EENG582
Artificial Neural Networks

Introduction

Sections 1.1 -1.2 – Introduction
Biologican and Artificial Neural Networks + Brain

Artificial Neural Networks

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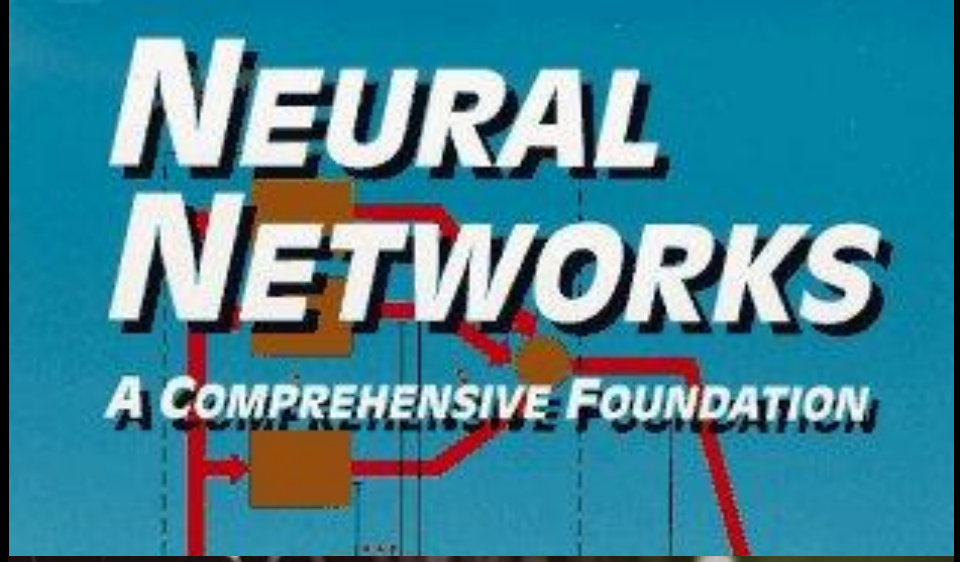
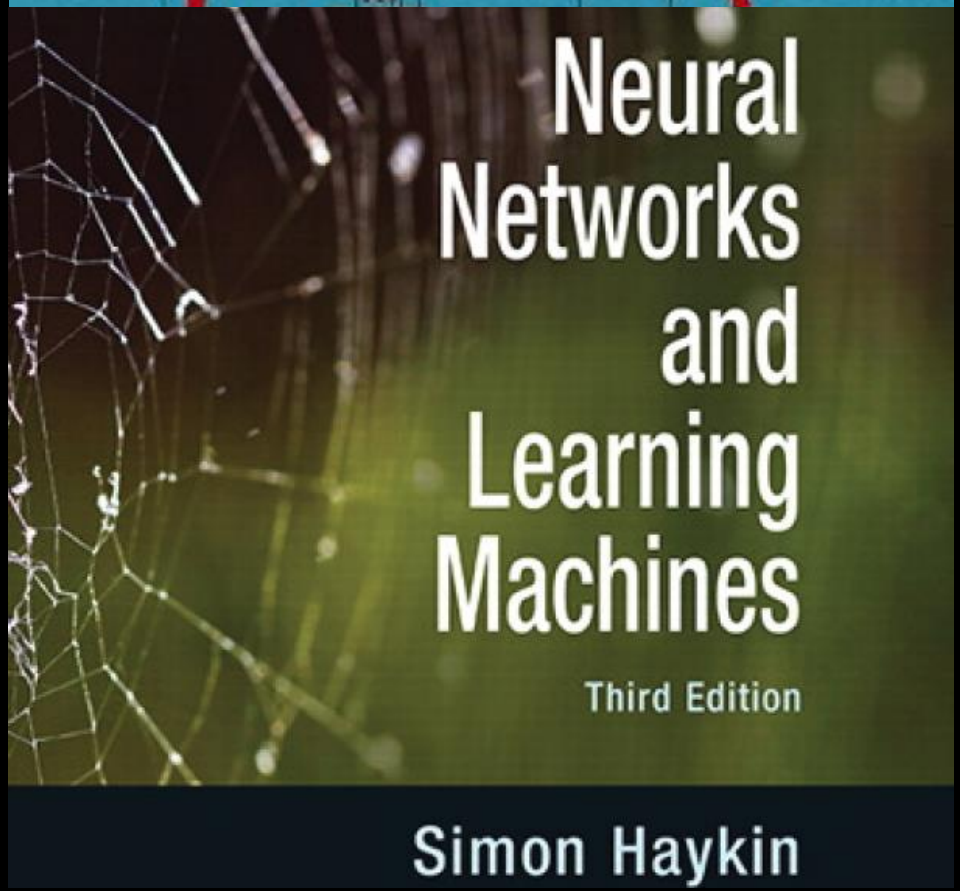
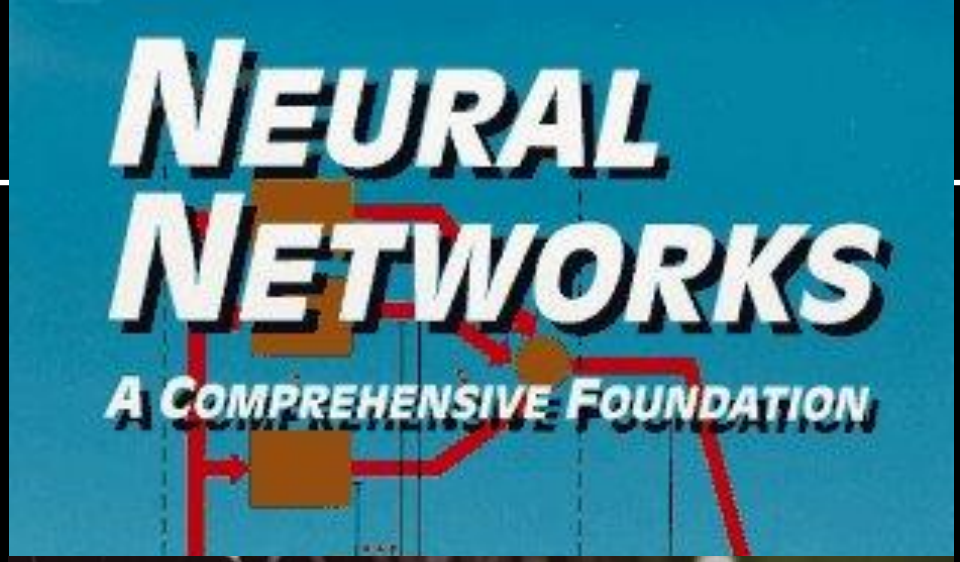
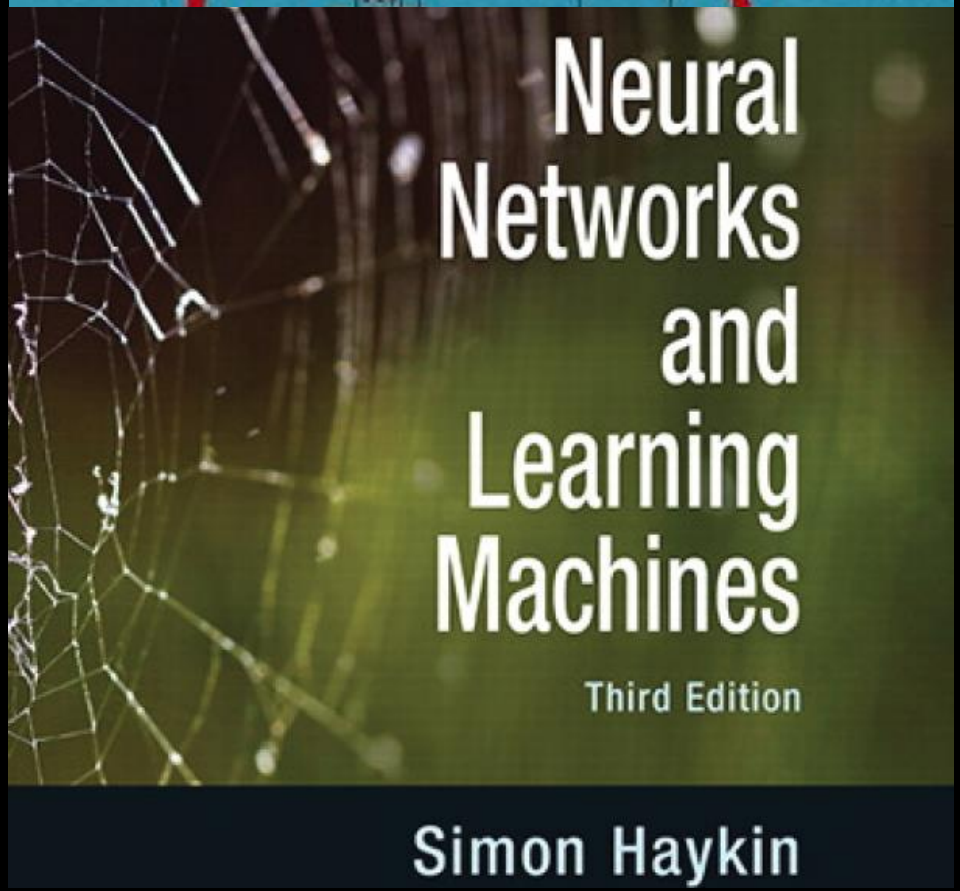




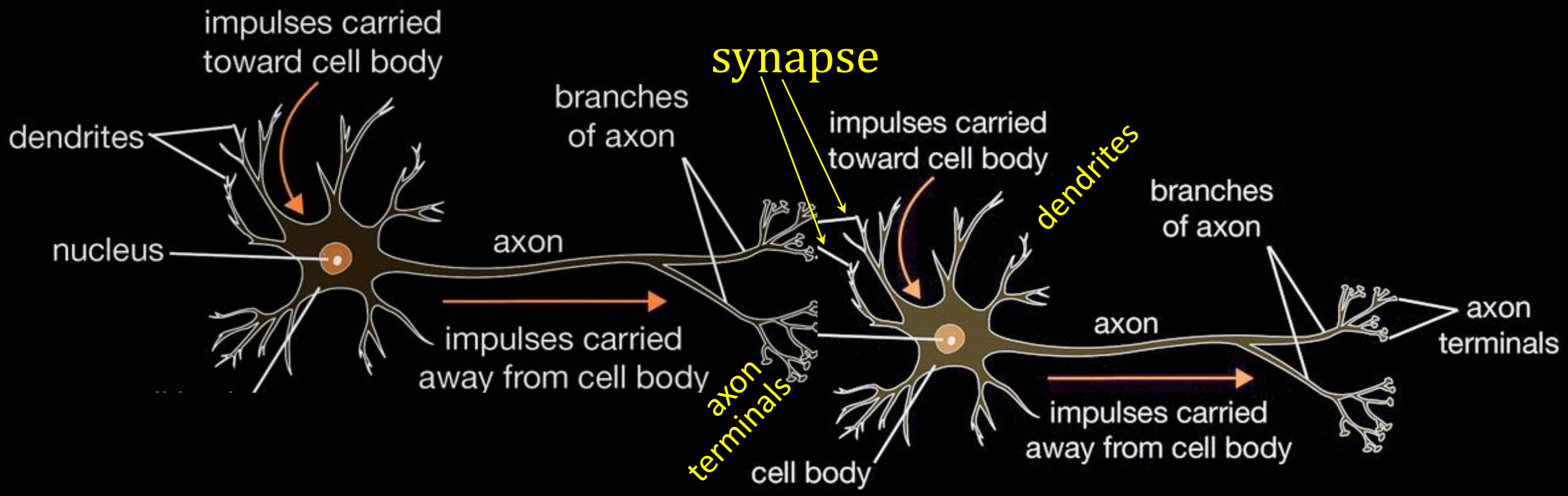
1 Introduction





What is a Biological Neural Network (BNN)?

- A Biological Neural Network is a network composed of a group of chemically connected or functionally associated neurons
- A single neuron may be connected to many other neurons
- Total number of neurons and connections in a network may be extensive



Source: https://www.cs.toronto.edu/~lczhang/360/lec/w02/terms.html

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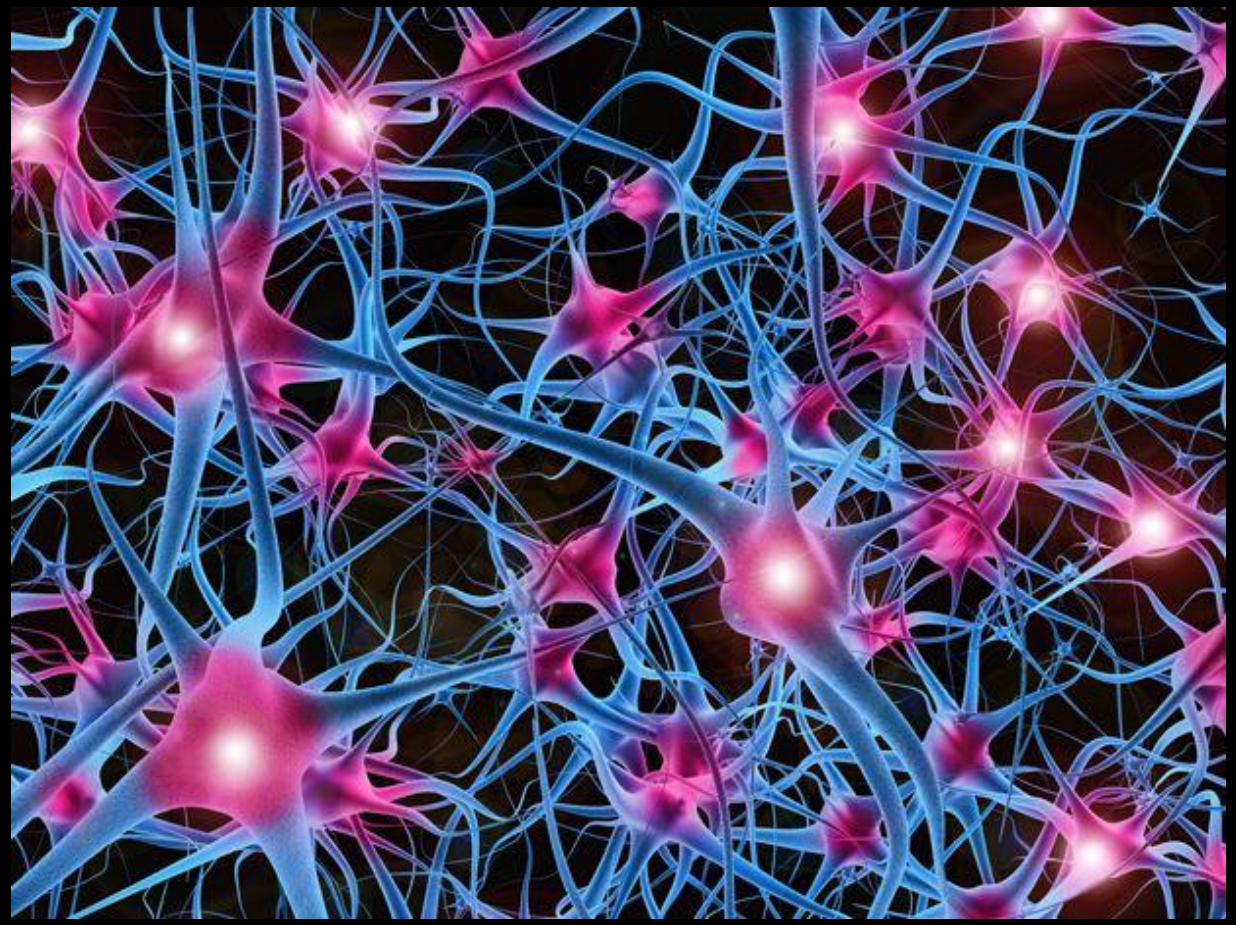
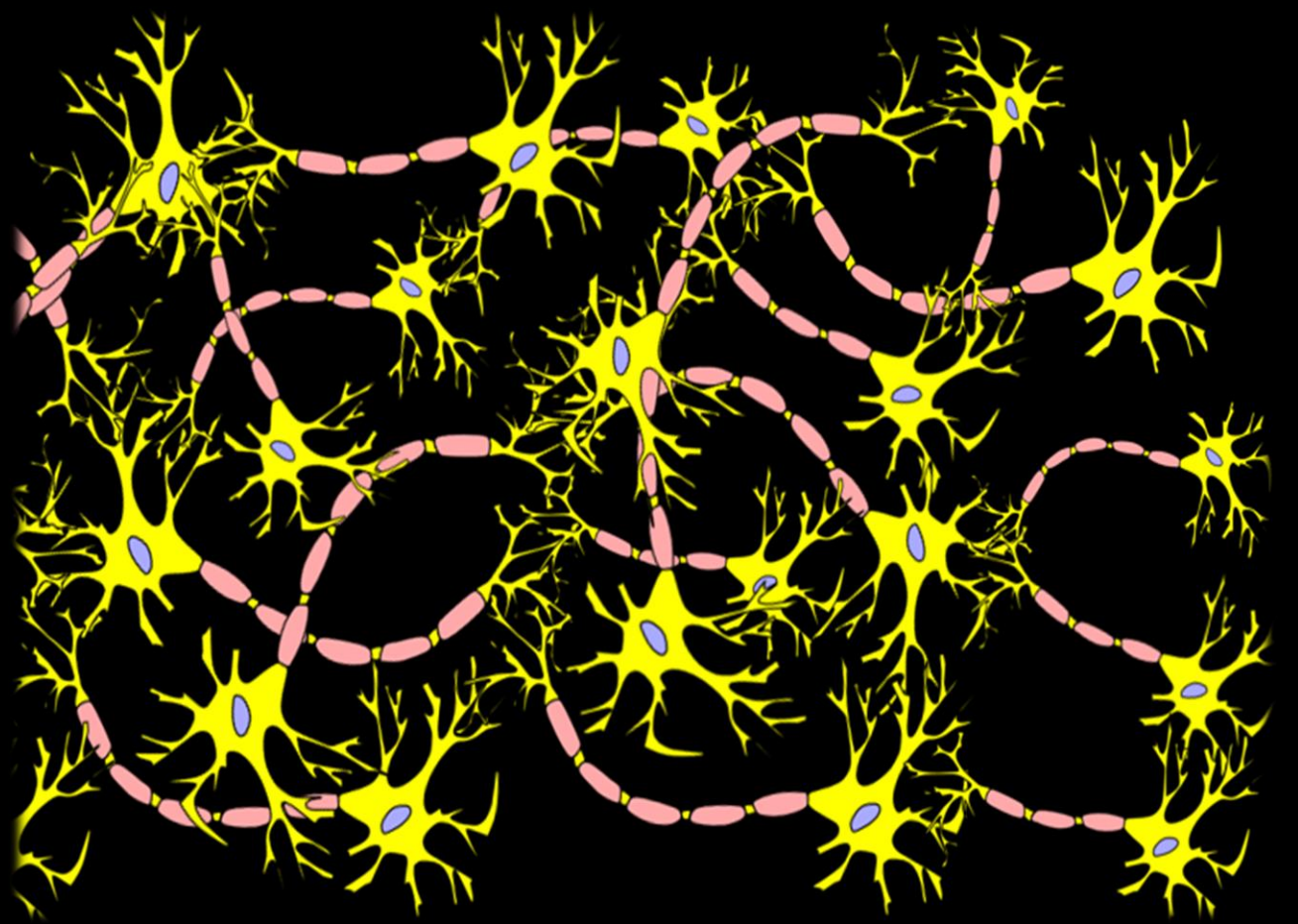


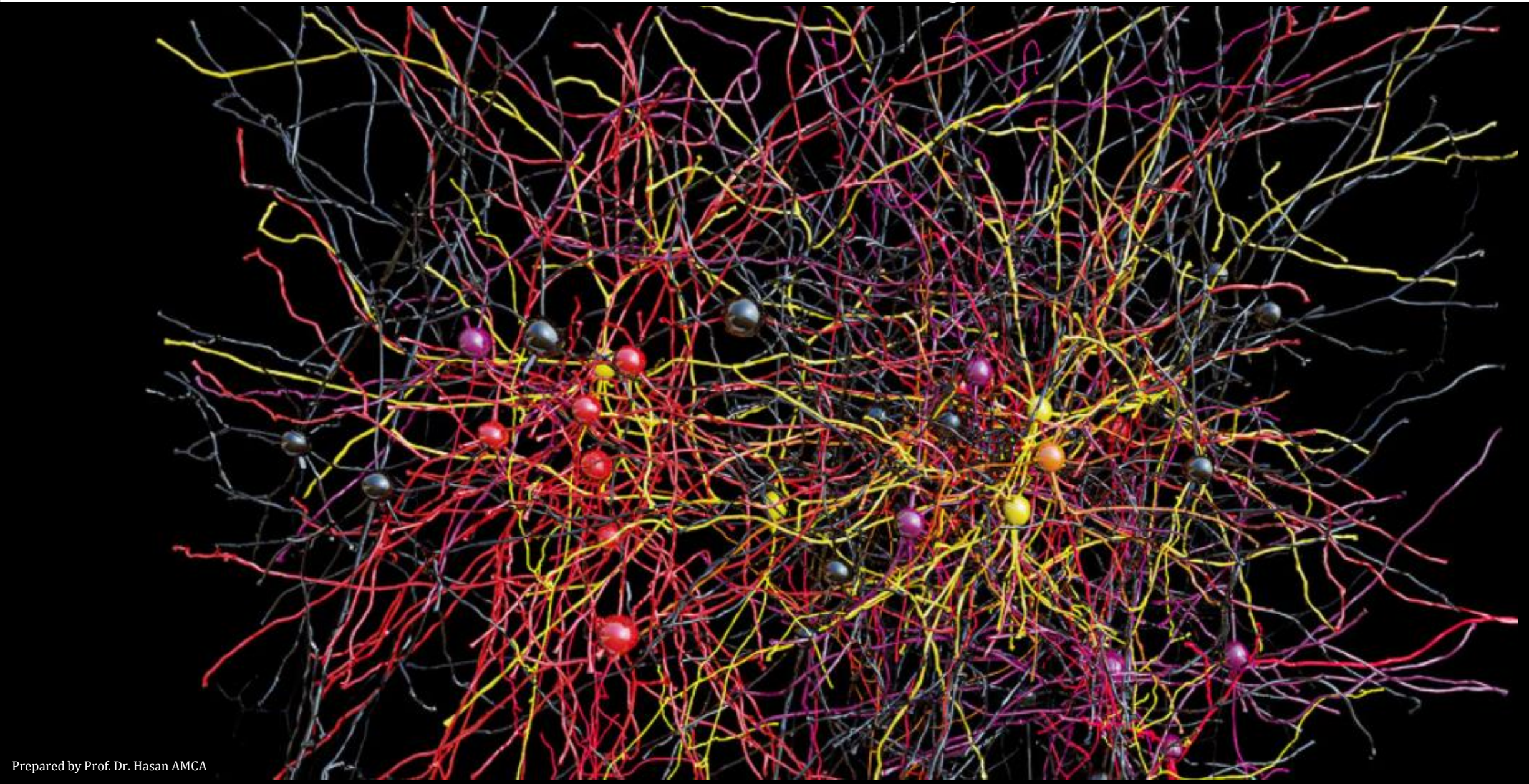
Actual Picture of Human Neurons



Model Representing Human Neurons

https://www.alamy.com/stock-photo-image-concept-of-a-network-of-neurons-in-the-human-brain-144400787.html

One of the Most Impressive Functional Brain Maps Ever From Harvard University Lab Mouse.

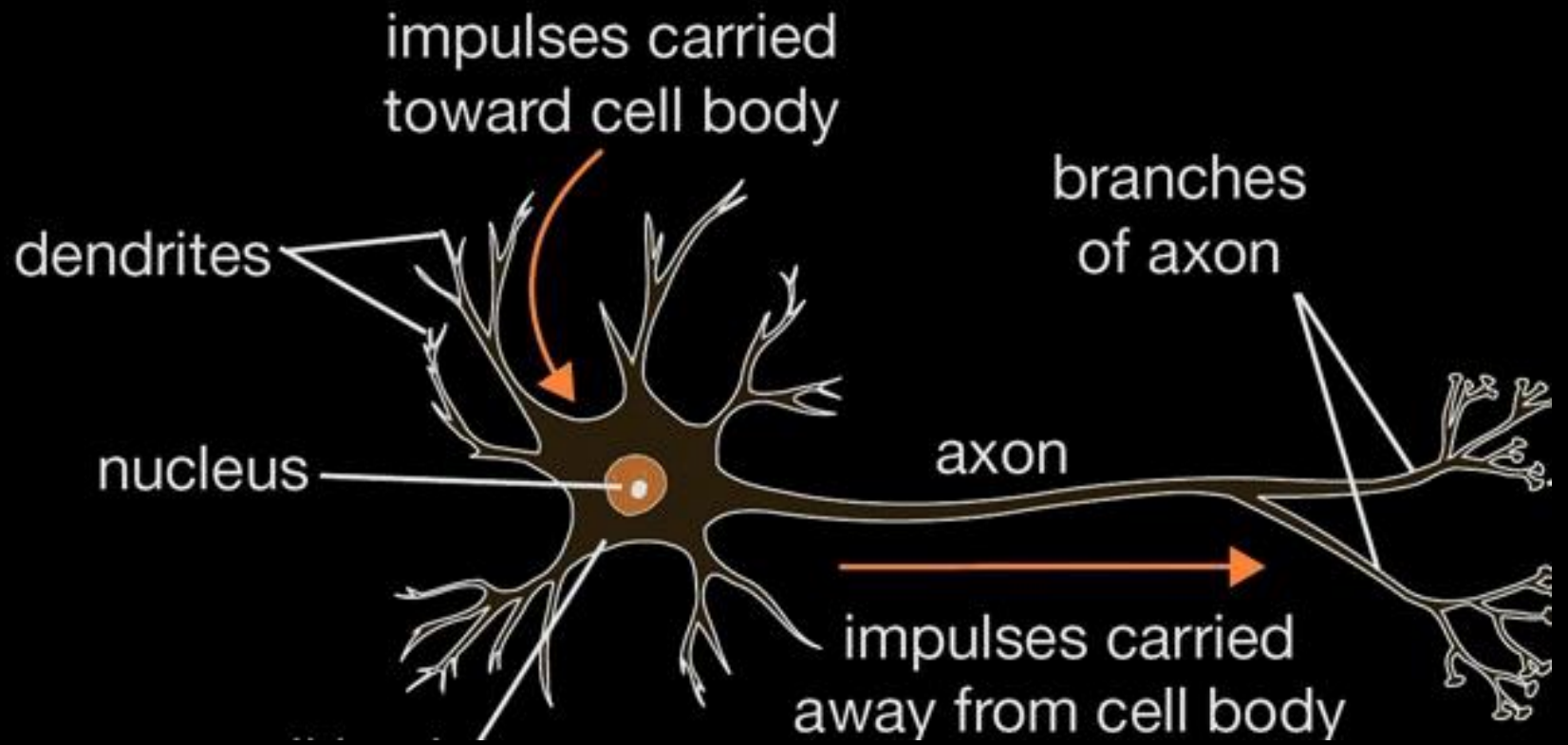


Read the story of a Mouse's brain

https://www.wired.com/2016/03/took-neuroscientists-ten-years-map-tiny-slice-brain/

Neurons are the Fundamental Units of BNNs

- Neurons (also called neurones or nerve cells) are the fundamental units of the brain and nervous system.
- Neurons are responsible for receiving sensory input from the external world,
  - ~ for sending motor commands to our muscles, and
  - ~ for transforming and relaying the electrical signals at every step in between.



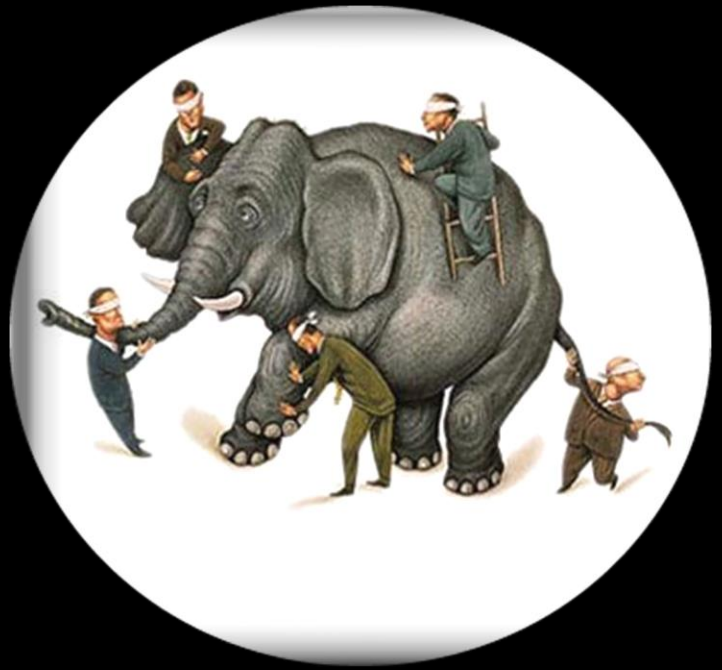
Source: https://www.cs.toronto.edu/~lczhang/360/lec/w02/terms.html

Neurons are the Fundamental Units of BNNs

Neurons are responsible for carrying the signals to perform certain activities such as pattern recognition perception and motor control

Pattern Recognition

VectorStock.com/26631293



Perception

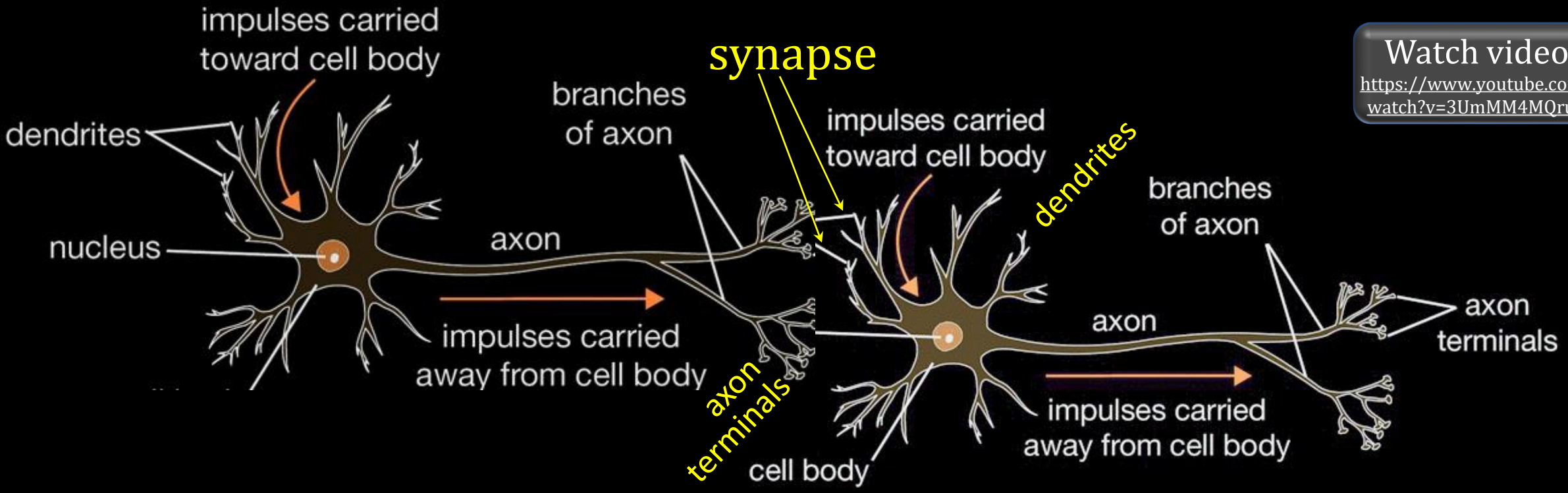
https://www.goconqr.com/quiz/3448871/six-blind-men-and-an-elephant-

Motor Control

ps://www.purdue.edu/hhs/hk/Biomechanics-MotorBehavior/research/motor-control/

Communication Between Neurons

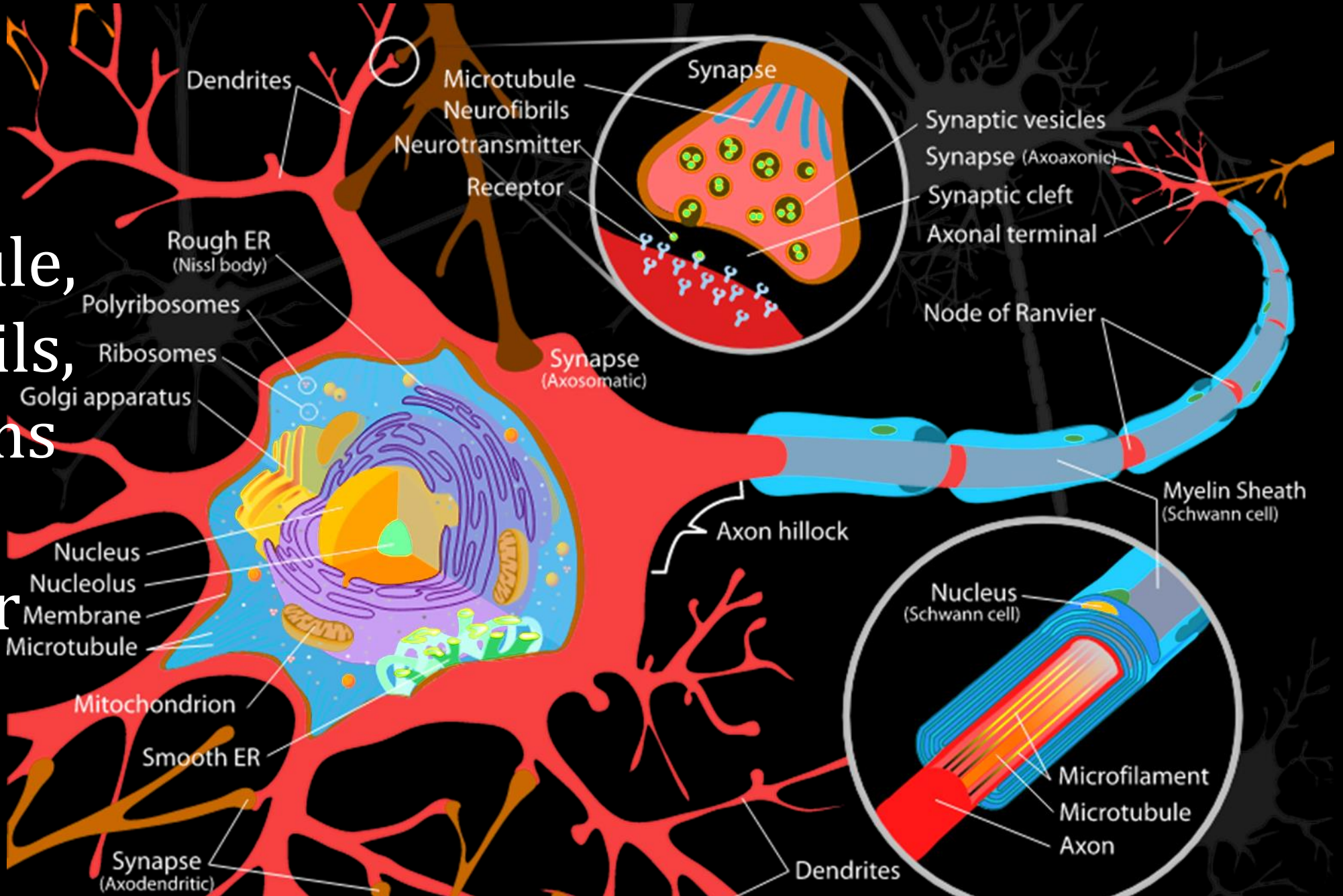
- Neurons pass information from one to another using action potentials
- They connect with one another at synapse, which are junctions between one neuron's axon and another's dendrite
- Information flows from the dendrite to the cell body through the axons to a synapse connecting the axon to the dendrite of the next neuron



Watch video
https://www.youtube.com/watch?v=3UmMM4MQru8

Source: https://www.cs.toronto.edu/~lczhang/360/lec/w02/terms.html

Microtubule, Neurofibrils, Neurotrans mitter, Receptor

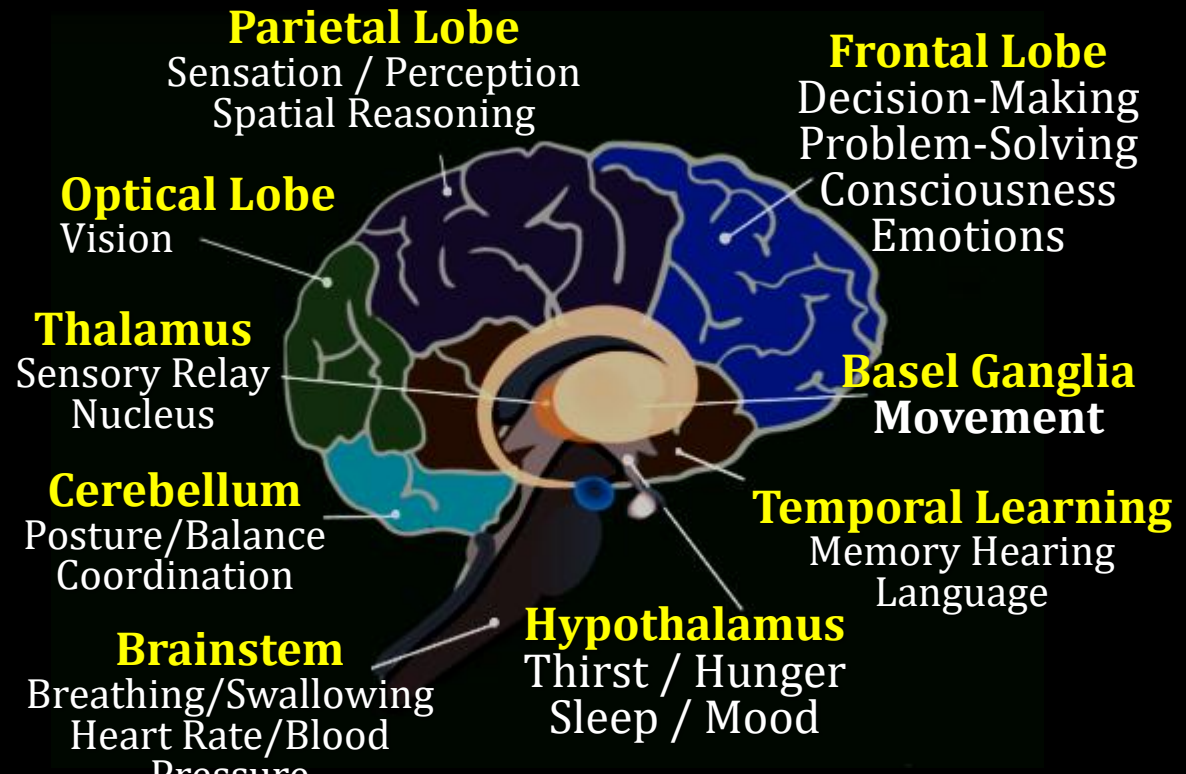


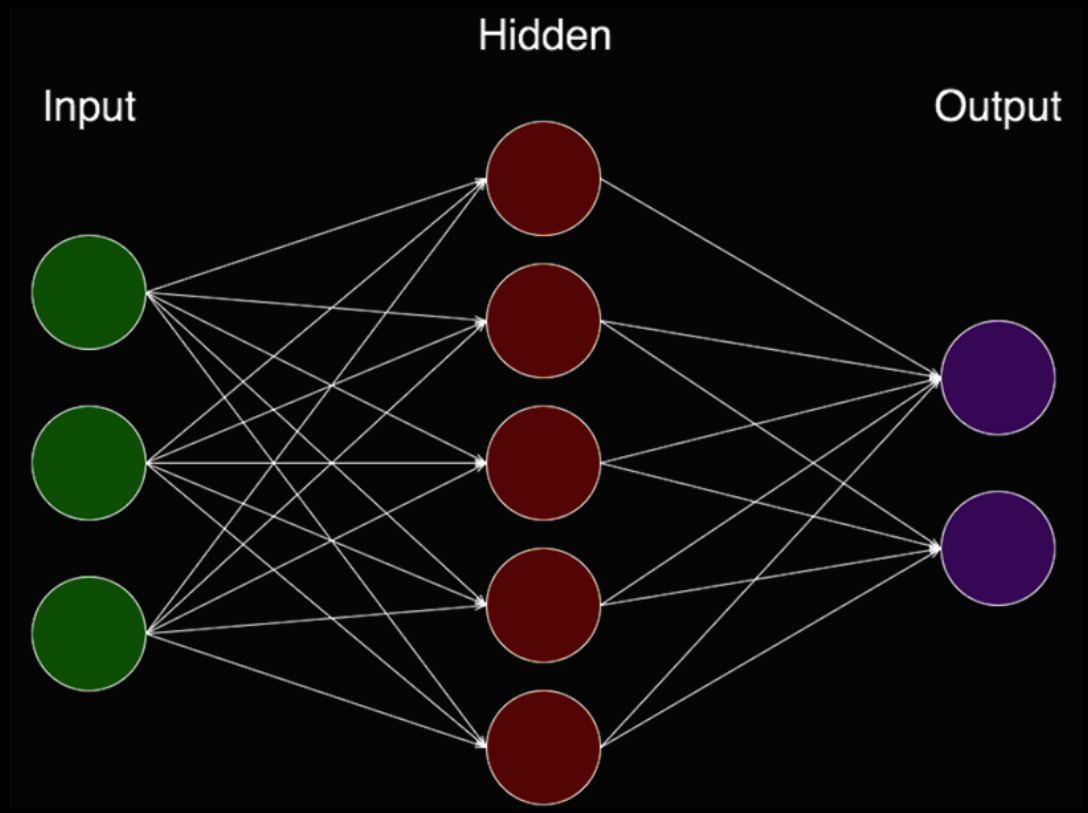
https://biologyreader.com/neurons.html

https://blogs.oracle.com/bigdata/neural-networks-in-deep-learning

How Does the Brain Work?

- At birth, a brain has great structure and the ability to build up its own rules through what we usually refer to as "experience."
- experience is built up over time, with the most dramatic development
  ~i.e., hard-wiring of human brain take place during first two years from birth
  ~but the development continues well beyond that stage





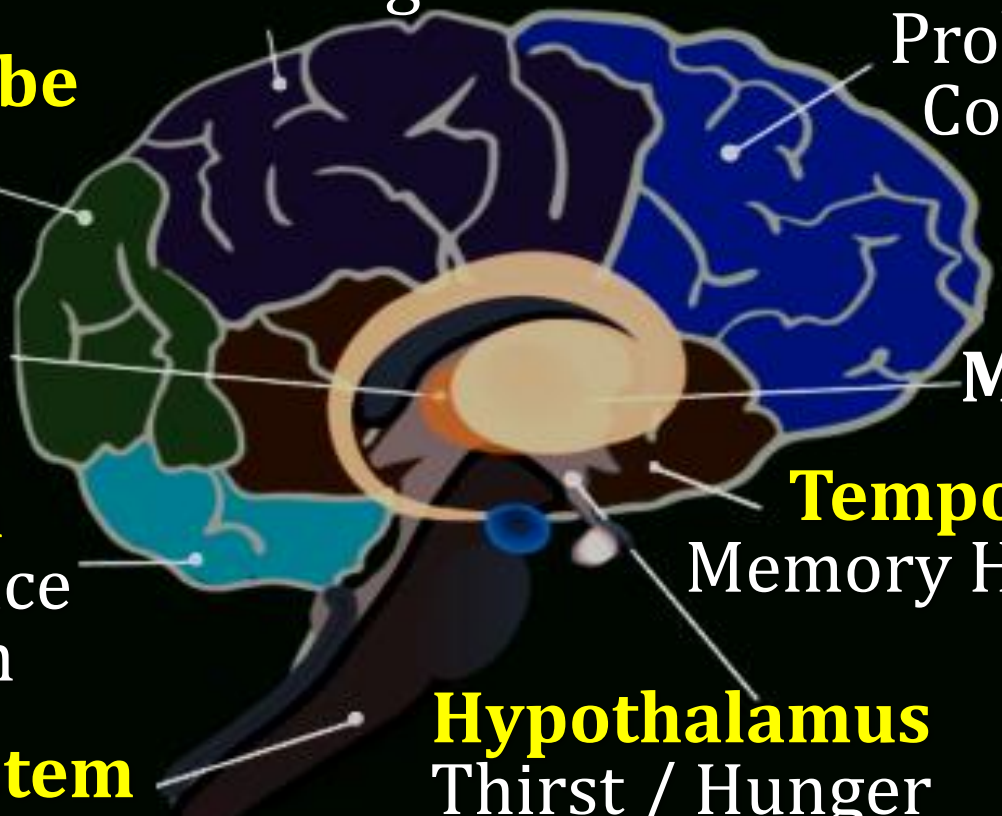
https://www.dana.org/article/how-does-the-brain-work/

How Does the Brain Work?

Parietal Lobe
Sensation / Perception
Spatial Reasoning

Frontal Lobe
Decision-Making
Problem-Solving
Consciousness
Emotions

Optical Lobe
Vision



Thalamus
Sensory Relay
Nucleus

Basel Ganglia
Movement

Cerebellum
Posture/Balance
Coordination

Temporal Learning
Memory Hearing Language

Hypothalamus
Thirst / Hunger
Sleep / Mood

Brainstem
Breathing/Swallowing
Heart Rate/Blood
Pressure

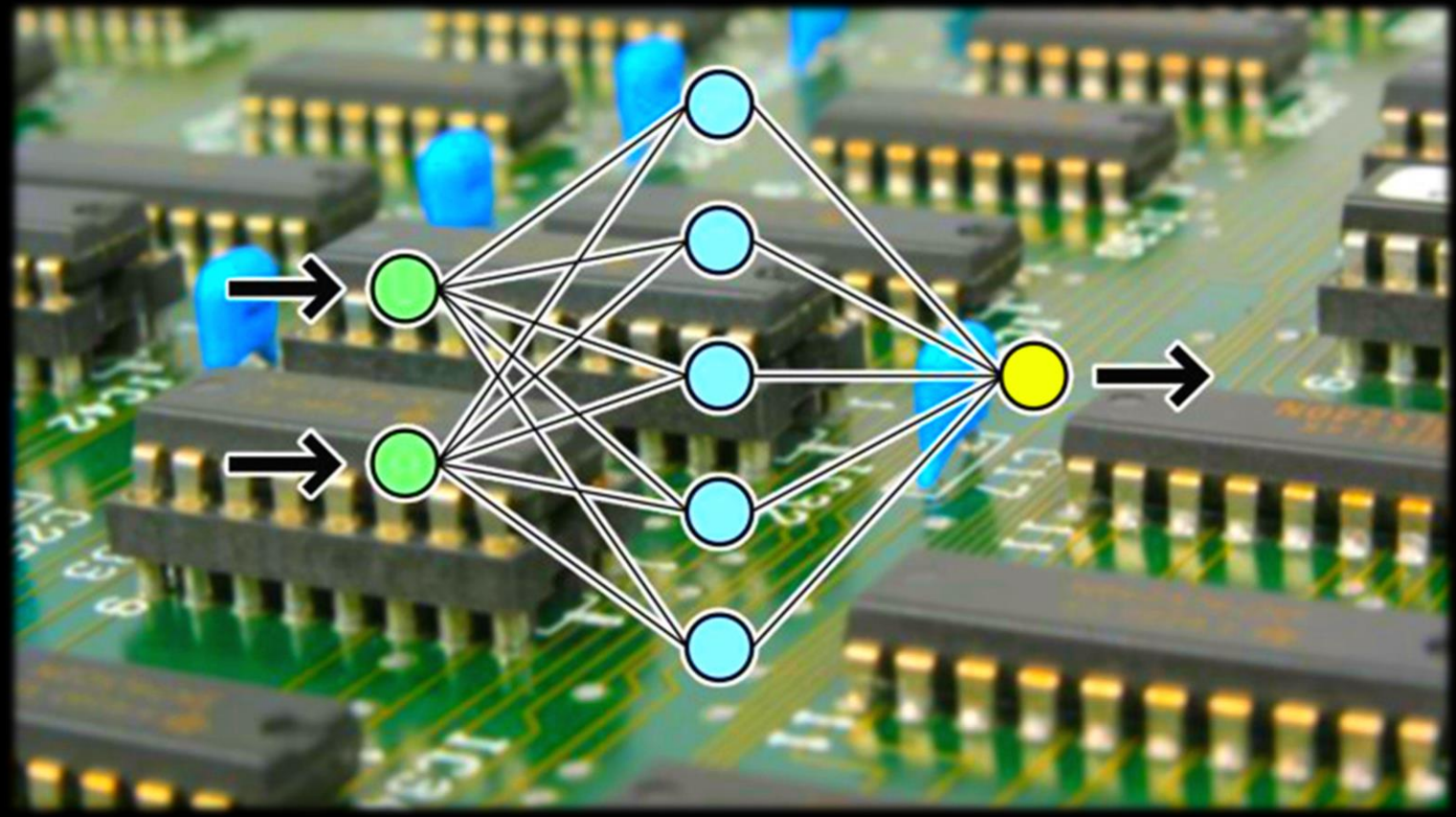
https://www.dana.org/article/how-does-the-brain-work/

How Does the Brain Work?

- A "developing" neuron is synonymous with a plastic brain: Plasticity permits the developing nervous system to adapt to its surrounding environment
- In its most general form

  ~ a neural network is a machine that is designed to model the way in which the brain performs a particular task or function of interest;

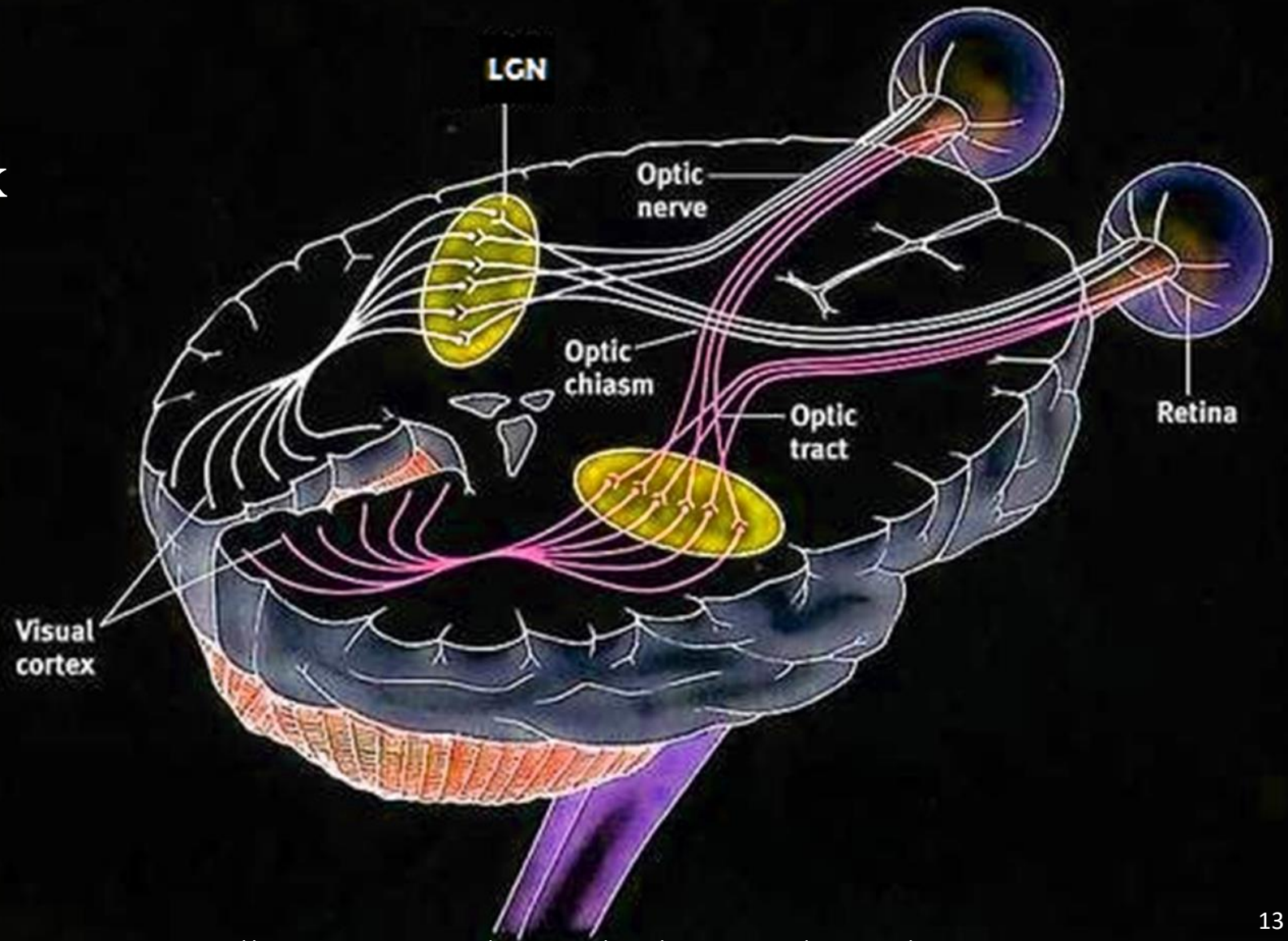
  ~ the network is usually implemented by using electronic components or is simulated in software on a digital computer



https://bdtechtalks.com/2020/11/09/fpga-vs-gpu-deep-learning/

How Does the Human Vision System Work?

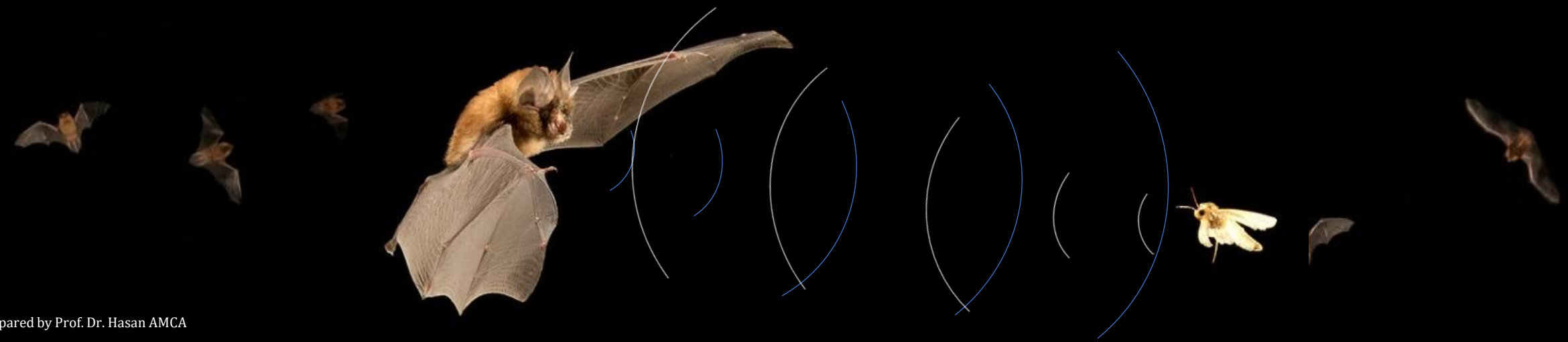
- Consider, for example, human vision, which is an information-processing task
  - ~ Which routinely accomplishes perceptual recognition tasks (e.g., such as a familiar face in a crowd) in approximately 100-200 ms,
  - ~ A comparable task may take days on a conventional computer



https://www.snapoholic.com/index.php/blog/photography/concepts/brain-vision-system

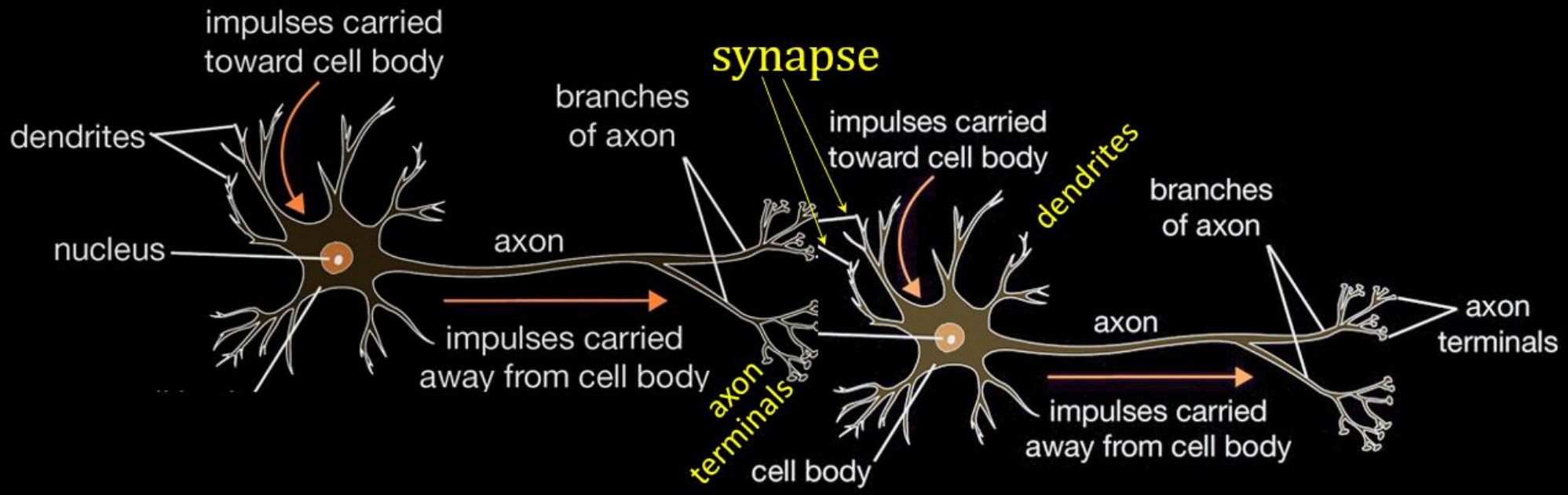
How Does the Human Vision System Work?

- As another example, consider the sonar (active echo-location System) of a bat
  - ~In addition to providing information about how far away a target (e.g., a flying insect) is,
  - ~a bat sonar conveys information about the relative velocity of the target,
  - ~The size of the target, the size of various features of the target, and the azimuth and elevation of the target.
- The complex neural computations needed to extract all this information from the target echo occur within a brain the size of a plum



1.1 What is an Artificial Neural Network?

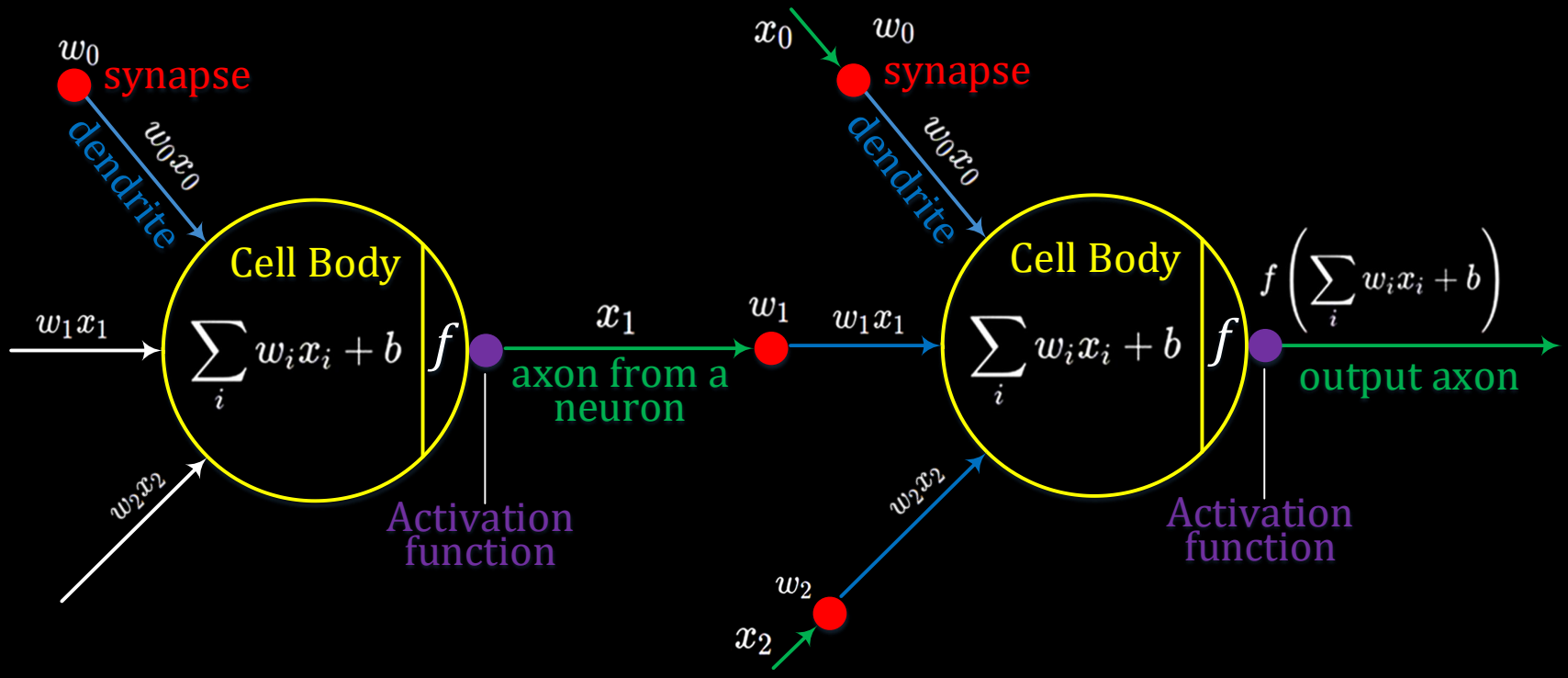
- Work on artificial neural networks has been motivated by the recognition that human brain computes in a different way from conventional digital computer
- A neuron receives the activation values x_i from neurons connected to its dendrites. The neuron needs to combine those activations.



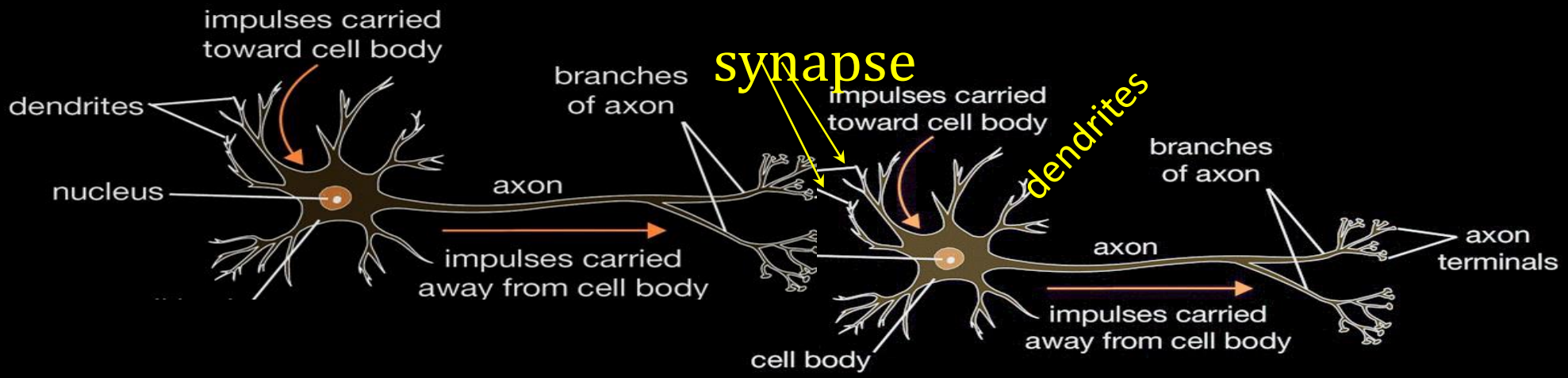
Source: https://www.cs.toronto.edu/~lczhang/360/lec/w02/terms.html

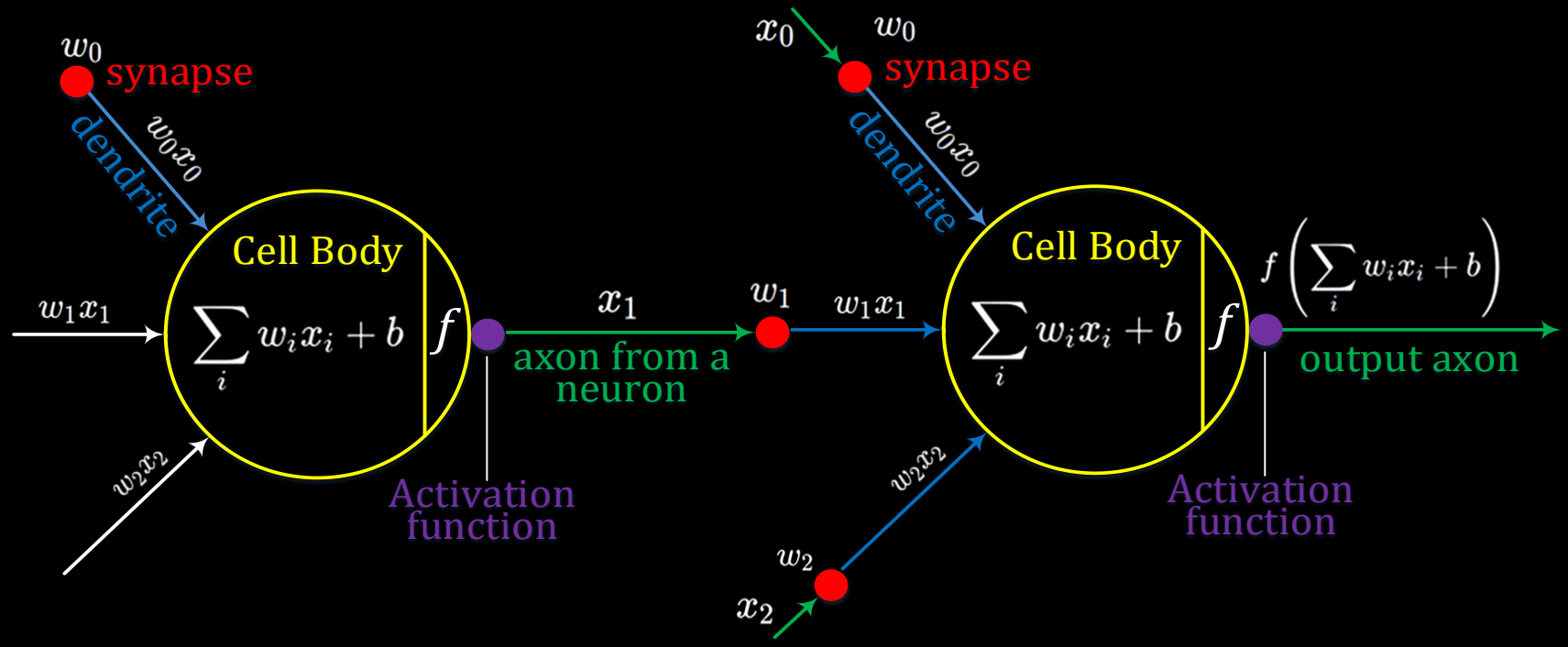
1.1 What is an Artificial Neural Network?

- The connections between neurons can be weak or strong
- The strength is represented by w_i and the amount of information "received" by the neuron is the product $w_i x_i$
- The total contributions are combined together, along with a bias b, forming the sum $b + \sum_i w_i x_i$

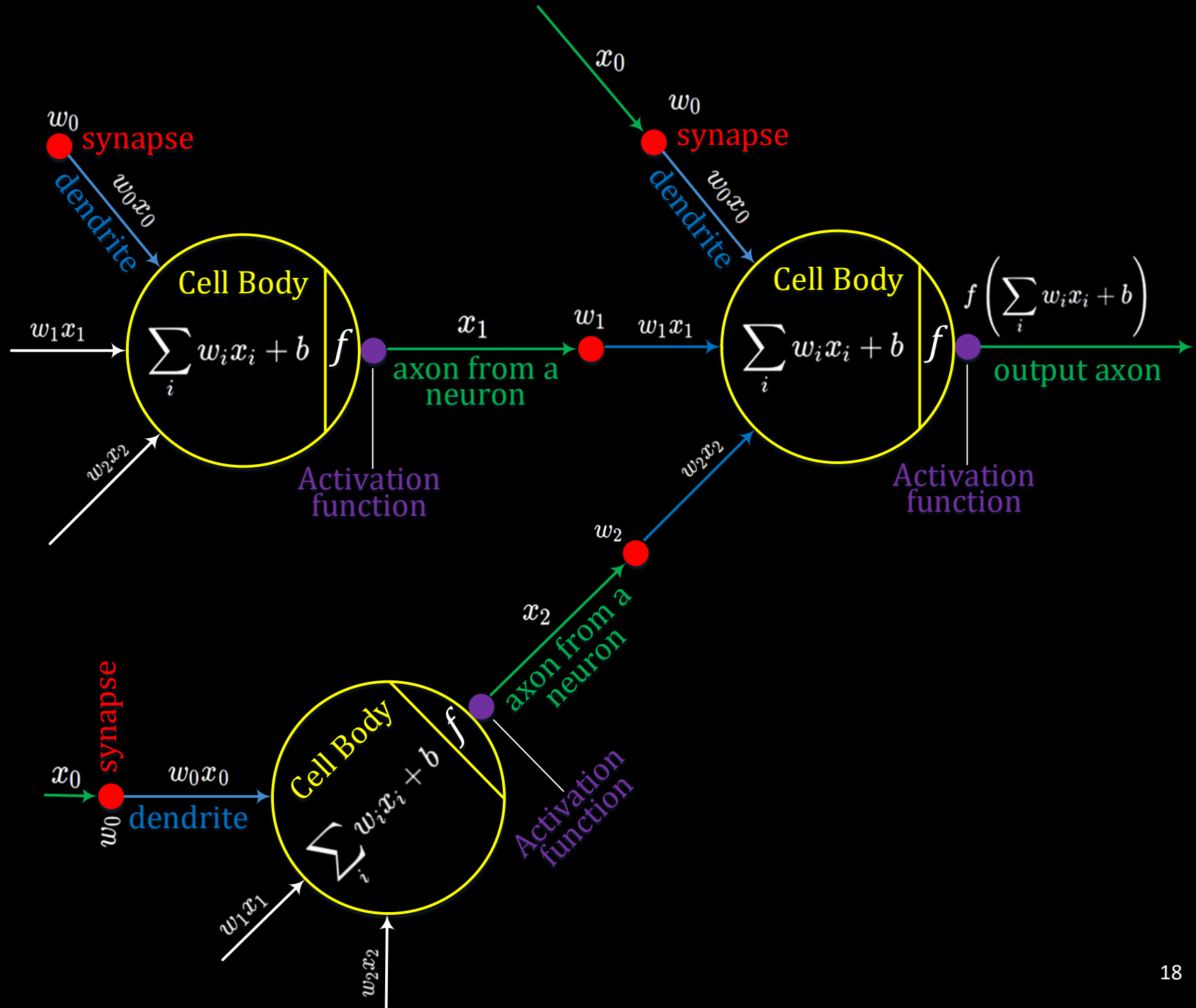


Artificial Neural Network Connections



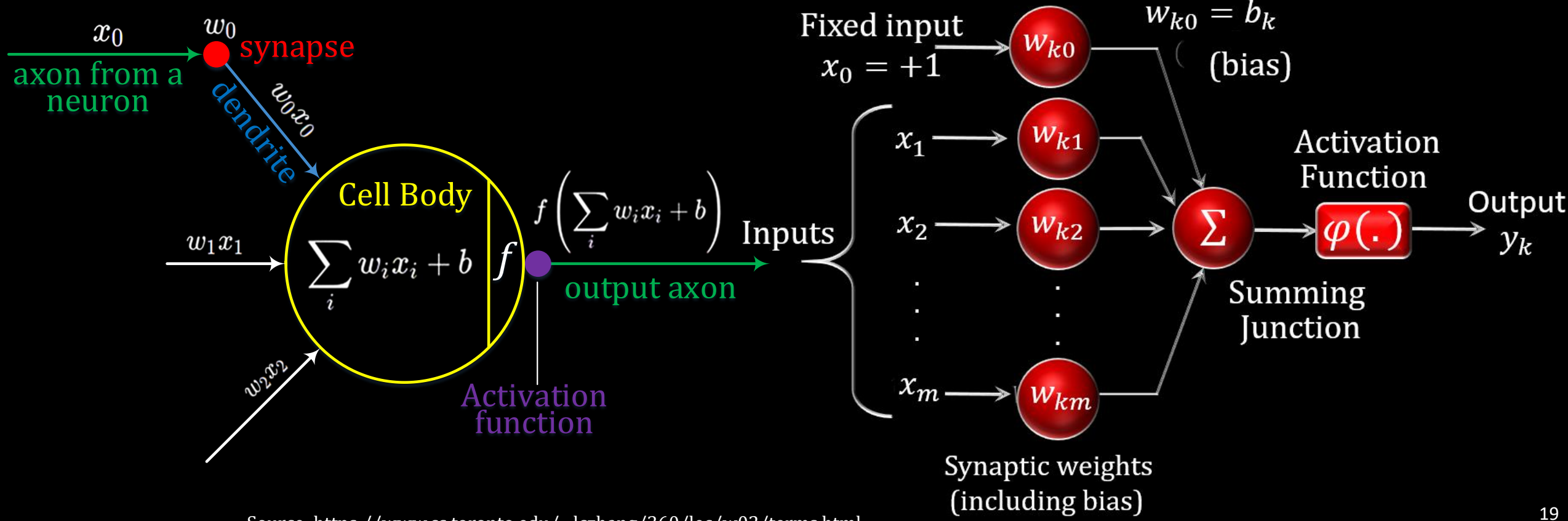


Artificial Neural Network Connections



1.1 What is an Artificial Neural Network?

- This value is then passed to a non-linear activation function f to produce the output $f(b + \sum_i w_i x_i)$
- This is the activation of the neuron and is the value passed to other neurons connected to its axon



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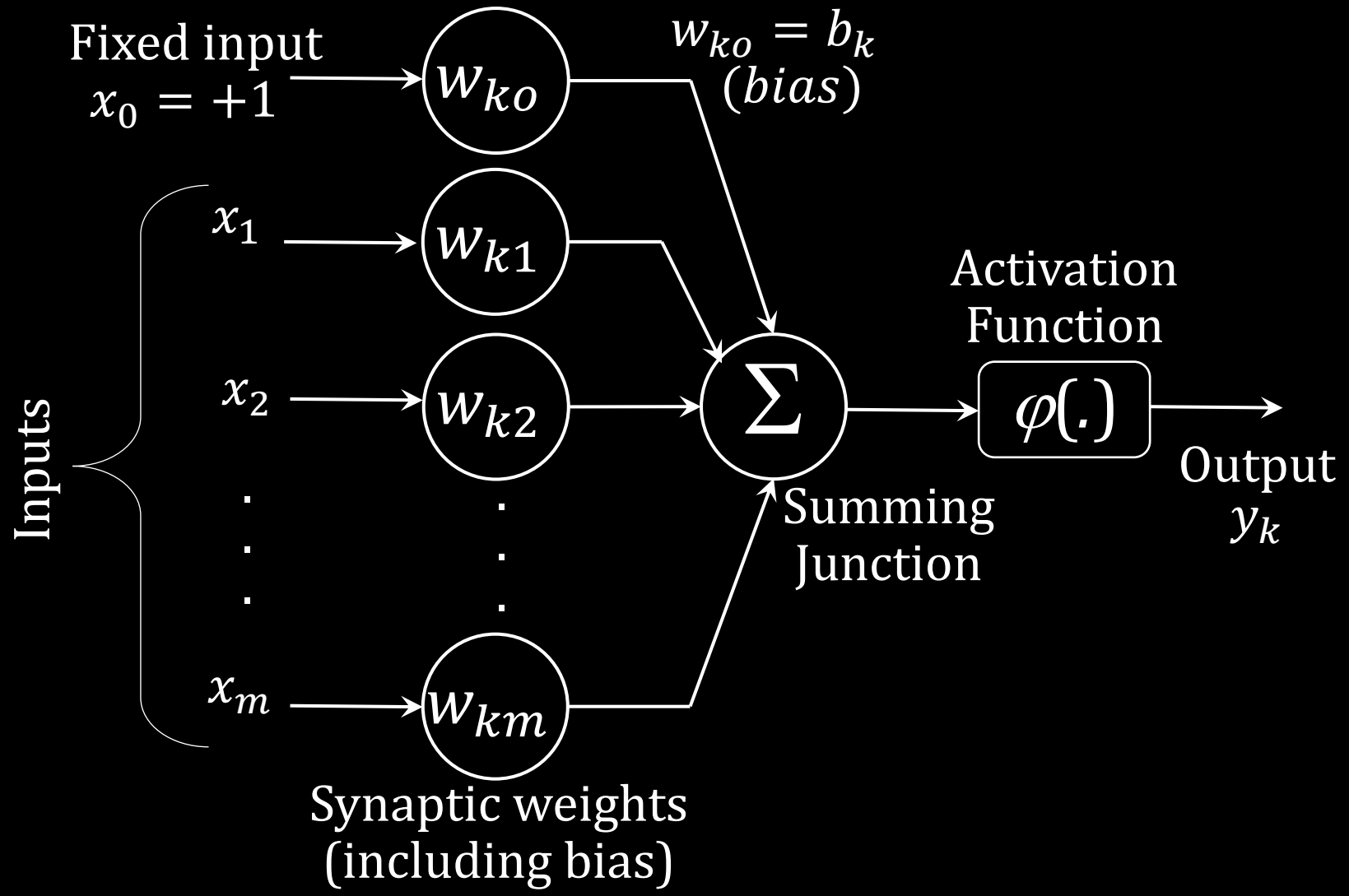

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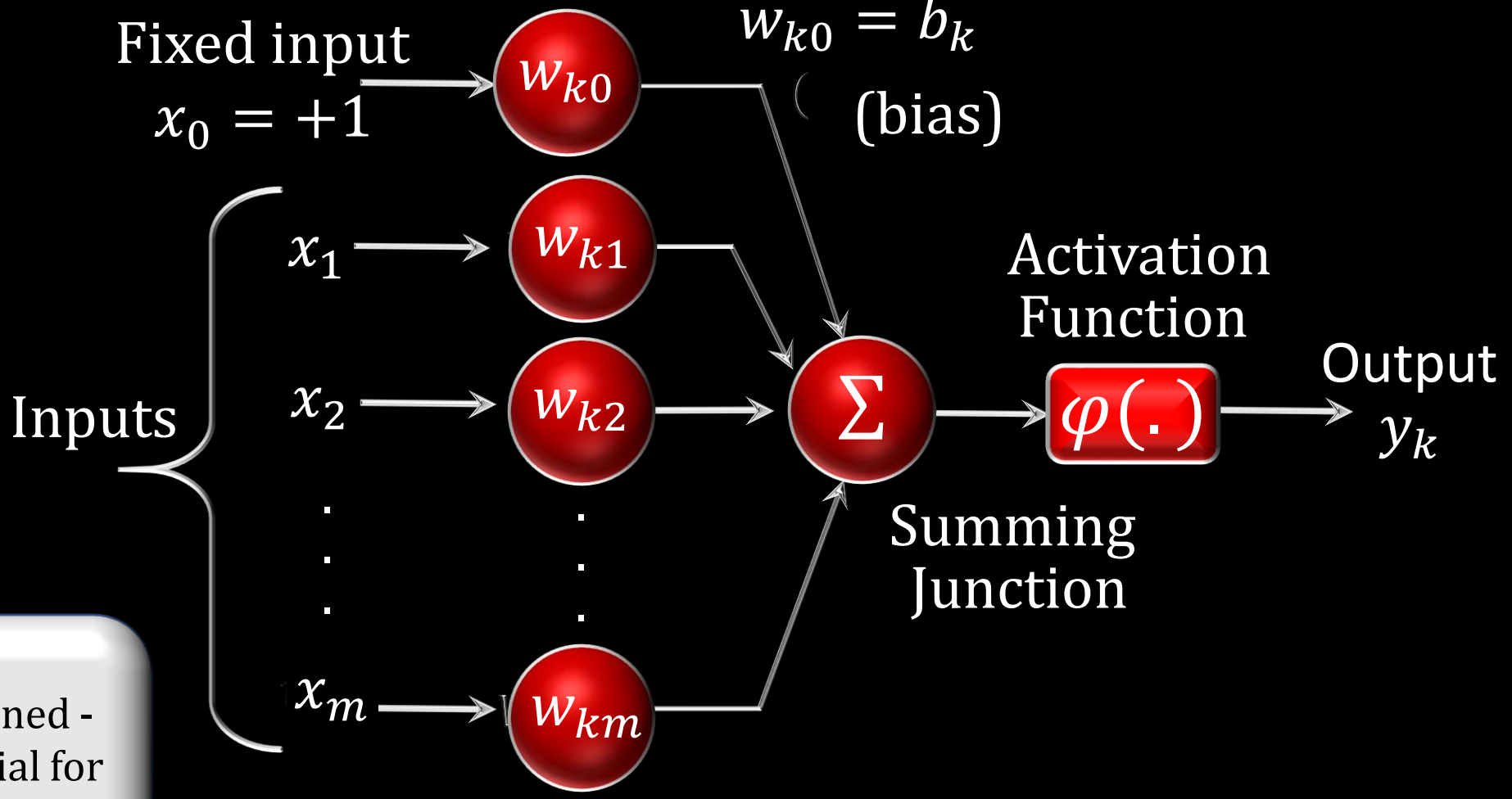
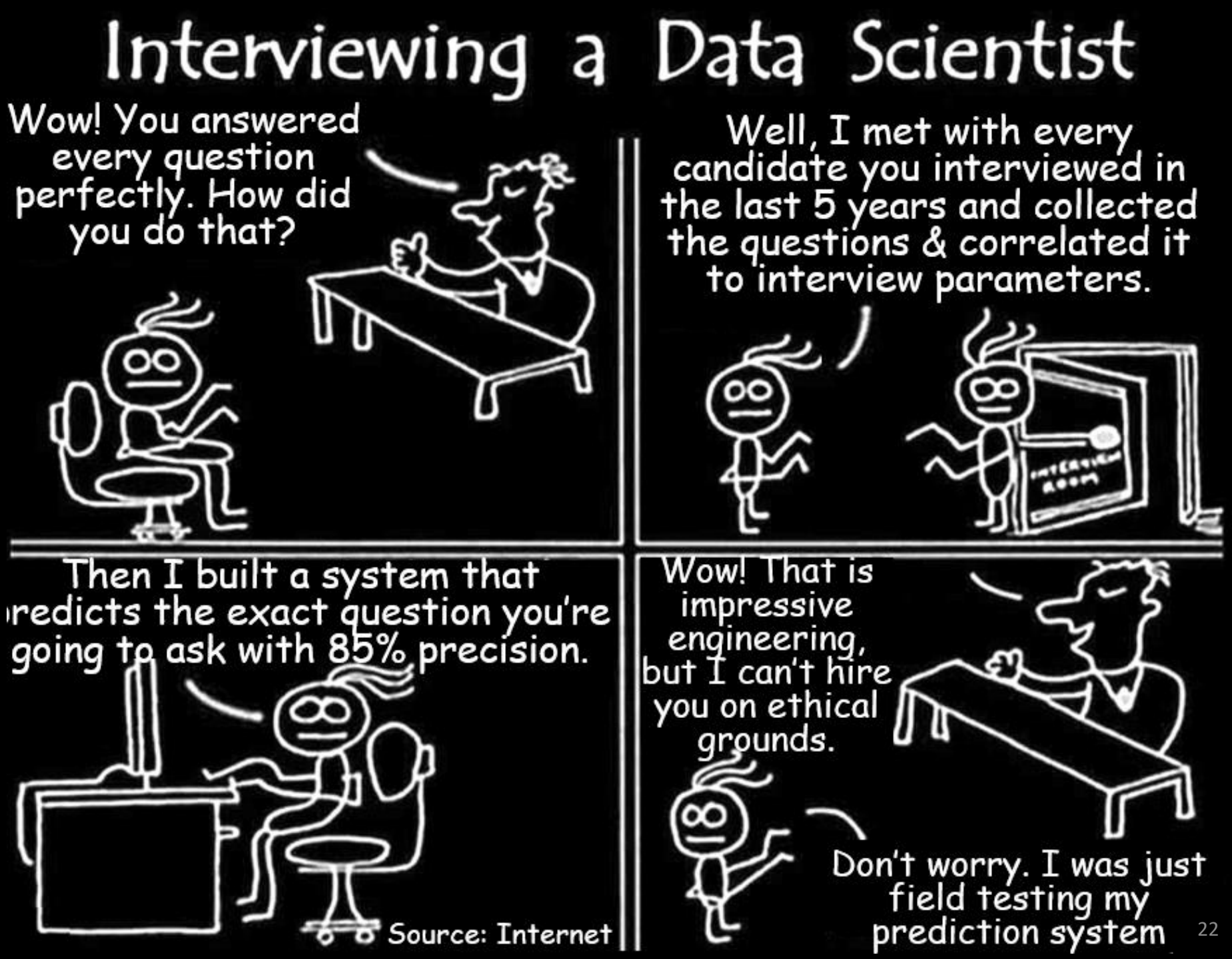


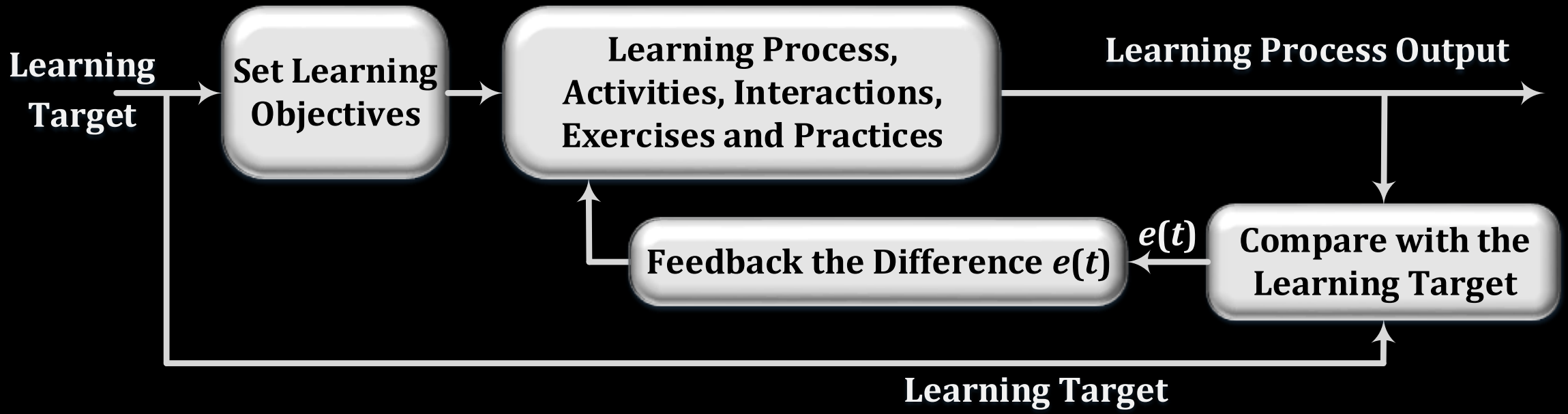
Watch Video
Neural Networks Explained - Machine Learning Tutorial for Beginners
https://www.youtube.com/watch?v=GvQwE2OhL8I&t=274s

The Learning Process



The Learning Process

- Our interest is confined to an important class of neural networks that perform useful computations through a process of learning.
- To achieve good performance, neural networks employ a massive interconnection of simple computing cells referred to as "neurons" or "processing units."



https://www.researchgate.net/publication/277648111_Evidences_of_validity_of_a_scale_for_mapping_professional_as_defining_competences_and_performance_by_Brazilian_tutors/figures?lo=1

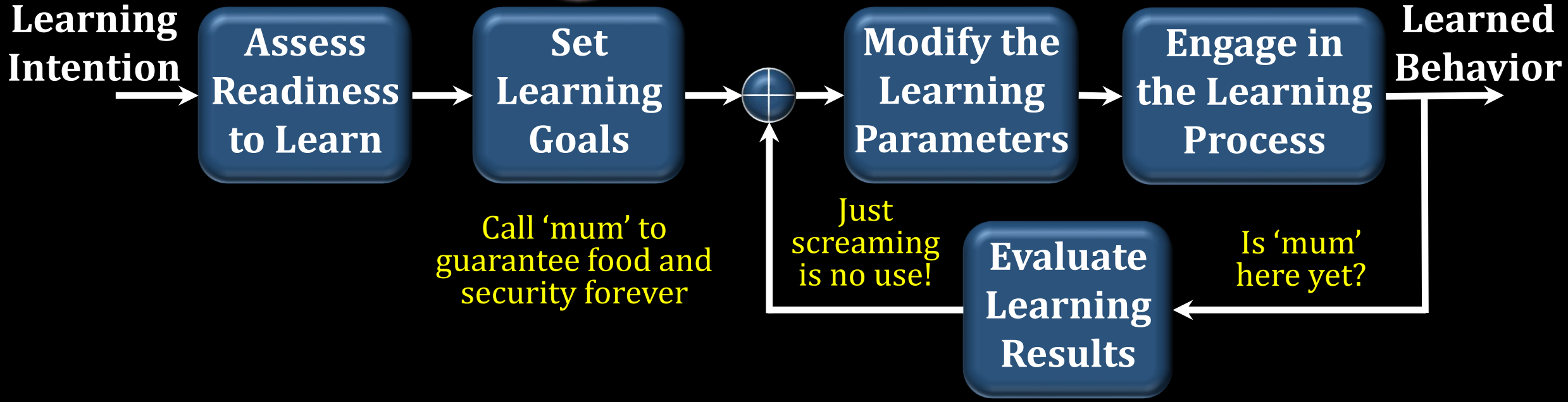
The Steps in the Learning Process

assess readiness, set goals, modify params, learn, assess, modify params

https://www.facebook.com/permalink.php?story_fbid=257829889686039&id=100063770887871

https://www.youtube.com/watch?v=3xZYN1UKPTY

Air pressure from lungs, shape of teeth, mouth, tongue and lips



Case Study: A new-born baby intends to talk and the trials and the learning process continuous forever…

The Learning Process

- We may thus offer the following definition of a neural network viewed as an adaptive learning machine as:

~ A *neural network* is a massively parallel distributed processor made up of simple processing units, which has a natural tendency for storing experiential knowledge and making it available for use.

~ A neural network resembles the brain in two respects:

1. Knowledge is acquired by the network from its environment through a learning process.
2. Interneuron connection strengths, known as synaptic weights, are used to store the acquired knowledge.

The Learning Algorithm

- The procedure used to perform the learning process is called a **Learning Algorithm,**
  ~ the function of which is to modify the synaptic weights of the network in an orderly fashion to attain the desired objectives

- It is also possible for a neural network to modify its own topology, which is motivated by the fact that neurons in the human brain can die and that new synaptic connections can grow

- Neural networks are also referred to in literature as neurocomputers, connectionist networks, parallel distributed processors, etc.

Benefits of Neural Networks

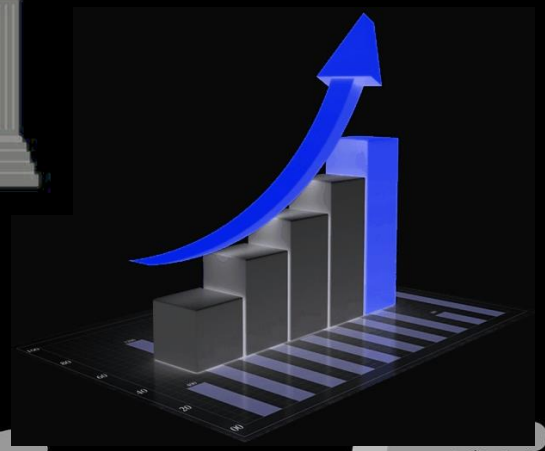
- A neural network derives its computing power through,
  1. **its massively parallel distributed structure and,**
  2. **its ability to learn and therefore generalize**

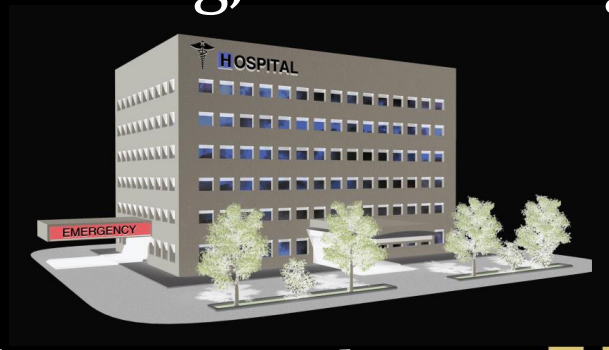
- Generalization refers to the neural network producing reasonable outputs for inputs not encountered during training (learning)

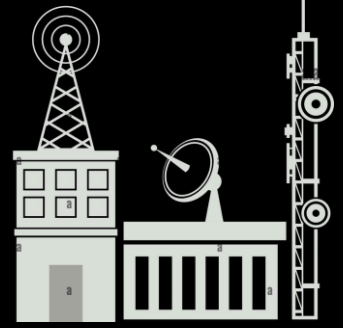
- These two information-processing capabilities make it possible for neural networks to solve complex (large-scale) problems that are currently intractable

Application Areas of Neural Networks

- Finance, Banking, Insurance
  - Loan approval, stock prediction, claim prediction, fraud detection
- Business, Marketing
  - Sale prediction, customer profiling, data mining
- Medicine
  - Diagnosis and treatment
- Industry
  - Quality control, machine/plant control
- Telecommunication
  - Adaptive filtering (equalizing)
- Speech recognition and synthesis

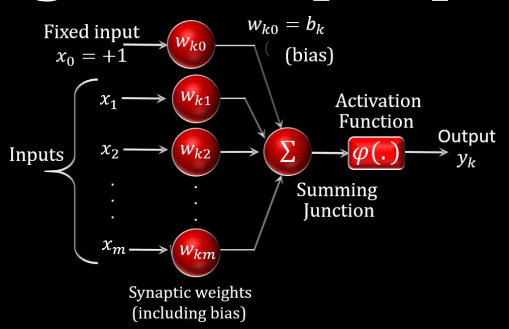


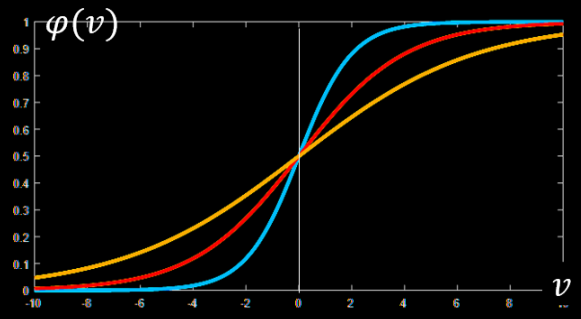




Properties and Capabilities of Neural Networks

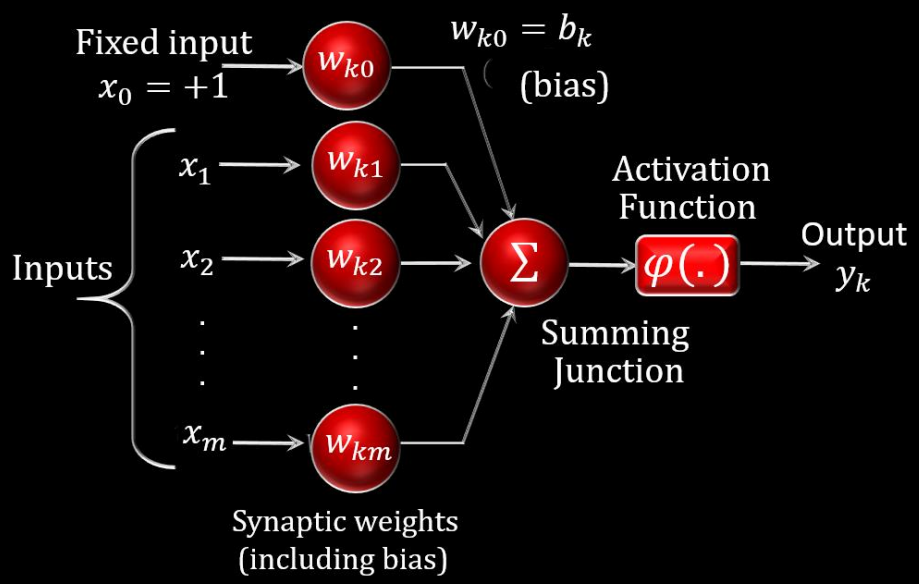
- Use of neural networks offers the following useful properties and capabilities [1, pp.25]:
  - ~ Nonlinearity
  - ~ Input-output mapping $y_k = \sum_{j=1}^{m} w_{kj} x_j + b_k$
  - ~ Adaptivity
  - ~ Evidential Response
  - ~ Contextual information
  - ~ Fault Tolerance
  - ~ VLSI Implementability
  - ~ Uniformity of Analysis and Design
  - ~ Neurobiological Analogy

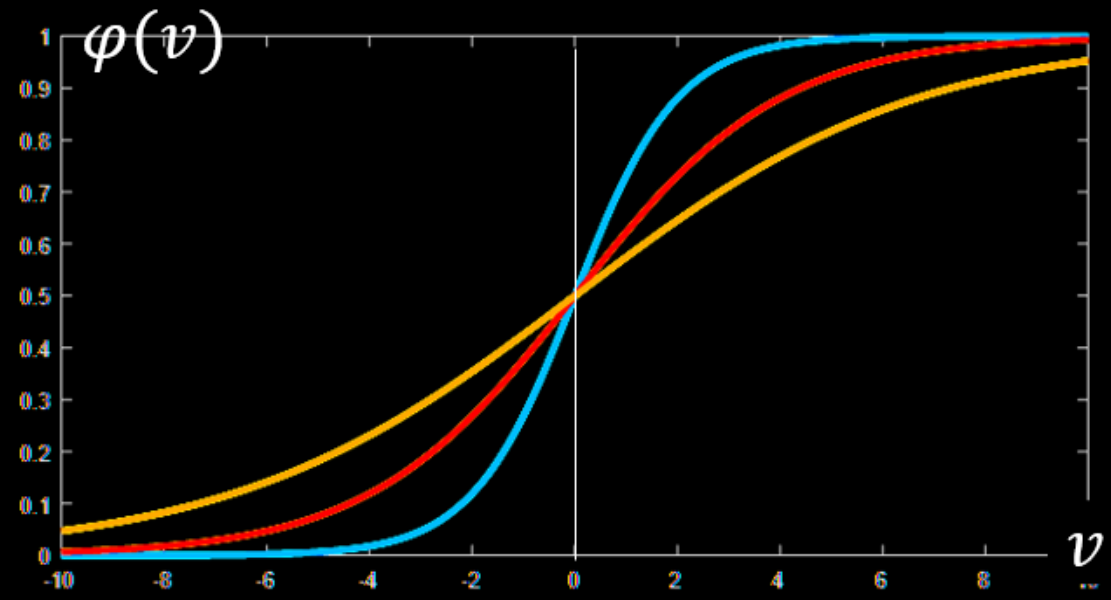




1. Nonlinearity

- An artificial neuron can be linear or nonlinear
- A neural network, made up of an interconnection of nonlinear neurons, who is itself nonlinear
- Nonlinearity is a highly important property, particularly if input signal (e.g., speech signal) is inherently nonlinear





2. Input-Output Mapping

- A popular for of learning called supervised learning involves modification of the synaptic weights of a neural network
  - ~ by applying a set of labeled training samples or task examples

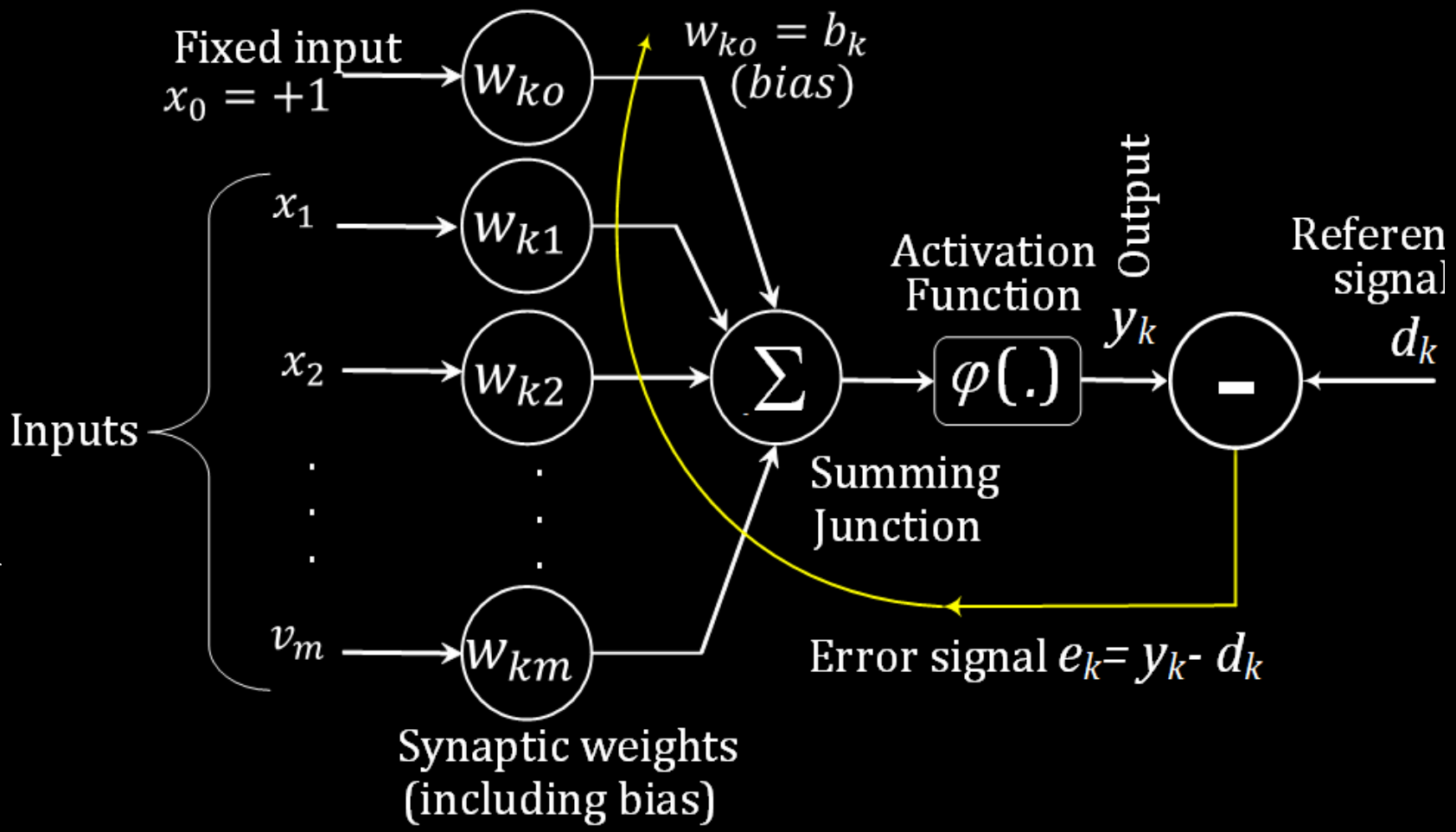
$$y_k = \sum_{j=1}^{m} w_{kj} x_j + b_k$$

- The synaptic weights (free parameters) of the network are modified to minimize the error,
  - ~ which is the difference between the desired response and the actual response of the network produced by the input signal
  - ~ in accordance with an appropriate statistical criterion

$$e_k = y_k - d_k$$

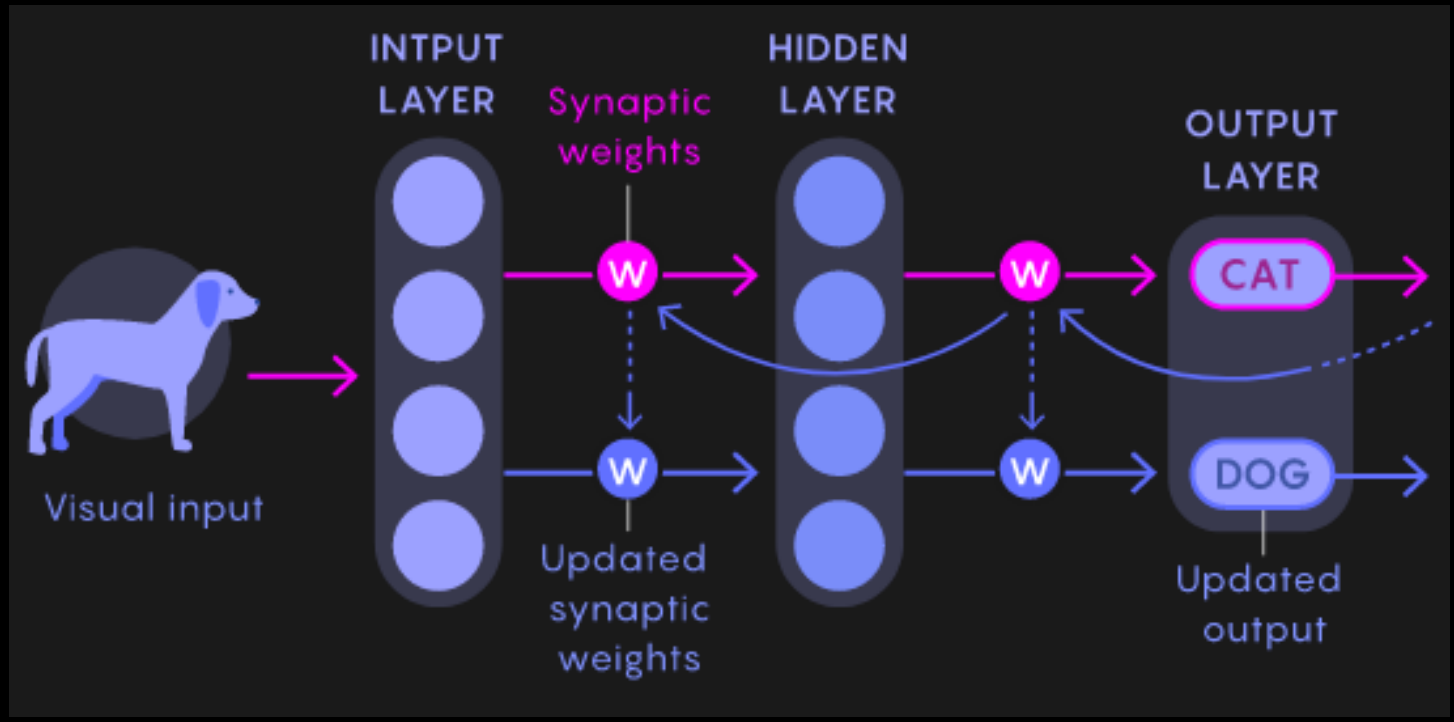
2. Input-Output Mapping

- Consider a pattern classification task, where the requirement is to assign an input signal (e.g. a physical object) to one of several prespecified categories (classes)
- The network learns from the examples by constructing an input-output mapping for the problem at hand



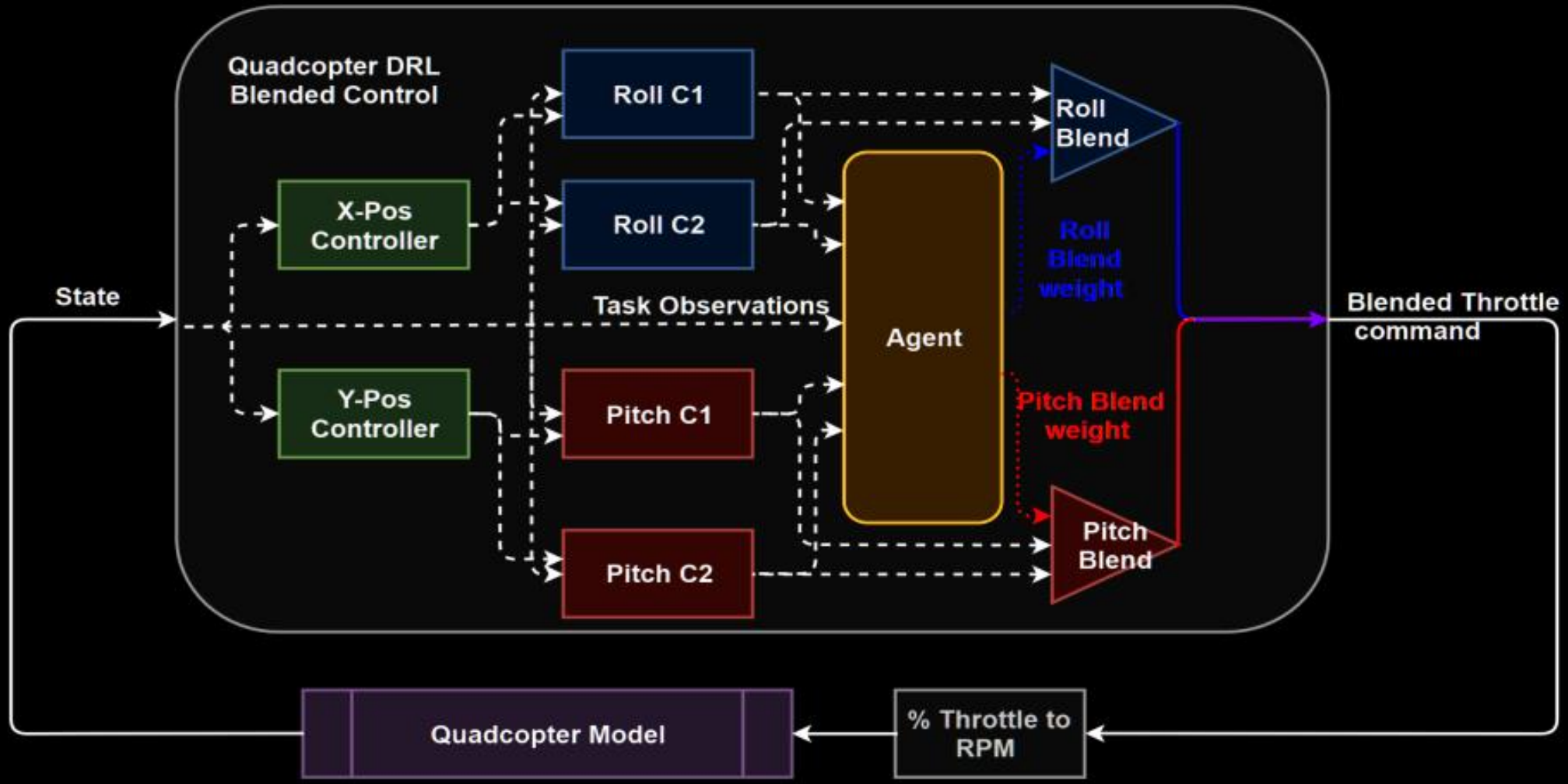
3. Adaptivity

- Neural networks have a built-in capability to adapt their synaptic weights to changes in the surrounding environment
  - ~ In particular, a neural network trained to operate in a specific environment can be retrained to track changes in the environmental conditions ensuring that the system remains stable



https://pubs.rsc.org/en/Content/ArticleLanding/2016/MB/C6MB00162A

3. Adaptivity

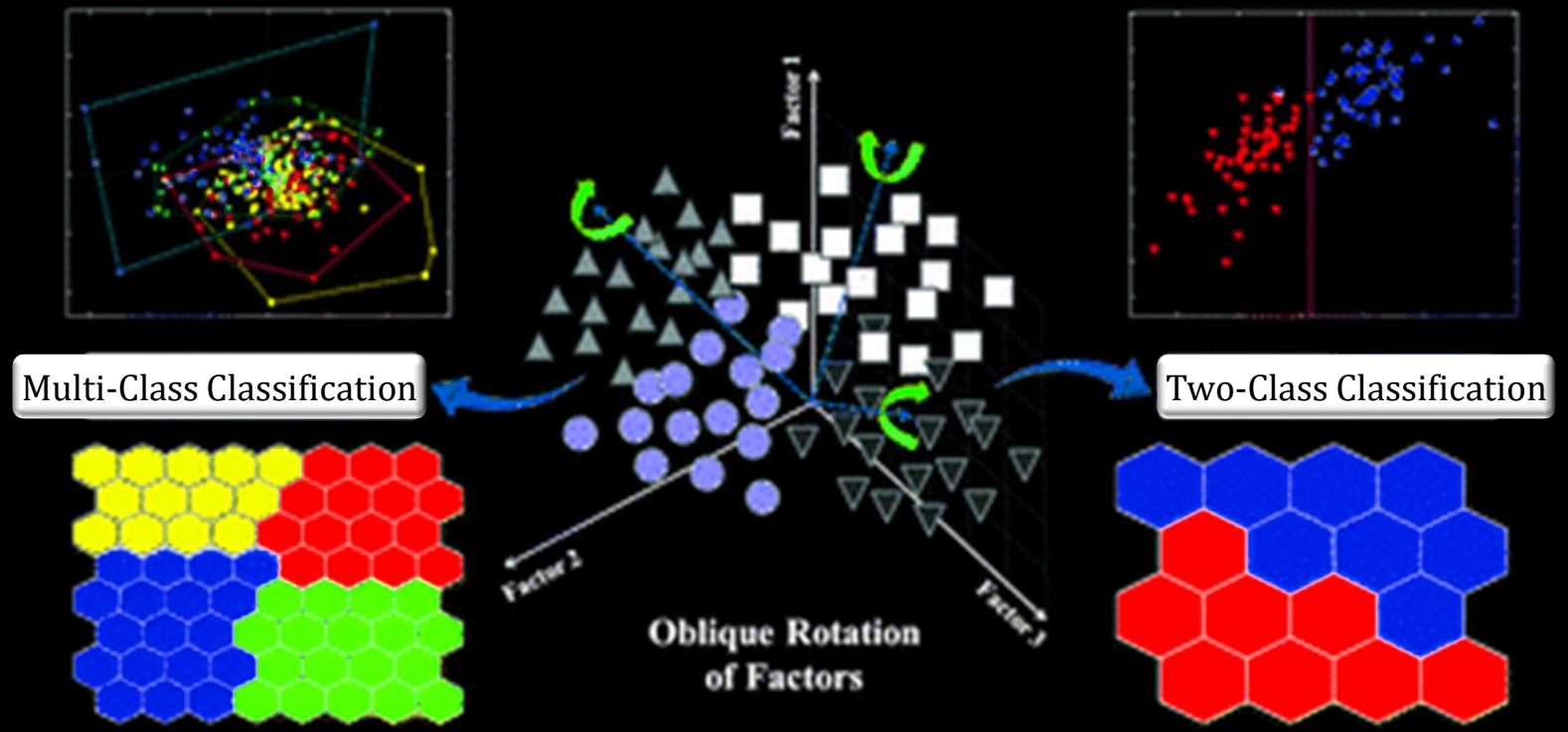


Quadcopter deep reinforcement learning blended control architecture as a fault tolerant control system

https://dx.doi.org/10.1109/ICUAS.2016.7502624

3. Adaptivity

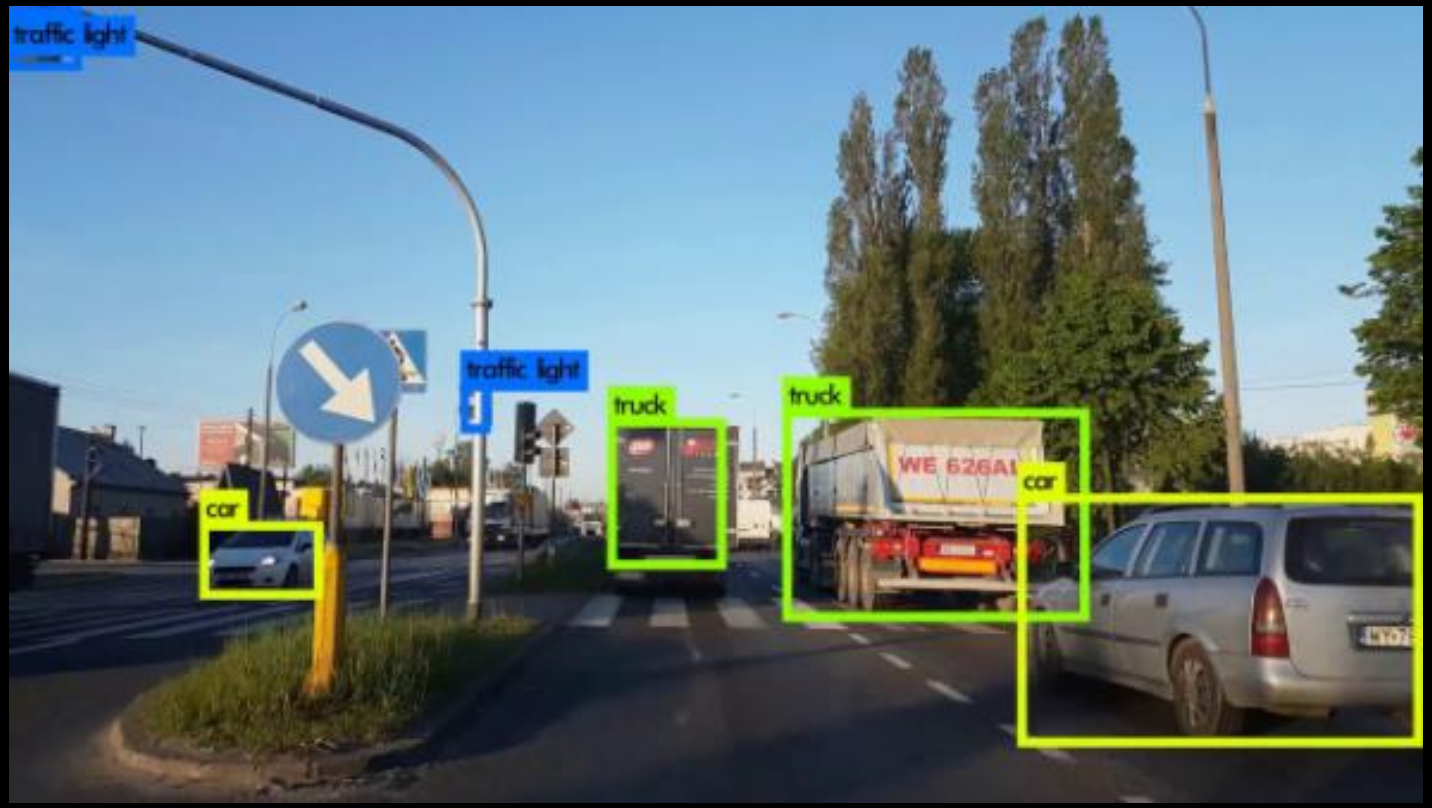
- The natural architecture of a neural network make it a useful tool in adaptive pattern classification, adaptive signal processing, and adaptive control for pattern classification, signal processing, and control applications



https://www.quantamagazine.org/artificial-neural-nets-finally-yield-clues-to-how-brains-learn-20210218/

4. Evidential Response

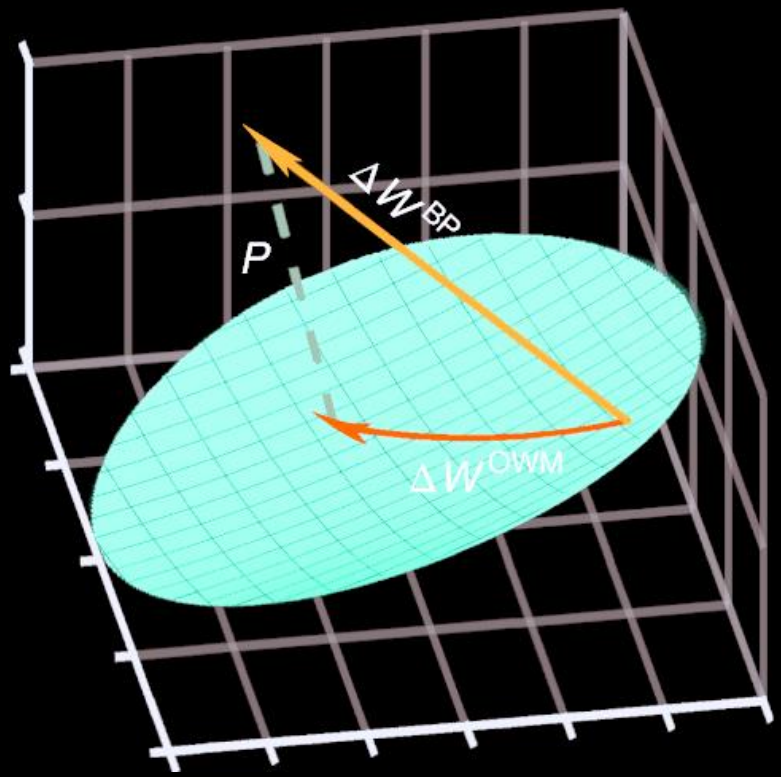
- In the context of pattern classification,
  - ~ a neural network can be designed to provide information
  - ~ not only about which particular pattern to select,
  - ~ but also, about the confidence in the decision made

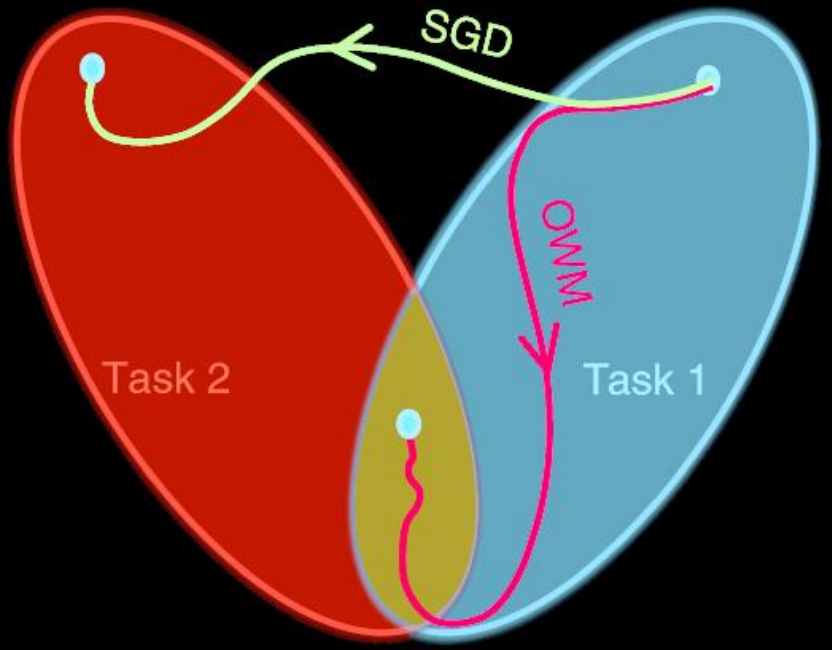


https://www.namedolami.top/ProductDetail.aspx?iid=107757848&pr=43.88

5. Contextual Information

- Knowledge is represented by the very structure and activation state of a neural network
- Every neuron in the network is potentially affected by the global activity of all other neurons in the network
- Consequently, contextual information is dealt with naturally by a neural network.





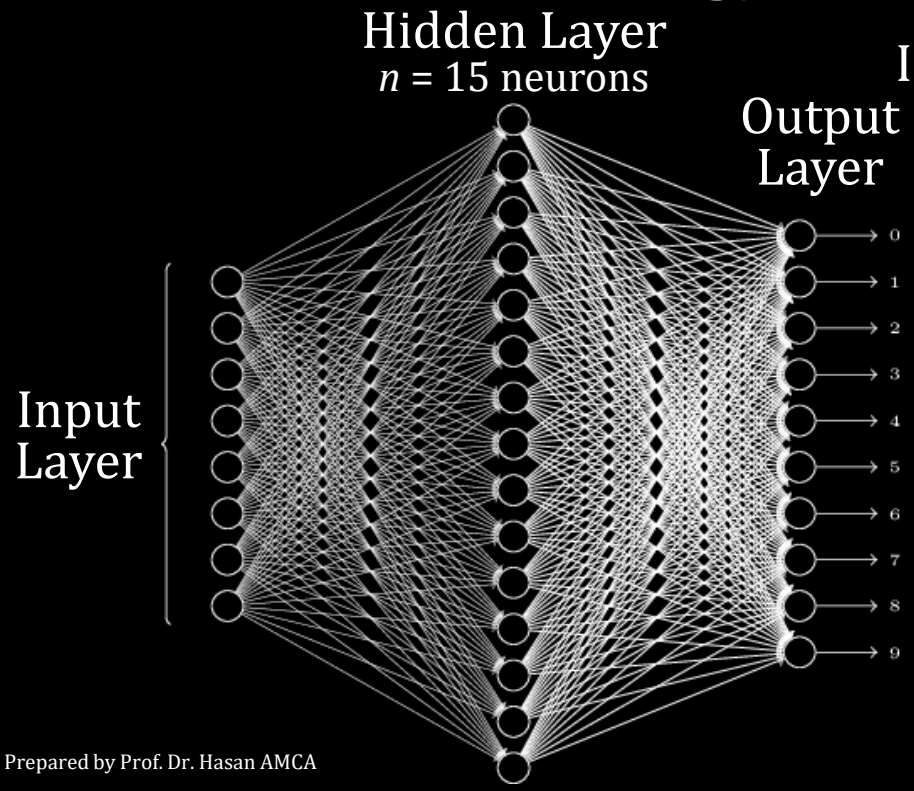
https://www.nature.com/articles/s42256-019-0080-x

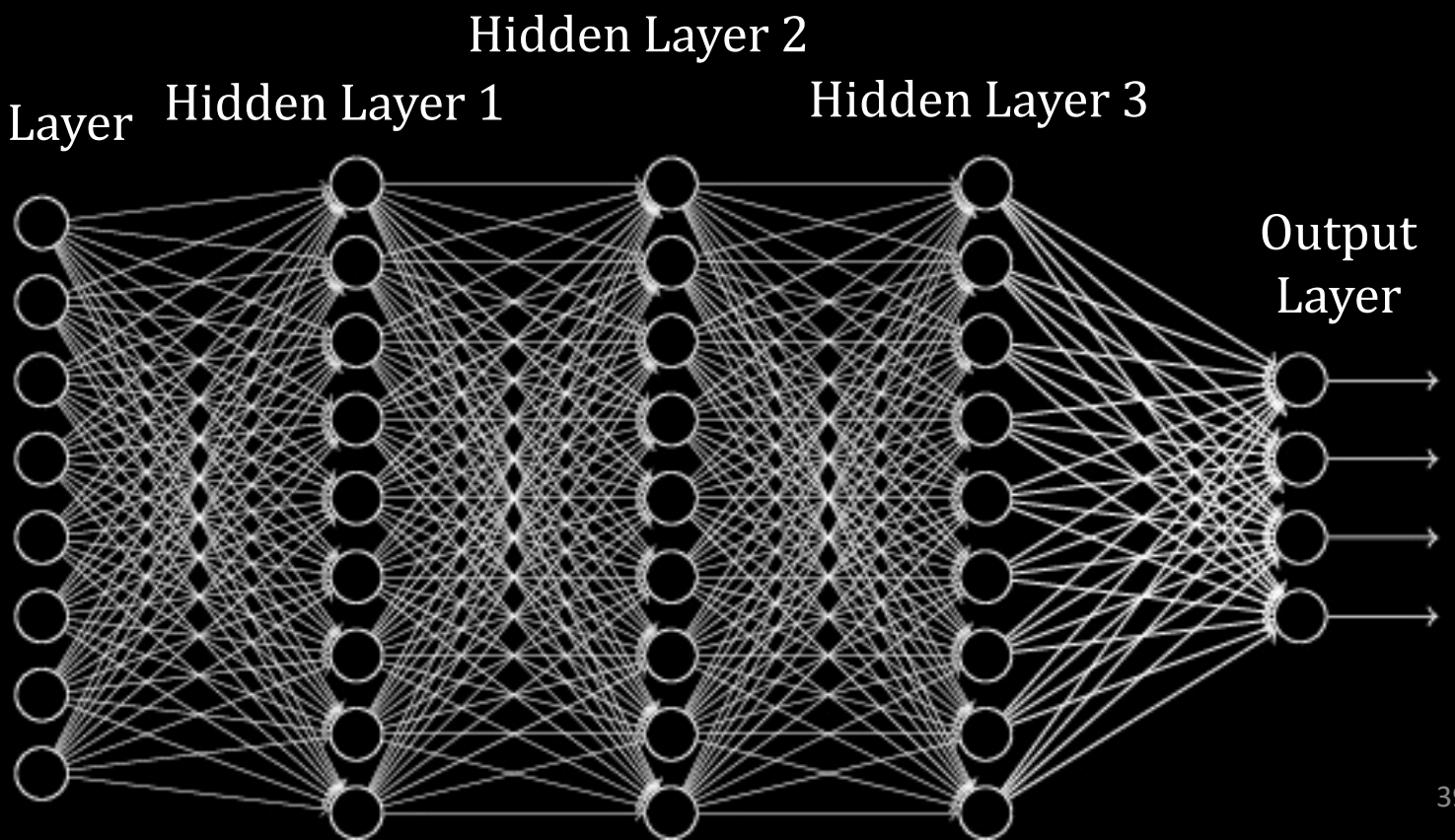
6. Fault Tolerance

- A neural network is inherently fault tolerant, or capable of robust computation, in the sense that its performance degrades gracefully under adverse operating conditions
  - ~ For example, if a neuron or its connecting links are damaged, recall of a stored pattern is impaired in quality
- However, due to the distributed nature of information stored in the network, the damage has to be extensive before the overall response of the network is degraded seriously
  - ~ Hence, graceful degradation in performance

7. VLSI Implementability

- The massively parallel nature of a neural network makes it
  - ~ potentially fast for the computation of certain tasks
  - ~ well suited for implementation using very-large-scale-integrated (VLSI) technology



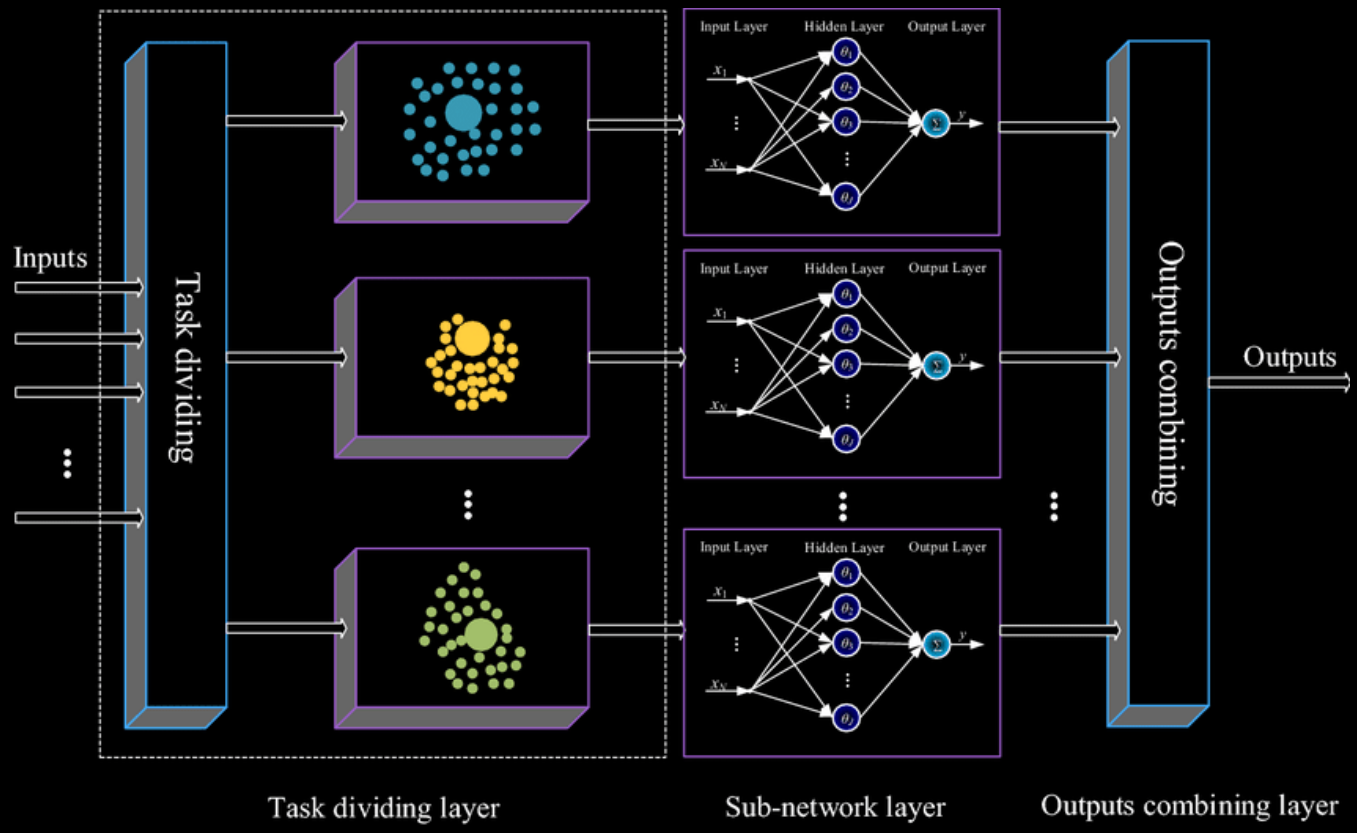


8. Uniformity of Analysis and Design

- Neural networks popularity as information processors manifests itself in different ways:

~ Neurons represent an ingredient common to all neural networks.

~ Modular networks can be built through integration of modules



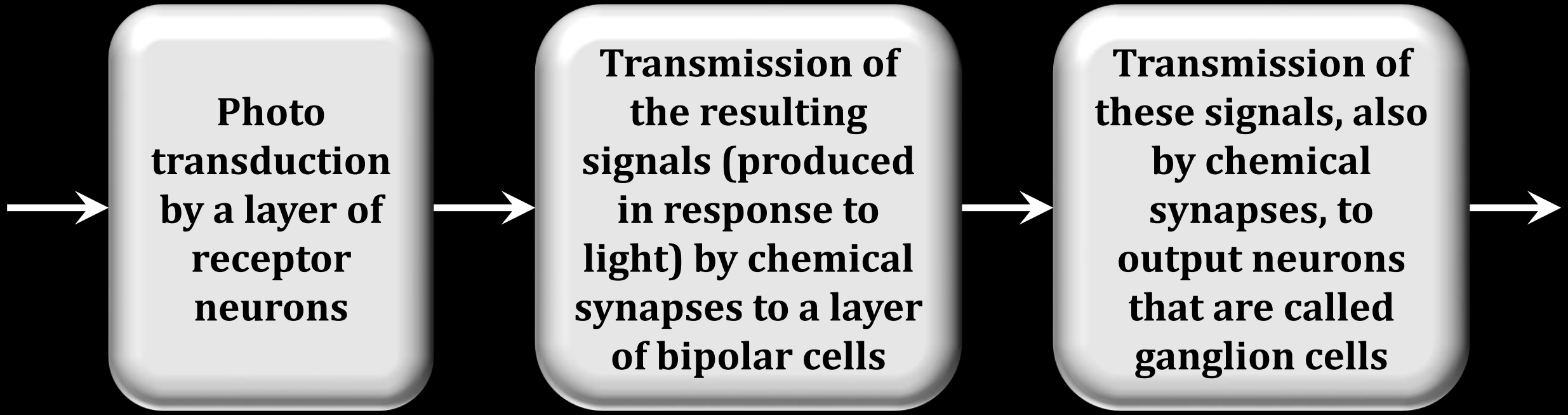
https://www.researchgate.net/figure/Structure-of-modular-neural-network_fig3_328127686

9. Neurobiological Analogy

- Neurobiologists look to (artificial) neural networks as a research tool for the interpretation of neurobiological phenomena, e.g.
  - The Vestibula Ocular Reflex (VOR) maintains visual image stability by making eye rotations that are opposite to head rotations.
  - The VOR's input is head's rotation, and its output is eye rotation.

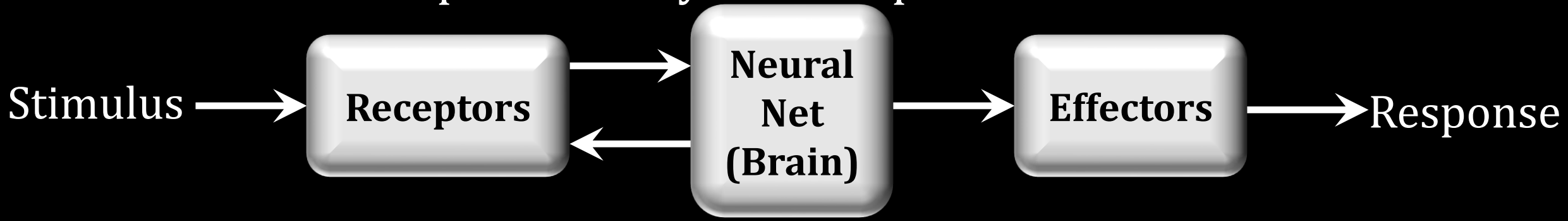
- Engineers look to neurobiology for new ideas to solve problems more complex than those based on conventional design techniques
  - Retina converts optical images into a neural-images by projecting it onto an array of receptors, for transmission down the optic nerve to a multitude of centers for further analysis

The Transformation Process from Optical to Neural Image in Vertebrate Retinas



1.2 The Human Brain

- Human nervous system modeled as a three-stage system is shown below
- The brain (neural net) receives information, perceives it and makes appropriate decisions
- Receptors convert stimuli from the human body or the external environment into electrical impulses that convey information to the neural net (brain).
- The effectors convert electrical impulses generated by the neural net into discernible responses as system outputs.

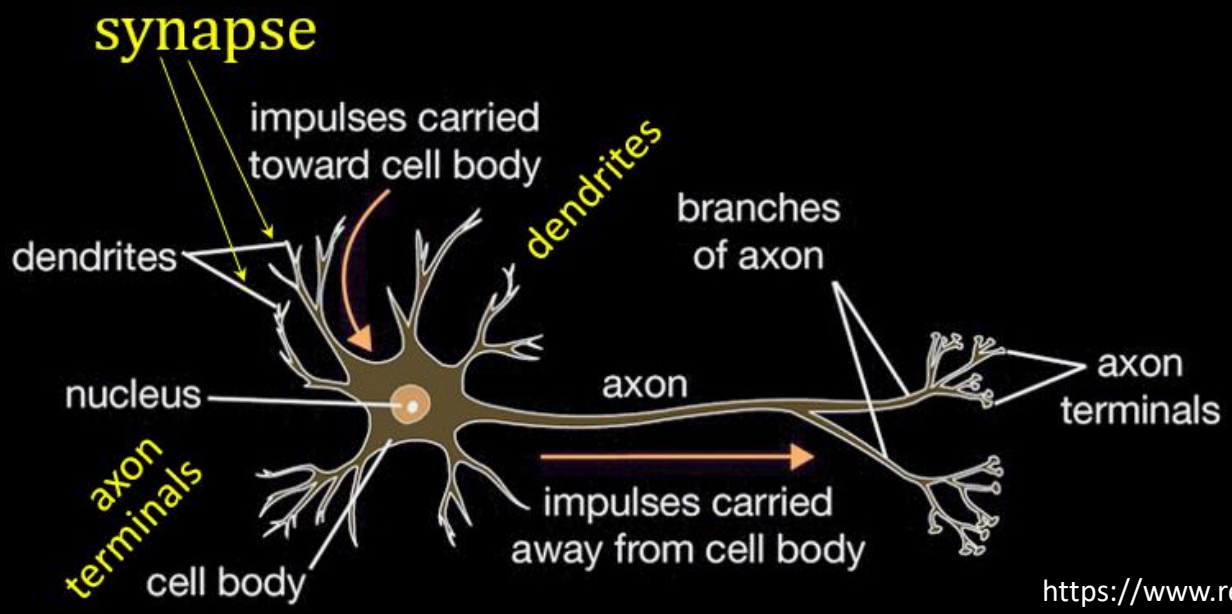


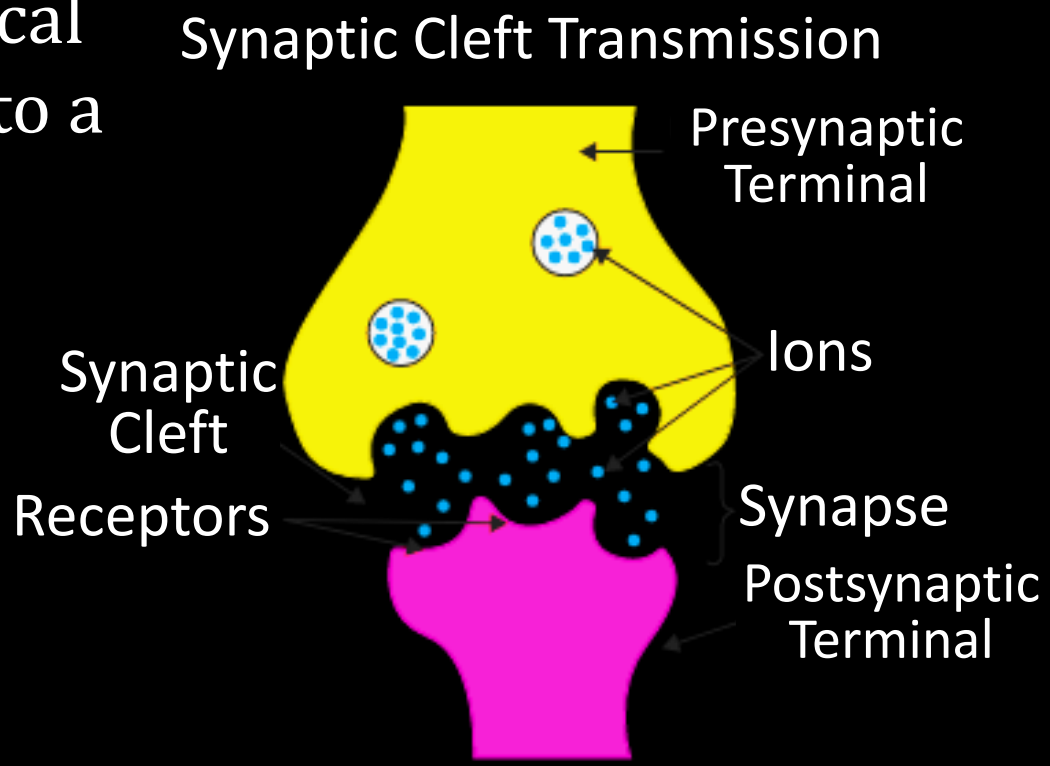
1.2 The Human Brain

- Neurons are 5-6 order of magnitude slower than silicon logic gates;
  - ~ Events in a silicon chip happen in the nanosecond (10-9 s) range, whereas neural events happen in the millisecond (10-3 s) range.
- However, the brain makes up the slow rate of operation of a neuron by having very large number of interconnected neurons (approximately 10 billion neurons in the human cortex, and 60 trillion synapses or connections (Shepherd and Koch, 1990).
  - ~ Energetic efficiency of the brain is approximately 10^{-16} joules/operation/sec
  - ~ Energetic efficiency of best computer today is $\approx 10^{-6}$ joules/operation/sec

1.2 The Human Brain

- Synapses are elementary structural and functional units that mediate the interactions between neurons.
- The most common kind of synapse is a chemical synapse, which converts a presynaptic electrical signal into a chemical signal and then back into a postsynaptic electrical signal





https://www.researchgate.net/publication/338015239_Superintelligent_Deep_Learning_Artificial_Neural_Networks/figures?lo=1&utm_source=google&utm_medium=organic

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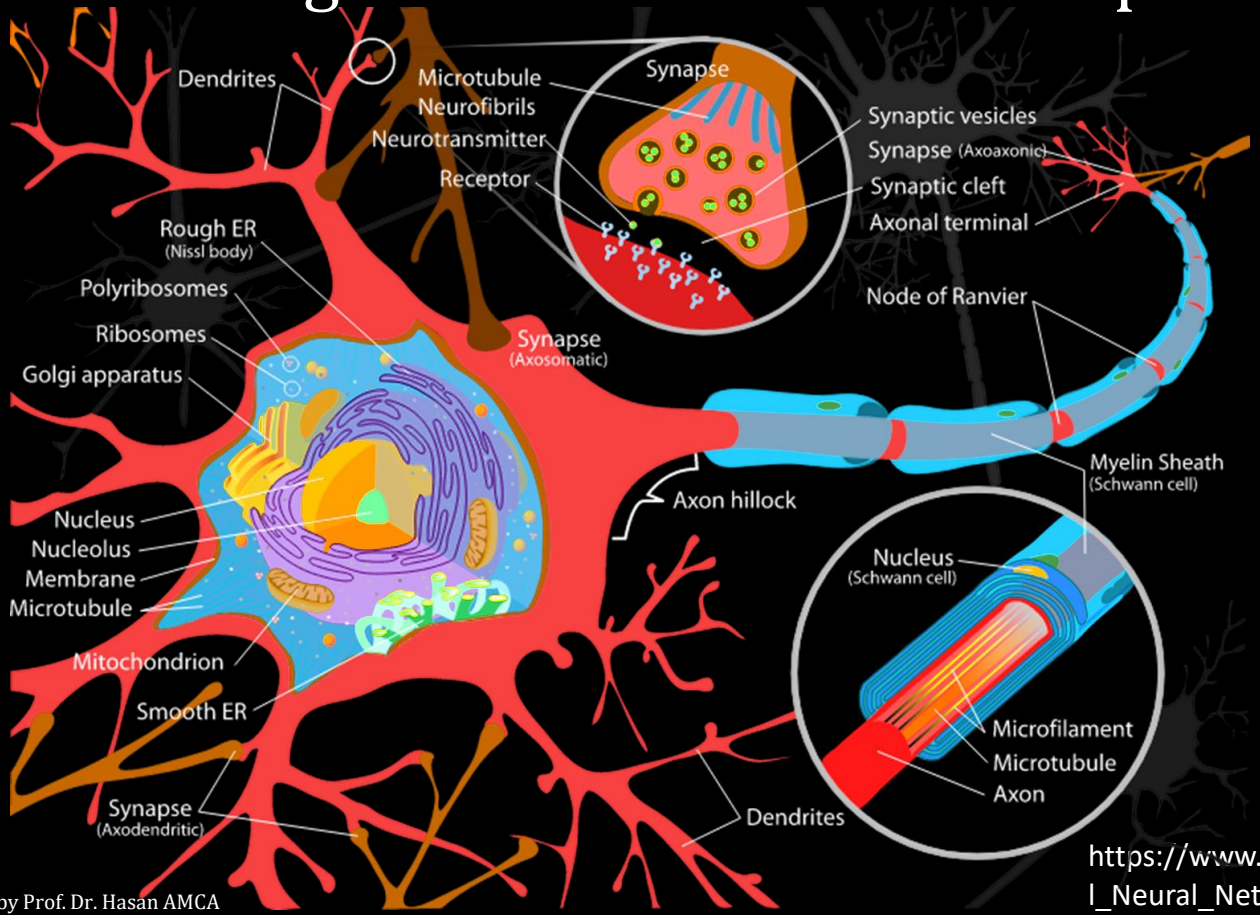
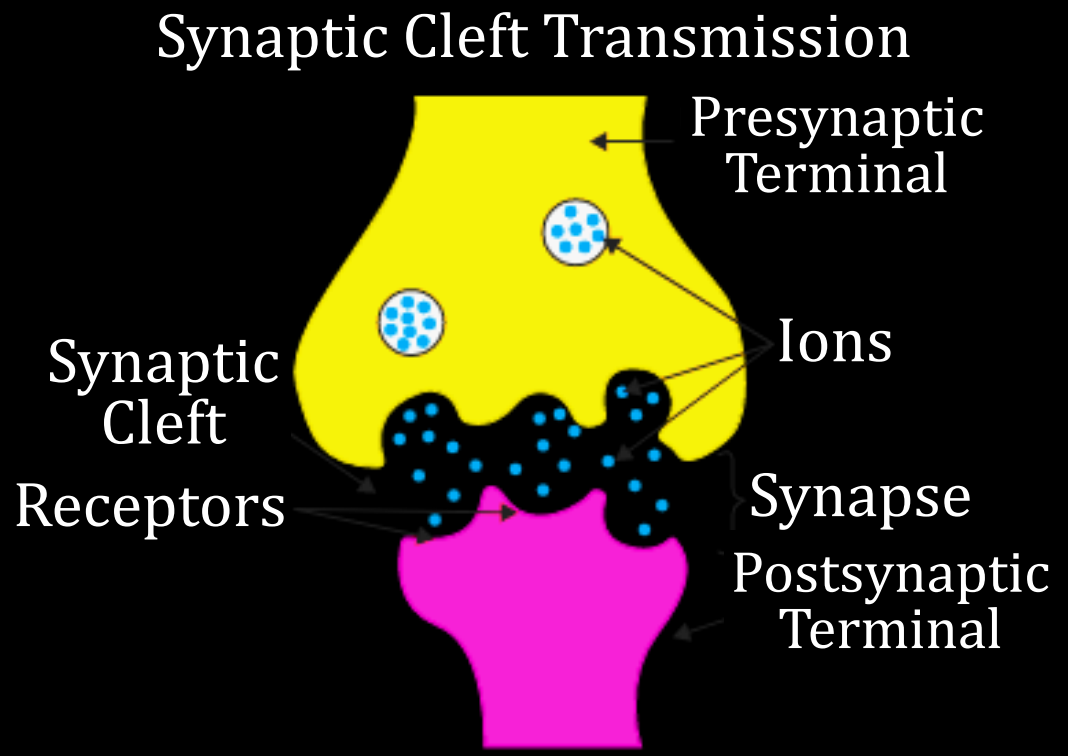
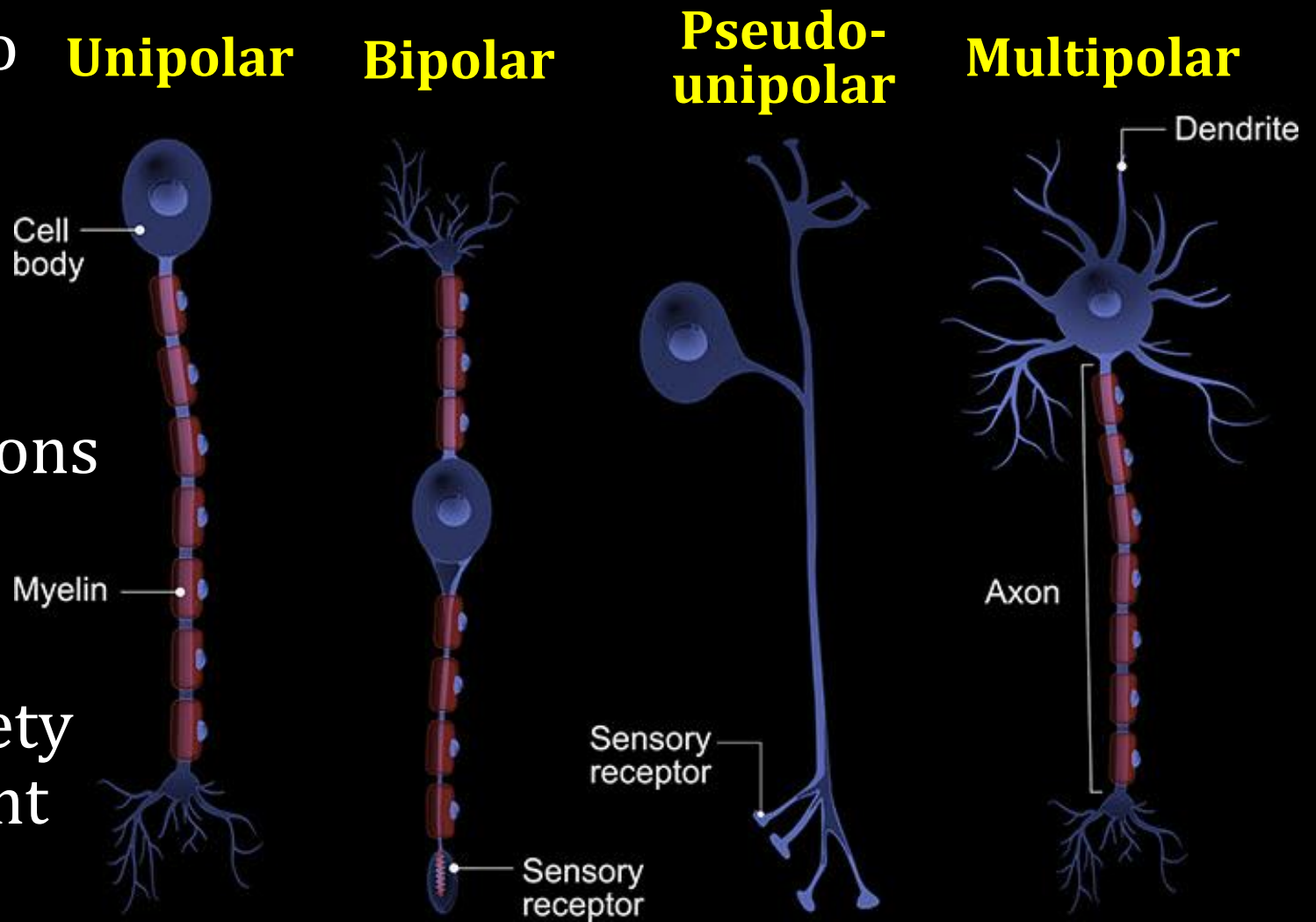




https://www.researchgate.net/publication/338015239_Superintelligent_Deep_Learning_Artificial_Neural_Networks/figures?lo=1&utm_source=google&utm_medium=organic

1.2 The Human Brain

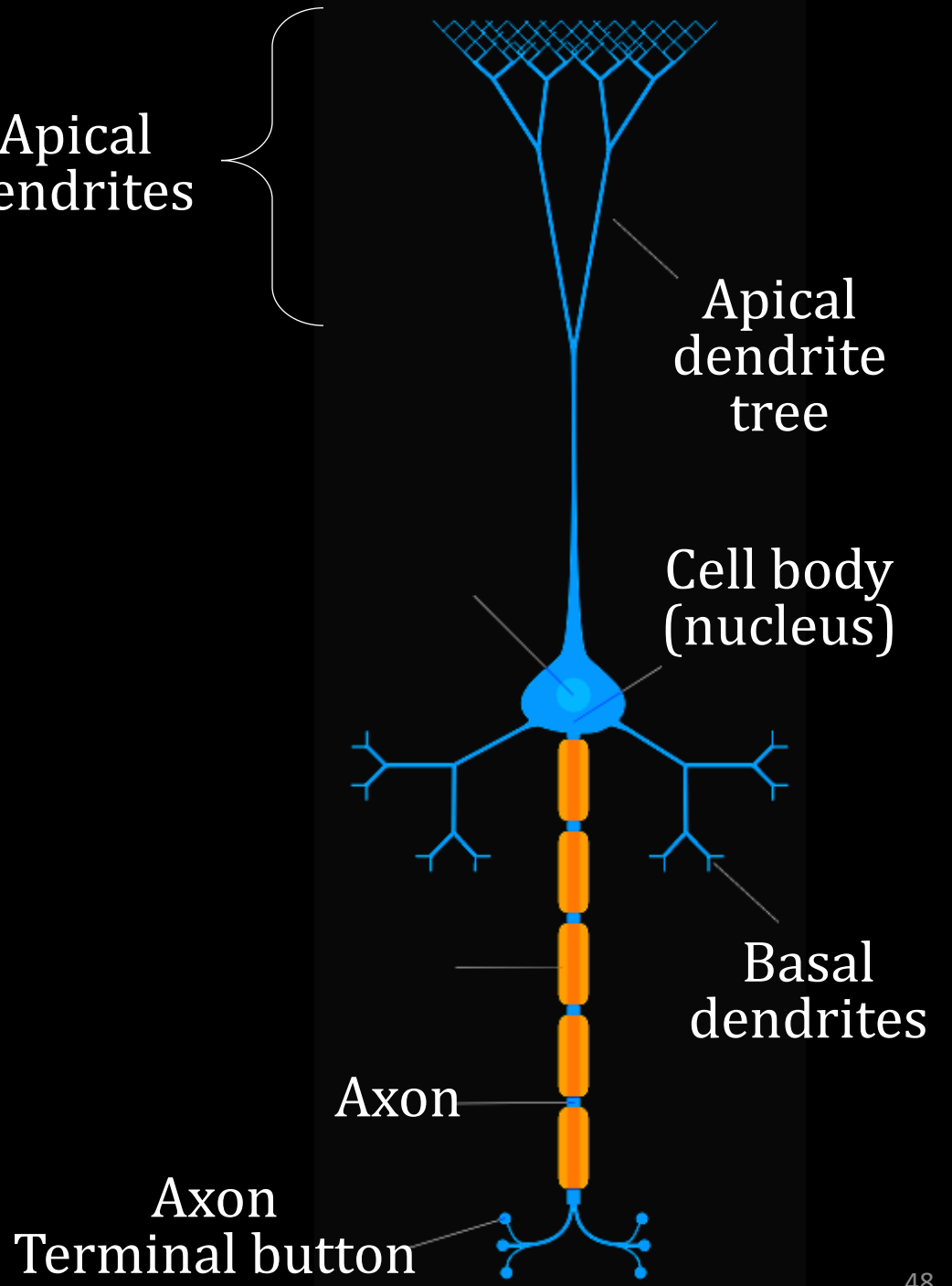
- Plasticity permits the developing nervous system to adapt to its surrounding environment by two mechanisms
  1. creation of new synaptic connections between neurons
  2. modification of existing synapses
- Neurons come in a wide variety of shapes and sizes in different parts of the brain.



https://qbi.uq.edu.au/brain/brain-anatomy/types-neurons

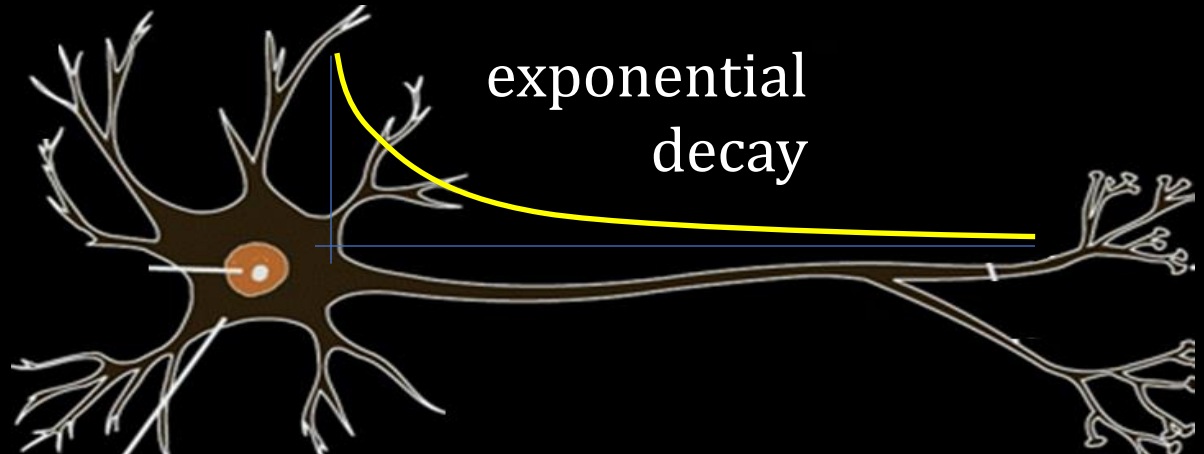
1.2 The Human Brain

- Figure 1.2 illustrates the shape of a pyramidal cell, which is one of the most common types of cortical neurons.
- Like many other types of neurons, it receives most of its inputs through dendritic spines;
  - see the segment of dendrite in the insert in Fig. 1.2 for details the pyramidal cell can receive 10,000 or more synaptic contacts it can project onto thousands of target cells.



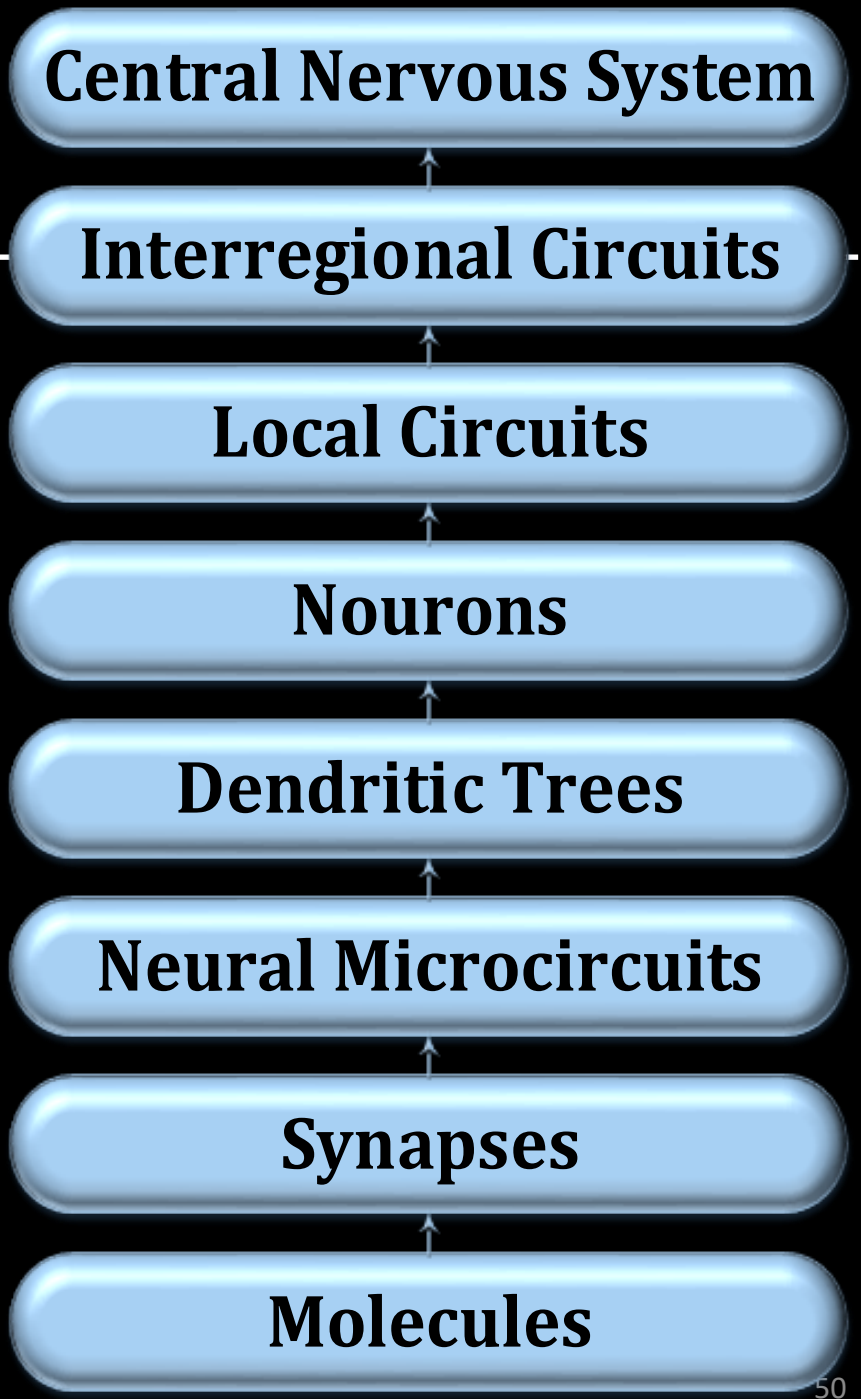
1.2 The Human Brain

- Majority of neurons encode their outputs as a series of brief voltage pulses
- These pulses, commonly known as action potentials, originate at or close to the cell body of neurons and then propagate across the individual neurons at constant velocity and amplitude
- The axon may therefore be modeled as an RC transmission line
- Analysis of signal propagation mechanism reveals that
  ~ when a voltage is applied at one end of an axon it decays exponentially with distance, dropping to insignificant level by the time it reaches the other end



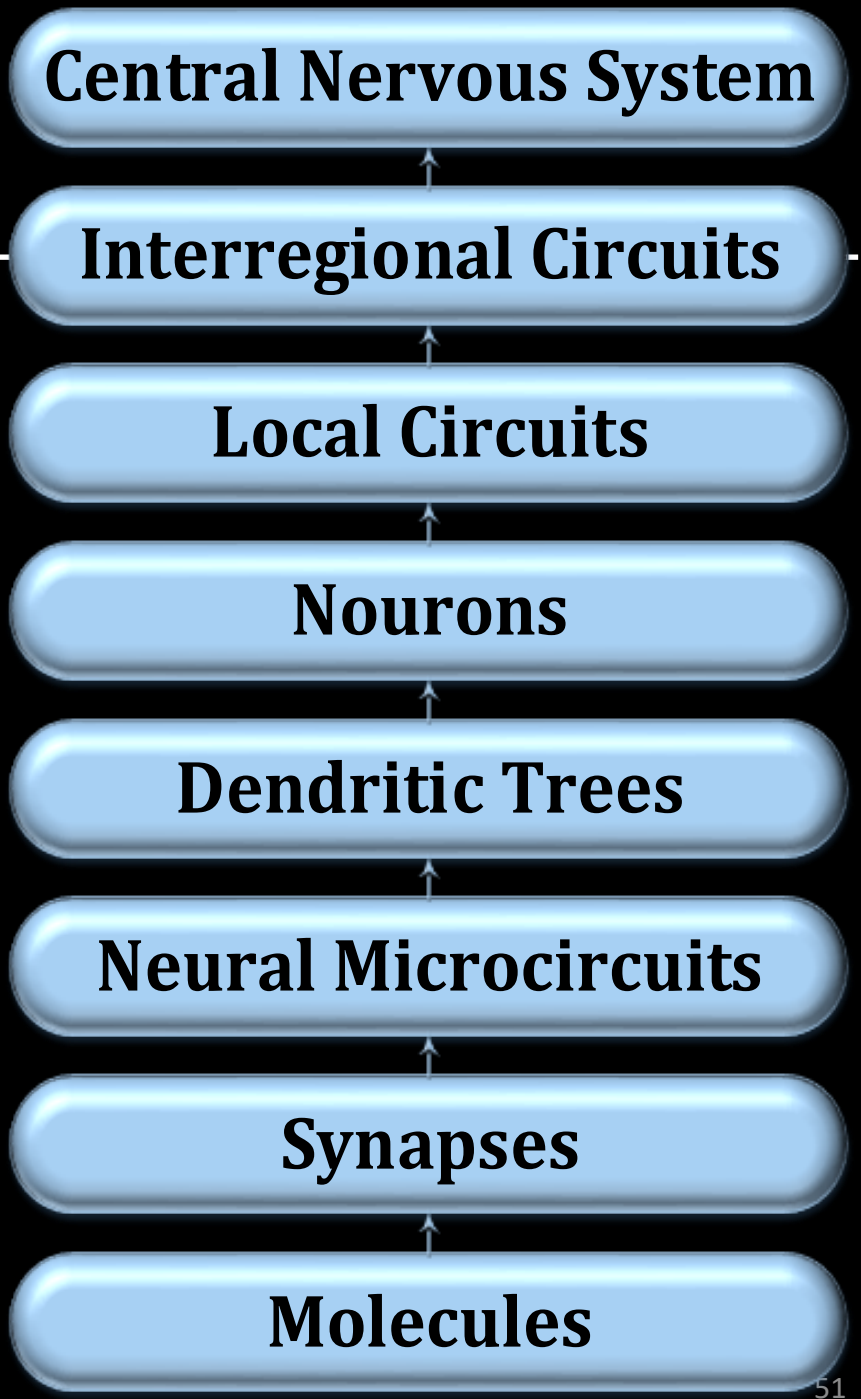
1.2 The Human Brain: Hierarchy of Interwoven Levels

- Fig. 1.3 shows a hierarchy of interwoven levels in the brain
- The synapses represent the most fundamental level, depending on molecules and ions for their action
- A neural microcircuit refers to an assembly of synapses organized into patterns of connectivity to produce a functional operation of interest



1.2 The Human Brain: Hierarchy of Interwoven Levels

- A neural microcircuit may be likened to a silicon chip made up of an assembly of transistors
- Microcircuits are in μm and their speed is in milliseconds
- Neural microcircuits are grouped to form dendritic subunits within the dendritic trees of individual neurons
- A neuron, ($\approx$100 μm), contains several dendritic subunits
- The local circuits are $\approx$1 mm in size made up of neurons



1.2 The Human Brain

- Topographic maps are organized to respond to incoming sensory information.
- These maps are often arranged in sheets, as in the superior colliculus, where the visual, auditory, and somatosensory maps are stacked in adjacent layers
- Figure 1.4 presents a cytoarchitectural map of the cerebral cortex
- This figure shows different sensory inputs (motor, somatosensory, visual, auditory, etc.)
- At the final level of complexity, the topographic maps and other interregional circuits mediate specific types of behavior in the central nervous system

Fig. 1.4: Cytoarchitectural map of the cerebral cortex

The different areas are identified by the thickness of their layers and types of cells within them.

Some of the most important specific areas are as follows.

Motor cortex: motor strip, area 4; premotor area, area 6; frontal eye fields, area 8.

Somatosensory cortex: areas 3, 1, 2. Visual cortex: areas 17, 18, 19.

Auditory cortex: area 41 and 42.