# What are Neural Networks?

- ***Neural Networks*** are networks of neurons, for example, as found in real (i.e. biological) brains
- ***Artificial neurons*** are crude approximations of the neurons found in real brains. They may be physical devices, or purely mathematical constructs.
- ***Artificial Neural Networks*** (ANNs) are networks of Artificial Neurons and hence constitute crude approximations to parts of real brains. They maybe physical devices, or simulated on conventional computers.
- From a practical point of view, an ANN is just a parallel computational system consisting of many simple processing elements connected together in a specific way in order to perform a particular task
- One should never lose sight of how crude the approximations are, and how over-simplified our ANNs are compared to real brains.

# Learning Processes in Neural Networks

Among the many interesting properties of a neural network, is the ability of the network to learn from its environment, and to improve its performance through learning. The improvement in performance takes place over time in accordance with some prescribed measure.

A neural network learns about its environment through an iterative process of adjustments applied to its synaptic weights and thresholds. Ideally, the network becomes more knowledgeable about its environment after each iteration of the learning process.

There are three broad types of learning:

1. Supervised learning (i.e. learning with an external teacher)
2. Unsupervised learning (i.e. learning with no help)
3. Reinforcement learning (i.e. learning with limited feedback)

# Historical Notes

**1943** McCulloch and Pitts proposed the McCulloch-Pitts neuron model

**1949** Hebb published his book *The Organization of Behaviour*, in which the Hebbian learning rule was introduced

**1958** Rosenblatt introduced the simple single layer networks called Perceptrons

**1969** Minsky and Papert's book Perceptrons demonstrated the limitation of single layer perceptrons

**1980** Grossberg introduced his Adaptive Resonance Theory (ART)

**1982** Hopfield published a series of papers on Hopfield networks

**1982** Kohonen developed the Self-Organizing Feature Maps

**1986** Back-propagation learning algorithm for multi-layer perceptrons was re-discovered, and the whole field took off again

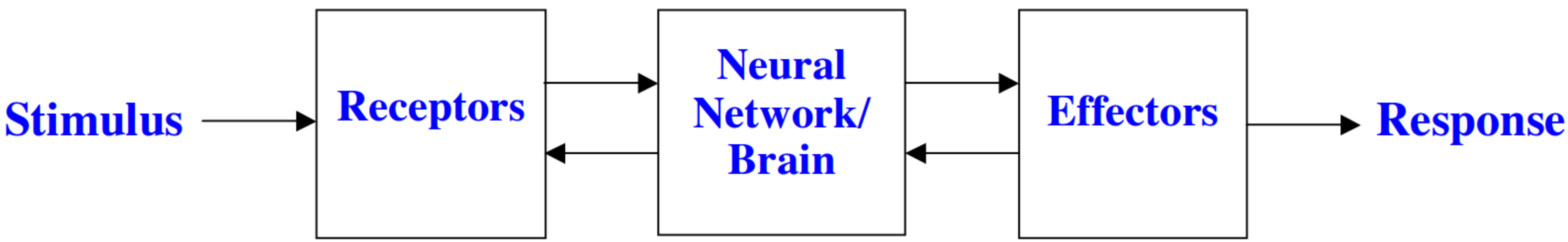
**1990s** ART-variant networks were developed

**1990s** Radial Basis Functions were developed

**2000s** Support Vector Machines were developed

# The Nervous System

The human nervous system can be broken down into three stages that may be represented in block diagram form as:




1 2 3

The receptors collect information from the environment – e.g. photons on the retina.

The effectors generate interactions with the environment – e.g. activate muscles.

The flow of information/activation is represented by arrows – feedforward and feedback.

Naturally, this module will be primarily concerned with how the neural network in the middle works, but understanding its inputs and outputs is also important.

# Brains versus Computers : Some numbers

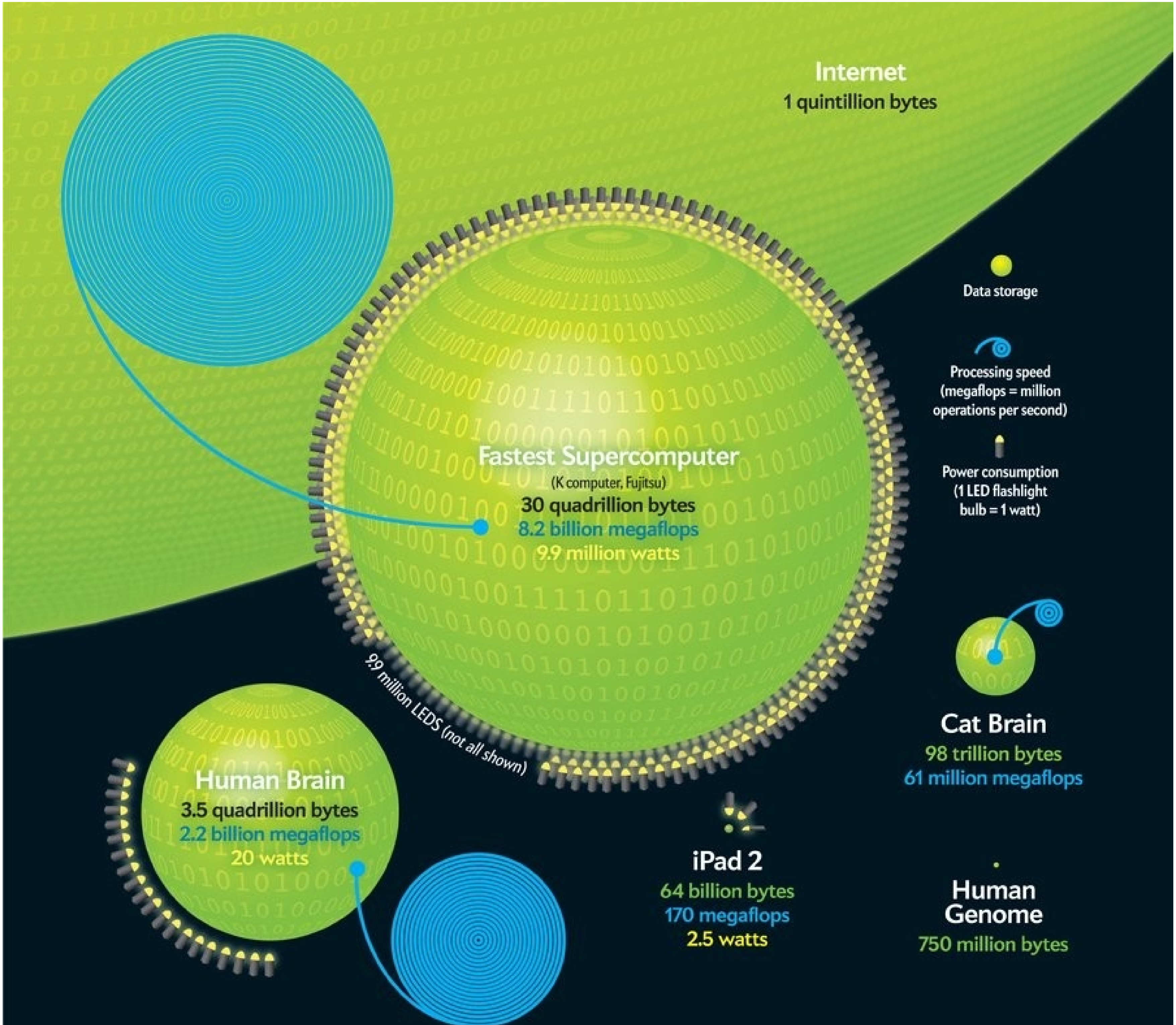
1. There are approximately 10 billion neurons in the human cortex, compared with tens of thousands of processors in the most powerful parallel computers.

2. Lack of processing units can be compensated by speed. The typical operating speeds of biological neurons is measured in milliseconds ($10^{-3}$ s), while current silicon chips can usually operate in nanoseconds ($10^{-9}$ s).

3. Each biological neuron is connected to several thousands of other neurons, similar to the connectivity in powerful parallel computers.

4. The human brain is extremely energy efficient, using approximately $10^{-16}$ joules per operation per second, whereas the best computers today use around $10^{-6}$ joules per operation per second.

5. Brains have been evolving for tens of millions of years, but computers have only been evolving for tens of decades, though different mechanisms are involved.




https://www.scientificamerican.com/article/computers-vs-brains/

# Brains versus Computers : Some numbers

**Fault tolerant:** The brain is fault tolerant, whereas the computer is not

**Adaptive:** The brain learns fast, whereas the computer doesn't even compare with an infant's learning capabilities

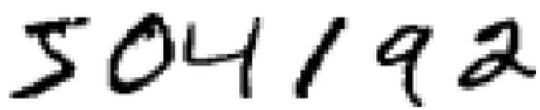
**Intelligence and consciousness:** The brain is highly intelligent and conscious, whereas the computer shows lack of intelligence

## Why are Artificial Neural Networks worth studying?

# Why are Artificial Neural Networks worth studying?

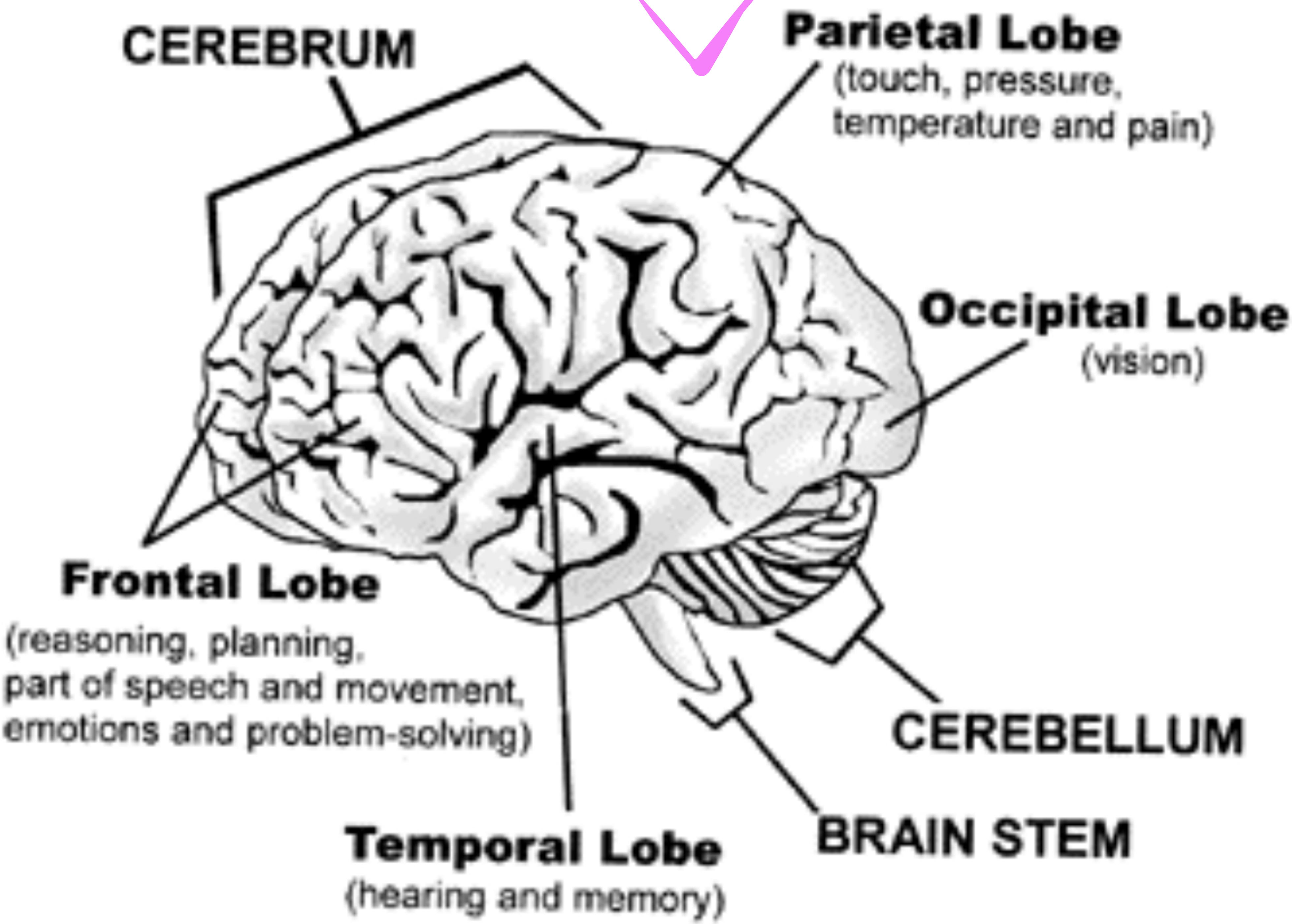
**Square root of 964,324 ?**

**Identify the following handwritten digits:**



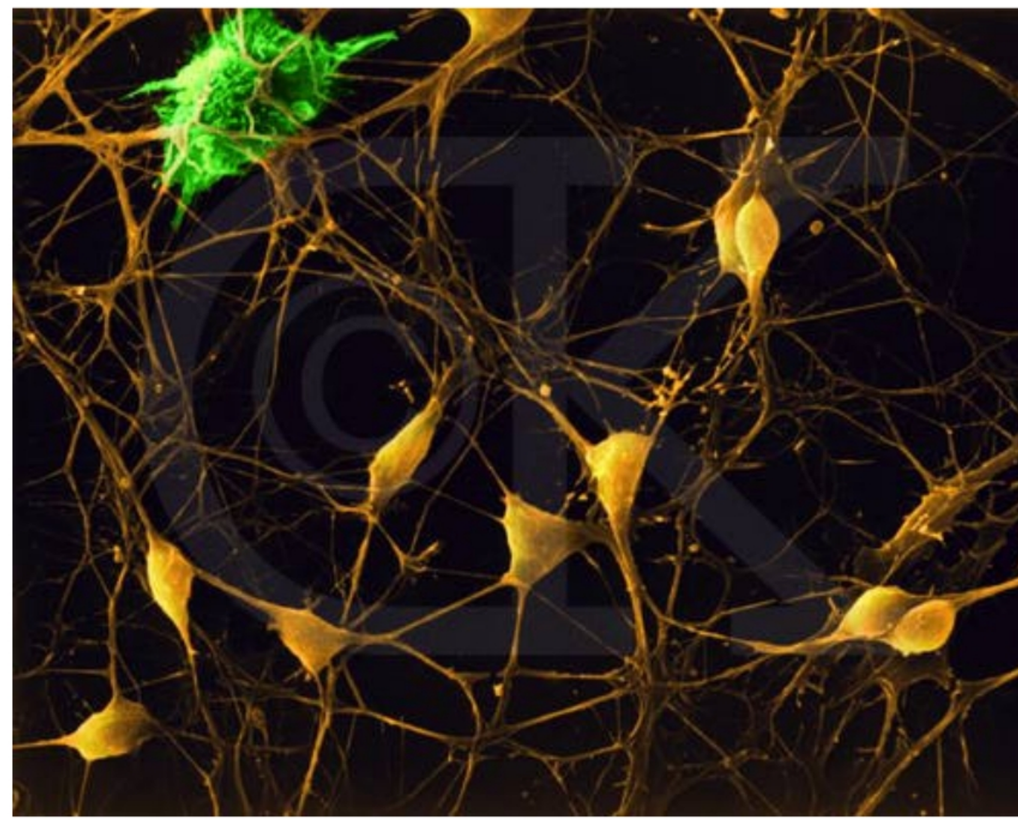
**Goal: perform “easy-for-a-human, difficult-for-a-machine” tasks -- often referred to as pattern recognition.**

# Structure of a Human Brain



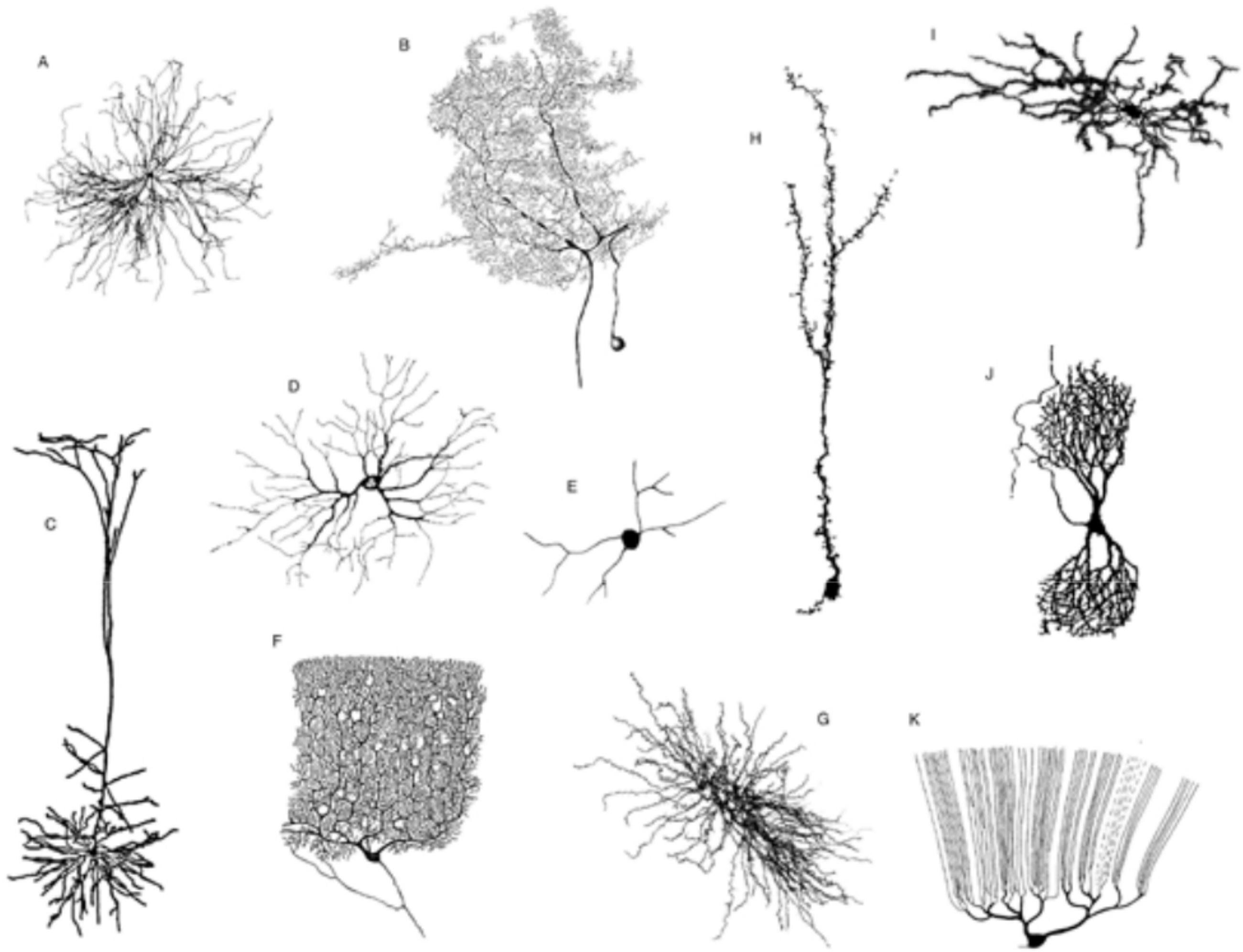
# Microscopic View of the Nervous System

- Nervous system is made up of cells
- A cell has a fatty membrane, which is filled with liquid and proteins known as cytoplasm as well as smaller functional parts called organelles
- There are two major types of brain cells: (1) neurons, and (2) glia
- Neurons are the principal elements involved in information processing in the brain
- Glia provide support and homeostasis to neurons.



# Neurons

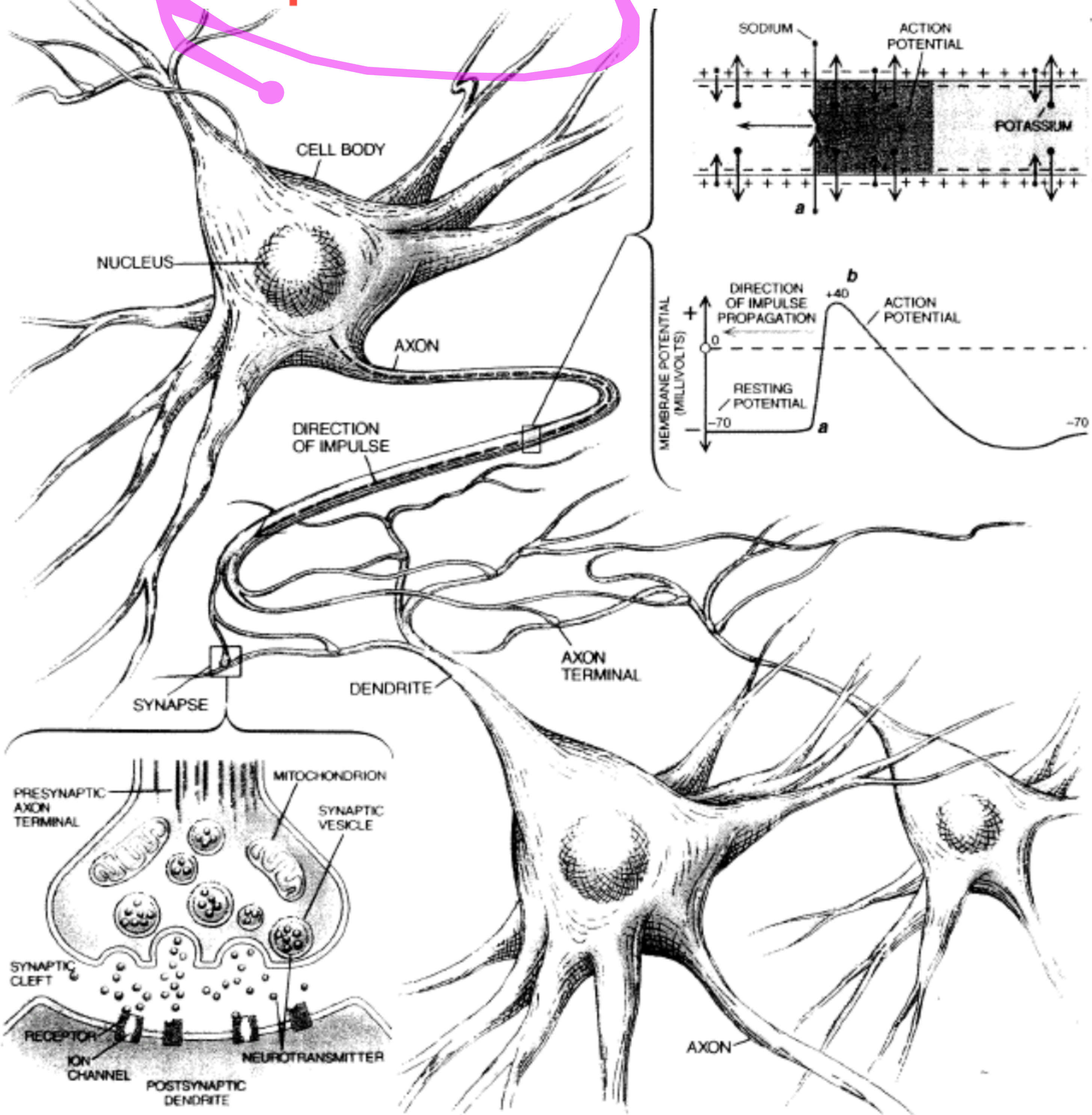
- Neurons are biological cells that a specialised to form networks and send electrical signals to each other
- They come in many different shapes and sizes



# Basic Components of Biological Neurons

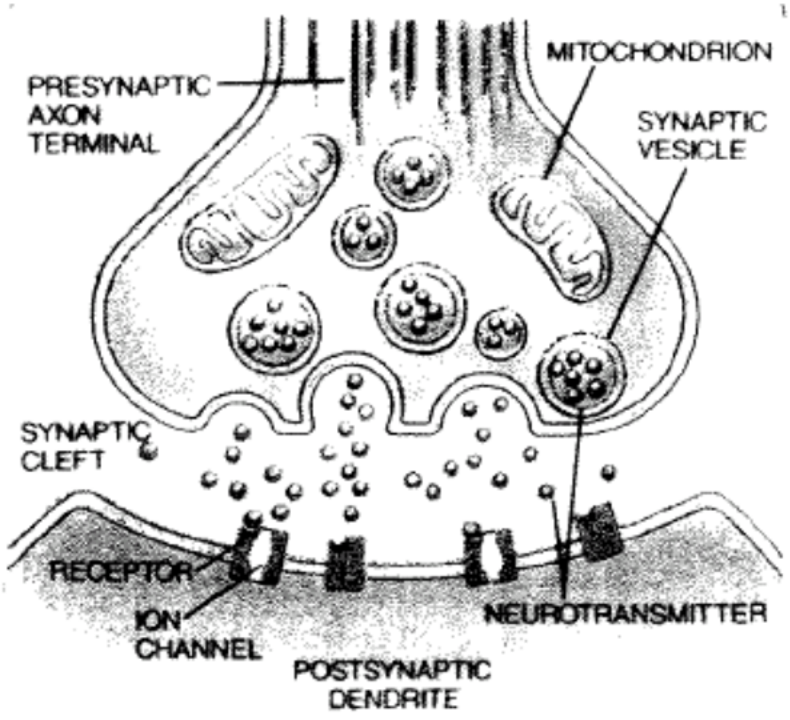
1. The majority of ***neurons*** encode their activations or outputs as a series of brief electrical pulses (i.e. spikes or action potentials).
2. The neuron's ***cell body (soma)*** processes the incoming activations and converts them into output activations.
3. The neuron's ***nucleus*** contains the genetic material in the form of DNA. This exists in most types of cells, not just neurons.
4. ***Dendrites*** are fibres which emanate from the cell body and provide the receptive zones that receive activation from other neurons.
5. ***Axons*** are fibres acting as transmission lines that send activation to other neurons.
6. The junctions that allow signal transmission between the axons and dendrites are called ***synapses***. The process of transmission is by diffusion of chemicals called ***neurotransmitters*** across the synaptic cleft.

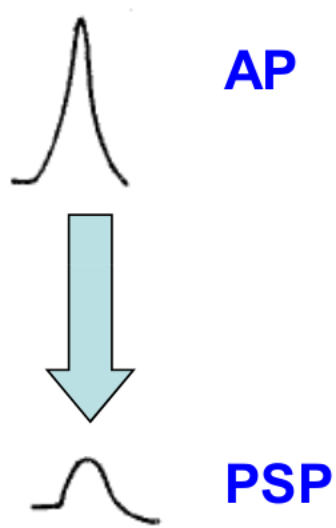
# Component Parts of a Neuron



# The Synapse

- The synapse converts an action potential (AP) into a postsynaptic potential (PSP)
- The presynaptic AP causes calcium (Ca) entry
- Ca causes vesicles of *neurotransmitter* to be released
- Neurotransmitter binds to postsynaptic receptors (ion channels), causing them to open
- The resulting ionic current generates the PSP



# Neural Signal Processing

The key components of neural signal processing are:

1. Signals from connected neurons are collected by the dendrites.
2. The cells body (soma) sums the incoming signals (spatially and temporally).
3. When sufficient input is received (i.e., a threshold is exceeded), the neuron generates an action potential or ‘spike’ (i.e., it ‘fires’).
4. That action potential is transmitted along the axon to other neurons, or to structures outside the nervous systems (e.g., muscles).
5. If sufficient input is not received (i.e. the threshold is not exceeded), the inputs quickly decay and no action potential is generated.
6. Timing is clearly important – input signals must arrive together, strong inputs will generate more action potentials per unit time.