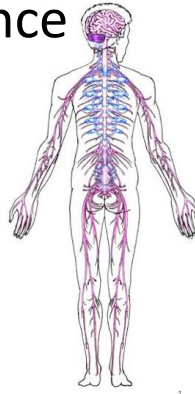# CISC 3250
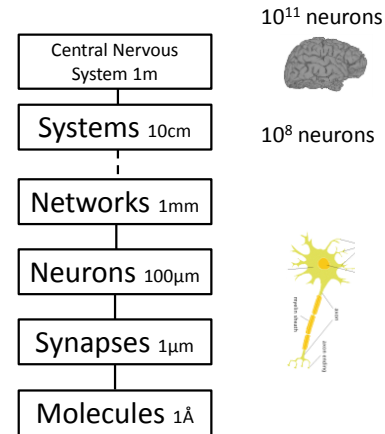# Systems Neuroscience

Neural systems and neuroanatomy

Professor Daniel Leeds
dleeds@fordham.edu
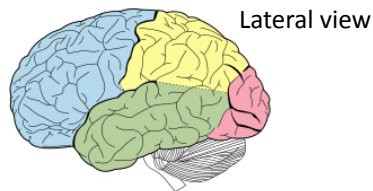JMH 332

1

Levels of organization
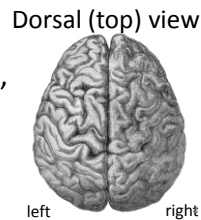
10^{11} neurons

Central Nervous System 1m

Systems 10cm 10^8 neurons

Networks 1mm

Neurons 100µm

Synapses 1µm

Molecules 1Å

2

Cerebral cortex broad divisions

- Four lobes
  - Frontal ▢
  - Parietal ▢
  - Temporal ▢
  - Occipital ▮

Lateral view
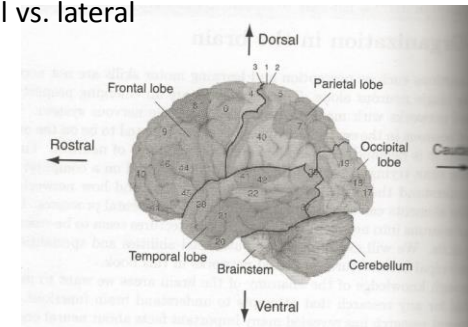
Dorsal (top) view

- Two hemispheres: left and right, linked by corpus callosum
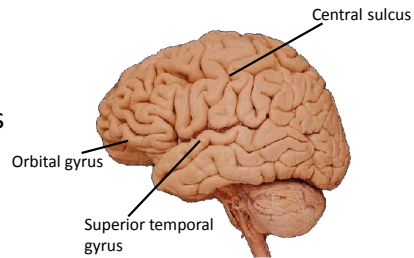
left   right

Navigating the cerebral cortex

- Dorsal/superior (top) vs. ventral/inferior (bottom)
- Anterior/rostral (front) vs. posterior/caudal (back)
- Medial vs. lateral

Dorsal
Frontal lobe
Parietal lobe
Rostral
Occipital lobe
Caudal
Temporal lobe
Brainstem
Cerebellum
Ventral

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Dividing the cerebral cortex surface

- Sulci – folds

- Gyri – bulges

Central sulcus

Orbital gyrus

Superior temporal gyrus
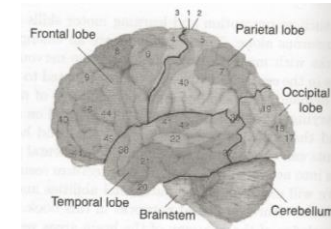
6

Functional divisions

- Frontal
  - Future planning, personality, <u>judgment</u>, social <u>behavior</u>
  - <u>Motor</u> cortex
- Temporal
  - <u>Auditory</u> cortex
  - <u>High-level vision</u>
- Parietal
  - <u>Spatial vision</u>
  - <u>Primary sensory cortex</u>
  - Visual-auditory-spatial <u>sensory integration</u>
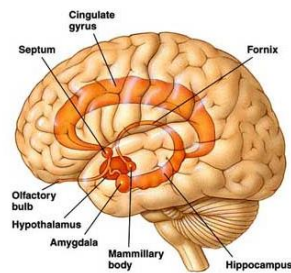- Occipital
  - <u>Primary visual cortex</u>

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Limbic system – memory/emotion

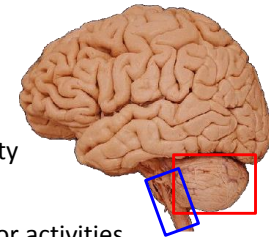Medial area of cerebral cortex

- Hippocampus: memory

- Amygdala: emotion

- Cingulate and parahippocampal gyri

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The brain beyond the neocortex

- Brain Stem
  - <u>Conduit</u> for spinal cord and cranial nerves
  - <u>Respiratory and cardiac</u> activity
- Cerebellum
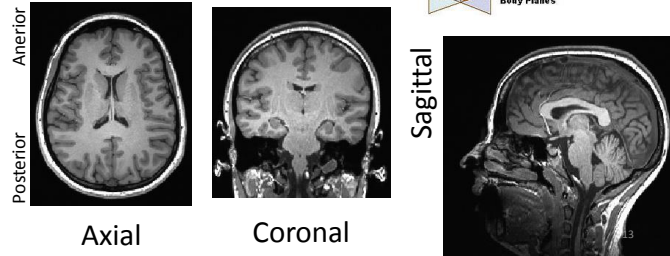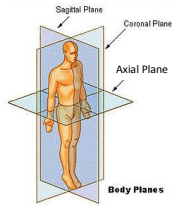 - Plan, coordinate, modify <u>motor</u> activities

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Two dimensional slices of the brain

- Axial (parallel with ground)
- Coronal (halo)
- Sagittal (in profile)

Anterior

Posterior

Axial

Coronal

Sagittal

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Grey and white matter

- Grey matter – soma, performs "computations"

- White matter (60% of brain) – axons, transmits information

- Tractography finds links between brain regions

Grey matter

White matter

Anerior

Posterior

Axial

Corpus callosum
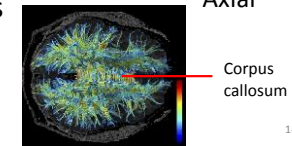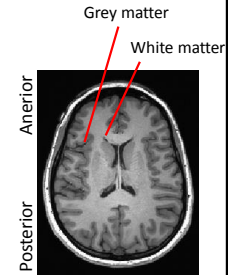
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Cortical processing networks

Perception "hierarchy"

- *Primary sensory areas* capture basic sensory properties, or "features"
- More complex representations in higher sensory areas
- Example: Vision
  – Primary visual cortex in occipital pole
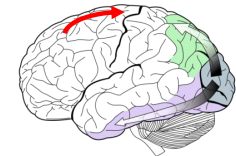 – Anterior flow of information in ventral ("what") and dorsal ("where") pathways
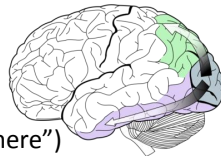
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Cortical processing networks

Action

- Motor planning and performance is achieved in stages within the frontal lobe
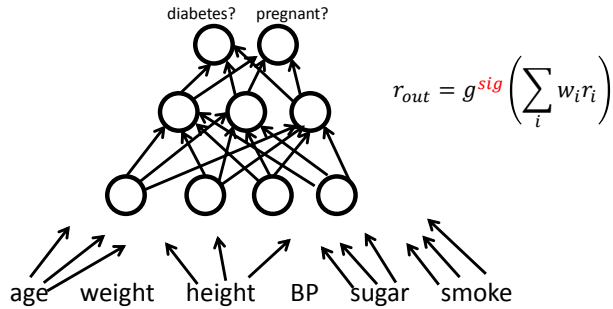- Motor correction is supervised by the cerebellum

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"Deep" learning

Multiple layers of computation in artificial intelligence

diabetes?   pregnant?

$$r_{out} = g^{sig}\left(\sum_i w_i r_i\right)$$

age   weight   height   BP   sugar   smoke

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Deep factor graphs

living

Not-breathing

animal   plant   vehicle
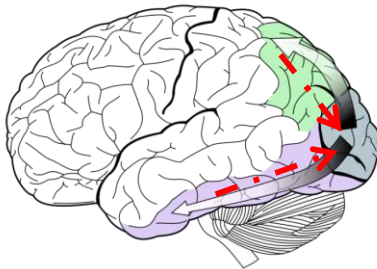
dog   cow   tree   pear   car   plane
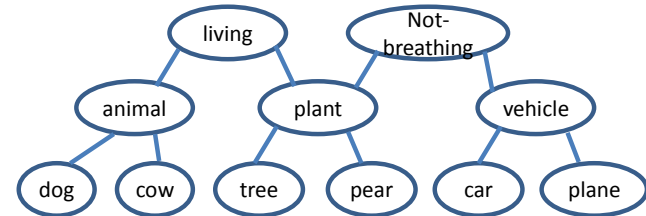
• Hierarchies in reasoning

• WordNet and ImageNet

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Complexity of cortical networks

• *Feedback*: connections in both directions along cortical "pathways"

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Recurrent neural networks

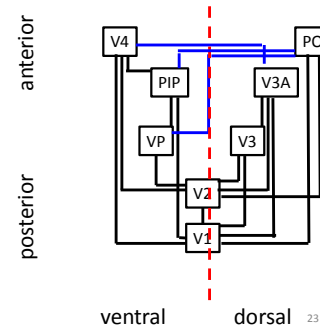The man walked up the steps into the barn to see
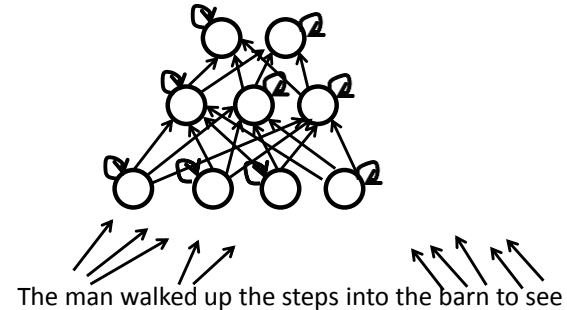
• E.g., Word2Vec: "barn" -> [3, 0, 1, 2, 0, 0, -2]

• Information represented as "neuron" outputs

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Complexity of cortical networks

- *Lateral connections*: collaboration among cortical regions at similar stage of processing

- *Multi-level connections:* shortcuts between "early" and "late" processing stages

anterior

posterior

ventral   dorsal   23

V4   PO
PIP   V3A
VP   V3
V2
V1

Cortical modules

Groups/"columns" of neurons encoding same property

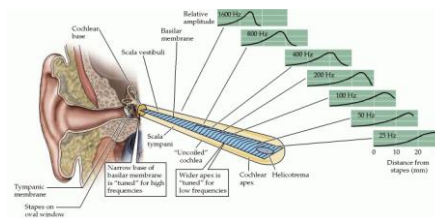Subdivisions within cortical region
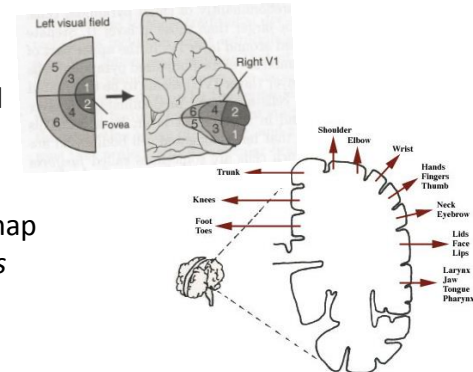
- Retinotopy
- Body part map *Homunculus*

Cortical modules

Groups/"columns" of neurons encoding same property

Subdivisions within cortical region

- Retinotopy
- Body part map *Homunculus*
- Tonotopy

http://www.ncbi.nlm.nih.gov/books/NBK10946/
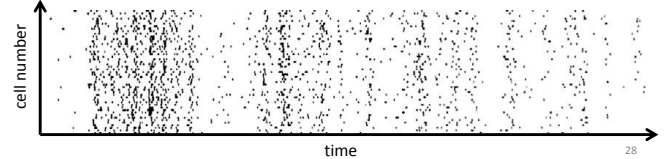
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Recording activity in the brain

- Electrode recordings
  - Invasive
  - Single neurons close together
- Neuroimaging
  - Non-invasive
  - Hundreds-millions of neurons broadly distributed
- Behavior
  - Non-invasive
  - Overall cognition

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Electrode recordings

- Membrane potentials
- Spike times
- High temporal resolution (ms)
- High spatial resolution (individual neurons)
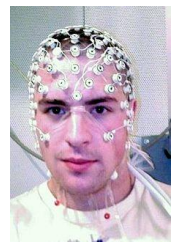- Low field of view (small recording area)

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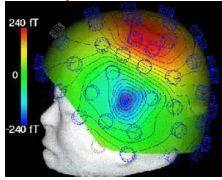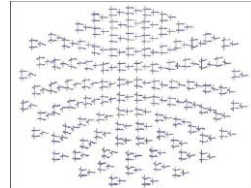## Electroencephalography (EEG)

- Records electric fields at skull surface
- ~100 sensors across the head
  low spatial resolution
- high (ms) time resolution
- cheap

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Magnetoencephalography (MEG)

- Records magnetic "dipoles" from deep in brain
- 300 sources found inside the head
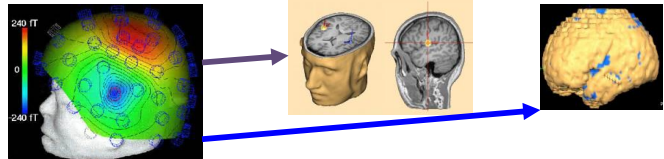 low spatial resolution
- ms time resolution
- expensive

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This slide uploaded late, not on exam 1
Source localization – EEG and MEG
From recordings at surface:
- extrapolate limited localized "dipoles" of activity within the brain
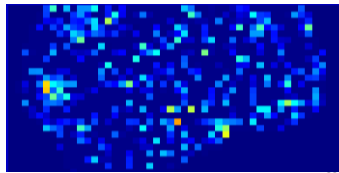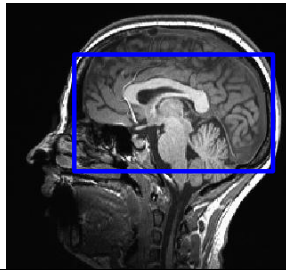- extrapolate broad regions of activity

https://www.cogsci.mq.edu.au/facilities/erp/documents/presentations/
an%20introduction%20to%20spatial%20analyses.pdf

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6

functional Magnetic Resonance Imaging (fMRI)

- Records concentration of blood oxygen
- 10,000+ cortical cubes (2x2x 2 mm^3) relatively high spatial resolution
- Low (0.5-4 seconds) time resolution
- expensive

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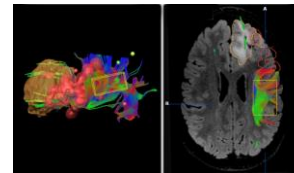## Tractography: Diffusion Tensor Imaging (DTI

Uses MRI

Track flow of water along axon tracts

- Pick source location, see where water flows to

Each color is a different white matter pathway

https://www.mayfieldclinic.com/PE-fMRI_DTI.HTM

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