Human Brains and Human Life 1 What is Distinctive about Neocortex?

The Prominence of the Neocortex in Humans

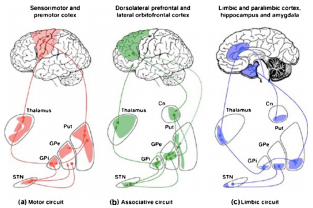
- The basic structure of the vertebrate brain appears to have been inherited from a common ancestor of today's vertebrates
  - In early vertebrates the pallium (from which the neocortex evolved) was very small
- The most striking change in the brain during primate and human evolution has been the vast expansion of the cerebral cortex
  - Suggesting that what it does is of major importance to those organisms in which it is most expanded (mammals, especially primates)

A Supplement, Not a Replacement

- Evolution tends to be very conservative
  - Solutions to problems are retained even as additions enable solutions to new problems
- Subcortical areas continue to regulate a host of behaviors
  - and can do so even in mammals in which the neocortex is disabled
- Regions in the neocortex are individually highly connected with regions elsewhere in the brain, especially via the thalamus
  - Cortical regions receive inputs from the thalamus and send outputs to it

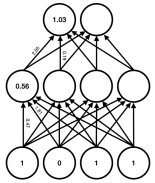
A (somewhat) radical suggestion

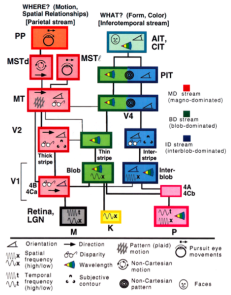
- The regions of the neocortex are specialized processing areas
  - The thalamus is the controller assigning jobs to different cortical areas
  - It is often coupled with the basal ganglia, which play a role in selecting what brain processes are permitted
- This suggestion is in the spirit of a way of viewing the genome
  - The genome is a library
  - The transcription factors acting on it control what information is accessed



The Neocortex: A System for Recognizing Patterns

- In Artificial neural networks (ANNs) nodes send activity to other nodes
  - connections are weighted
  - nodes respond by summing input and applying a non-linear function
- These networks are extremely powerful in recognizing patterns in inputs





The Power of ANNs

- With enough units at the intermediate layer, even a three layer network can categorize input patterns in any desired way
  - By training through an error correction process (e.g., back propagation) a network can learn to respond to training items
    - and generalize to additional cases
- Deep learning involves the incorporation of multiple layers of nodes between inputs and outputs
  - When trained on tasks comparable to human visual tasks, the networks allocate units in much like they are in our visual cortex
- ANNs can also be trained to drive motor activity, learning from feedback when its actions fail
- Supporting the idea that what the neocortex is a pattern processing system much like ANNs

Associationism vs. Structured Reasoning

- A tradition stemming back to the empiricists of the 17th century (Locke, Hume) holds that thinking involves the forming of associations between thoughts (concepts)
  - From seeing many dark clouds followed by rain, form an association "Dark clouds are likely to result in rain."
- The opposing rationalist tradition (Descartes, Leibniz) dismissed associationism as inadequate
  - Thought requires systematic relations between concepts
  - Thinking (reasoning) exploits such relations. What can you infer from

    IF er is een ijsstorm, THEN pennen bevatten inkt

    Er is een ijsstorm

    ∴ ??
  - Note: we can carry out logical inference without knowing what we are talking about
    - We can use words in a grammatically correct way even if we don't know what they mean

Symbolic AI vs ANNs: Is Pattern Recognition Enough?

- Early proposals for constructing computer programs that could think were developed in the rationalist tradition
  - Information was coded in structured representations (like those of logic)
  - The programs consisted of rules that were applied to to these representations
  - Generating new representations (e.g., solutions to problems) from those already encoded
- Artificial neural networks are associationist
  - Rationalist challenge: How can they hope to simulate reasoning?

Discussion Question

Consider an activity you are very good at performing (riding a bike, driving a manual transmission car). Can you convey your knowledge in a set of rules?

A. Sure. I learned it from someone else telling me the steps and I can do the same
B. Yes, but it is very hard. I may leave out steps, but when you fail, I will realize what I left out, and add those steps in
C. No. I can capture some of the basics in rules, but my knowledge, as manifest in what I do, goes far beyond what I can convey

Explicit Knowledge vs Procedural Knowledge

- We often identify what we know with what we are able to say
  - We test knowledge of a domain by knowledge of facts stated explicitly in language
  - We test reasoning by the ability to manipulate explicitly represented information
- But there are many domains in which we know how to do things without being able to produce explicit representations
  - Conscious thinking about what we are doing often impairs performance
  - On basic logic exams I tell students they shouldn't think during the exam
    - What does that say about logic?

Discussion Question

When Aristotle, Boole, and others created systems of logic, they often presented themselves as articulating the rules of thought. How do logical inference rules relate to thinking

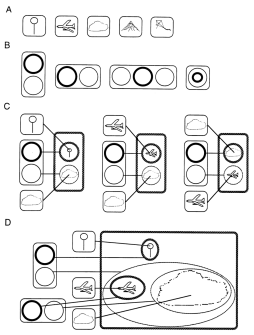
A. They describe how humans typically reason
B. They are normative principles that specify how humans ought to reason
C. They don't apply to thought directly, but to our ability to use language in activities such as law and science
D. Other

An ANN Gambit

- Strategy: train an ANN to work with external symbols that are structured and conform to that structure
  - Such a system will generalize beyond the examples on which it is trained
    - it may do so in a way that is mostly correct, but also makes errors
- Do these errors show that ANNs just aren't the right tools for modeling human performance?
  - Do speakers of a language make "mistakes"?
  - Do "experts" make inference mistakes?
- Challenge from the rationalist: if we don't use structured representations in our thought, how did we ever construct systems like languages that do?

Can One Generate Systematic and Abstract Thinking from Visual Experience?

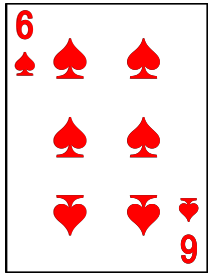
- Barsalou has proposed that our concepts are grounded in our visual experience
  - Areas later in the visual stream identify abstract patterns that leave out differentiating detail
  - Some areas represent object identity, others spatial relations
  - These can be jointly triggered by complex experiences
    - balloon is above the cloud
    - airplane is beneath the cloud
- When we imagine things, we activate the same regions of the visual system as are activated with visual experiences
  - Barsalou proposes that our thinking involves reactivation of the same areas involved in sensory experience, but now under our control, not the sensory world



Differences Between ANNs and the Neocortex

- ANNs are reactive systems
  - they respond to inputs that are presented to them
  - but do nothing if nothing if they don't receive an input
- Multiple ways of studying activity in the brain (single cell recording, EEG, resting state fMRI) all point to ongoing activity in the brain/neocortex when no task is presented
  - this activity is not random, but structured in various ways

Tell me what you see



Top-Down Influences on Perception

- Ongoing activity in the brain affects how individual stimuli are perceived: top down influences
- What do you see?

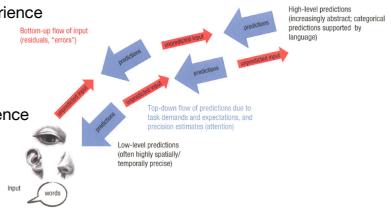
Richard Gregory's Chaplin Head Illusion

A radical idea

- Much of our thinking about the brain views it as responsive to stimuli
  - but remember the skin brain hypothesis
    - activity is ongoing in the brain, generating rhythmic behavior
- A radical idea: maybe brain activity in general doesn't start with stimuli but occurs endogenously
  - Organisms act even without inputs (activity is the default state)
  - Sensory inputs modulate ongoing brain activity

Predictive Coding

- Friston, Clark, and others propose that the brain is primarily engaged in prediction
- If nothing conflicts with our predictions, we see what we expect to see
- Only when experience conflicts with predictions do we process the input
- What we experience most of the time is our self-generated illusion



Lupyan and Clark, 2015

Where Do Predictions Come From?

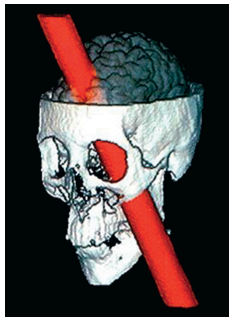
- The predictive coding framework suggests that there is a central predicative intelligence that drives all subsequent reasoning.
- A widely adopted view is that regions in the front of the brain—the prefrontal cortex—play an executive function directing activity elsewhere
  - Locus of working memory: the ability to keep a small number of items in memory so as to use them in directing responses
  - Director of attention: enable some information processed elsewhere to be accessed and other information ignored

Prefrontal Cortex and Cognitive Control

- Cognitive Control: "the ability of our thoughts and actions to rise above mere reactions to the immediate environment and be proactive: to anticipate possible futures and coordinate and direct thought and action to them. It is a hallmark of intelligent behavior. " (Miller and Wallis, 2013)
- A central executive is thought to be lodged in the prefrontal cortex
  - The area of the brain that is most expanded in primates, and even more so in humans
  - An area that has connections to most other regions of the neocortex and to many subcortical areas
    - Subregions within the prefrontal cortex are themselves highly interconnected

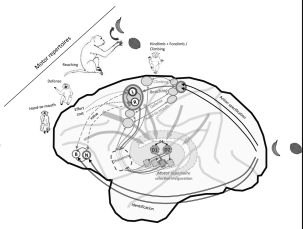
Phineas Gage: “Gage is no longer Gage”

- In an accident during railroad construction an iron bar projected through prefrontal areas of Gage's brain
  - He seemed to recover
  - But was a changed person
    - Previously a responsible foreman, he became irresponsible and vulgar
    - He no longer could manage his affairs
- Supporting the hypothesis that prefrontal areas act as the central executive regulating the rest of the brain and, thereby, our bodies



Distributed Decision Making

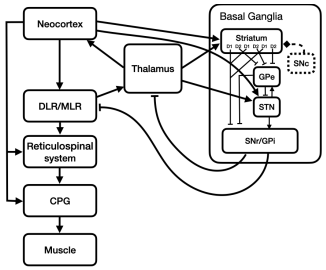
- Cisek and Thur propose an alternative—areas involved in different actions are all involved in decisions to perform actions
  - They engage in a competition
  - The first to recruit other areas ends up directing activity
- The multiple neural activities that figure in action (sensory processing, affective processing, etc.) interact in decisions about behavior



Cisek and Thur, 2018

The Role of the Basal Ganglia in Regulating Other Brain Areas

- The basal ganglia, a collection of ganglia in the mid and forebrain, are connected in loops with other parts of the brain, including the neocortex
- The way the nuclei are organized suggests they facilitate competitions
  - and that they play a role in selecting which other brain areas are allowed to act and which are shut down



What Does the Prefrontal Cortex Do?

- Even if it is not the central executive, it may play a distinctive role in human cognition and behavior
  - Extract from other cortical areas more abstract patterns and abstract representations of actions
  - Enabling abstract reasoning
    - science
    - law
    - philosophy
- Prefrontal areas do not do so independently of the rest of the brain
  - but through coupling with more basic sensory, motor, and affective processes
    - when we engage in abstract reasoning
      - we are still prone to draw, gesture, etc.
      - use metaphors and analogies that connect to more concrete phenomena

Puzzles

- The view of the prefrontal cortex as the central executive offers a neuroscientific account of who we are
- If the prefrontal cortex is not the central executive, where is it to be found?
- Could it be that there is no central executive—no one in charge?
- Who, then, am I?