Brain-Inspired Artificial Intelligence

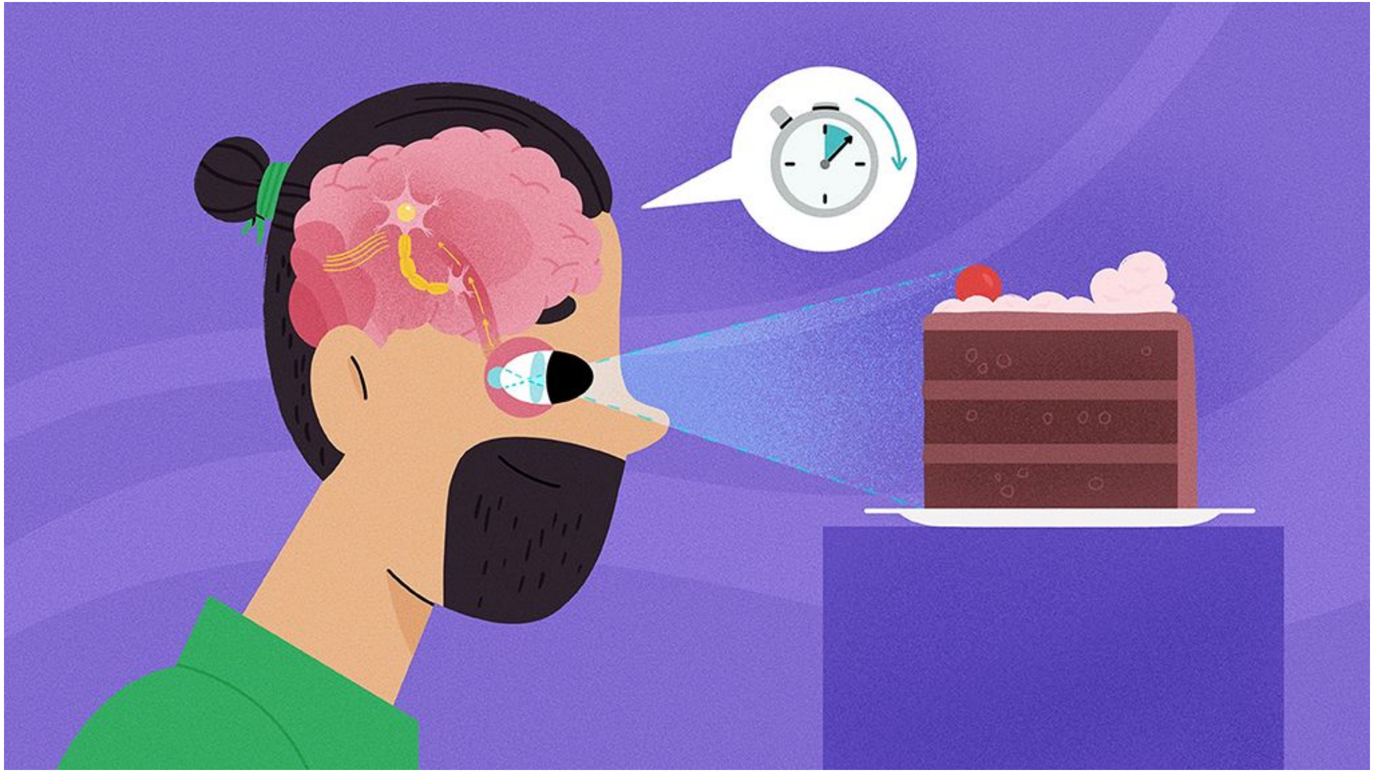
Naiti Bhatt
University of Edinburgh

Roadmap

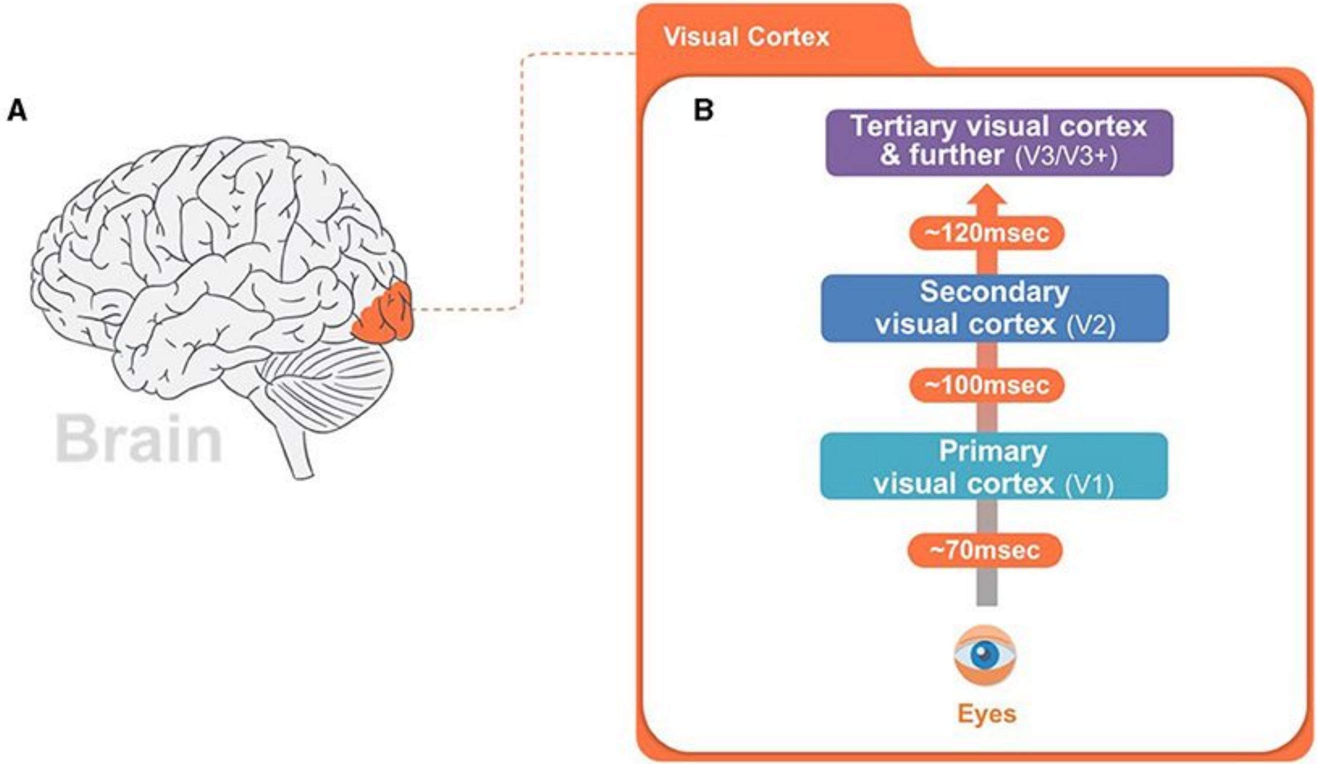
- ➔ Pre-reading Discussion
- ➔ Introduction to Vision
- ➔ Neurobiological Visual System
- ➔ Introduction to Neural Networks
- ➔ Convolutional Neural Networks

Pre-Reading Discussion

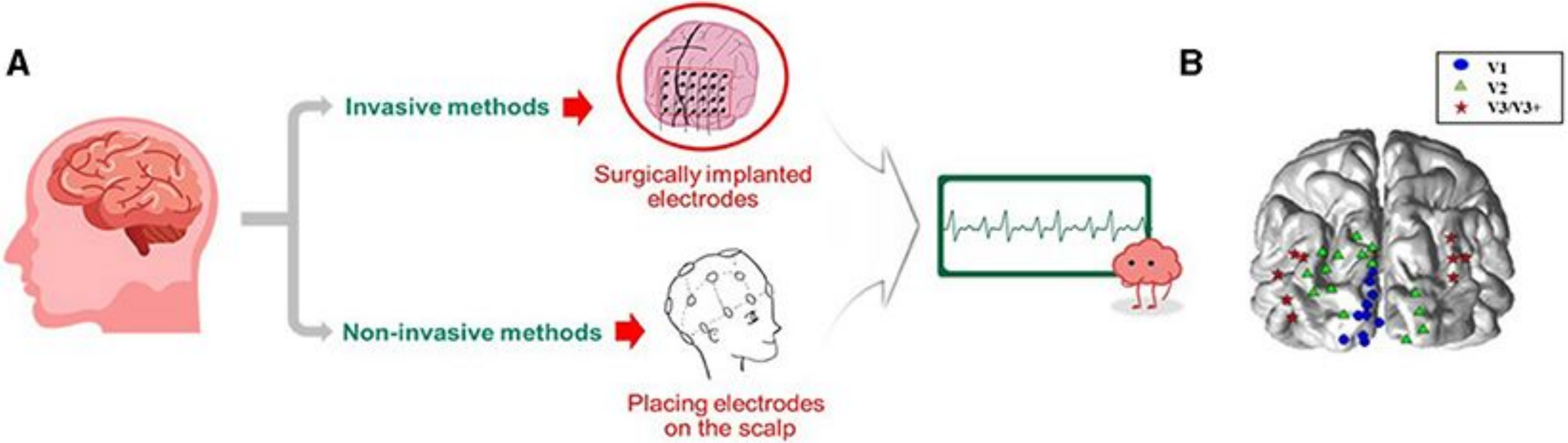
How Does the Brain Allow the Eyes to See?



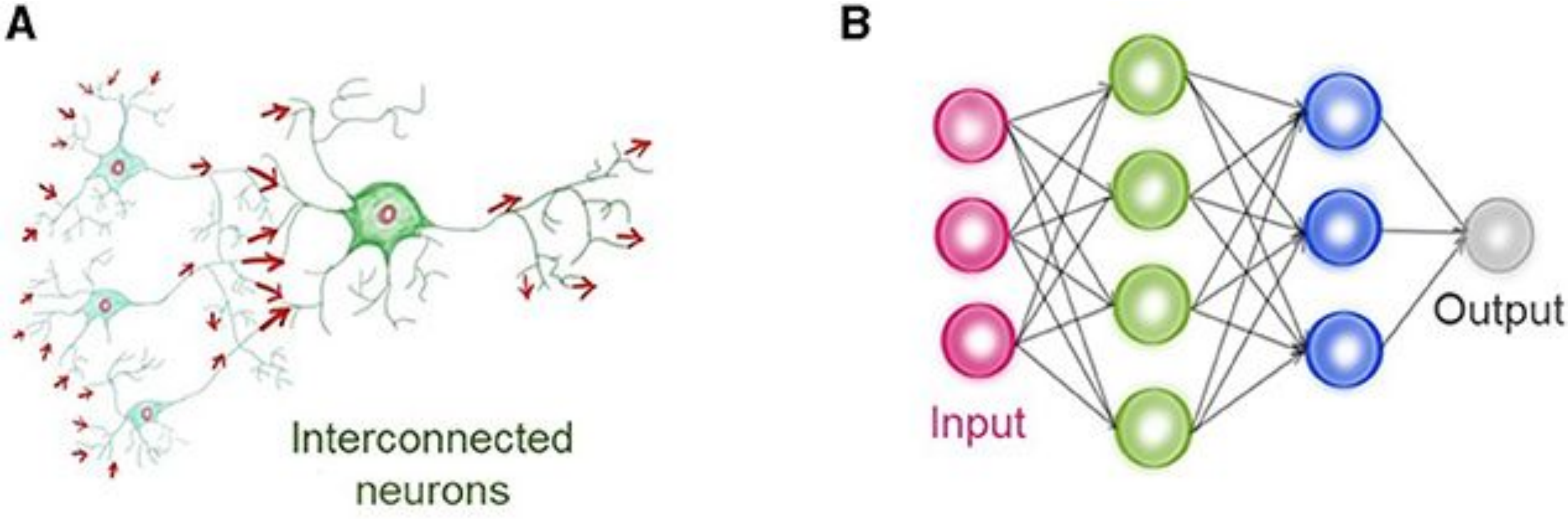
Levels of the visual system and their information processing times.



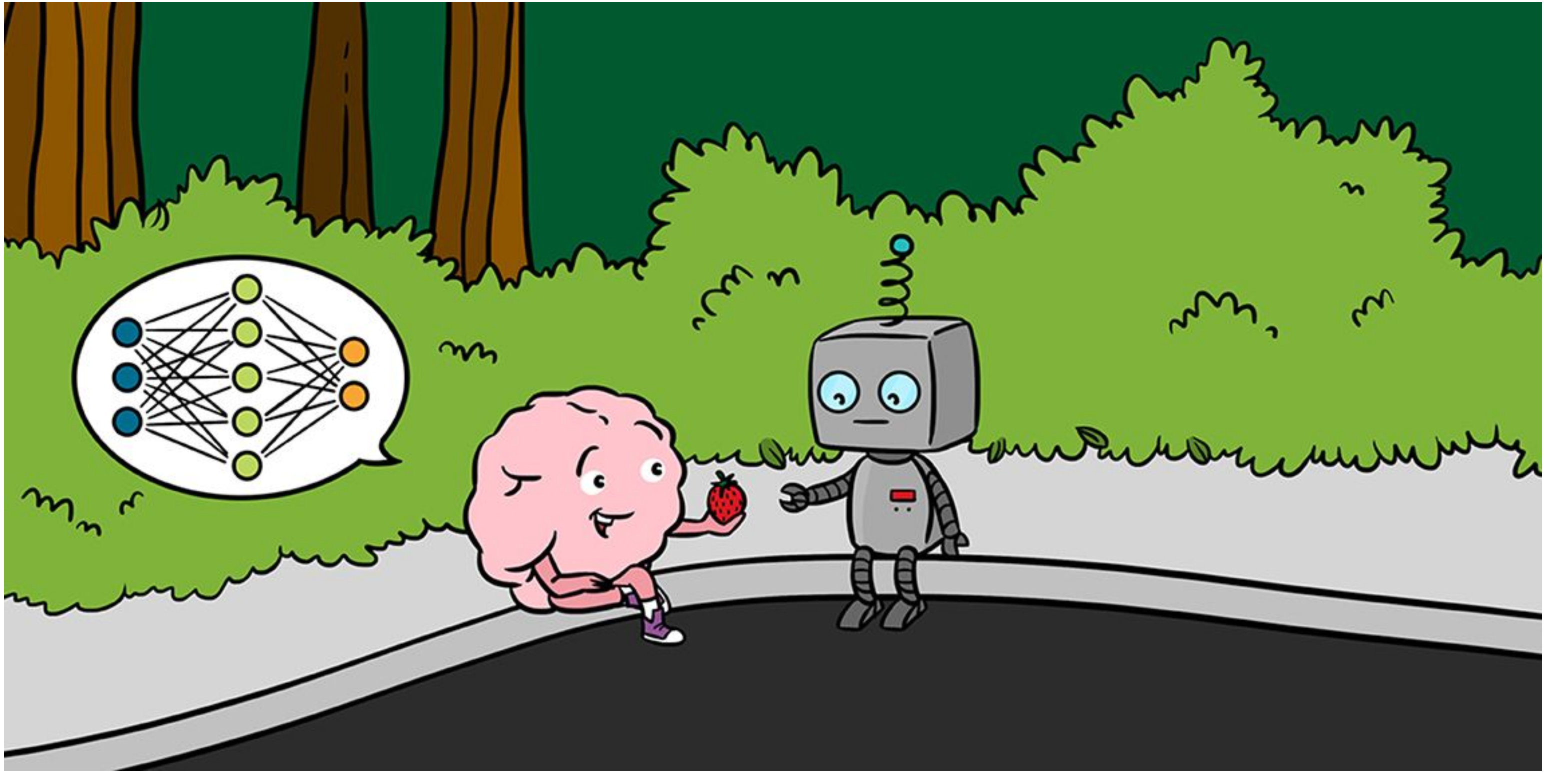
Measuring neural activity in visual cortex using electrodes



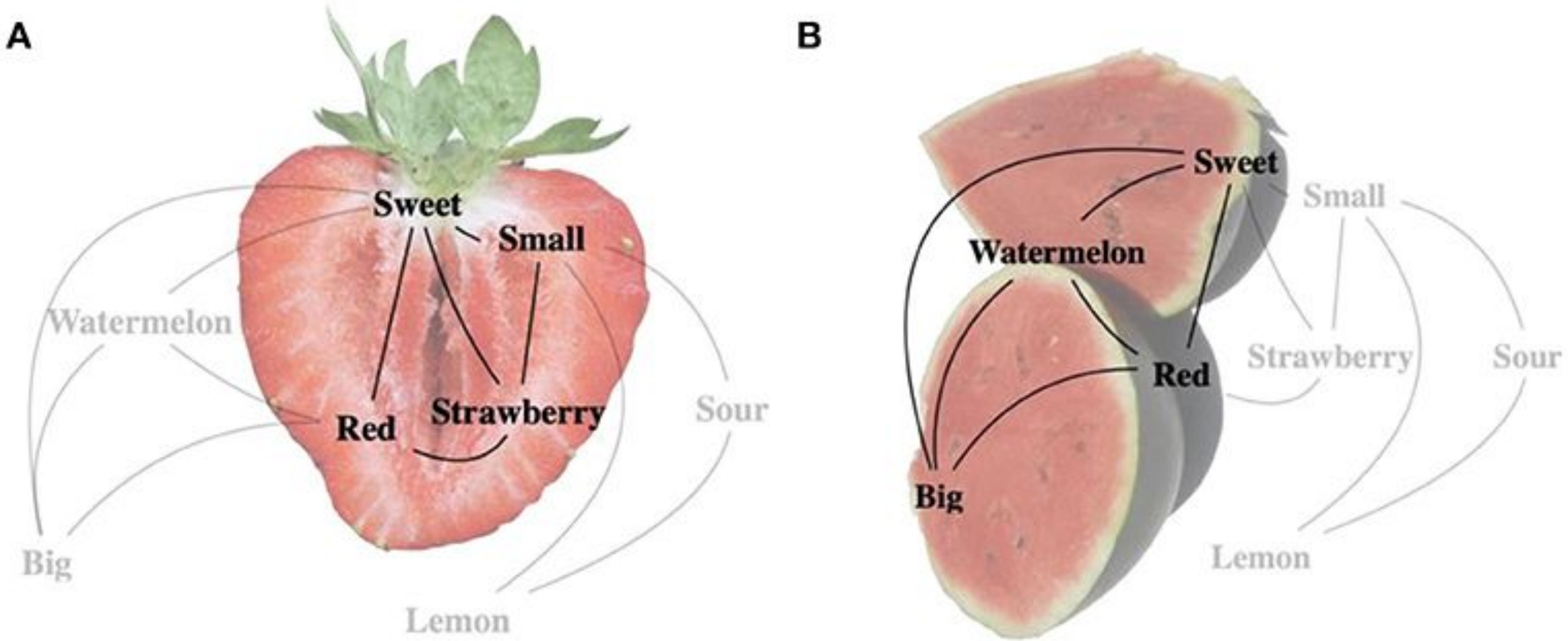
Neurons and neural networks



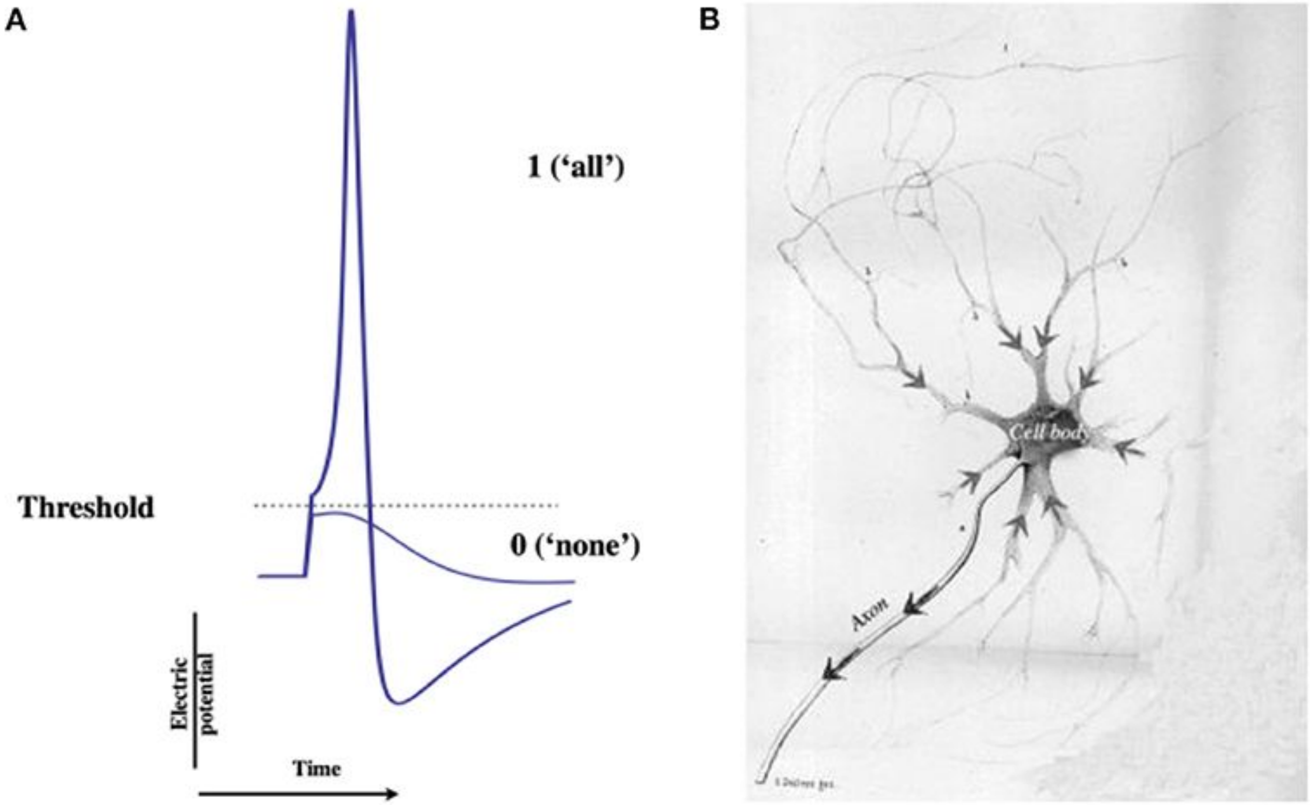
How Are Nerve Cells And Artificial Intelligence Similar?



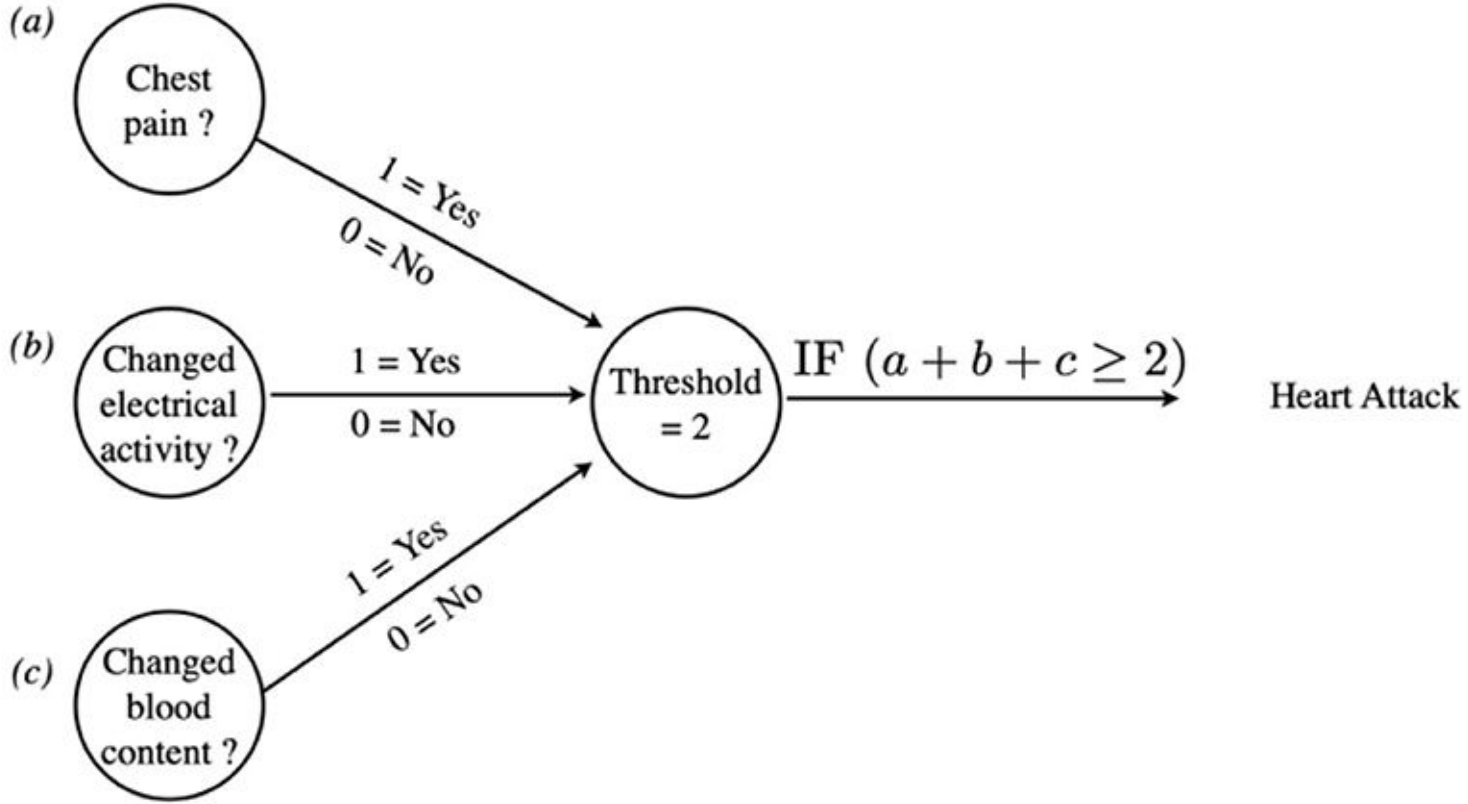
Thinking as traversing the edges of a conceptual network



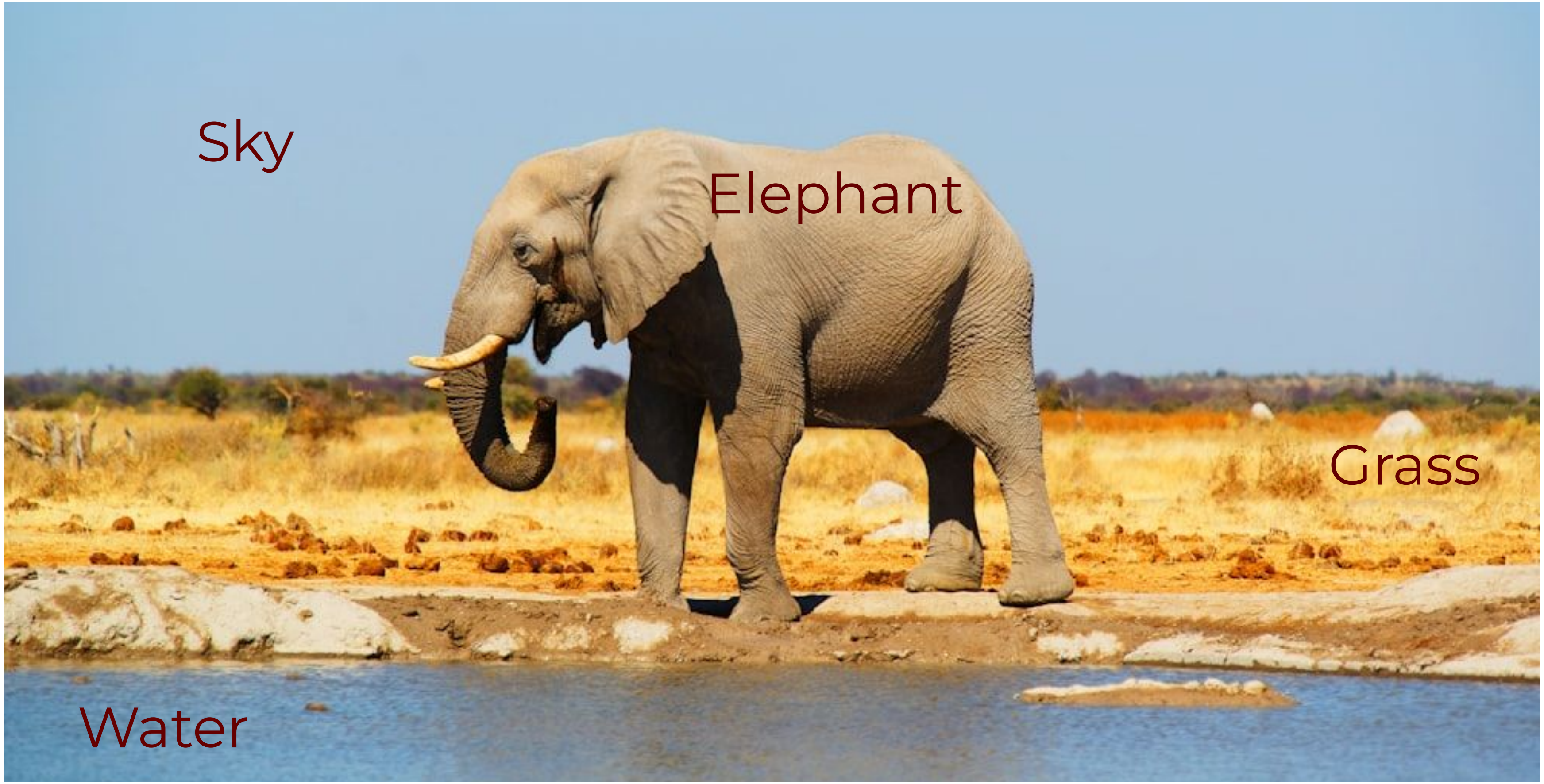
Action Potentials in a Neuron (Nerve Cell)

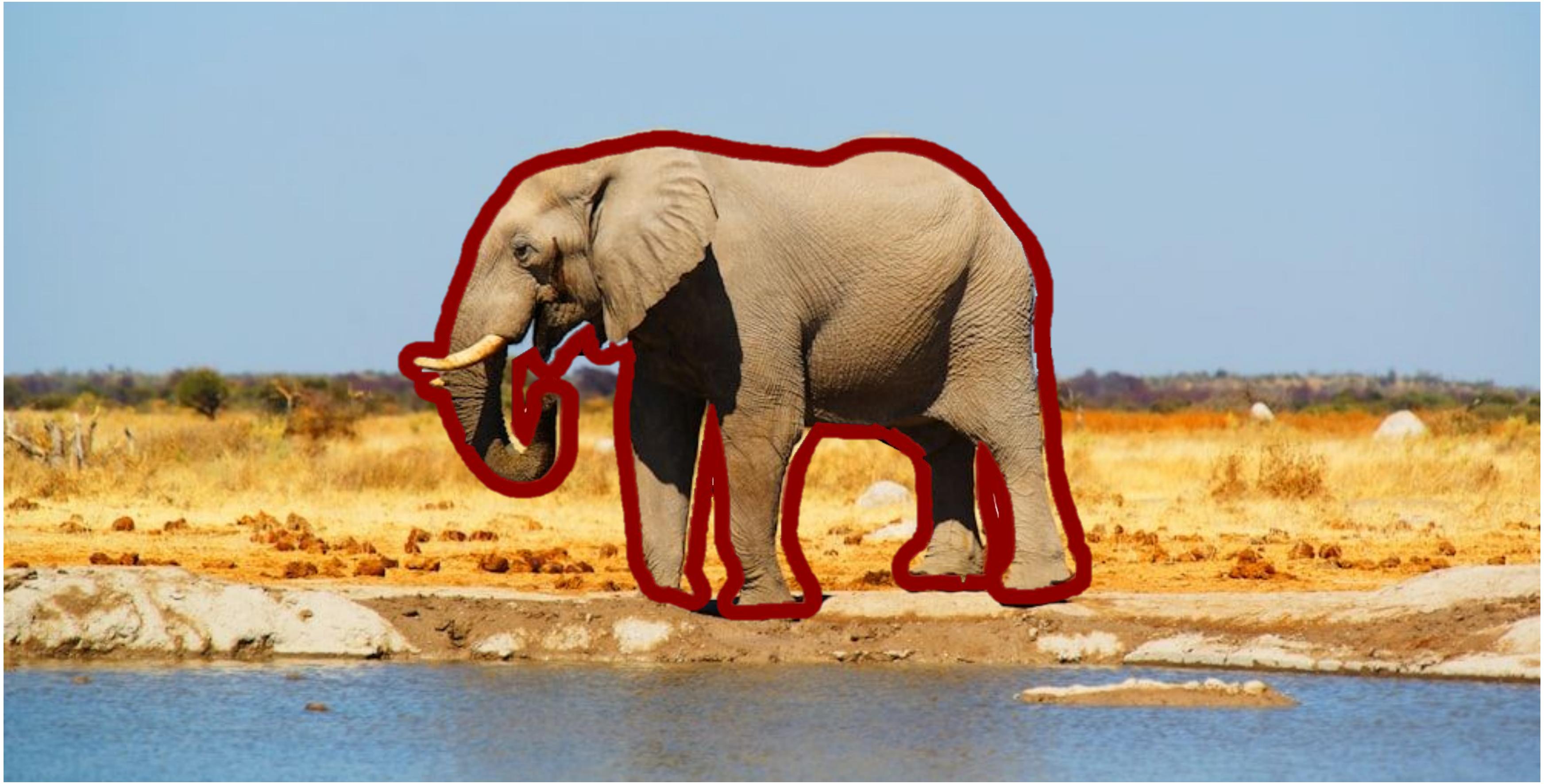


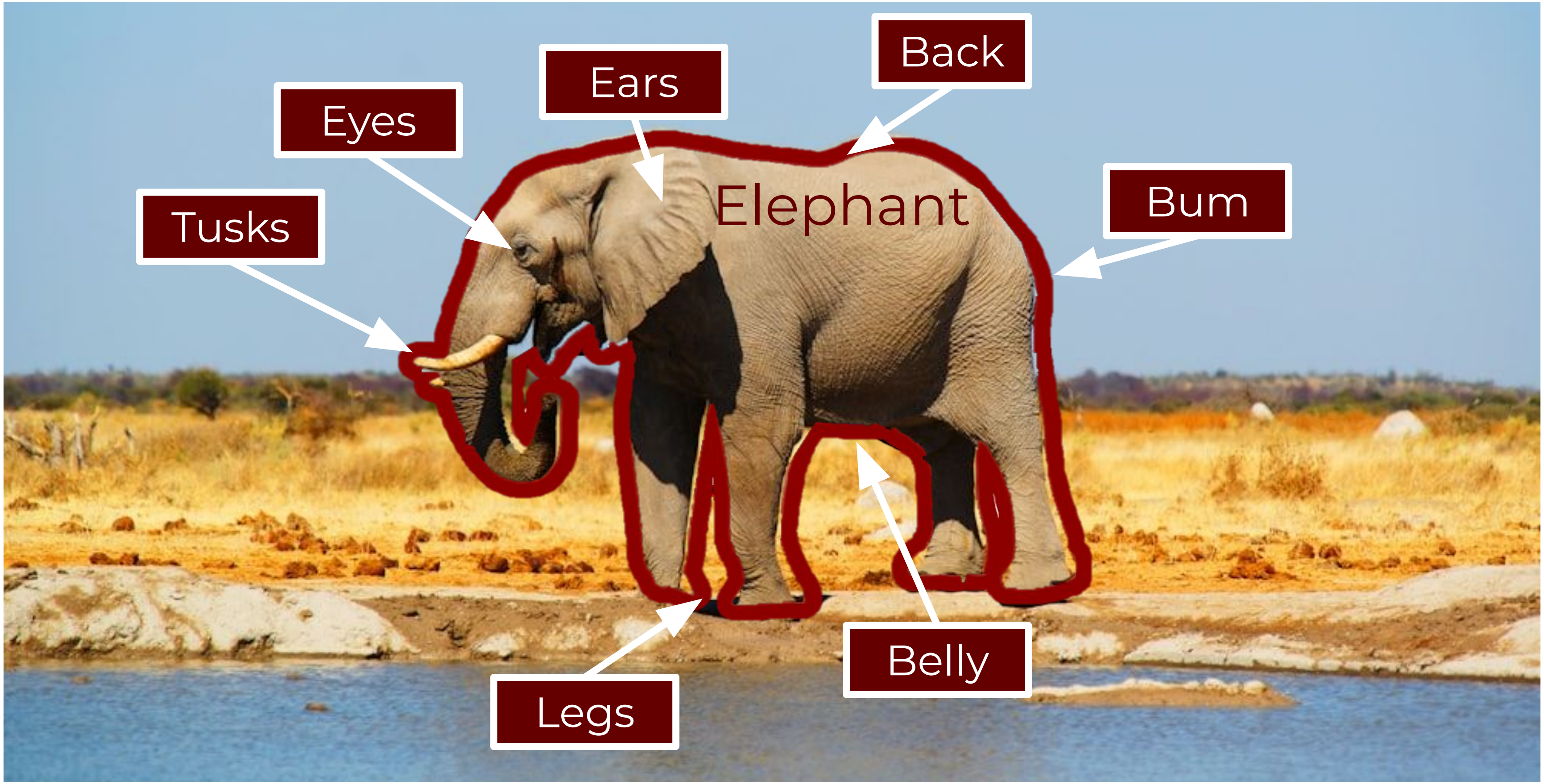
Artificial Neural Networks



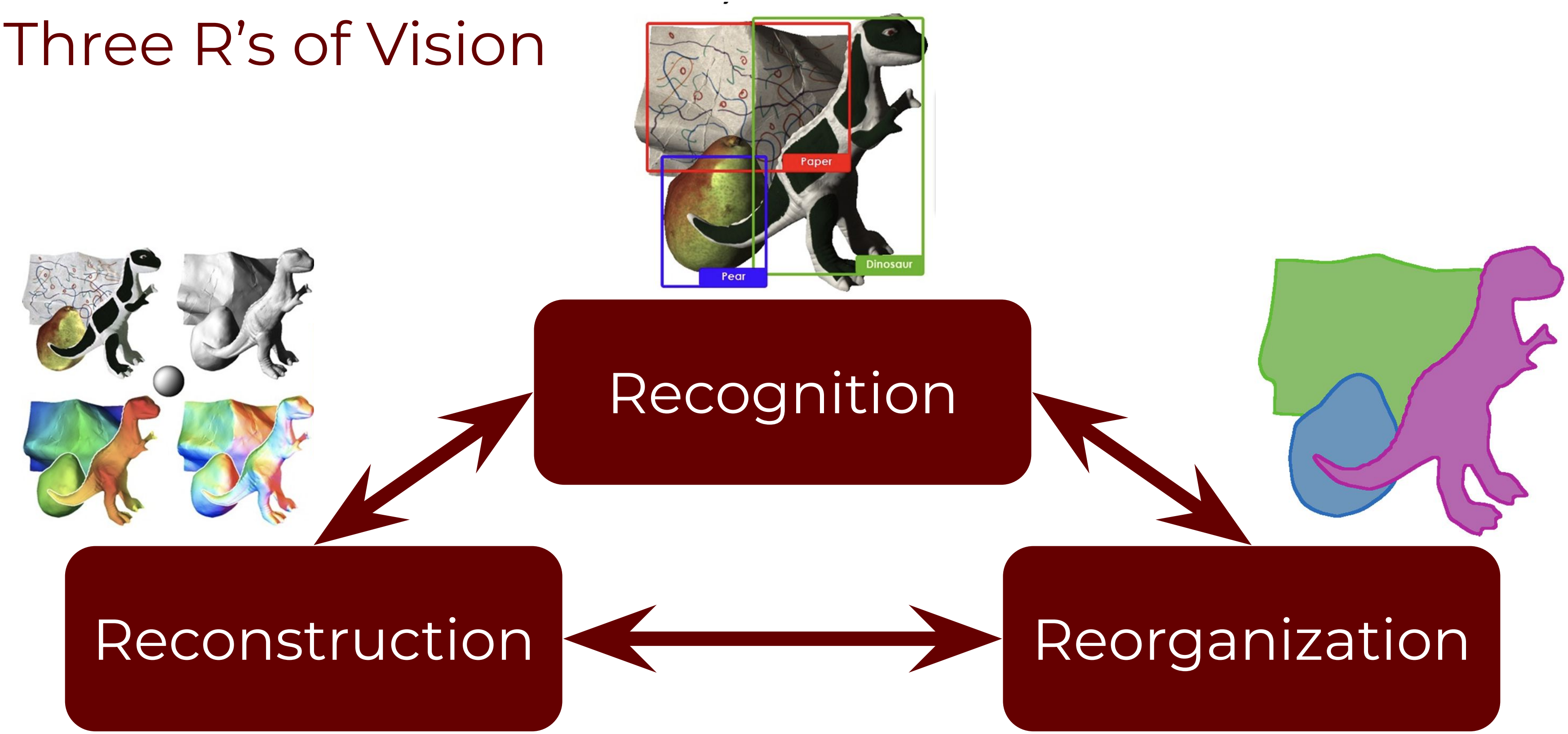
Introduction to Vision


Sky
Elephant
Grass
Water




Back
Ears
Eyes
Tusks
Elephant
Bum
Belly
Legs

Three R’s of Vision



Aspects of Vision

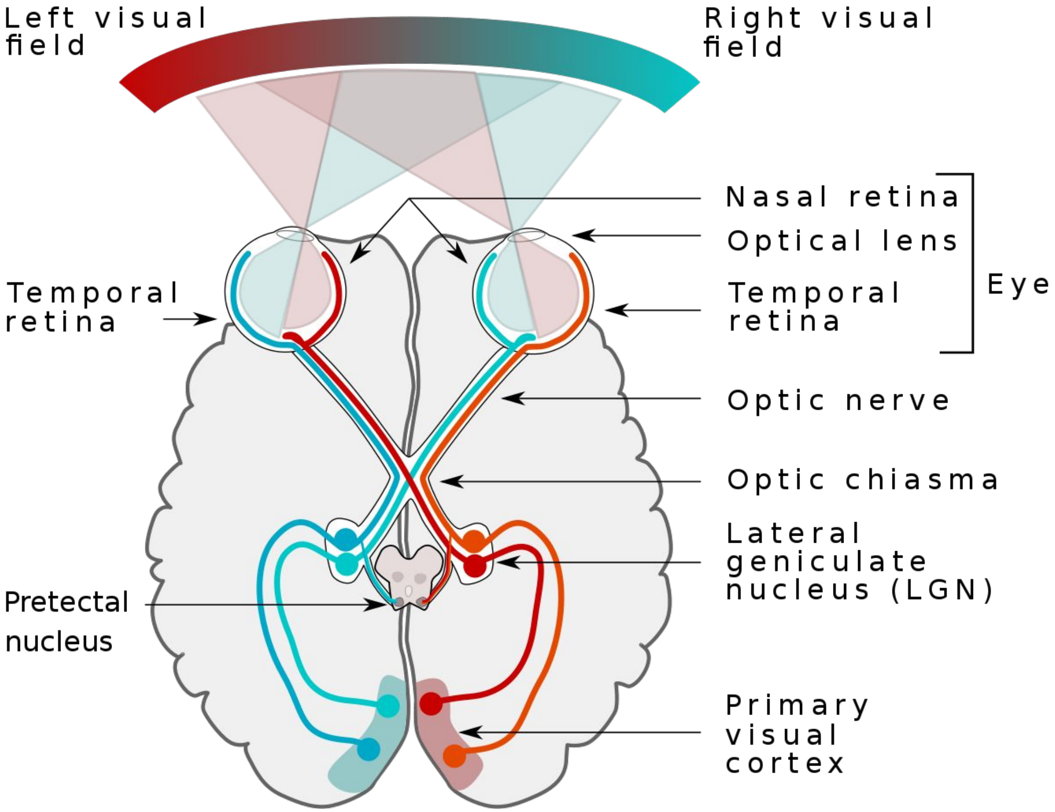
- **Perceptual**
  - Predict what a human would perceive in an image
- **Neuroscientific**
  - Understand the mechanisms in the retina and the brain
- **Functional**
  - How laws of optics, and the statistics of the world we live in, make certain interpretations of an image more likely to be valid

Aspects of Human ↔ Computer Vision

- **Perceptual**
  - Computer should be **interpretable & consistent** with human
- **Neuroscientific**
  - Human system is **source of ideas** for computer vision models
- **Functional**
  - Human ↔ Computer **match is strongest** at this level

Neurobiological Visual System

Overview of Human Visual System



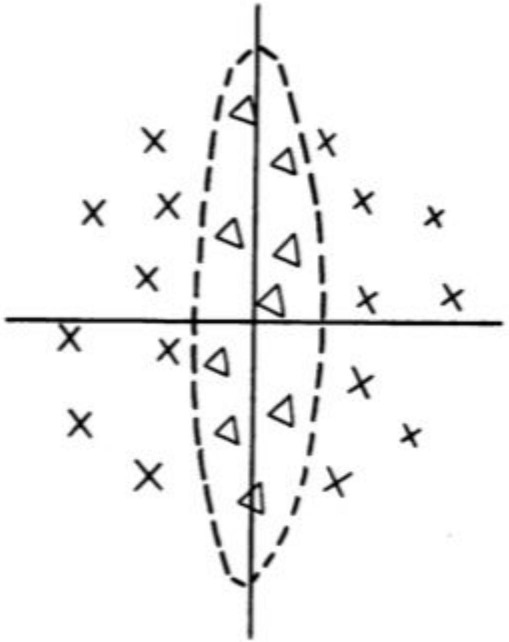
Receptive Fields (RFs)

Receptors

The receptive field of a receptor is simply the a
which light strikes that receptor.

Neurons, etc.

For any other cell in the visual system, the rece
by which receptors connect to the cell in quest

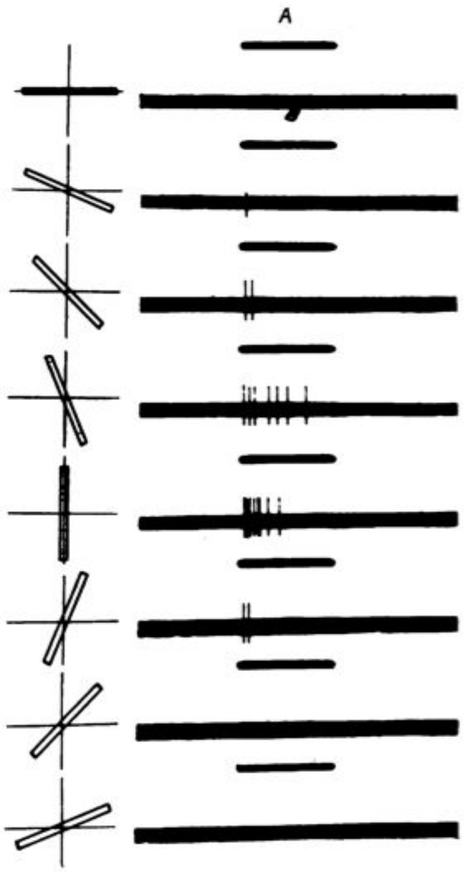


Hubel & Wiesel: 1959

Measured neuronal responses in cat striate cortex (V1)

Receptive fields...

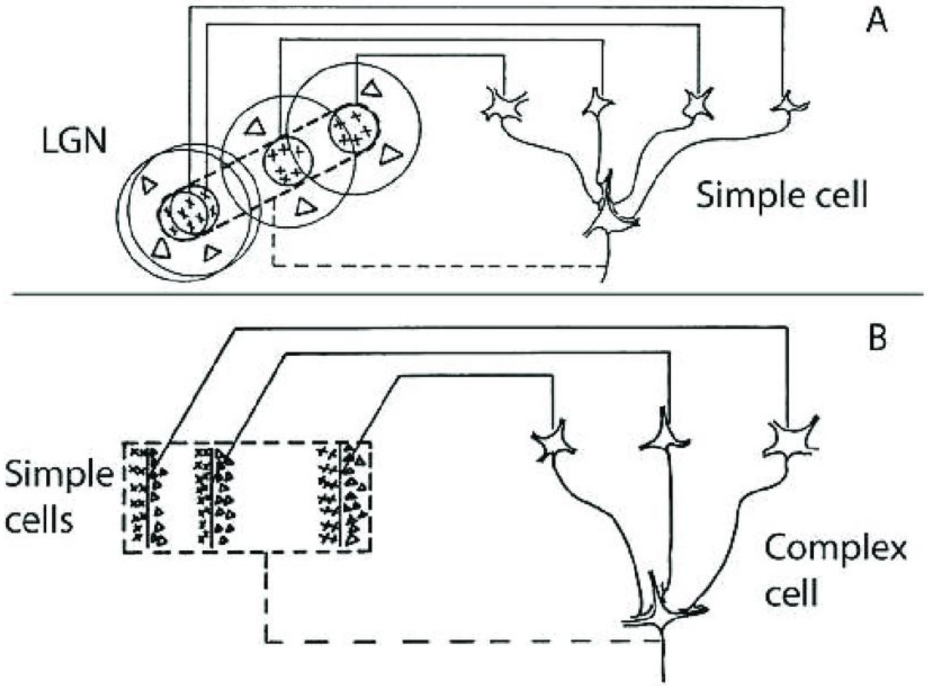
- respond depending on the orientation of input light
- contain excitatory and inhibitory regions
- are oriented in a horizontal, vertical, or oblique manner



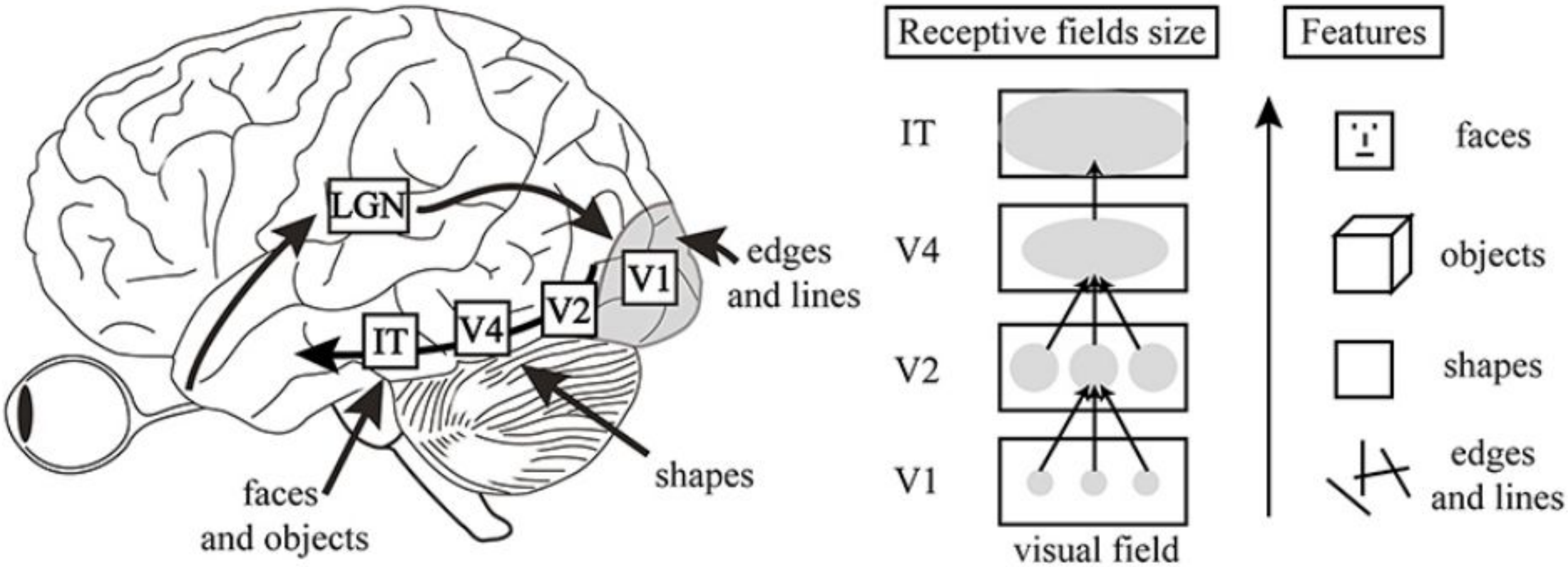
Hubel & Wiesel: 1962

Striate cortex (V1) contains two cell types:

- Simple (S) cells
    - Encode and elongate retinal RFs
    - Susceptible to fuzziness and noise
- Complex (C) cells
    - Fine-tune and orient S-cell RFs
    - Robust against S-cell shortcomings

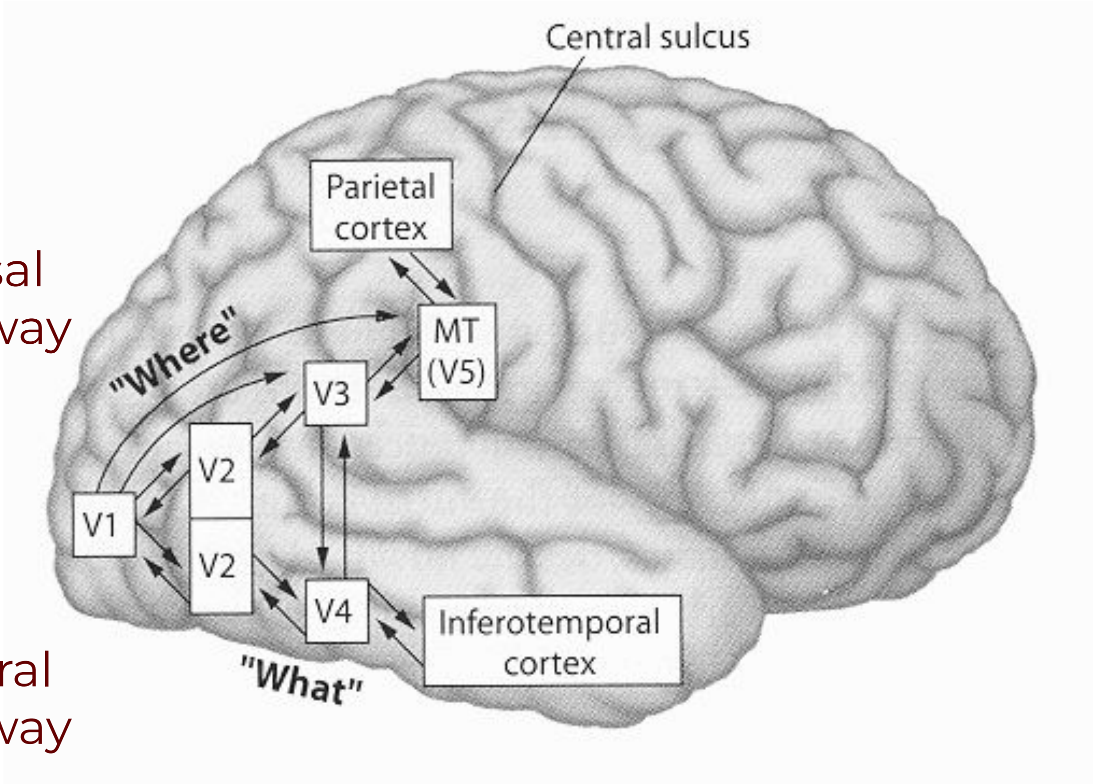


Human Visual Cortex Ventral Pathway



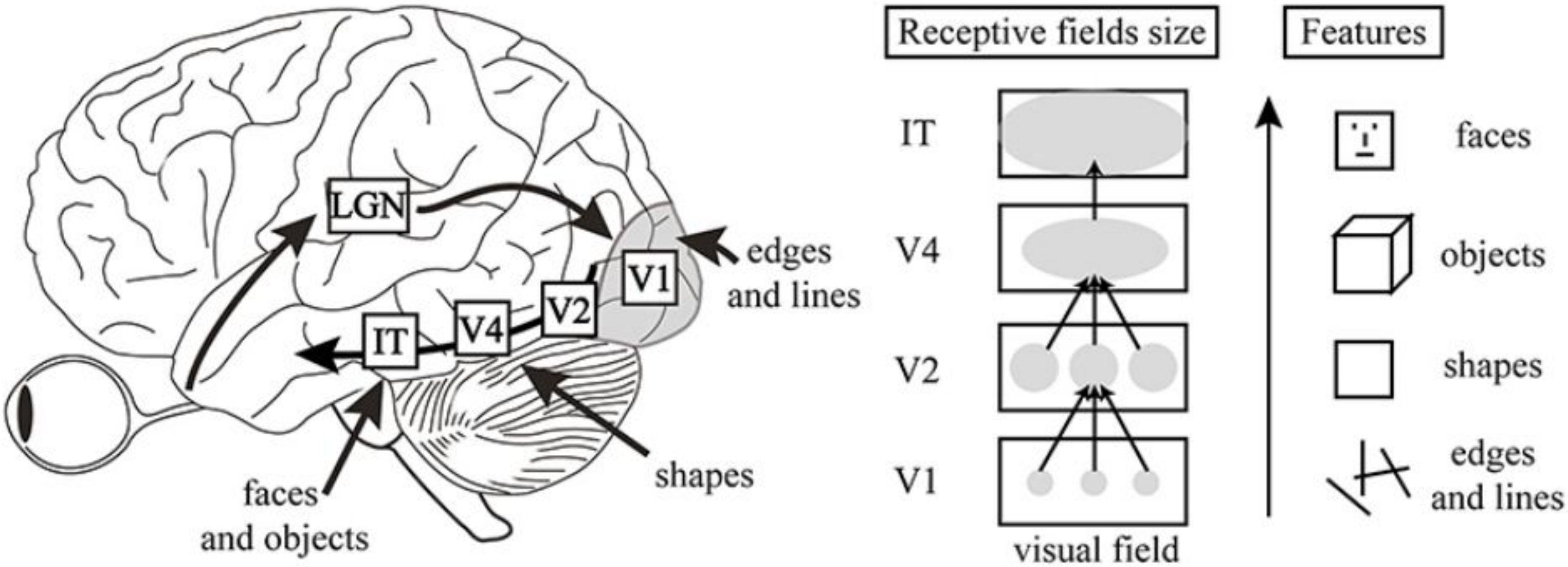
Post-Striatal Processing

Dorsal pathway



Ventral pathway

Human Visual Cortex Ventral Pathway



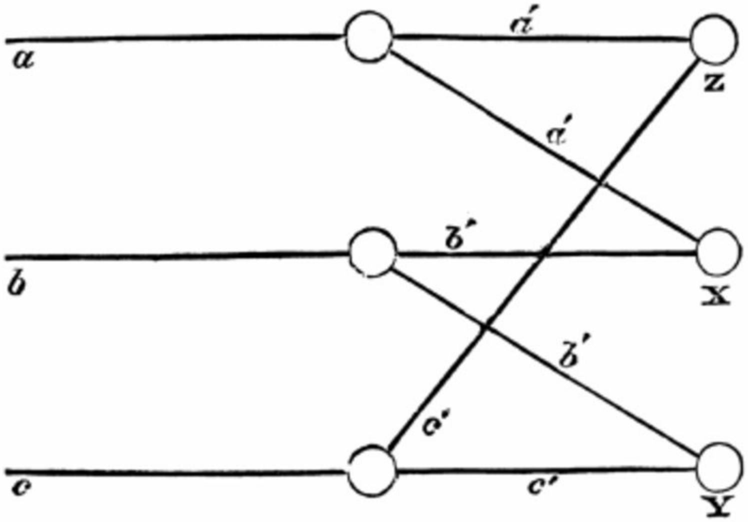
Introduction to Neural Networks

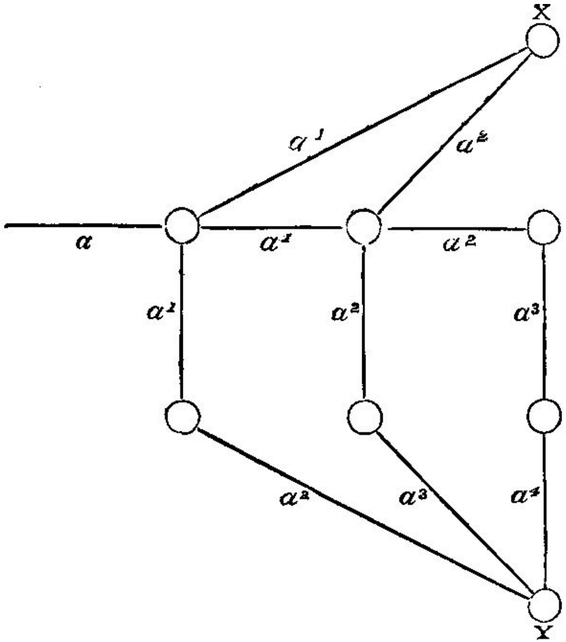
Neural Networks as Cognitive Models

- The earliest model of cognition was associationism
    - Humans learn through association

Neural Networks as Cognitive Models

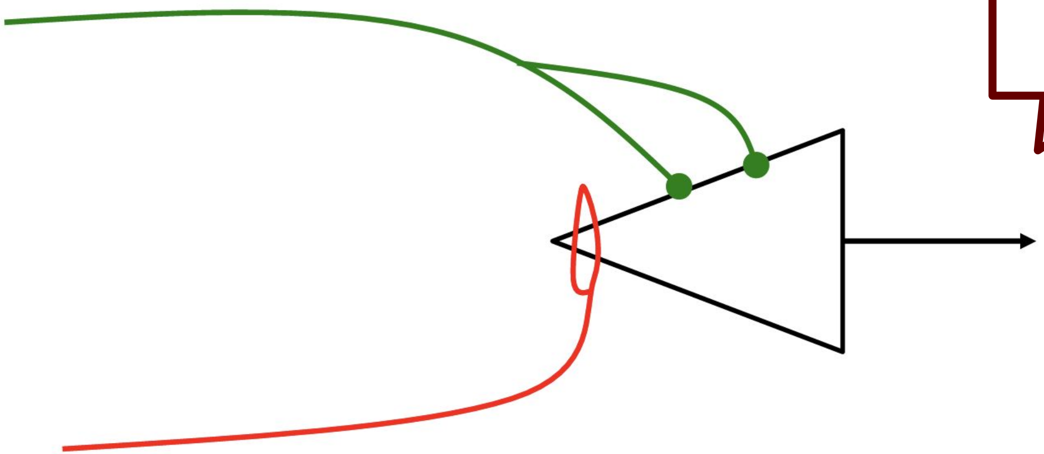
- The more recent model of the brain is connectionist
  - Neurons connect to neurons
  - Information is encoded in connections





Neural Networks as Connectionist Machines

- **McCullough & Pitt Model**: Neurons as Boolean threshold units
    - Models the brain as performing propositional logic
    - No learning rule!



This is a Single Neuron Model!

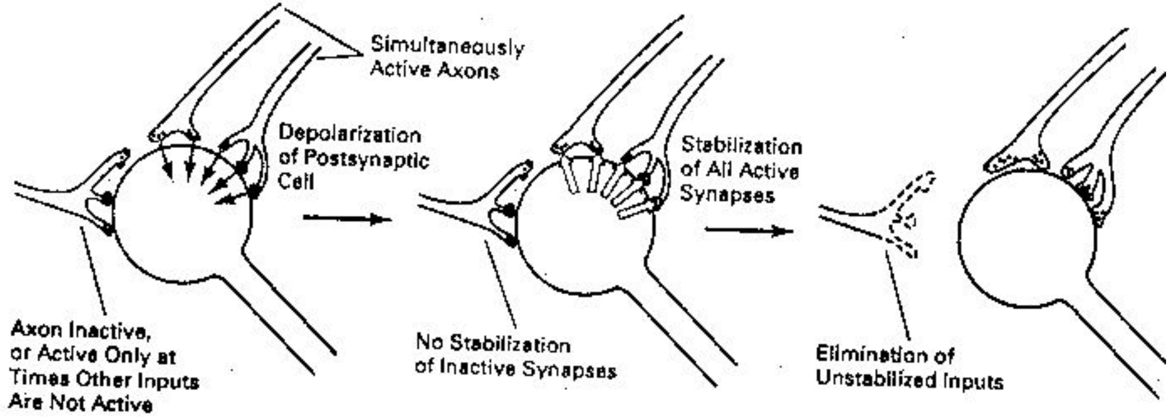
Neural Networks as Connectionist Machines

- **Hebb learning rule**
    - As neuron $\boldsymbol{x_i}$ repeatedly excites neuron $\boldsymbol{y}$, its ability to excite $\boldsymbol{y}$ improves

The formulaic basis of many machine learning algorithms!

$$w_i = w_i + \eta x_i y$$

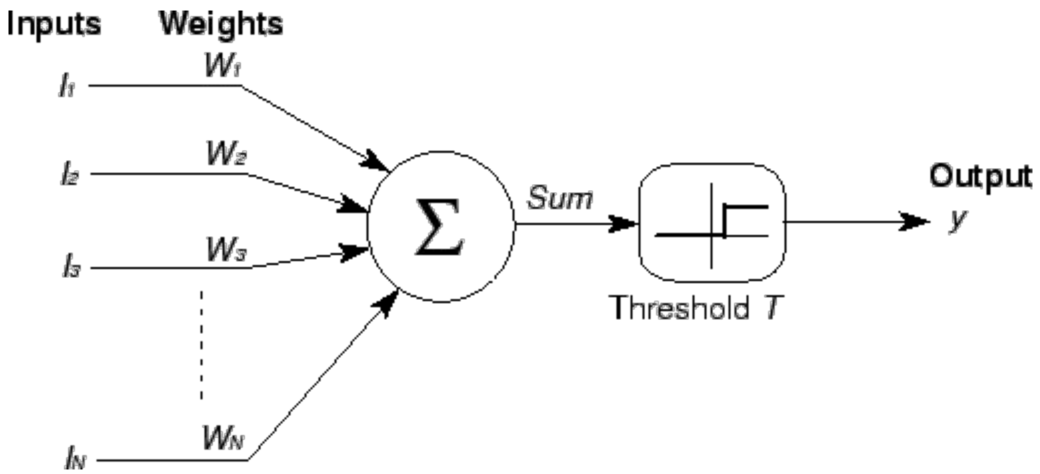
Weight of $\boldsymbol{i}^{\text{th}}$ neuron's input to output neuron $\boldsymbol{y}$



Neurons that fire together wire together!

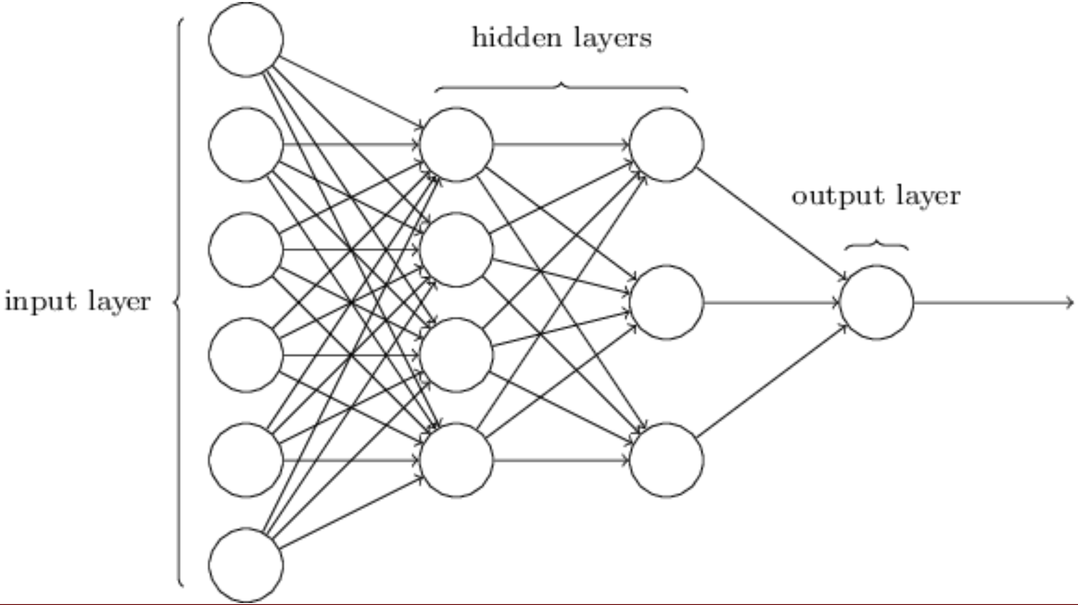
Neural Networks as Connectionist Machines

- **Rosenblatt perceptron**
  - McCulloch and Pitt neuron with a provably convergent learning rule
  - Number of inputs combine linearly
  - Threshold logic: Neuron fires if combined input exceeds threshold



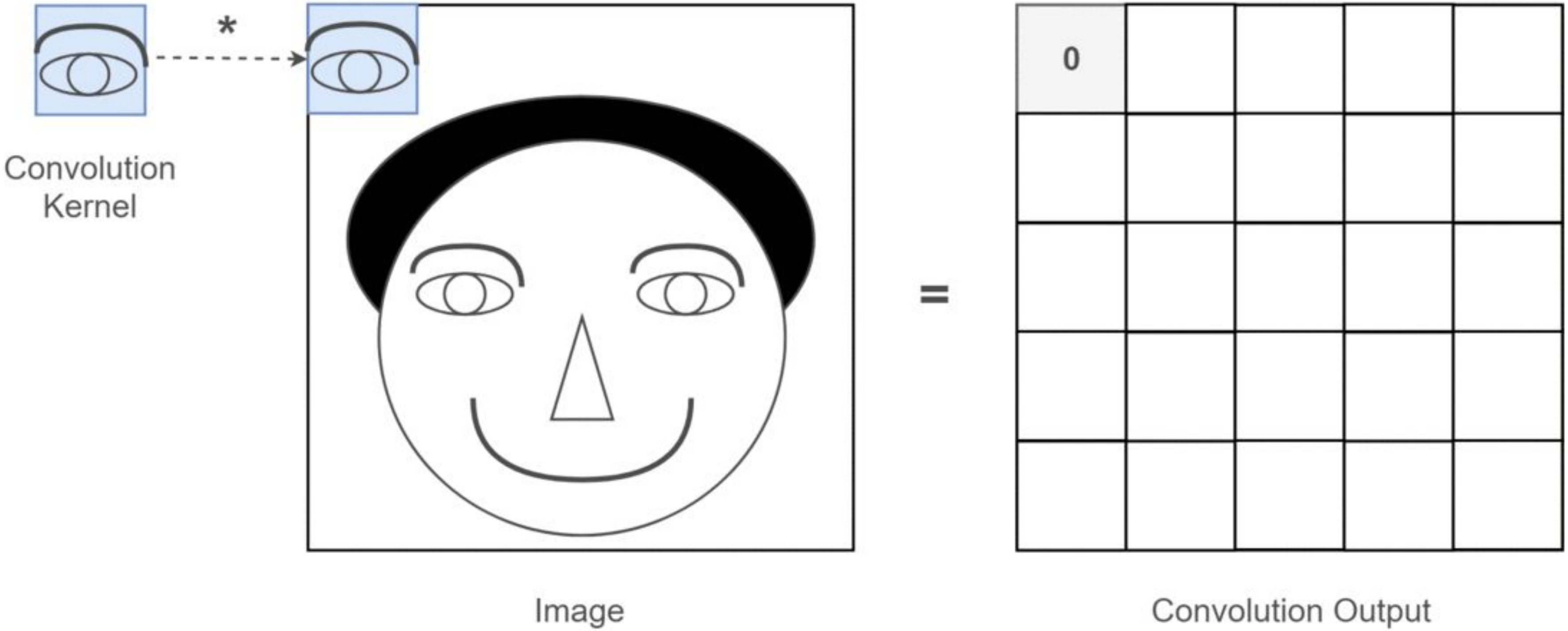
Neural Networks as Connectionist Machines

- **Minsky & Papert Multi-Layer Perceptron (MLP)**
  - Individual elements are perceptrons that detect features
  - Fires if the combination of features match a desired class of signal



Convolutional Neural Networks

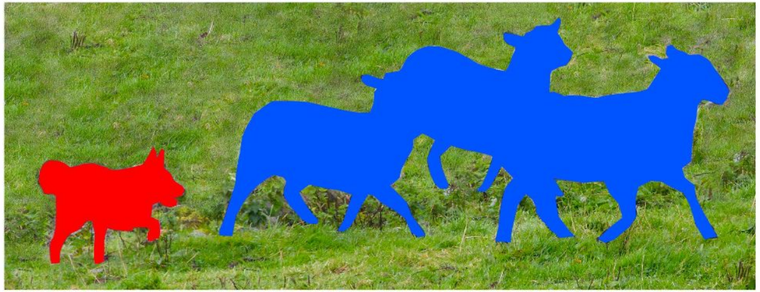
Convolution combines two signals to form a third!



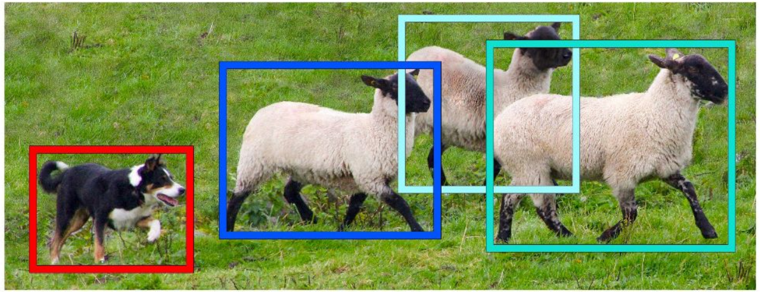
Back to vision…

Types of Computer Vision Tasks

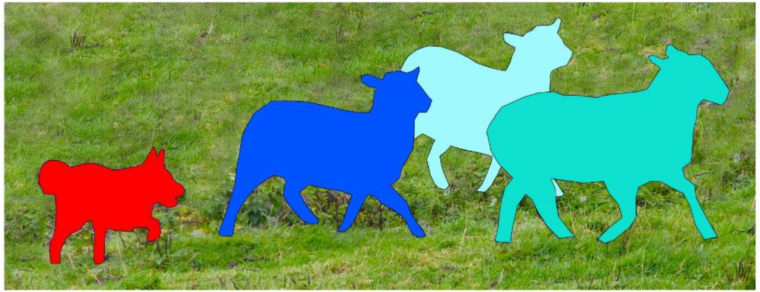
Image Recognition



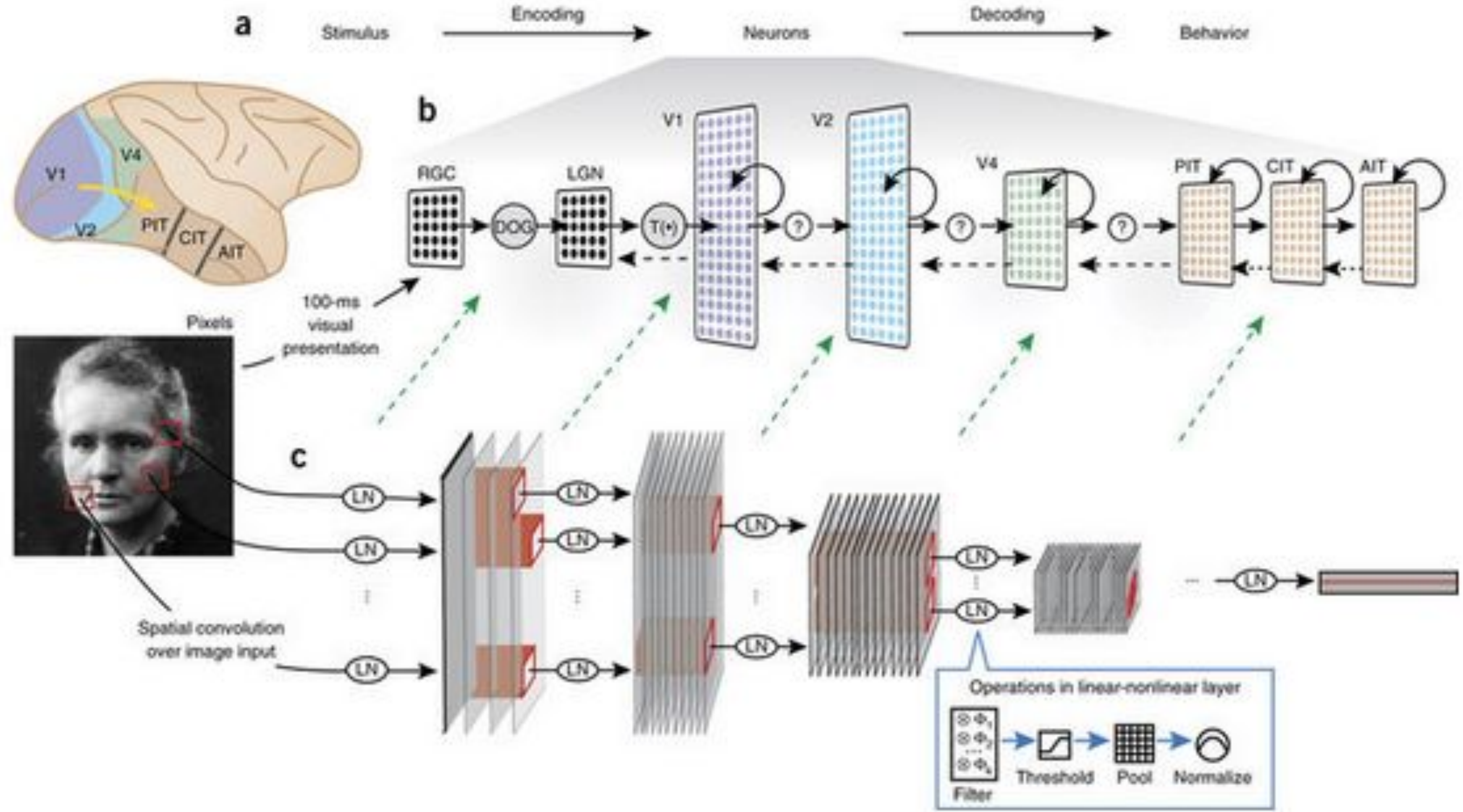
Semantic Segmentation



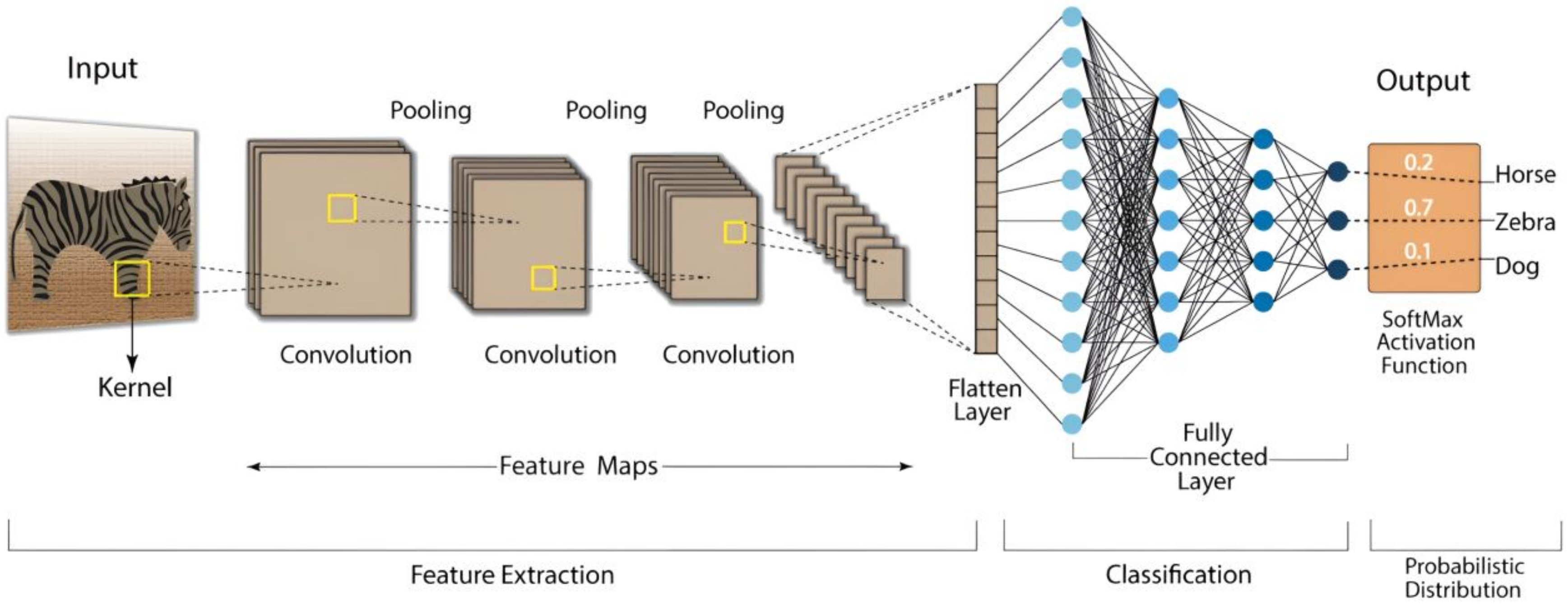
Object Detection



Instance Segmentation


a
Stimulus
Encoding
Neurons
Decoding
Behavior
b
V1
V4
V2
PIT
CIT
AIT
RGC
DOG
LGN
T(•)
V1
V2
V4
PIT
CIT
AIT
Pixels
100-ms visual presentation
c
LN
Spatial convolution over image input
Operations in linear-nonlinear layer
Filter
Threshold
Pool
Normalize

Convolution Neural Network (CNN)



Appendix

Neural Networks as Connectionist Machines

- Neural network models comprise networks of neural units
- McCullough and Pitt model: Neurons as Boolean threshold units
    - Models the brain as performing propositional logic
    - But no learning rule
- Hebb's learning rule: Neurons that fire together wire together
    - Unstable
- Rosenblatt's perceptron: Provably convergent learning rule
    - But individual perceptrons are limited in their capacity
- Multi-layer perceptrons can model arbitrarily complex Boolean functions