

- Sciences are often ordered by which is thought to be more basic (or more widely applicable)
- Objects in the world are often thought to be ordered
  - Size
  - Composition



What is Reduction?

- In general, reduction is the project of trying to account for something in terms of something more basic
  - Strong Version: To reduce one thing to another is to show that it just is that other thing
    - If you know the reducing thing, then you have fully accounted for (explained) the thing being reduced
  - Weaker Version: To reduce one thing to another is to show that its activities are partly explained by the other thing
    - Knowing the reducing thing contributes to explaining the reduced thing
    - And?
- Antireductionist arguments maintain that the project of reduction (in one or both varieties) is misguided

David Marr and Reduction

- David Marr viewed himself as resisting the strong pull of reductionism in neuroscience in the 1970s
  - Neuroscientists such as Hubel and Wiesel and their successors showed what individual neurons do
- His objection: knowing more about what the components of the brain do would not provide insight into how the brain works
  - That required
    - Understanding how the parts worked together to transform representations (algorithm)
    - Understanding what tasks the brain is performing with respect to its environment (computational theory)

Clicker Question

Which of the following is NOT one of Marr's three levels of analysis?

A. The computational level
B. The organism level
C. The representation and algorithm level
D. The implementation level

Marr's Three Levels of Analysis

Computational theory	Representation and algorithm	Hardware implementation
What is the goal of the computation, why is it appropriate, and what is the logic of the strategy by which it can be carried out?	How can this computational theory be implemented? In particular, what is the representation for the input and output, and what is the algorithm for the transformation?	How can the representation and algorithm be realized physically?

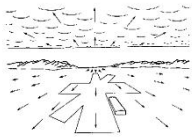
Figure 1–4. The three levels at which any machine carrying out an information-processing task must be understood.

Adopting the Computational Stance towards a Cash Register

- What sort of machine is a cash register?
- Why use addition to figure out what you owe when you check out of a grocery store?

Adopting the Computational Stance toward Vision

- If you are moving or are interacting with moving objects, it is critical to know
  - whether you and the object will make contact
  - how long until you make contact
- Ecological psychology (James Gibson) seeks to explain behavior in response to information available in the environment
  - Environments afford different actions to different organisms
  - Organisms just need to "pick up" this information
- Marr: Gibson got the computational level but failed to pursue the representation and algorithm level
  - think about Chemero



Need All Three Levels of Analysis

- Marr maintained that neuroscientists need to work at all three levels of analysis—one could not reduce one to the other
  - Computation: Neuroscientists needed to keep in focus what demands the environment posed for the information processing system
  - Representation and Algorithm: Neuroscientists need to develop an account of the procedures by which the information processing system performs operations on representations
  - Implementation: Neuroscientists need to figure out how neural processes implement these algorithms

Contrasting Meanings of Reduction

- *Reduction* generically refers to explaining a given phenomenon in terms of something more basic
- But the alternative senses of explanation offer a different view of reduction
  - On the received (D-N) view, laws are central to explanation
    - Laws are in turn explained by deriving them from more basic laws

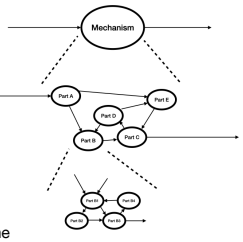
      Laws of reducing science (Neuroscience)

      Boundary Conditions

      ∴Laws of the reduced science (Psychology)
  - On the mechanistic picture, the operations of parts of a mechanism are explained by decomposing them into their own parts and operations
    - But at each level one must recompose the parts--understand how they are organized so as to work together
    - The lower-level parts are not privileged since we also need to understand the organization and context in which the mechanism functions,, which is not found at the lower-level

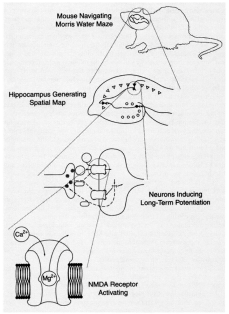
Mechanistic Explanation and Reduction

- The reductionistic part of mechanistic research is decomposing a mechanism—identifying its parts and determining what operations they perform
  - The 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 are organized 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 and so affect its functioning



Levels in the Explanation of Rodent Navigation

- The entities (parts) of a mechanism may themselves be mechanisms
  - One explains how they perform the activity (operation) in virtue of the parts and operations within them
  - Important to note that there is now a new explanatory goal—explain the operation within the previous mechanism
- Explanatory hierarchies bottom out in activities left unexplained
  - The question that motivated the inquiry can be answered without explaining these activities
  - Someone else, however, may find it worthwhile to explain them
  - Or some puzzles arise that require decomposing the lowest level mechanism yet further



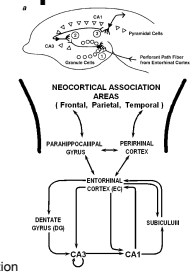
Discussion Question

Why would researchers find it valuable to recompose a mechanism?

A. Only if they can recompose a mechanism and show that it is productively continuous can they have confidence they have accounted for the phenomenon
B. If one can recompose a mechanism, then one is in position to build a system that produces the same phenomenon
C. From failures to recompose the mechanism successfully one may learn of many other parts through which one can productively intervene on the mechanism (or treat broken mechanisms)
D. From failures to recompose the mechanism successfully one can learn more about how organization determines what the whole system does

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 could generate cognitive maps
  - Moving 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 also 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
  - This situation may figure in the gradual training of cortex
    - McNaughton and collaborators have shown synchronous firing both 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 two decades they have again become the focus of research
  - Memories may be surprisingly 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

Clicker Question

What is Bickle's ruthless reduction alternative to the multiple bridge view?

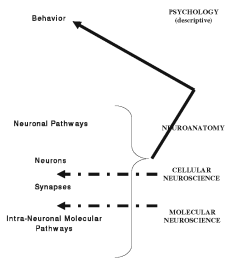
A. Intervene behaviorally and track at the cellular/molecular level
B. Intervene at the cellular/molecular level and track behaviorally
C. Defend the claim that the behavioral level is autonomous from the cellular/molecular level
D. Reduce theories at the behavioral level directly to theories at the cellular/behavioral level

Skipping the Intermediaries

- Bickle's ruthless reductionism cuts right through the intermediary levels to that of cell and molecular processes
- Strategy: Intervene at the molecular or cell level, detect effects at the behavioral level
  - "intervene causally at the level of cellular activity or molecular pathways within specific neurons (e.g., via genetically engineered mutant animals);
  - "then track the effects of these interventions under controlled experimental conditions using behavioral protocols well accepted within experimental psychology."
- "One only claims a successful explanation, a successful search for a cellular or molecular mechanism, or a successful reduction, of a psychological kind when one successfully intervenes at the lower level and then measures a statistically significant behavioral difference."

Skipping the Intermediaries

- "When this strategy is successful, the cellular or molecular events in specific neurons into which experimenters have intervened, ***in conjunction with the neuronal circuits in which the affected neurons are embedded***, leading ultimately to the neuromuscular junctions bridging nervous and muscle tissue, directly explain the behavioral data."



What Role for Higher Levels in the Brain?

- Servants of the cell and molecular level research. Useful to answer questions such as:
  - What are good experimental protocols for tracking behavioral outcomes for the psychological phenomenon we seek the cellular and molecular mechanisms of?
  - Where shall we begin making our cellular and molecular interventions? (The possibility space in both brains and intra-neuron molecular pathways is enormous!)
  - What kinds of neural activities seem to be involved? (Spiking frequency? Spiking pattern? Field potentials? Synaptic plasticity? This list only scratches the surface of possibilities, and each entry involves quite different molecular mechanisms.)
- These questions are (only) heuristic: they serve "the search for underlying cellular and ultimately molecular mechanisms."

Discussion Question

What motivates Bickle's contention that when one has successfully intervened at the cellular/molecular level and changed behavior, one has explained that behavior?

A. If manipulations at the molecular level succeed in altering behavior, they must have affected something causally relevant
B. Explanation should focus on the lowest level at which one can find causally relevant factors
C. Higher-levels don't identify factors that can independently alter the phenomenon—they do so only by altering cellular and molecular factors
D. Other

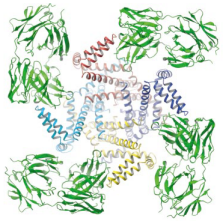
Clicker Question

What is the major point on which mechanistic reduction differs from ruthless reduction?

A. Mechanistic reduction rejects the value of investigations at the cellular/molecular level
B. Mechanistic reduction emphasizes the importance of identifying and reconstituting the full mechanism responsible for the phenomenon
C. Mechanistic reduction doesn't appeal to the behavioral level to track the effects of lower-level interventions
D. Mechanistic reduction does not focus on theories as the units to be reduced

How Far Down Should the Reductionist Go?

- Bickle's answer: As far down as researchers can intervene directly and produce changes in the phenomenon to be explained
- We are already in the early days of "intervene biophysically and track behaviorally"
  - Tools such as nuclear magnetic resonance imaging is making it possible to image the structure of proteins
  - Proteins have "active sites" at which they mind substrates and catalyze reactions
  - The overall structure of proteins is continuously changing, and this often affects the ability of molecules to bind to the active sites
  - In many areas of biology, one can identify structural changes that affect the phenomenon of interest



Voltage-dependent potassium ion (K^+) channel

Discussion Question

Is neuroscience reductionistic in a manner that is challenging to our understanding of who we are?

A. Yes
B. No
C. Uncertain