Computational cognitive neuroscience: 6. Brain Areas

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Brain areas

• Terminology for referring to different parts of the brain -- for everything except lateral and medial, three different terms for the same spatial reference are given.
Gross anatomy of the brain

- Left panel shows the major lobes of the outer **neocortex** layer of the brain, and right panel shows some of the major brain areas internal to the neocortex (i.e. **subcortical** areas).
Two hemispheres: all structures come in pairs

- The vertebrate cerebrum (brain) is formed by two cerebral hemispheres that are separated by a groove, the medial longitudinal fissure.
- The brain can thus be described as being divided into left and right cerebral hemispheres.
- Macroscopically the hemispheres are roughly mirror images of each other, with some subtle differences such as the **Yakovlevian torque** seen in the human brain, which is a slight warping of the right side, bringing it just forward of the left side.
White matter: the pathways of communication

3 types:

- **Projection tracts** that extend vertically between higher and lower brain areas and the spinal cord, and carry information between the brain and the rest of the body.

- **Commissural tracts** cross from one cerebral hemisphere to the other through bridges called commissures – corpus callosum, + anterior and posterior commissures.

- **Association tracts** that connect different regions within the same hemisphere of the brain.
Subcortical areas

- **Hippocampus**: "ancient" form of cortex called "archicortex“, crucial for storing new episodic memories;
- **Amygdala**: recognizes emotionally important stimuli, and alerts the rest of the brain about them;
- **Cerebellum**: important role in motor coordination, and learning / remembering motor skills
- **Thalamus**: primary pathway for sensory information on its way to the neocortex;
- **Basal Ganglia**: critical role in motor control and executive functions.
Cortical areas: Brodmann’s areas

- Gross division of the cerebral cortex.

- Korbinian Brodmann (17.11.1868 – 22.08.1918), a German neurologist defined the cerebral cortex into 52 distinct regions based on their cytoarchitectonic characteristics, known as Brodmann areas.

- His nomenclature is still used today.
Cortical areas: Brodmann’s numbering system

- Brodmann's numbering system for the different areas of the neocortex, based on anatomical distinctions such as the thickness of different cortical layers. These anatomical distinctions are remarkably well correlated with the functional differences in what different brain areas do (see the Networks Chapter and slides).
The occipital lobe: VISION

- Occipital lobe contains the primary visual cortex (V1) (Brodmann's area 17), located at the very back tip of the neocortex, and higher-level visual areas that radiate out (towards the more frontal areas) from it. This is the main lobe in visual processing.
The temporal lobe: AUDITION

- Contains the primary auditory cortex (A1), and associated higher-level auditory and language-processing areas.
- In addition, visual appearance of objects gets translated into verbal labels (and vice-versa), and also where we learn to read.
- The most anterior region of the temporal lobes appears to be important for semantic knowledge.
The parietal lobe: SPACE

- Contains the primary somatosensory cortex (S1), which processes somatosensory input and guides the motor actions as well.
- In some parts of parietal cortex, neurons translate between different frames of reference, for example converting spatial locations of the body (from somatosensation) to visual and other sensory coordinates.
The frontal lobe: ACTION

- Contains the primary and higher-level motor areas including the planning areas for the output actions, integrates information from sensory areas as well as the emotional areas, etc. Provides motivation, goal planning, associations, abstract thoughts, etc.
• Language is the ability to acquire and use complex systems of communication (Wikipedia).
• Human language has the properties of productivity, recursivity, and displacement (we can talk about things that are now not here).
• Wittgenstein argued that philosophy is really the study of language.
Left and right hemispheres do different things

- Prefrontal cortex
- Speech center
- Writing
- Auditory cortex (right ear)
- General interpretive center (language and mathematical calculation)
- Visual cortex (right visual field)
- Prefrontal cortex
- Anterior commissure
- Analysis by touch
- Auditory cortex (left ear)
- Spatial visualization and analysis
- Visual cortex (left visual field)

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Left hemisphere

- Frontal Lobe (action)
  - Premotor
    - Sequential thinking
    - Takes ideas, actions and words, and puts them into linear sequence
  - Motor
    - Controls muscles on right side
    - Imagination, Creativity, "Yes"
    - Inhibitions, "No"
    - What NOT to SAY, Worrying (talking to yourself about what not to do)
  - Emotional memory
    - Language memory, stories
    - Face Names
    - Memory

- Parietal Lobe (spatial)
  - Body Senses
    - On right side
    - Right Hand
    - Symbols
      - Match body to "left" "right" words
      - Math symbols: +, -, =, x²
  - Grammar
    - Spatial arrangement of language
  - Spelling Phonics Reading
    - Phonemes
    - Word sounds
    - Vision of Alphabet
      - Recognizing letters and groups (ch, th, ng)
      - Letter shapes (b, p, q)
      - Lines, Angles (l, v)
  - Matching vision of letters with sounds of words
  - Matching vision

- Occipital Lobe (vision)
  - Muscle Coordination
    - Speed of Repetitive action
  - Balance
  - Cerebellum

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Right hemisphere

- Parietal Lobe (spatial)
  - Spatial Sense
    - Mental Math
    - Body 3D awareness
    - Touch 3D recognition
    - Object 3D rotation
    - Construction
    - Navigation

- Frontal Lobe (action)
  - Body Senses on Left side
    - Fingers
  - Motor controls muscles on LEFT side
  - Imagination, Creativity, "Yes"
    - Create new patterns of behavior, art, music, actions, designs, etc.
    - Impulsive Action
  - Inhibitions, "No"
    - What Not to do
    - Right/wrong behavior
    - Manners
    - Conscience

- Occipital Lobe (vision)
  - Vision
    - I (from eye)
      - Lines
      - Angles
    - II (from ear)
      - Distance
      - Motion
      - Shape
    - III (from ear)
      - Object Recognition
      - Intervals
      - Pitch
  - Music
    - Harmony (spatial)
  - Music memory
  - Visual memory
  - Memory
  - Face memory

- Temporal Lobe (memory)
  - Right Brain

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The brain has more in store

- There are more than 50 neurotransmitters (NT) in the brain

- Glutamate is the major excitatory NT and GABA is the major inhibitory NT

- In addition, there are 3 major “neuromodulatory” NTs

- Norepinephrine (= noradrenalin), serotonin and dopamine
Dopamine (DA)

- The brain includes several distinct DA pathways, one of which plays a major role in reward-motivated behavior.
- Most types of reward increase the level of dopamine in the brain, and most addictive drugs increase dopamine neuronal activity.
- Other brain dopamine pathways are involved in motor control and in controlling the release of various hormones.
- These pathways and cell groups form a dopamine system, which is called a DA neuromodulatory system.
Serotonin - 5-hydroxytryptamine (5-HT)

- It is popularly thought to be a contributor to feelings of well-being and happiness.
- In general, it mediates gut movements and the animal's perceptions of resource availability.
- In more complex animals, resources also can mean social dominance.
- In response to the perceived abundance or scarcity of resources, mood may be elevated or lowered. This may somewhat depend on how much serotonin the organism has at its disposal.
Noradrenaline (NA) / Norepinephrine (NE)

- The general function of NA is to mobilize the brain and body for action.
- In the brain, NA increases arousal and alertness, promotes vigilance, enhances formation and retrieval of memory, and focuses attention; it also increases restlessness and anxiety.
- The noradrenergic neurons in the brain form a system, that, when activated, exerts effects on large areas of the brain. The effects are manifested in alertness, arousal, and readiness for action.
The major roles of neuromodulators

- Norepinephrine (NA): alertness, concentration and (mental) energy;
- 5-HT (serotonin): compulsive behaviour, irritability, aggression;
- Dopamine (DA): pleasure, reward, motivation;
- These 3 major neuromodulators contribute to the mood and hence to the cognitive functioning of the brain.
Acetylcholine (ACh): another neuromodulator

- ACh is the neurotransmitter used at the neuromuscular junction—i.e. the motor neurons in the spinal chord release Ach in order to activate muscles.

- In the cortex, ACh mediates increased responsiveness to sensory stimuli.

- Another function of ACh in the cortex is to modulate learning and plasticity in the cortex.
Comparing and contrasting major areas

• The evolutionarily older areas like the basal ganglia, cerebellum, and hippocampus, employ a separating form of activation dynamics, meaning that they tend to make even somewhat similar inputs map onto more separated patterns of neural activity – i.e. the major way of dynamics is separation.

• The neocortex represents an important innovation. In terms of activation dynamics, it builds upon the attractor dynamics. This means a strong ability to develop representations that integrate across experiences to extract generalities, instead of always keeping everything separate all the time.

• The cost for this integration ability is that the system can now form the wrong kinds of generalizations, which might lead to bad overall behaviour. But the advantages apparently outweigh the risks, by giving the system a strong ability to apply previous learning to novel situations.
Learning rules across the “plastic” areas of the brain

<table>
<thead>
<tr>
<th>Area</th>
<th>Learning Signal</th>
<th>Dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reward</td>
<td>Error</td>
</tr>
<tr>
<td>Basal Ganglia</td>
<td>+++</td>
<td>---</td>
</tr>
<tr>
<td>Cerebellum</td>
<td>---</td>
<td>+++</td>
</tr>
<tr>
<td>Hippocampus</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Neocortex</td>
<td>++</td>
<td>+++</td>
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</tbody>
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- Comparison of learning mechanisms and activity/representational dynamics across four primary areas of the brain. +++ means that the area definitely has given property, with fewer +'s indicating less confidence in and/or importance of this feature. --- means that the area definitely does not have the given property, again with fewer -'s indicating lower confidence or importance.
Development of the brain

- 4 weeks, 5 weeks and 3 months
Neurogenesis

- First, the neurons have to assume their position, then they can form connections. Position of neurons as well as their connectivity is determined genetically during early development.
Development of brain synaptic connectivity

- Peter Huttenlocher discovered that synapses are created in the first few months of a child's development (i.e. after about 28 weeks = 6 months of gestation), and then "pruned", by examining the brains of about 50 people, mostly infants and young children who had died unexpectedly, but also a few adults, one of them age 90.
Development of synaptic connectivity in the brain

The Aging Brain

A normal human brain may shrink up to 15% over a lifetime.

Note: Chimpanzee brains are roughly one-third the size of human brains. Source: George Washington University, Proceedings of the National Academy of Sciences.
Summary: “division of labour in the brain”