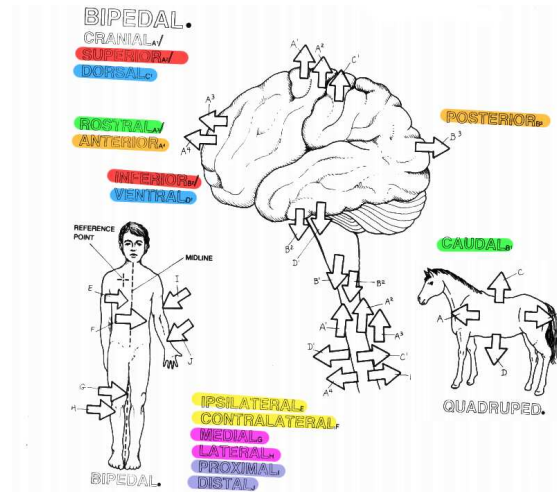


## Overview

- Basic neuroscience terminology
- A Roadmap to the course

## Words Describing Spatial Orientation

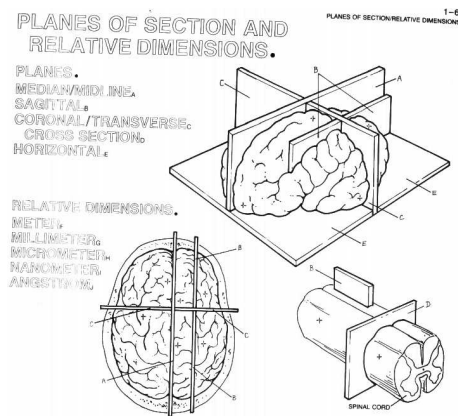


- Rostral/Caudal
- Anterior/Posterior
- Dorsal/Ventral
- Superior/Inferior
- Lateral/Medial
- Proximal/Distal

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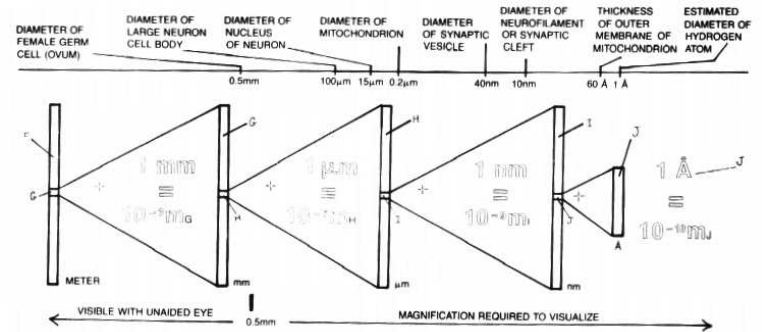
## Words Describing Sectional Planes



- Coronal, Horizontal, Sagittal, Median

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## Measurement Units



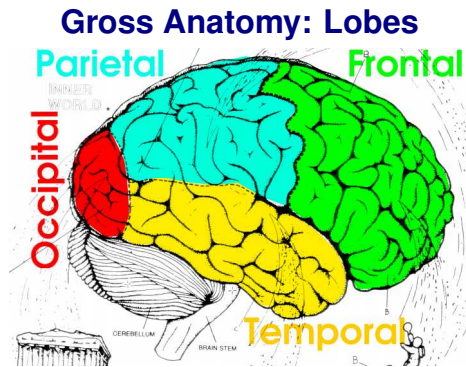
- 1 m
- 1 mm = 10<sup>-3</sup> m
- 1 μm = 10<sup>-6</sup> m
- 1 nm = 10<sup>-9</sup> m (visible light: about 400 nm ~ 700 nm)
- 1 Å = 10<sup>-10</sup> m

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## Sensory Modalities

- Visual: shape, color, spatial frequency, movement, etc.
- Auditory: pitch, intensity
- **Somatosensory**: bodily sensation
  - **Kinesthetic**: sense of bodily movement
  - **Proprioceptive**: sense of bodily configuration in space (stretch of and load on muscle fibers)
  - Tactile: sense of touch
  - **Vestibular**: sense of bodily balance
  - **Nociceptive**: pain
  - Sense of temperature
- Gustatory: taste (chemical)
- Olfactory: smell (chemical)

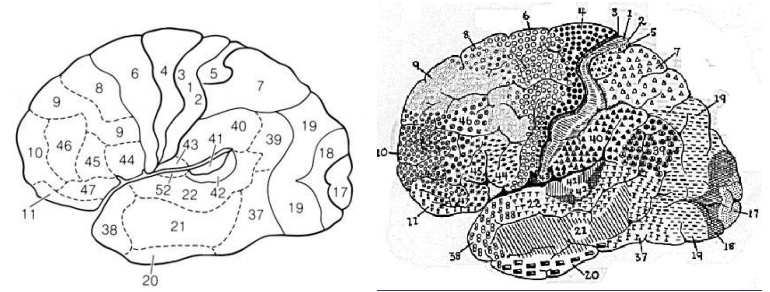
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- Frontal: higher cognition, motor function
- **Parietal** (par-éye-er-tal): association, somatosensory (bodily sense)
- **Occipital** (ox-ée-pee-tal): low-level visual function
- Temporal: auditory function, high-level vision

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## Gross Anatomy: Cytoarchitectonics

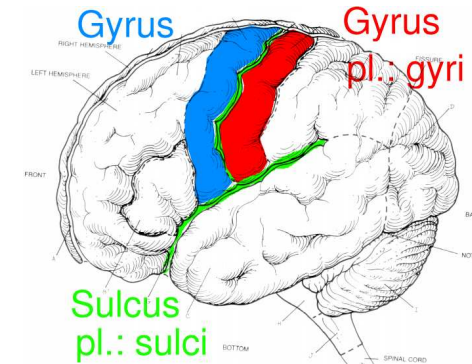


- Brodmann (1909) mapped out the cortex based on distribution of cell types and other histological differences.
- Amazingly, these areas did show distinct functionality!
- So, the numbers got stuck and is still in use: V1 is area 17, for example.

Figure source: <http://psychlops.psy.uconn.edu/Jlab/Resources/Anatomy/grossanat2.html>  
<http://www.radiology.wisc.edu/Med.Students/neuroradiology/fmri/>

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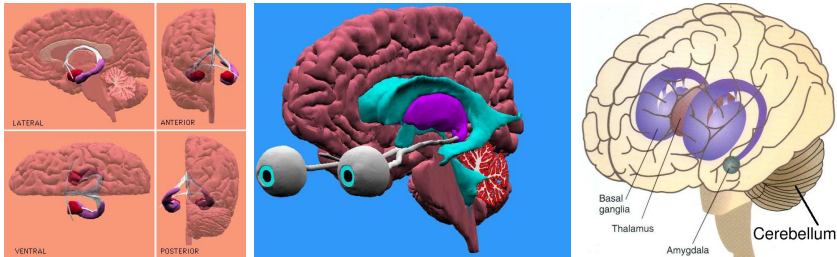
## Gross Anatomy: Main Features



- Gyrus (pl.: gyri): hills
  - Somatosensory cortex (S1: shown in red)
  - Primary motor cortex (M1: shown in blue)
- Sulcus (pl.: sulci (sulk-eye)): grooves. (syn.: fissure)
  - Central sulcus (green; vertical): separates S1 and M1.
  - Lateral fissure (green; diagonal): separates frontal-parietal with temporal lobe.

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## Major Nuclei



Left: hippocampus (purple), amygdala (red); Middle: thalamus (purple)

- Thalamus, Hippocampus, Basal Ganglia (Caudate, Putamen), Amygdala, Olfactory Bulb, Cerebellum
- Midbrain, Pons, Medulla, Hypothalamus
- Tectum (Superior/Inferior Colliculus)

Figures are from <http://mail.biocfarm.unibo.it/aunsnc/Default.htm> and <http://general.rau.ac.za/psych/Resources/Honours/Neuropsych/Downloads/downloadstr/Lect2-opt/basalganglia.jpg>

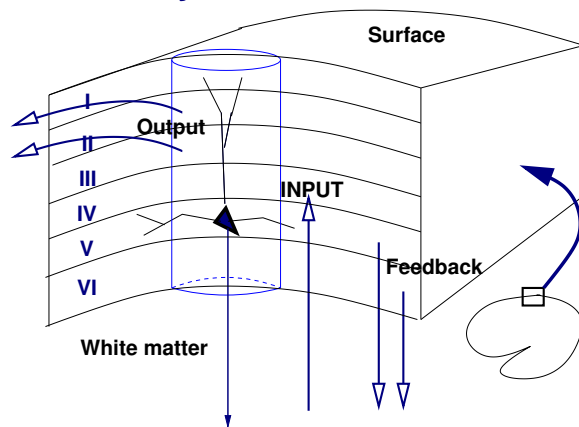
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## Function of Subcortical Nuclei

- Hippocampus: Episodic and navigational memory
- Basal Ganglia: motor initiation
- Amygdala: emotion
- Cerebellum: motor coordination/learning

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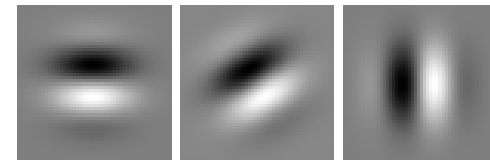
## Layers in the Cortex



- The cortex consists of 6 distinct layers (different cell types).
- Cells in a vertical column have similar response properties, and they form a functional unit (or a module).

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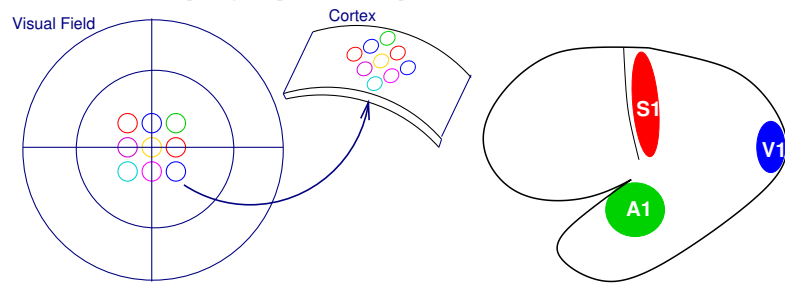
## Receptive Fields of Neurons



- Neurons in the cortex show *graded* response to specific stimulus.
- For example, visual cortex neurons show vigorous response when stimulated with inputs such as the above.
- The receptive fields are *limited in size* and are *spatially localized*, i.e., neurons respond to inputs only in a small patch of the entire field of view (the *visual field*).
- Similar stimulus specificity applies to other sensory modalities. For example, auditory cells respond to specific frequency in sound wave form.

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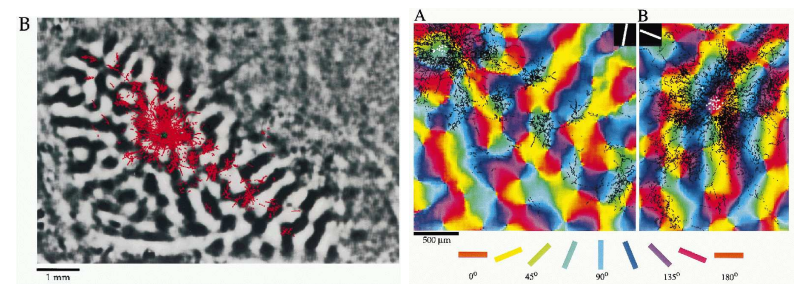
## Topographic Maps in the Cortex



- In many sensory areas, nearby location in the stimulus space are mapped to nearby neurons in the cortex.
- Thus, it is like a map of the sensory space, thus the term *topographic organization*.
- The primary visual cortex and the somatosensory cortex are arranged in such a way. The maps are sometimes distorted.

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## Maps of Complex Sensory Features

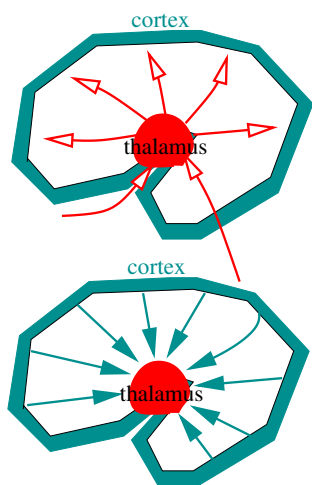


Bosking et al. *J. of Neurosci.* (1997)

- An orderly map of oriented features in tree shrew V1 is shown.
- Dark bands are highly responding areas to a particular orientation angle.
- Orientation response is measured one at a time, and the results are overlaid in color.
- Other maps: ocular dominance, spatial frequency, direction of motion, etc.

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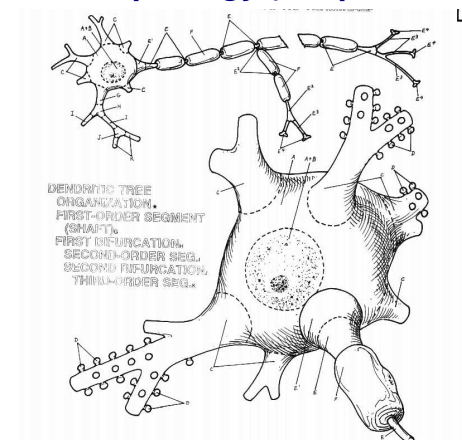
## More Than Just the Cortex: The Thalamus



- All sensory input except for olfactory data are *relayed* through the thalamus to reach the cortex.
- There is a *massive feedback* from cortex to thalamus, sometimes reaching up to 10 times more feedback than feedforward fibers.
- The thalamus is surrounded by a thin layer of inhibitory neurons called the *Thalamic Reticular Nucleus* (TRN or nRt).

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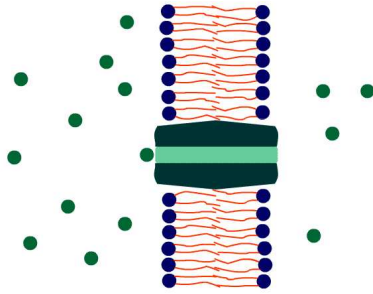
## Neuron Morphology (Shape, Structure)



- Dendrite, Axon, Synapse, Soma, Axon hillock
- Dendritic spine, Axon terminal (bouton)
- Myelin, Node of Ranvier

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## Movement of Ions in the Neuron



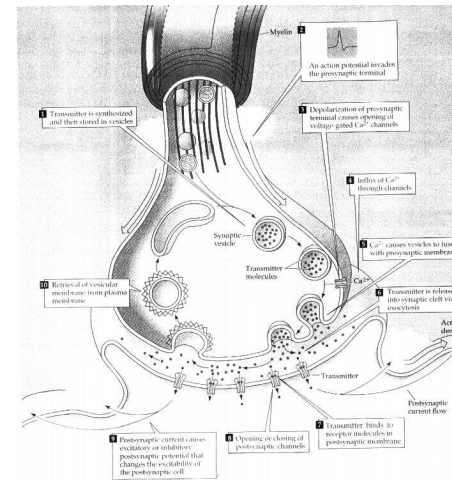
- Ion concentration: intracellular (high  $K^+$ ), extracellular (high  $Na^+$ ,  $Ca^{2+}$ ), etc.
- Ions move from high area to low-concentration area.
- Ion channels either allow or block the passage of ions: voltage-gated, ligand-gated, etc.
- $Na^+ - K^+$  pump maintains ion concentration.
- Ion channels: voltage-gated, ligand-gated (ionotropic), etc.

## Other Neurotransmitters

- Acetylcholine - voluntary movement of the muscles
- Norepinephrine - wakefulness or arousal
- Dopamine - voluntary movement and emotional arousal
- Serotonin - memory, emotions, wakefulness, sleep and temperature regulation
- Glycine - spinal reflexes and motor behaviour
- Neuromodulators - sensory transmission-especially pain

Source: <http://en.wikipedia.org/wiki/Neurotransmitter>.

## Electrical Signaling in Neurons

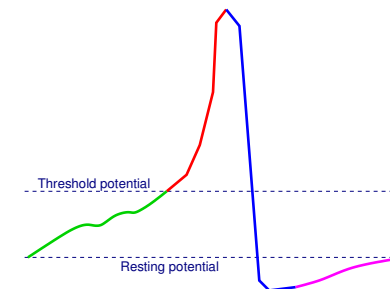


From Purves et al. (1997)

- Action potential: the propagation of abrupt increase in voltage (or, the cell spikes or fires)
- Postsynaptic potential (or PSP): change in voltage due to transmitter binding at postsynaptic membrane; can be either *excitatory* (EPSP; additive,  $Na^+$  efflux) or *inhibitory* (IPSP; subtractive,  $Cl^-$  influx).
- Neurotransmitters:
  - GABA:  $\gamma$ -amino butyric acid, a major *inhibitory* neurotransmitter (others include Glycine)
  - Glutamate: a major *excitatory* neurotransmitter (AMPA, NMDA)

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## Action Potential



- Threshold voltage reached (green).
- Voltage-gated  $Na^+$  channels open: Rapid increase in membrane voltage (red: called **depolarization**).
- High voltage triggers voltage-gated  $K^+$  channels to open: Abrupt decrease in membrane voltage (blue: called **hyperpolarization**).
- Recovery to resting potential (purple).

## Other Common Terms

- Connections: Afferent (incoming, sensory), Efferent (outgoing, motor), Lateral/Horizontal (to the side, tangential to the cortex), Corpus Callosum (connects two hemispheres)
- Developmental division of brain structures:
  - Prosencephalon (forebrain): telencephalon (cortex, basal ganglia, hippocampus, olfactory bulb, basal forebrain), diencephalon (thalamus, hypothalamus)
  - Mesencephalon (midbrain): Midbrain, superior and inferior colliculus
  - Rhombencephalon (hindbrain): metencephalon (cerebellum, pons), myelencephalon (medulla)

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## Framework for Brain Function

Computational approach:

- Manipulation or processing of:
  - Representations
  - Symbols
  - Information
  - Data
  - Neural codes

Strongly influenced by the highly successful *computational revolution*, which gave birth to the fields of Cognitive Science and AI in the 50's.

**Issue:** *Computation* is an ill-defined term. What is computation? Anything a Turing machine can implement? What about falling rocks? Are they computing the gravitational constant? What about thermostats?

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## Computation in the Brain

What is at the core of brain function?

- Rational thinking?: Logic
- Optimal decision?: Optimization
- Maximally efficient?: Information theory
- Good guesswork?: Probability/Statistics

All of these tend to emphasize *optimality* of behavior. But if something is optimal, for a given problem there can be only one solution – the optimal solution. However, if that is the case, where is the freedom of choice in human action, and how can creativity be accounted for?

Because we are not optimal and are limited, we have what we call intelligence (c.f. bounded rationality of Herbert Simon).

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## How Does the Brain Compute

- That is the main question to be addressed in this course.
- How do we approach this problem?
  - Survey the current state of the art in computational approaches and in neuroscience.
  - Survey minor opinions on the subject.
  - Derive an integrative perspective: make connections, see how things relate, and find the missing link.

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## A Roadmap to the Course

There are five major components to this course:

- **The Input:** How does the input distributions and cooccurrence in sensory signals shape the brain and mind?
- **Structure and Function:** How does the orderly structure arise in the brain and how is it related to the function of the brain? How is it shaped by the input?
- **The output:** How does the motor system influence our understanding of the brain function?
- **The Principles:** What are the principles governing neural function that give rise to intelligent and complex behavior? What are the principles of interaction among the above two?
- **Time:** Role of time in the brain.