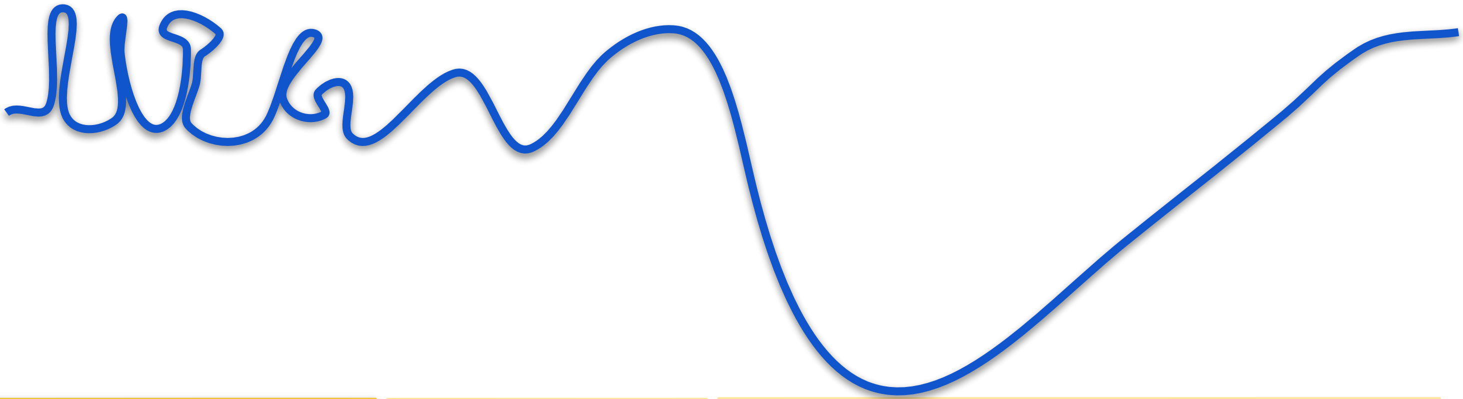
Computing with Signals



DA 623

Jan - May 2024

IIT Guwahati

Instructors: Neeraj Sharma

Lecture-19

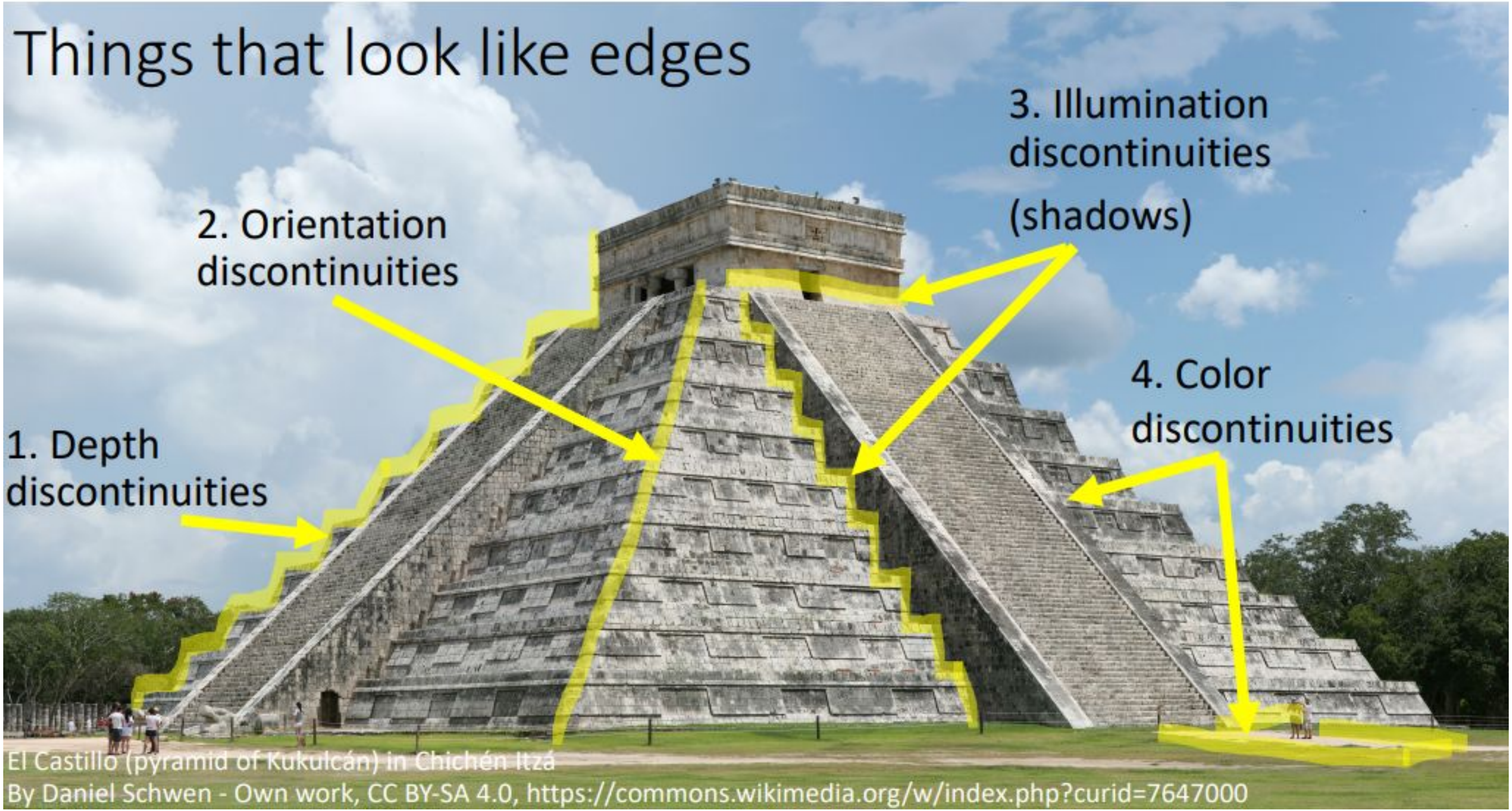
Edge Detection

What is an Edge?

Rapid change in image intensity within small region

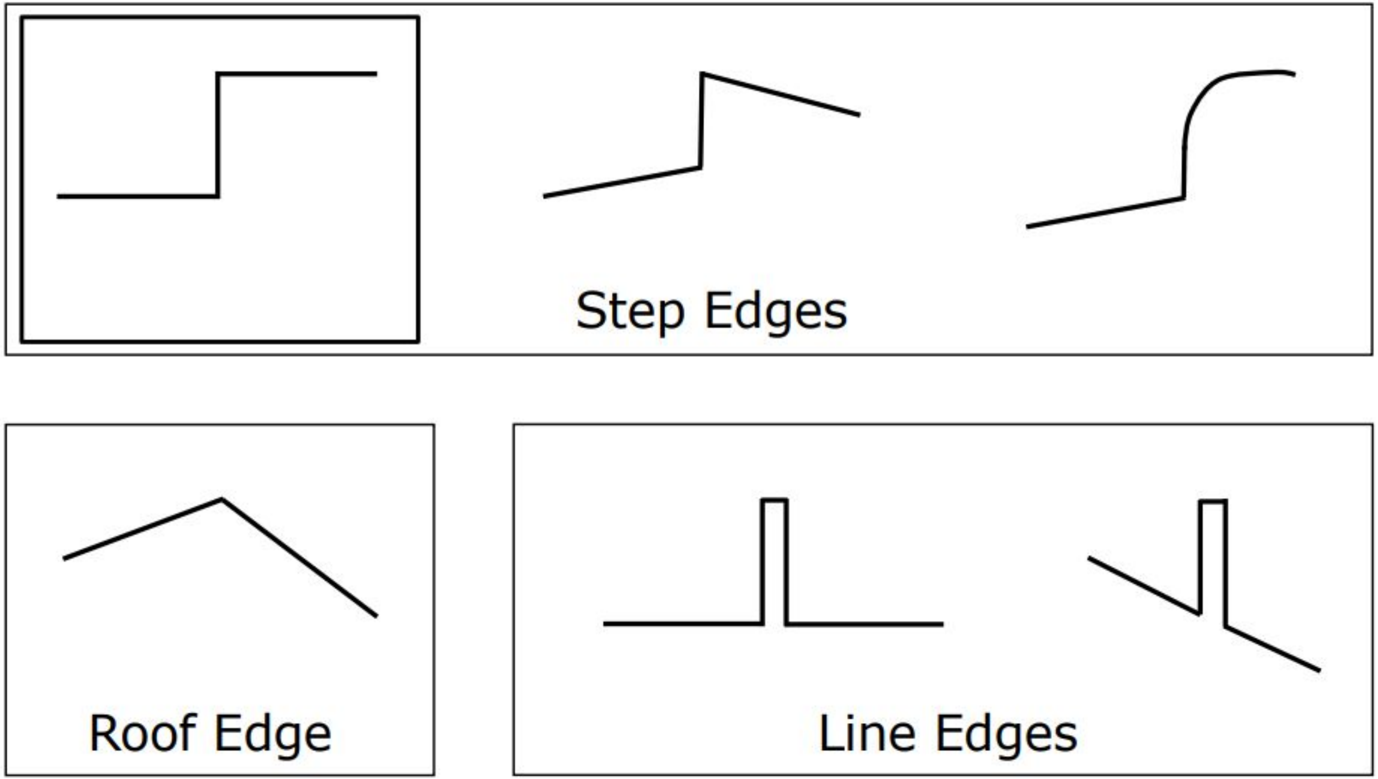
Reference:
https://fpcv.cs.columbia.edu/Monographs

Things that look like edges

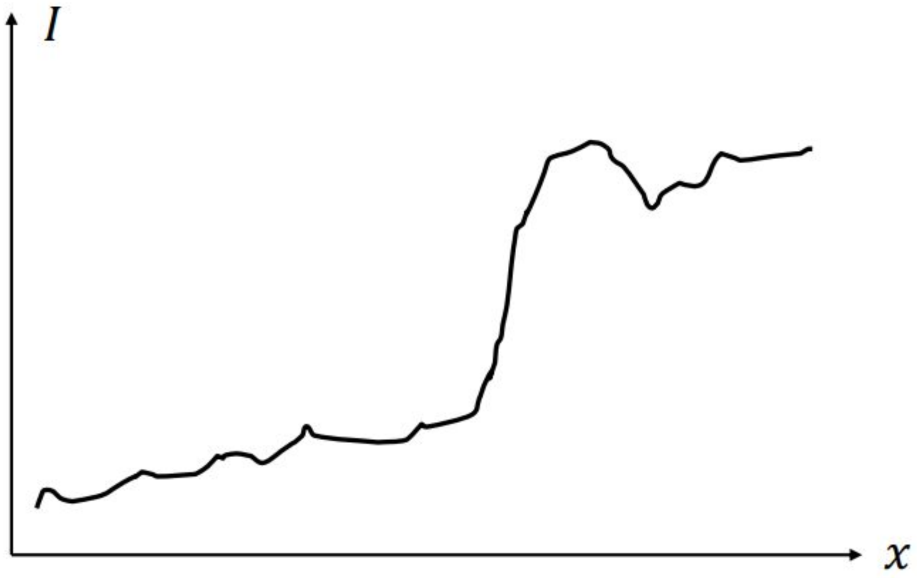


El Castillo (pyramid of Kukulcán) in Chichén Itzá

Types of Edges



Real Edges



Problems: Noisy Images and Discrete Images

Edge Detector

We want an Edge Operator that produces:

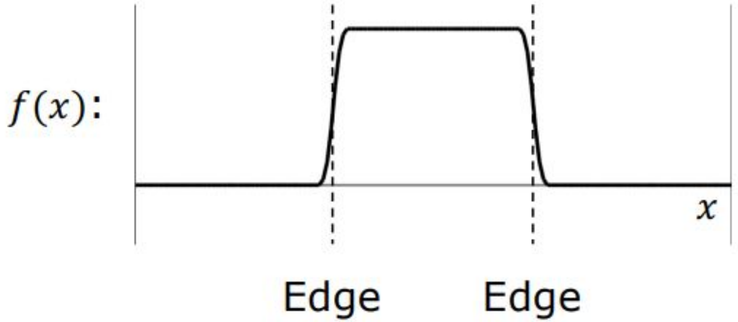
- Edge Position
- Edge Magnitude (Strength)
- Edge Orientation (Direction)

Performance Requirements:

- High Detection Rate
- Good Localization
- Low Noise Sensitivity

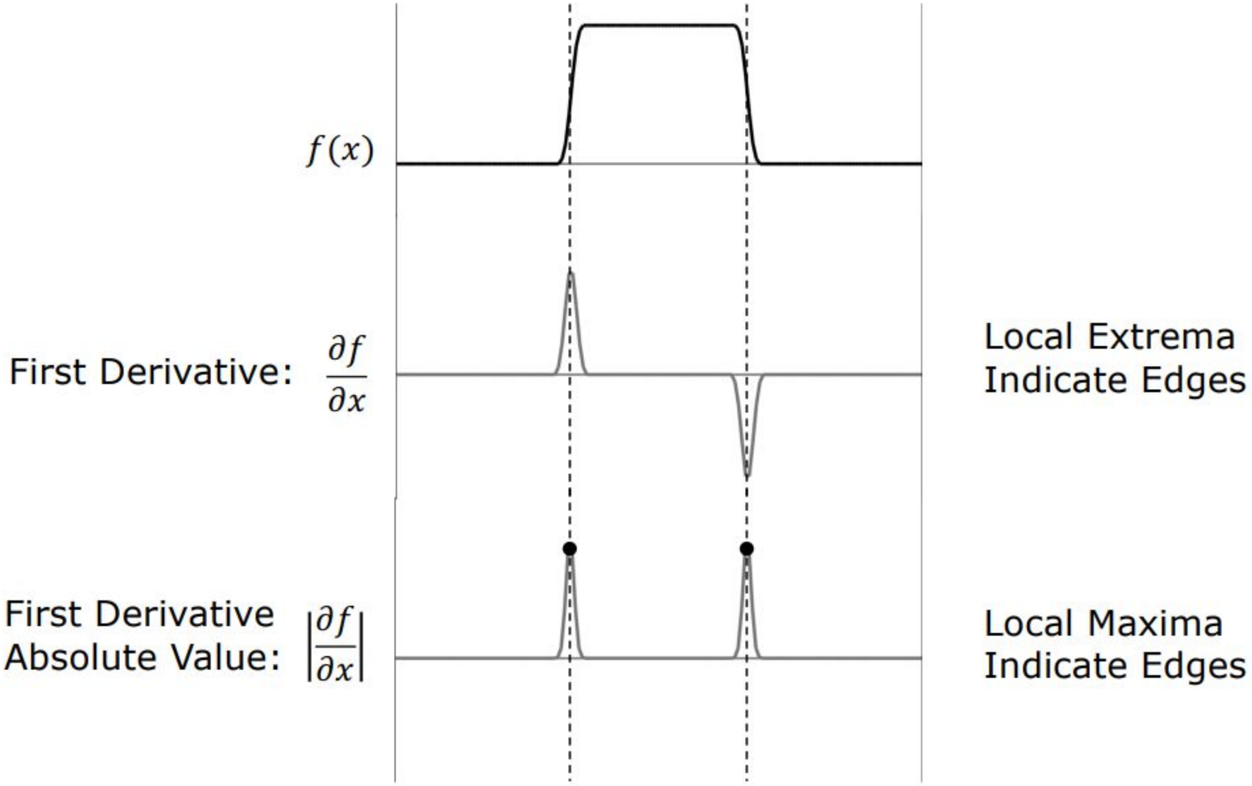
1D Edge Detection

Edge is a rapid change in image intensity in a small region.



Basic Calculus: Derivative of a continuous function represents the amount of change in the function.

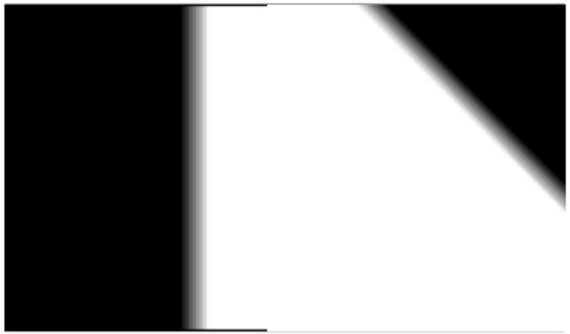
Edge Detection Using 1st Derivative



Provides Both Location and Strength of an Edge

2D Edge Detection

$I(x, y)$:



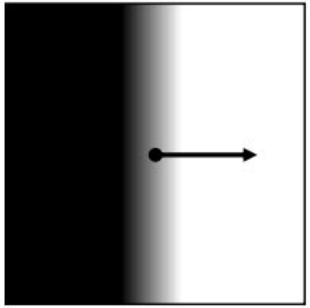
Basic Calculus: Partial Derivatives of a 2D continuous function represents the amount of change along each dimension.

Gradient (∇)

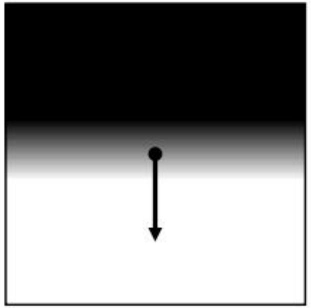
Gradient (Partial Derivatives) represents the direction of most rapid change in intensity

$$\boxed{\nabla I = \left[\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}\right]}$$

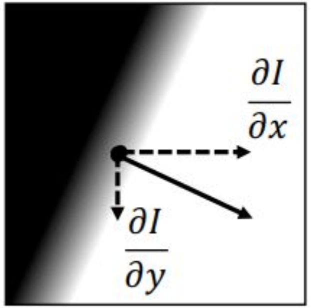
Pronounced as "Del I"



$$\nabla I = \left[\frac{\partial I}{\partial x}, 0\right]$$



$$\nabla I = \left[0, \frac{\partial I}{\partial y}\right]$$

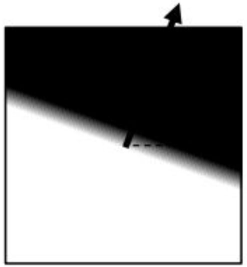


$$\nabla I = \left[\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}\right]$$

Gradient (∇) as Edge Detector

Gradient Magnitude $S = \|\nabla I\| = \sqrt{\left(\frac{\partial I}{\partial x}\right)^2 + \left(\frac{\partial I}{\partial y}\right)^2}$

Gradient Orientation $\theta = \tan^{-1}\left(\frac{\partial I}{\partial y} / \frac{\partial I}{\partial x}\right)$



Discrete Gradient (∇) Operator

Finite difference approximations:

$$\frac{\partial I}{\partial x} \approx \frac{1}{2\varepsilon}\left(\left(I_{i+1,j+1} - I_{i,j+1}\right) + \left(I_{i+1,j} - I_{i,j}\right)\right)$$

$$\frac{\partial I}{\partial y} \approx \frac{1}{2\varepsilon}\left(\left(I_{i+1,j+1} - I_{i+1,j}\right) + \left(I_{i,j+1} - I_{i,j}\right)\right)$$

$I_{i,j+1}$	$I_{i+1,j+1}$
$I_{i,j}$	$I_{i+1,j}$

ε

Can be implemented as Convolution!

$$\frac{\partial}{\partial x} \approx \frac{1}{2\varepsilon}\begin{array}{|c|c|}\hline -1 & 1 \\ \hline -1 & 1 \\ \hline\end{array} \qquad \frac{\partial}{\partial y} \approx \frac{1}{2\varepsilon}\begin{array}{|c|c|}\hline 1 & 1 \\ \hline -1 & -1 \\ \hline\end{array}$$

Note: Convolution flips have been applied

Comparing Gradient (∇) Operators

Gradient	Roberts	Prewitt	Sobel (3x3)	Sobel (5x5)
$\frac{\partial I}{\partial x}$	$\begin{matrix} 0 & 1 \\ -1 & 0 \end{matrix}$	$\begin{matrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{matrix}$	$\begin{matrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{matrix}$	$\begin{matrix} -1 & -2 & 0 & 2 & 1 \\ -2 & -3 & 0 & 3 & 2 \\ -3 & -5 & 0 & 5 & 3 \\ -2 & -3 & 0 & 3 & 2 \\ -1 & -2 & 0 & 2 & 1 \end{matrix}$
$\frac{\partial I}{\partial y}$	$\begin{matrix} 1 & 0 \\ 0 & -1 \end{matrix}$	$\begin{matrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{matrix}$	$\begin{matrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{matrix}$	$\begin{matrix} 1 & 2 & 3 & 2 & 1 \\ 2 & 3 & 5 & 3 & 2 \\ 0 & 0 & 0 & 0 & 0 \\ -2 & -3 & -5 & -3 & -2 \\ -1 & -2 & -3 & -2 & -1 \end{matrix}$

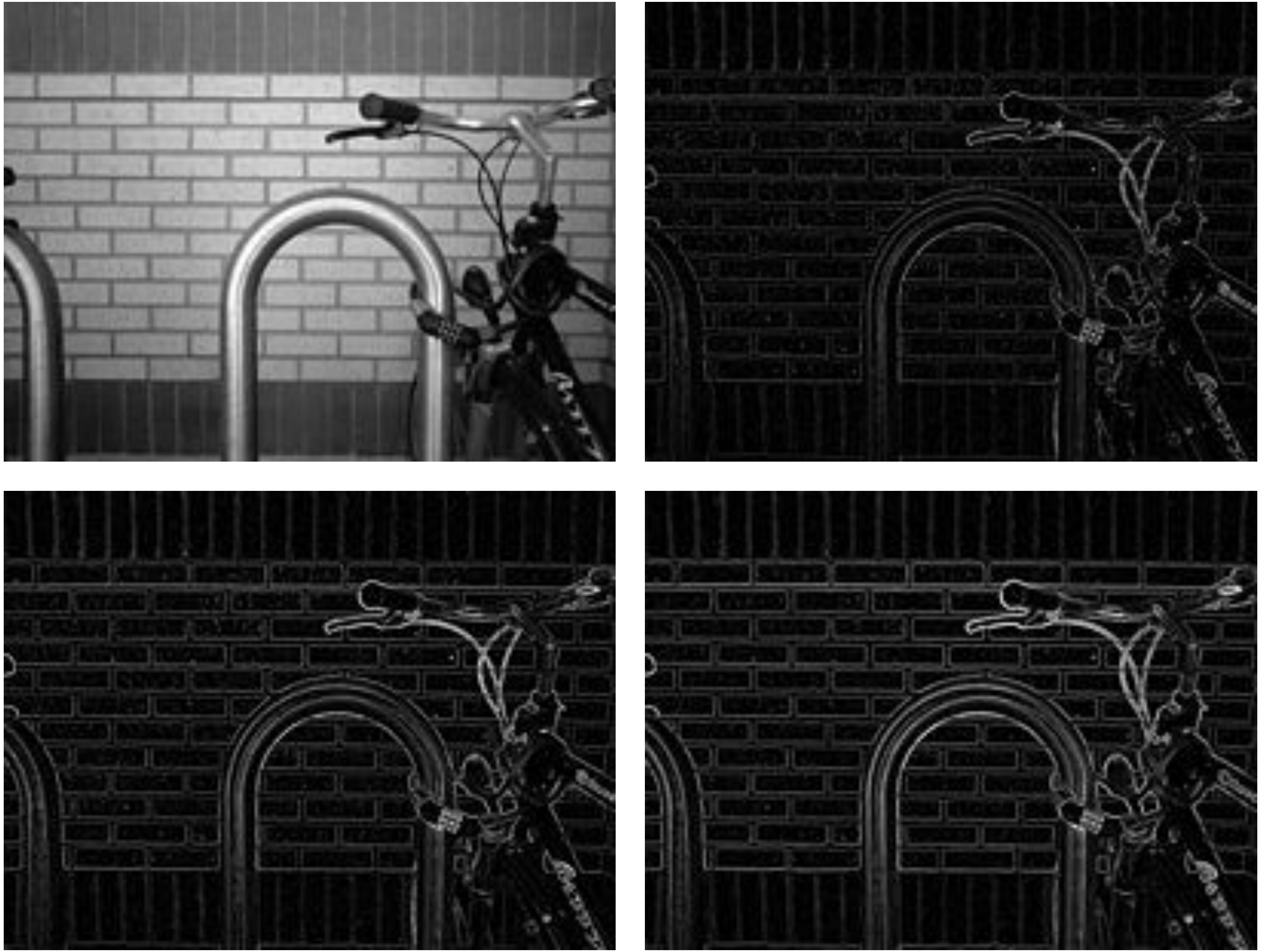
Good Localization
Noise Sensitive
Poor Detection

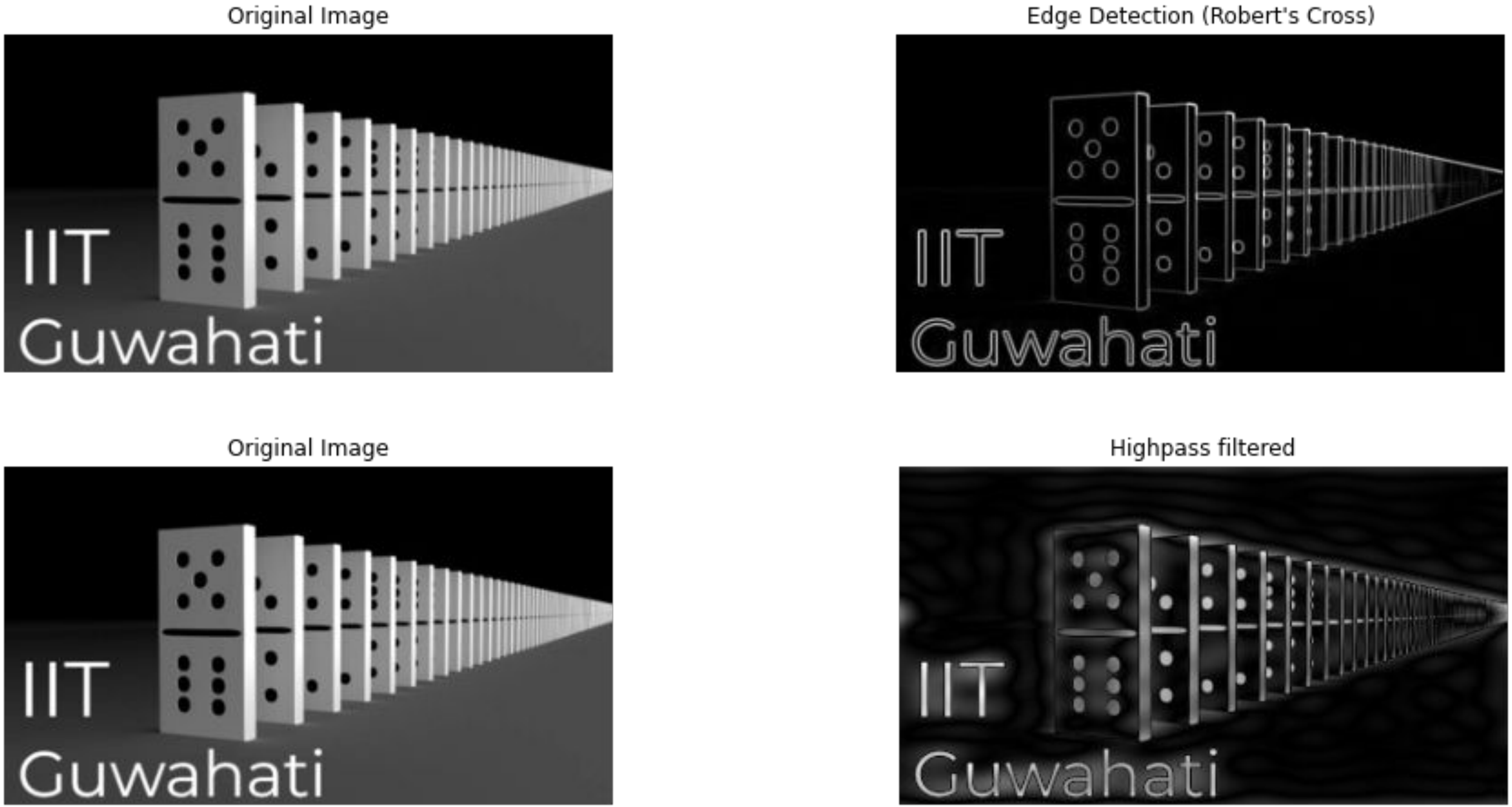
Poor Localization
Less Noise Sensitive
Good Detection

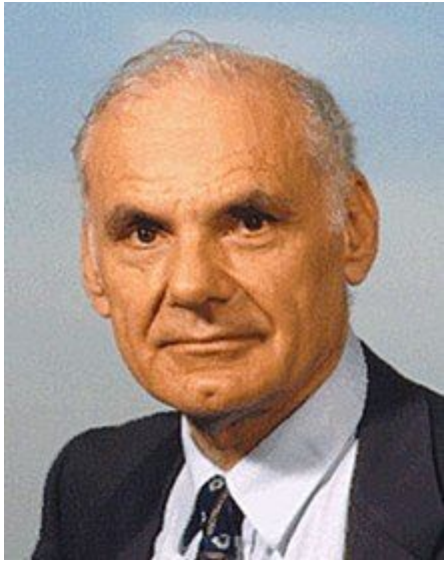
Comparing Gradient (∇) Operators

Gradient	Roberts	Prewitt	Sobel (3x3)	Sobel (5x5)
$\frac{\partial I}{\partial x}$	$\begin{matrix} 0 & 1 \\ -1 & 0 \end{matrix}$	$\begin{matrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{matrix}$	$\begin{matrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{matrix}$	$\begin{matrix} -1 & -2 & 0 & 2 & 1 \\ -2 & -3 & 0 & 3 & 2 \\ -3 & -5 & 0 & 5 & 3 \\ -2 & -3 & 0 & 3 & 2 \\ -1 & -2 & 0 & 2 & 1 \end{matrix}$
$\frac{\partial I}{\partial y}$	$\begin{matrix} 1 & 0 \\ 0 & -1 \end{matrix}$	$\begin{matrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{matrix}$	$\begin{matrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{matrix}$	$\begin{matrix} 1 & 2 & 3 & 2 & 1 \\ 2 & 3 & 5 & 3 & 2 \\ 0 & 0 & 0 & 0 & 0 \\ -2 & -3 & -5 & -3 & -2 \\ -1 & -2 & -3 & -2 & -1 \end{matrix}$

Good Localization Noise Sensitive Poor Detection	→	Poor Localization Less Noise Sensitive Good Detection




Original Image
Edge Detection (Robert's Cross)
Original Image
Highpass filtered
IIT
Guwahati



Lawrence Roberts

Draper Prize in 2001 "for the development of the Internet"

His Ph.D. thesis s titled - "Machine Perception of Three-Dimensional Solids"

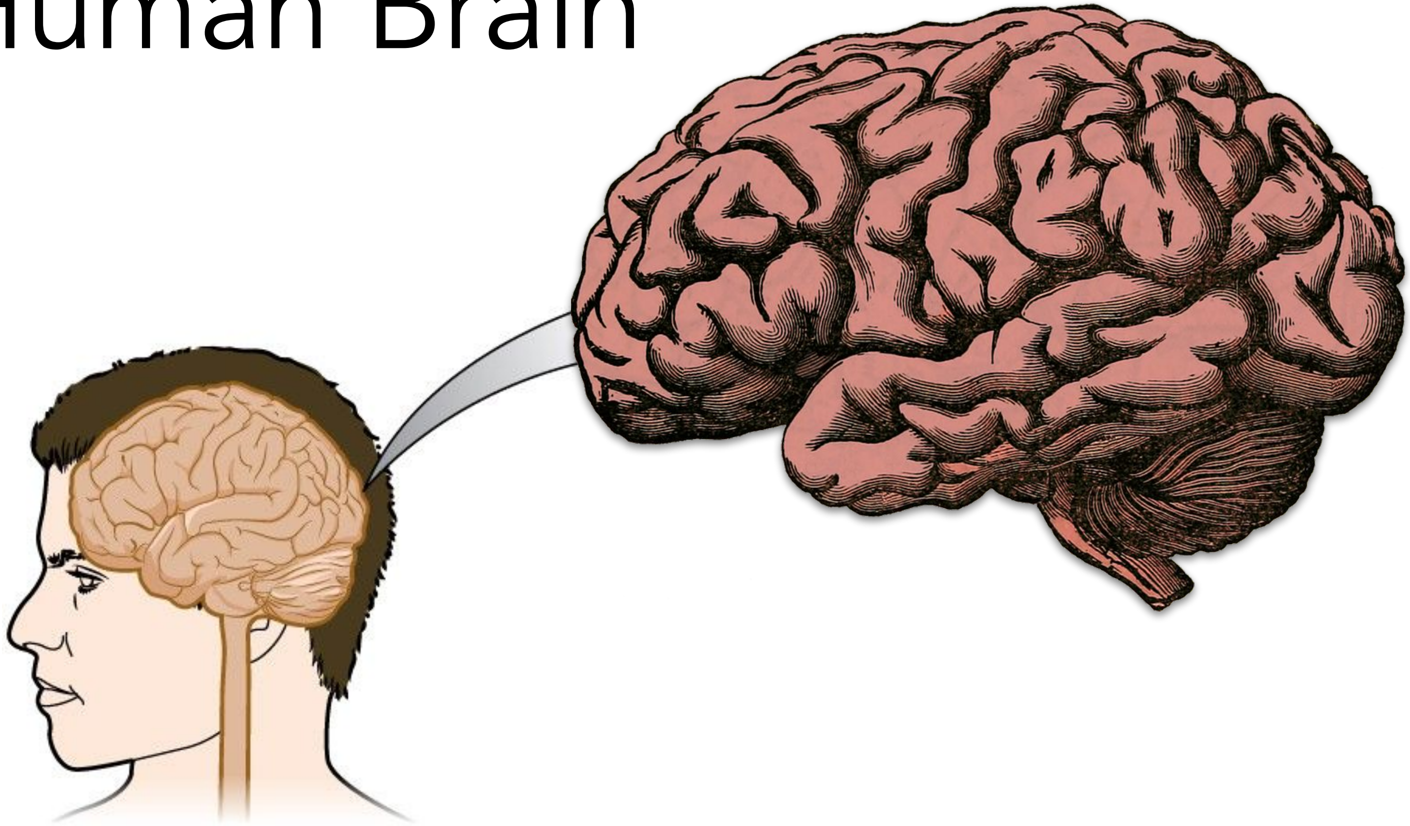
Contents

- A glance into human brain
    - Contributions of Cajal
    - Neurons as information processing units in the cortex
    - Different regions of brain

- Sound
    - Physical aspects: direct sound and reflected sound
    - Hearing in insects, animals and humans
    - Hearing mechanism: Mosquitoes and Humans
    - Speech production mechanism

- Audio
    - Sound files: sampling, quantization, and storage
    - Time-series data: features
    - Time-frequency representation - Spectrograms

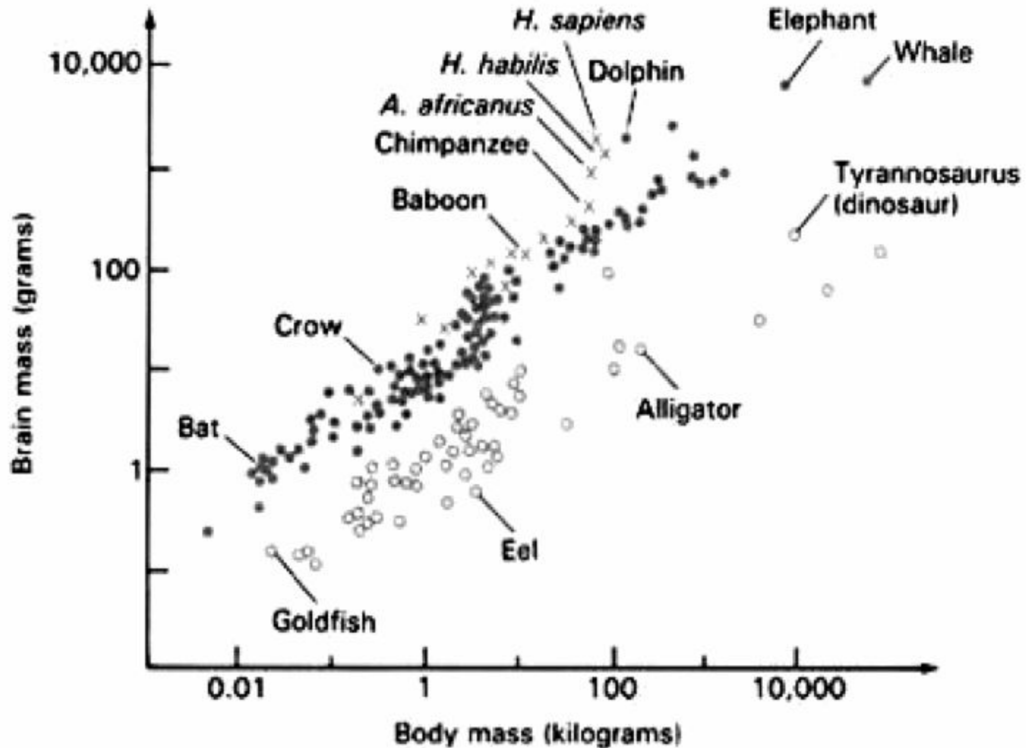
Human Brain



[Image Source: National Institutes of Health]

Brain size across animals

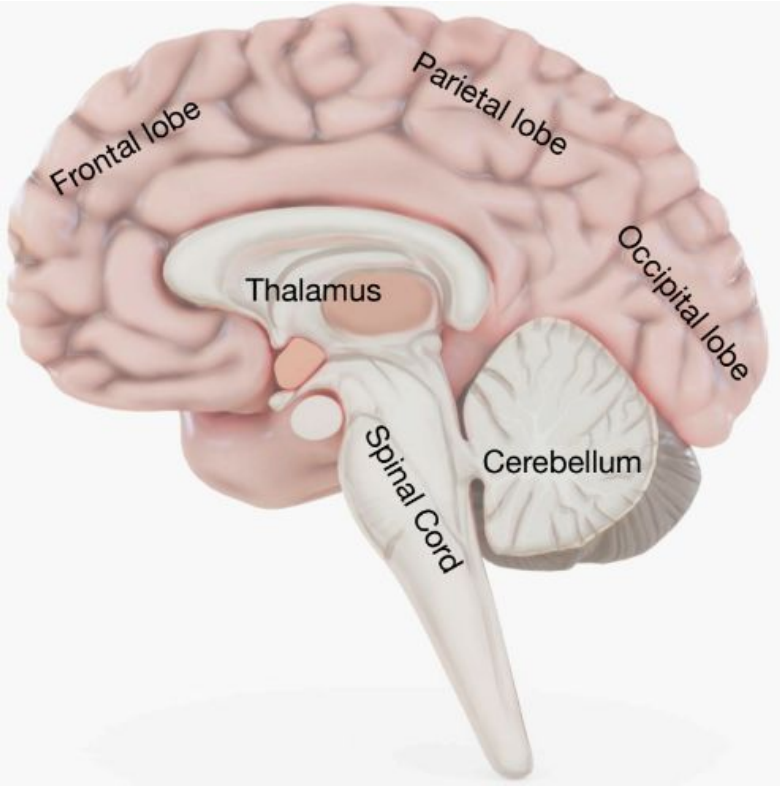
Does brain size correlate with intelligence?



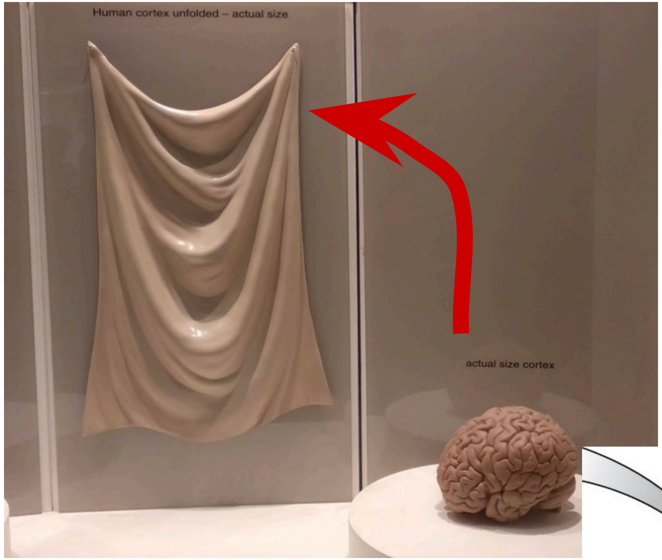
[Image Source: National Institutes of Health]

Human Brain

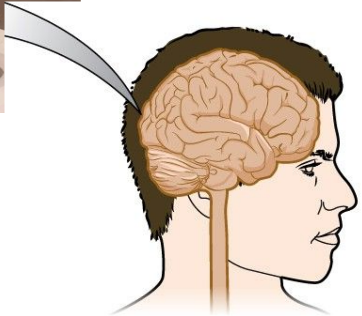
Labelling different regions



Human Brain



It is a lot like a lump mass of tissue, packed under our skull.



What is inside the lump mass?

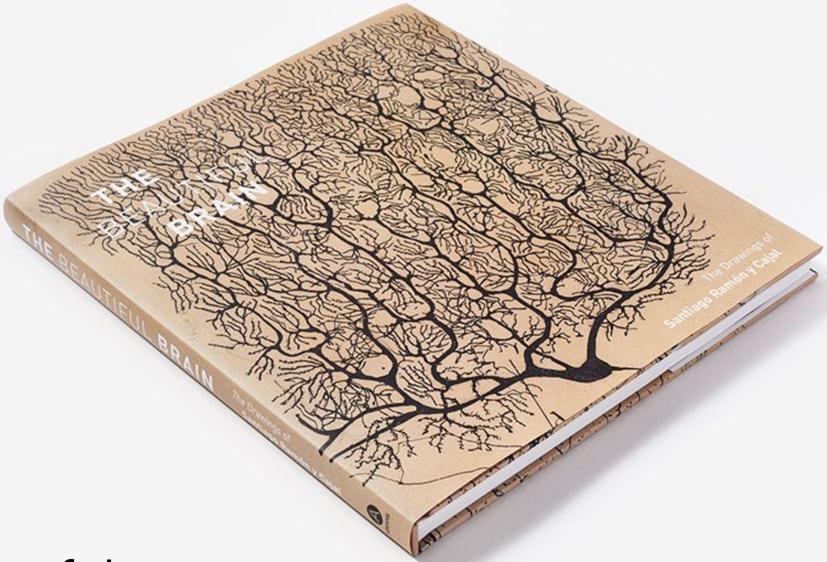
Human Brain

4th Century BC: Aristotle proposed that the brain is a secondary organ, that served as a cooling agent for the heart

2nd Century AD: Galen expanded on Aristotle's ideas, suggesting that the brain controls mental processes.

17th Century: Thomas Willis identified the brain as the primary organ responsible for mental functions.

1906 Nobel Prize in Physiology



The Beautiful Brain:

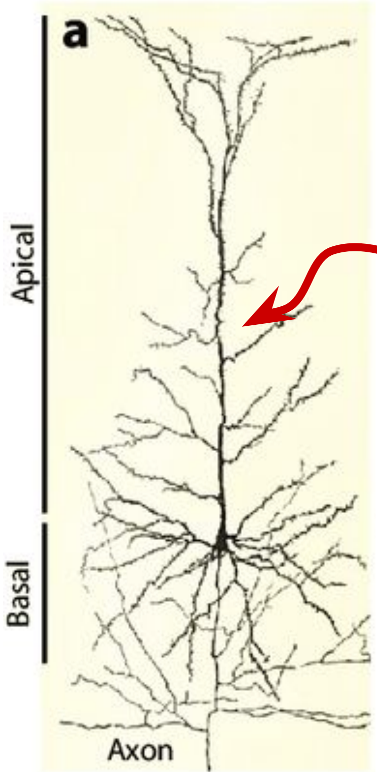
The Drawings of Santiago Ramon y Cajal

Human Brain

19th Century: Camillo Golgi developed the silver staining method, which allowed the visualization of entire neurons, contributing to the reticular theory.

Late 19th Century: Santiago Ramón y Cajal's neuron doctrine challenged the reticular theory.

Zooming into brain tissue

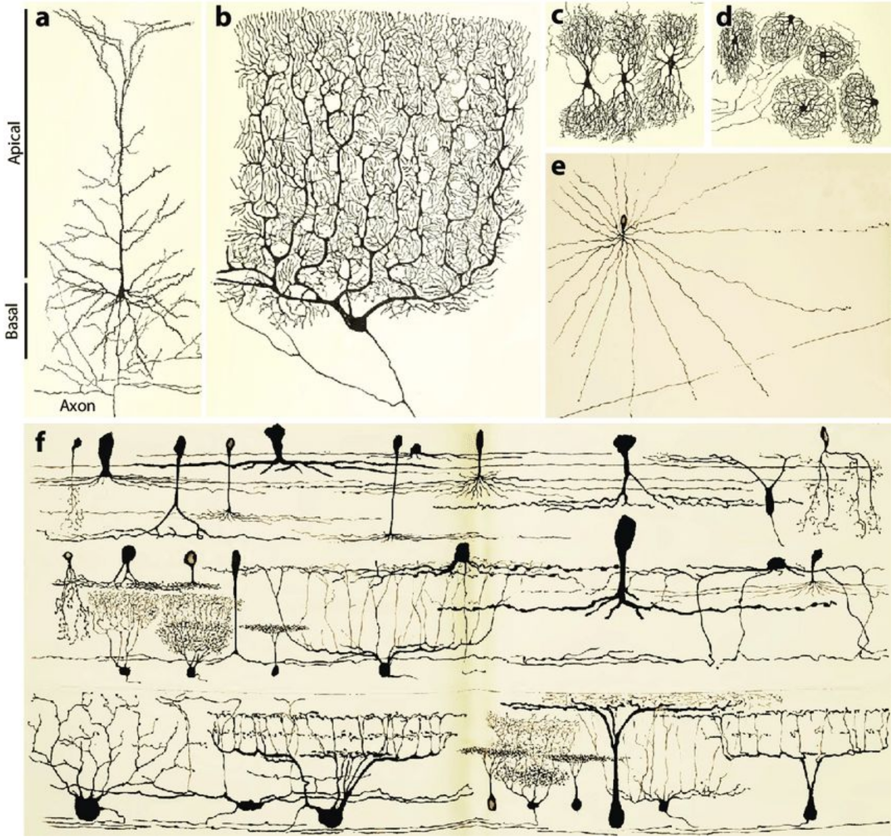


A type of cell in the brain - referred to as neuron (make up the grey matter)

Neurons

- Different types of neurons packed inside the brain
- Some more in count than others
- Distributed in a layer-wise fashion

Inspiration behind design of artificial neural networks

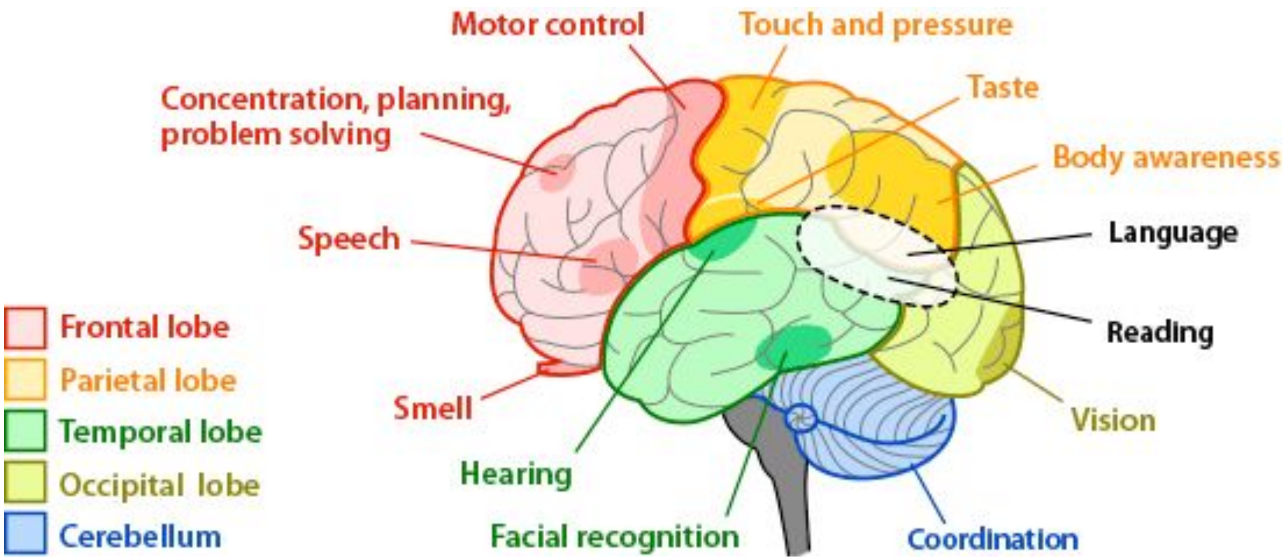


Human Brain

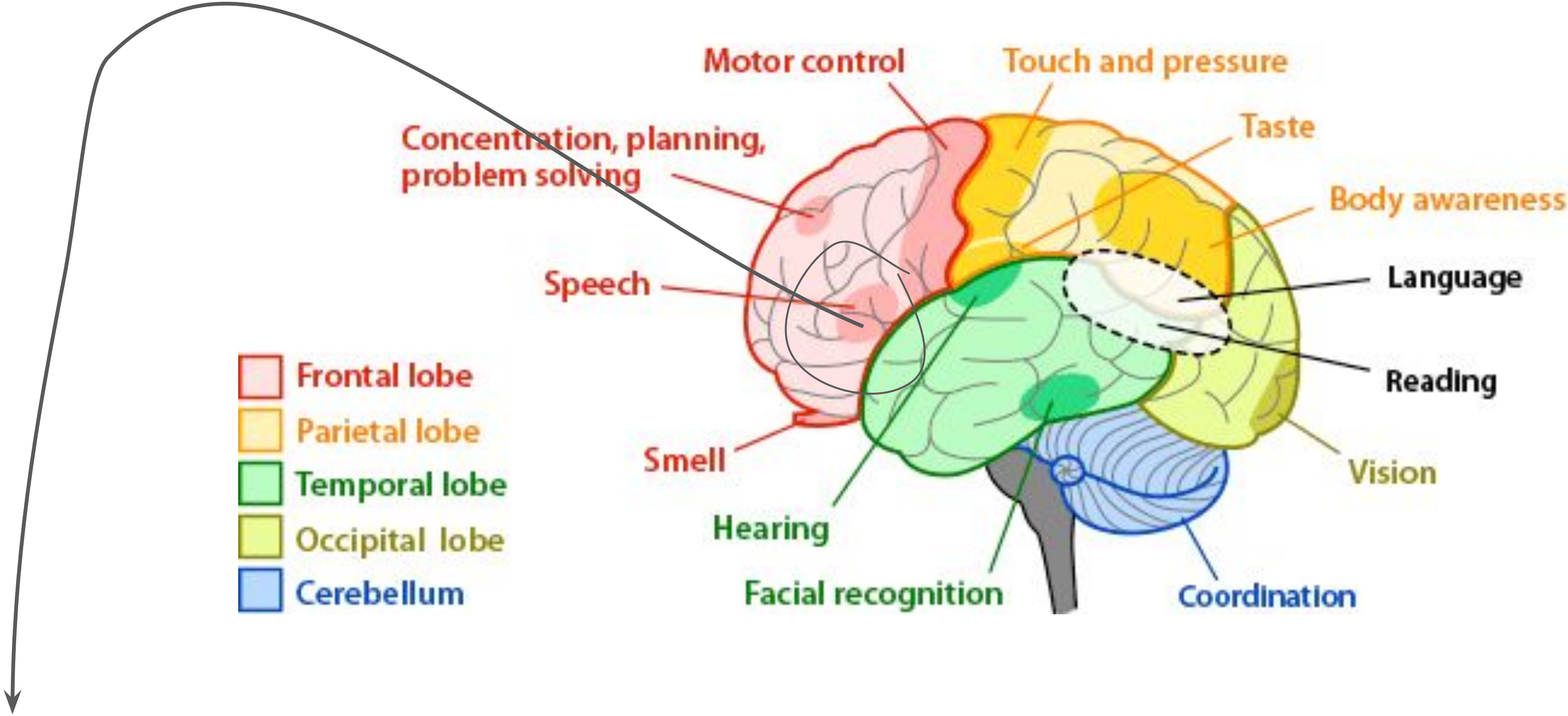
20th Century: Advancements in neuroimaging, electrophysiology, and molecular biology led to a deeper understanding of brain function, including the discovery of neurotransmitters and the mapping of brain regions.

21st Century: Ongoing research continues to uncover the brain's complexities, including the study of neural networks, brain plasticity, and the genetics of brain disorders.

Human Brain - what does it do?



https://askabiologist.asu.edu/brain-regions



Speech - what kind of signal is that?

To be continued ....