Introduction to the physiology of perception

Human Perception for Information Technology,

DT2350, HT 2015,

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Definitions of perception

- The interpretation of sensory information
  (Hayes & Orrell, 1987)
- A dynamic search for the best interpretation of available data
  (Gregory, 1966)
- Perception is “the process of assembling sensations into a usable mental representation of the world” (Coon, 1983)
- The processes by which stimuli are selected, organised and interpreted (Solomon, 2006)

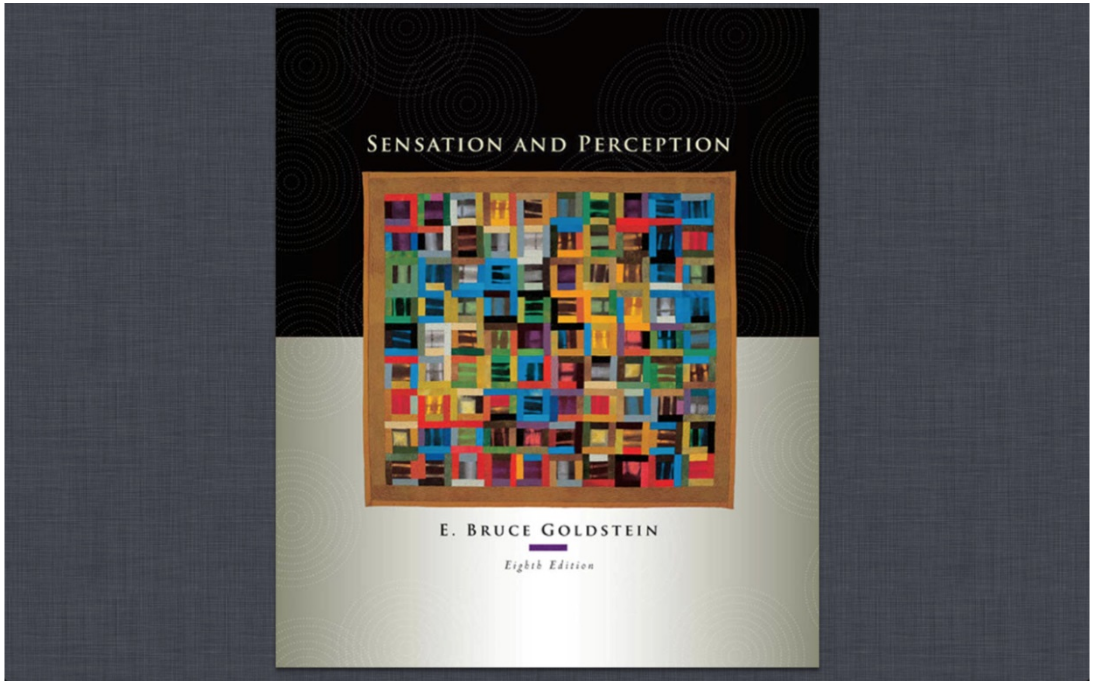
Perception is not a simple passive registration of sensory input, it is a process where we actively select, order and interpret information in order to understand and interact with the environment

Sensation and perception

- Sensation
  - Biochemical and neurological responses to external stimuli
  - Detect the presence of a signal in the environment
  - Is there something out there and how intense is the signal?
- Perception
  - The organization, identification, and interpretation in order to represent, understand and interact with our environment
  - Where is the object, what is it, is it moving, how does it affect me?

Chapter 2 in:
Introduction to the Physiology of perception

- How can stimuli (signals in the environment) be transduced into neural impulses and transmitted to our brain?

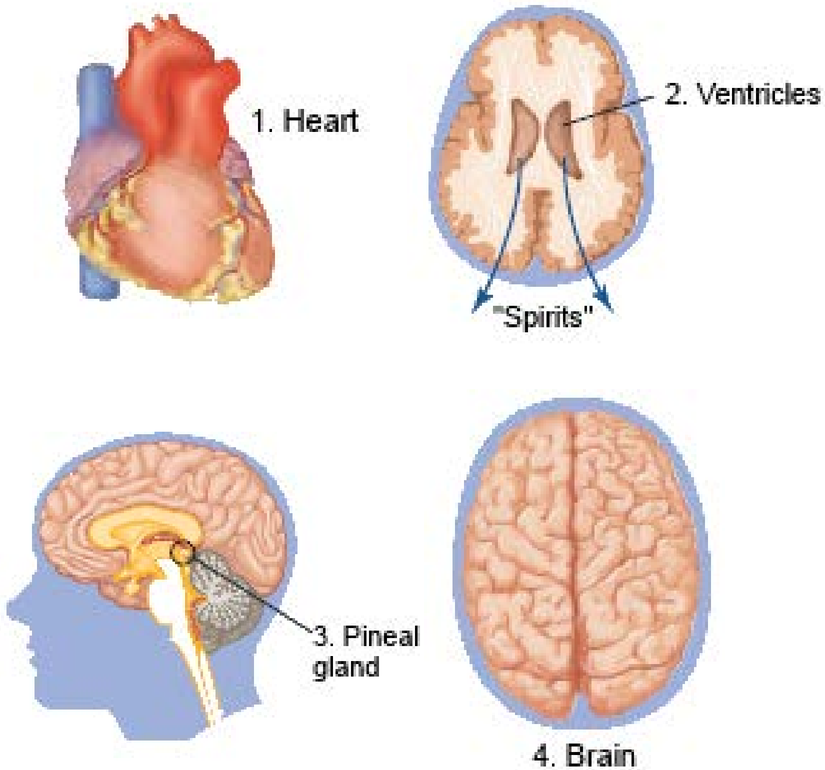


Stimulus and response

- Stimulus
  - An external environmental trigger
- Response
  - An internal reaction to the stimulus

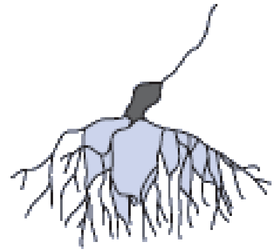
The history of the physiological approach

1. Mind and soul was located in the heart (Aristotle 384-322 B.C.)
2. Thoughts and emotions originated from the *ventricles* (Galen, 130-200 A.D.)
3. The “seat of the soul” located in the Pineal gland (Descartes, 1630s)
4. Different functions located in different areas of the brain (The anatomy of the brain, Willis, 1664)

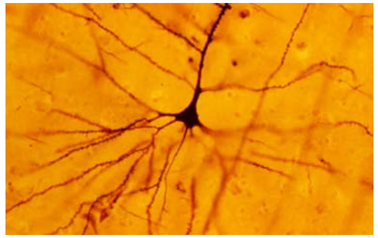


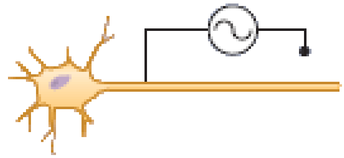
The history of the physiological approach

5. The nervous system consists of distinct elements or cells (“staining”, Golgi, 1870s)
6. Single neuron recording (Adrian, 1920s)
7. Neural networks (modern)

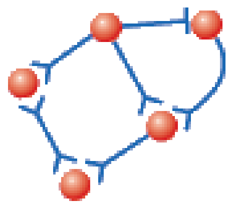


5. Golgi stained neuron





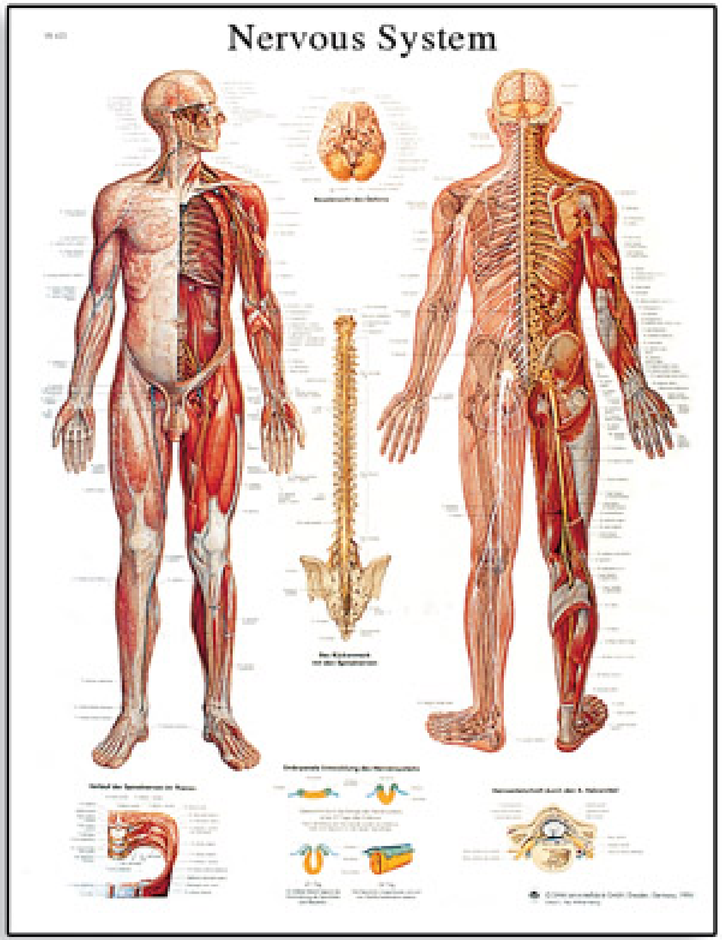
6. Single neuron recording



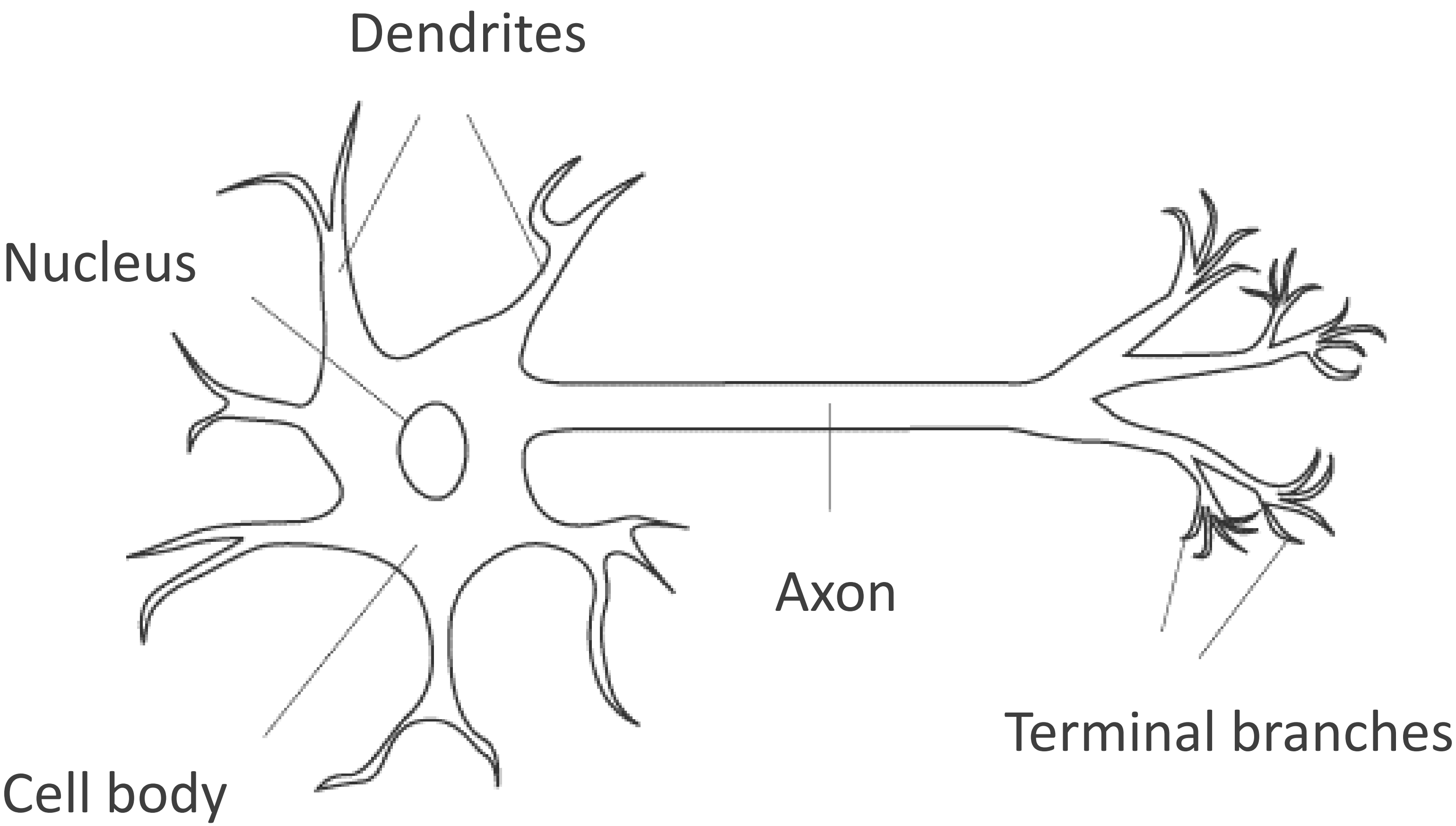
7. Neural networks

The connection between environmental stimuli and perception

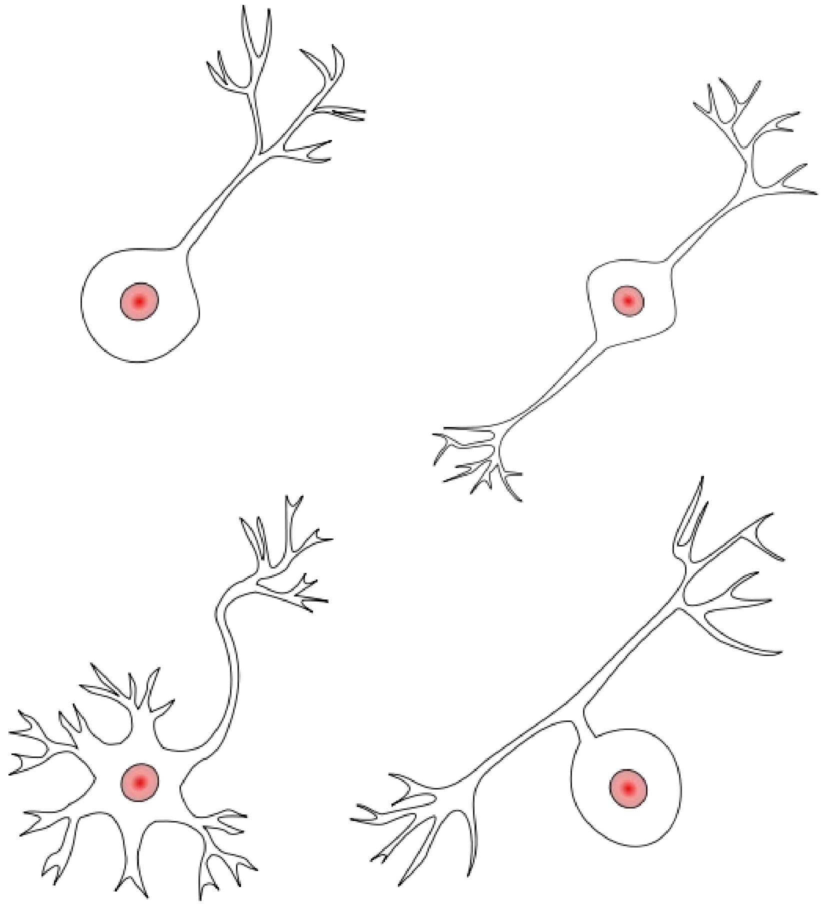
- The nervous system is the part of the body that sends information about external stimuli to the brain
- The nervous system consists of special type of cell called *neuron* or *nerve cell*



Structure of neurons

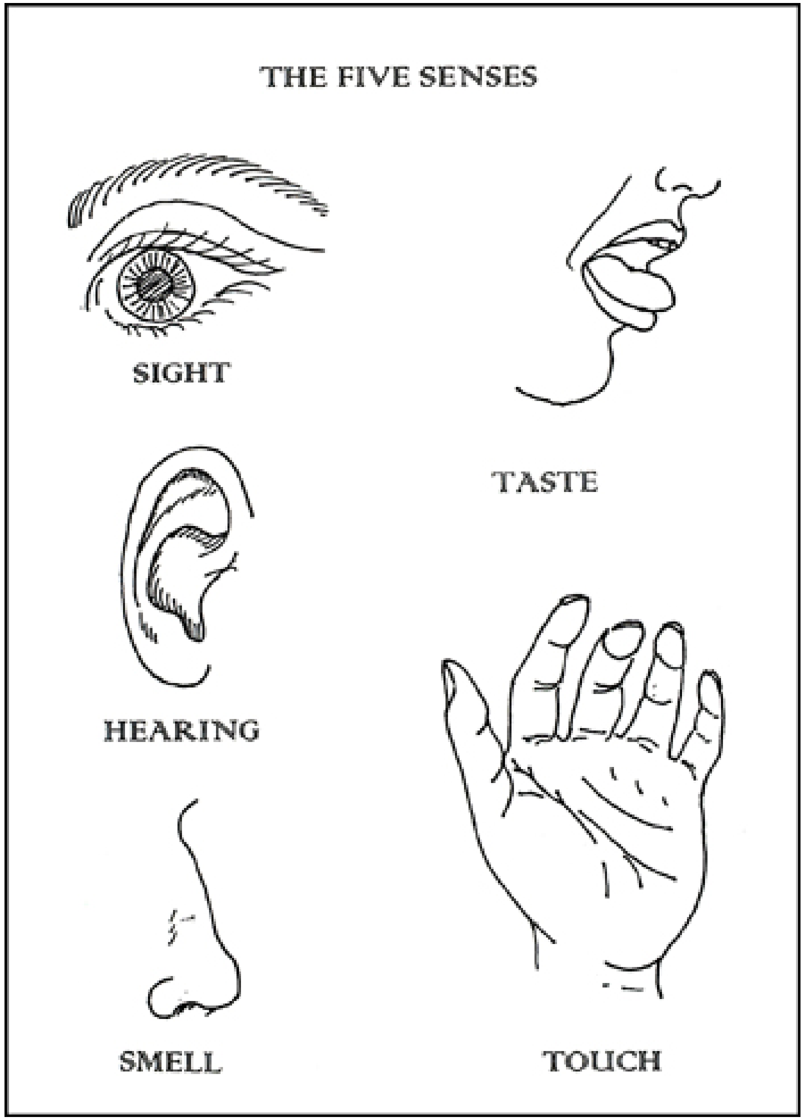


Different types of neurons



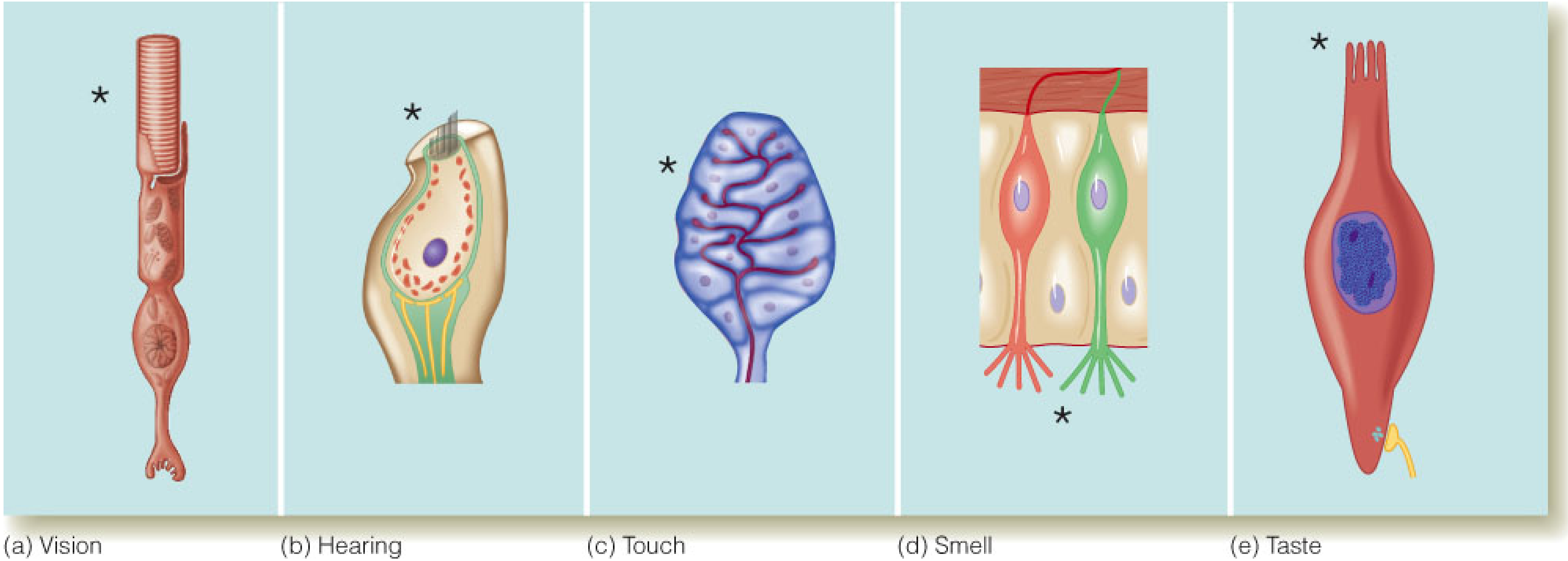
The senses

- "Five senses"
  - Sight
  - Taste
  - Hearing
  - Smell
  - Touch
- Additional senses
  - Temperature
  - Kinesthetic
  - Pain
  - Balance
  - …



Receptors

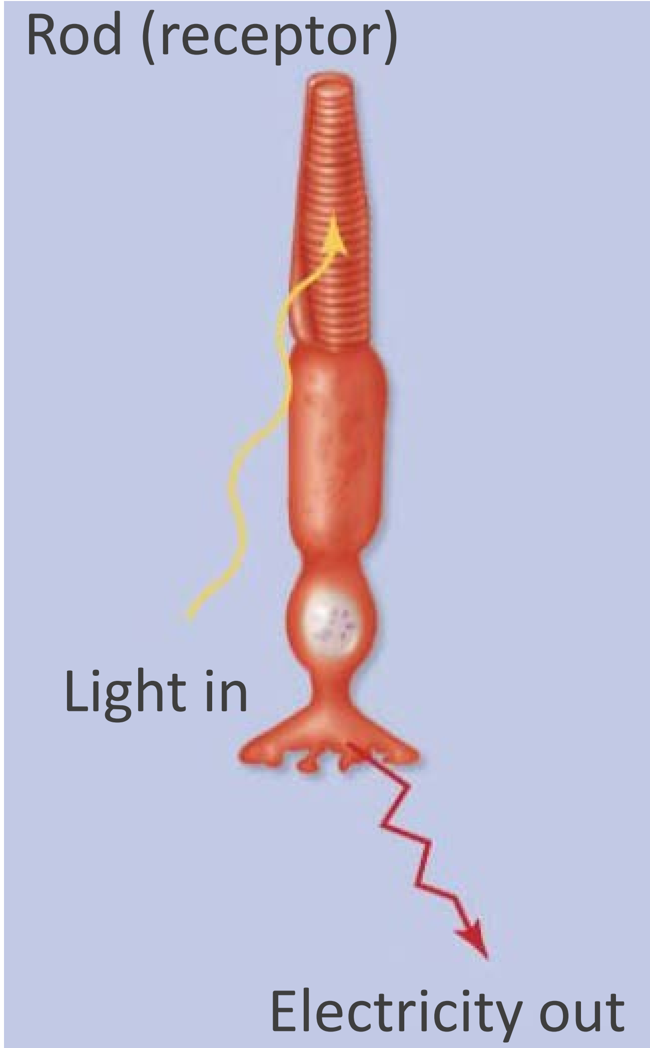
Neurons that connects our nervous system with the external environment



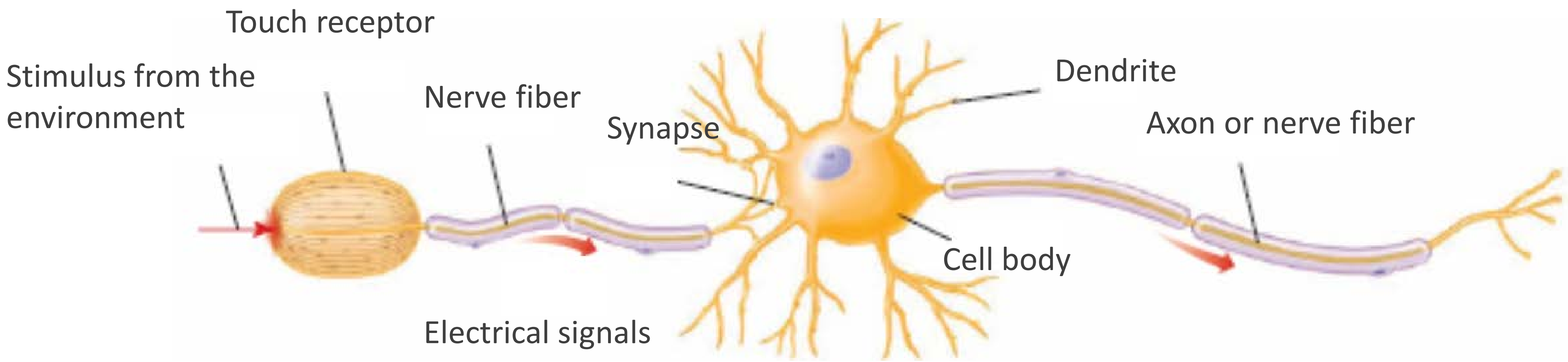
* Reacts to environmental stimuli

Transduction

- The transformation of electrical energy in the environment into electrical neural signals

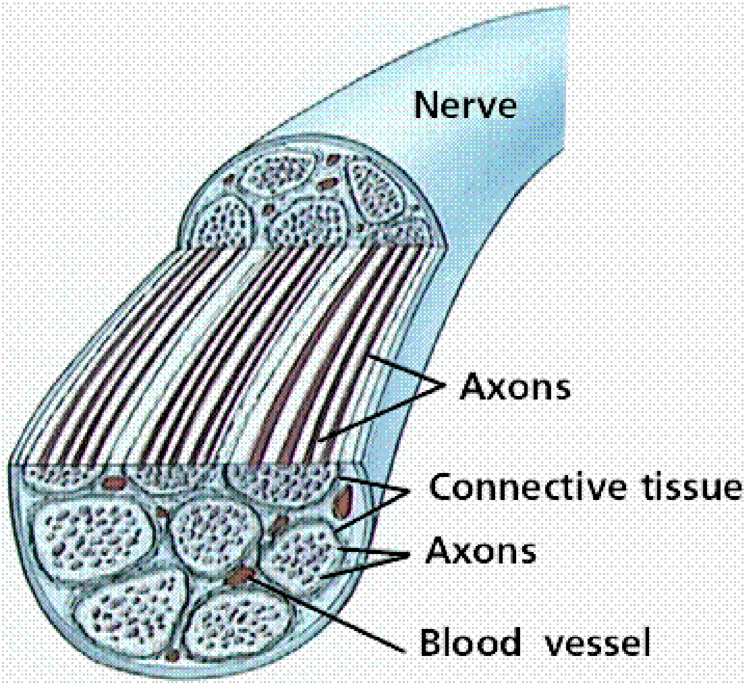


Sensory input



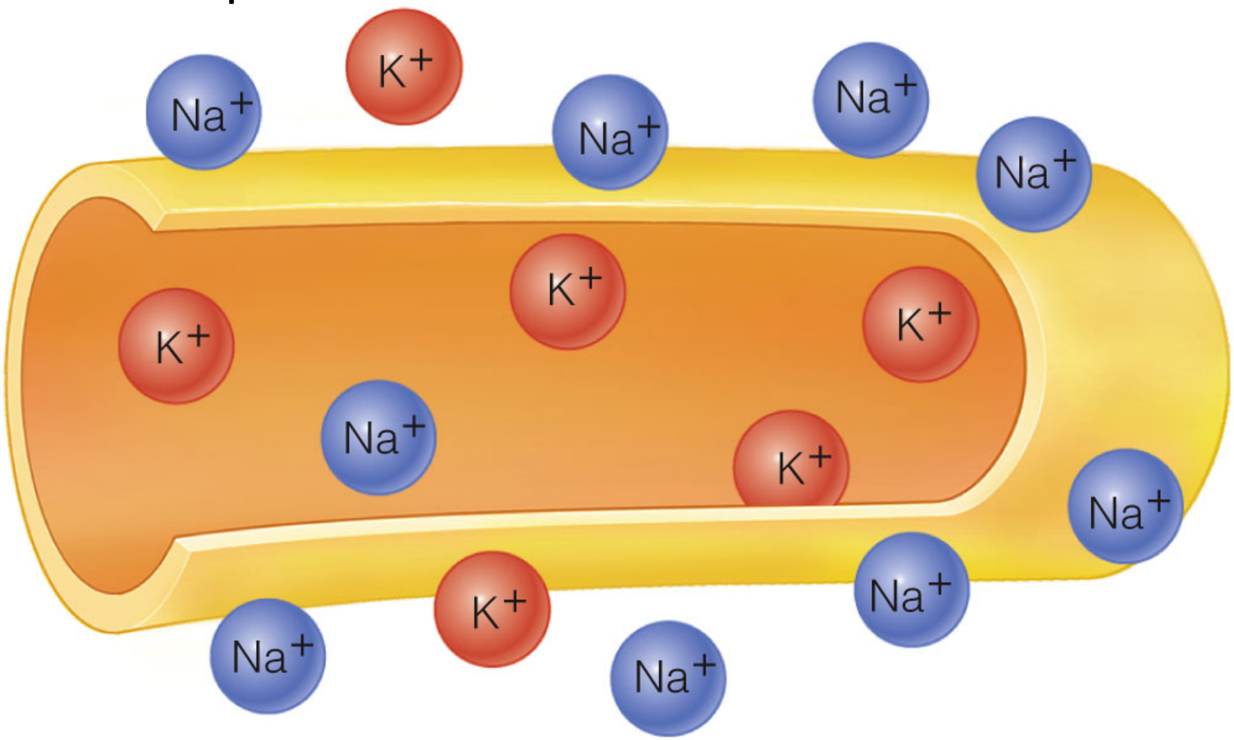
Nerve

- A cable like bundle of axons (nerve fibres) from many neurons



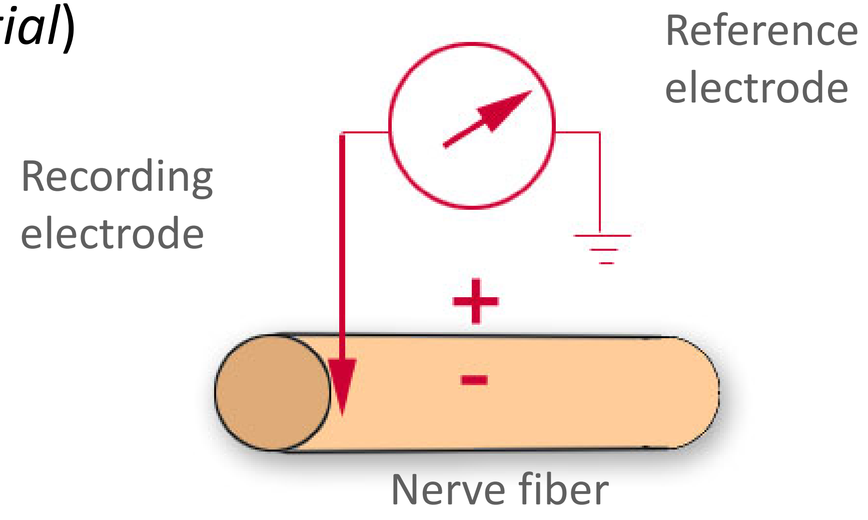
The chemical basis of neurons

- The electrical signals in neurons are created and conducted through liquid
- Sodium Na+ and potassium K+



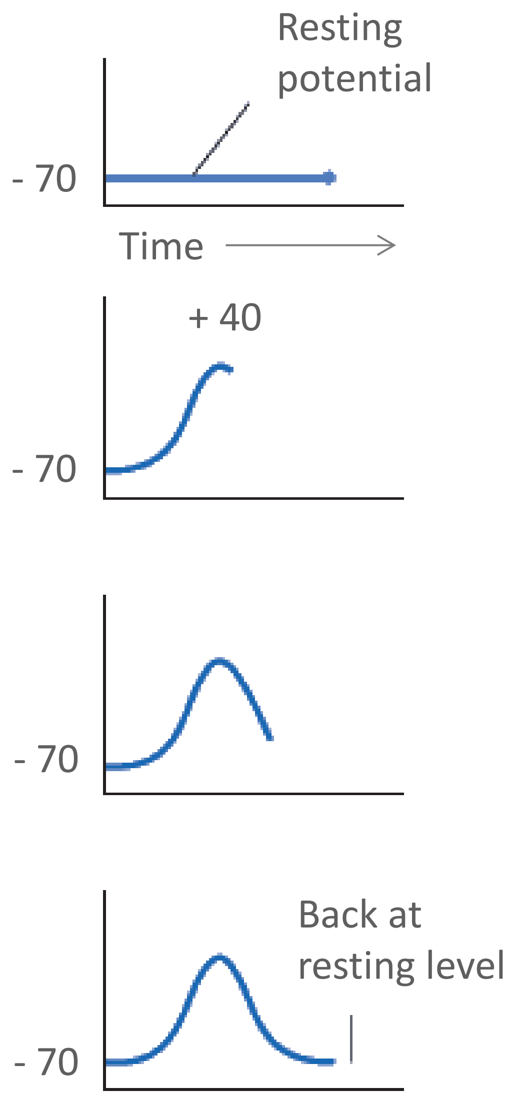
Membrane Potential

- The *difference* in electrical potential between the interior and exterior of a nerve fiber (axon)
- Used to measure electrical activity in neurons
- The difference is measured using *microelectrodes*
  - Shafts of glass or metal that records electrical signals from a single neuron
- A resting fiber has a difference of about -40 to -80 millivolt between the inside and the outside the fiber (*resting potential*)



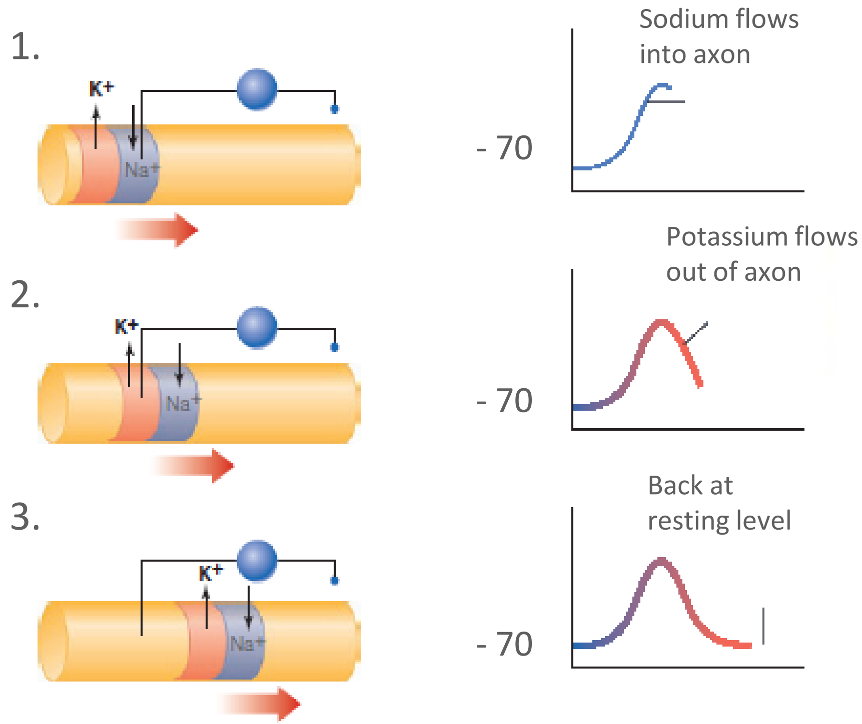
Action potential

- When a nerve impulse passes, the charge inside of the fiber changes and the difference increase (deploarisation)
- After the nerve impulse has passed, the neuron returns to its resting state
- The action potential lasts about 1 millisecond



Chemical bases of Action Potentials

- Neurons are surrounded by a solution rich in *ions*
- The solution outside the axon is rich in sodium (Na^+) and the inside is rich in potassium (K^+)
- The action potential is created by the flow of sodium and potassium ions across the cell membrane
- This flow of Na^+ and K^+ is caused by a change in the fiber's *selective permeability*

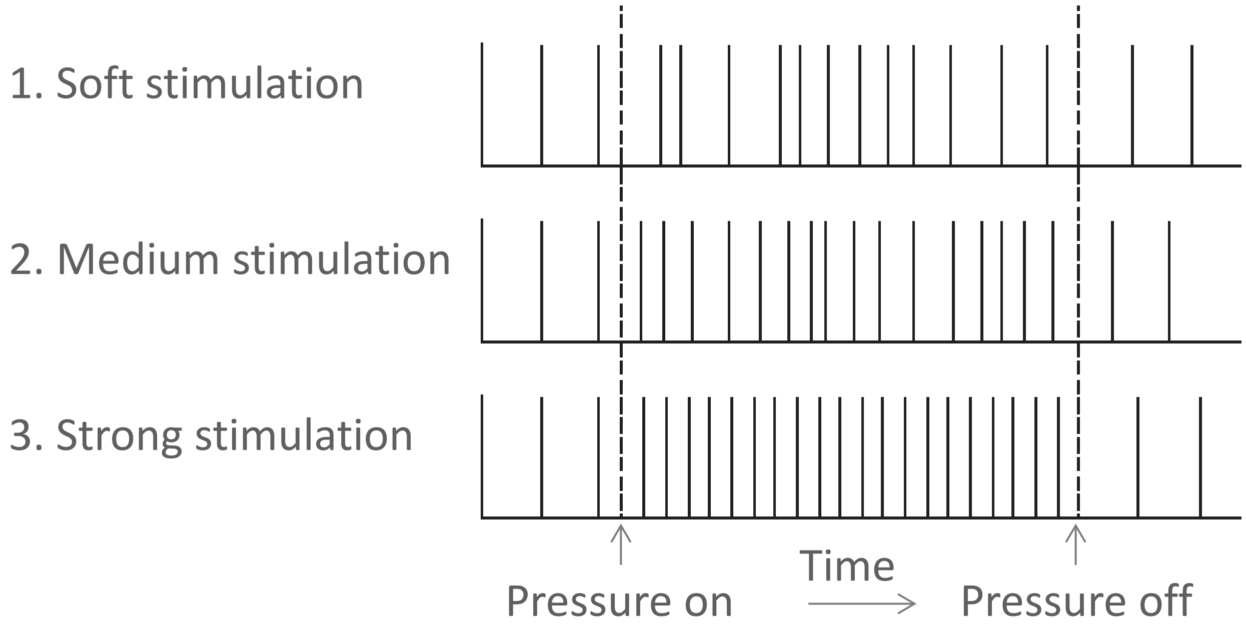


Film: Action potentials

http://www.youtube.com/watch?v=ifD1YG07fB8

Basic properties of Action Potentials

- Propagated response
  - Action potential travels long distances without decreasing in size
- The intensity of the stimulus does not affect size of the response
  - The intensity of the stimulus does not affect the *size* of the action potentials, only the *rate* of firing.



Basic properties of Action Potentials

- Refractory period
  - The axon’s upper limit of firing rate
  - The time after an action potential when the membrane is not excitable
  - Prevents the signal from travelling backwards long the axon
  - About 1 millisecond (500-800 impulses per second)
- Spontaneous activity
  - Action potentials that occur without any stimulus
  - Establishes a firing threshold
  - A change in firing rate provides information about the intensity of a stimulus

The Synapse: Transmission of Neural Impulses across the gap

- An action potential is passed on to the next neuron through a *synapse*
- A synapse is a process that releases *neurotransmitters*, chemicals stored in the synaptic vesicles (cavities) of the sending neuron
- In a synapse, an action potential cause neurotransmitters to be:
  - released by the presynaptic neuron
  - received by the postsynaptic neuron on *receptor sites*, areas in the receiving neuron that are sensitive to specific neurotransmitters
  - matched like a key to a lock into specific receptor sites.
  - used as triggers for voltage change in the postsynaptic neuron.

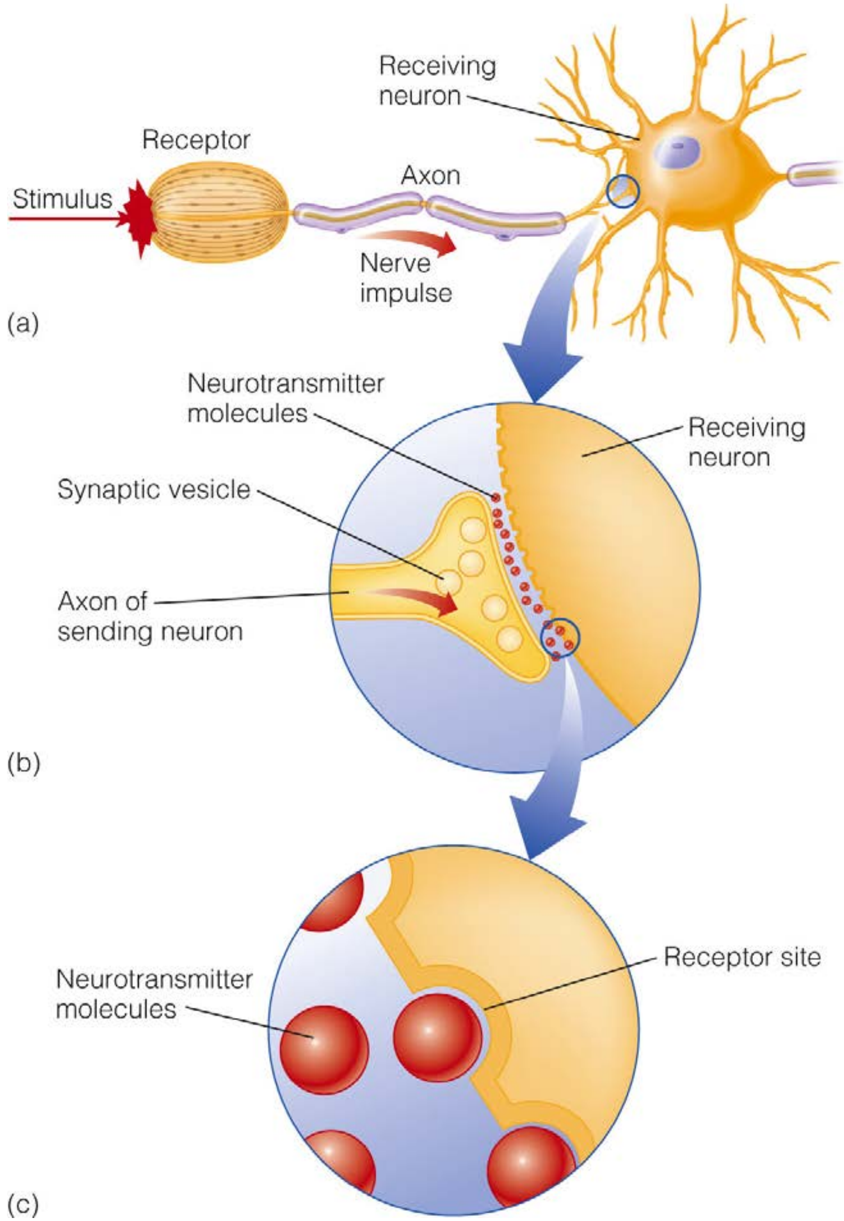
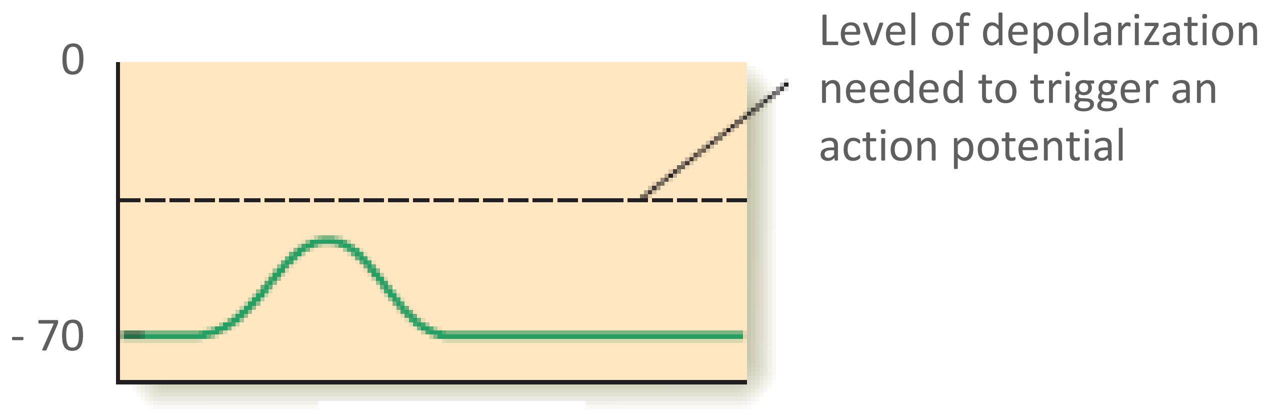


Figure 2.11 Synaptic transmission from one neuron to another. (a) A signal traveling down the axon of a neuron reaches the synapse at the end of the axon. (b) The nerve impulse causes the release of neurotransmitter molecules from the synaptic vesicles of the sending neuron. (c) The neurotransmitters fit into receptor sites and cause a voltage change in the receiving neuron.

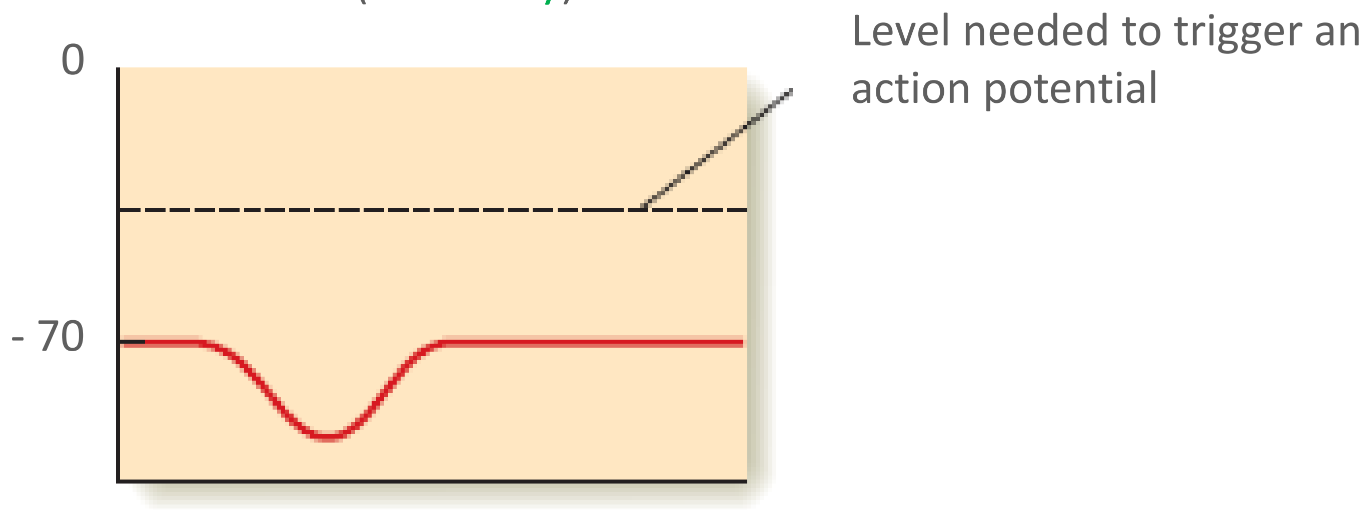
Types of Neurotransmitters

- Excitatory transmitters - cause depolarization
  - Neuron becomes more positive
  - Increases the likelihood of an action potential
- Inhibitory transmitters - cause hyperpolarization
  - Neuron becomes more negative
  - Decreases the likelihood of an action potential

Depolarization and hyperpolarization

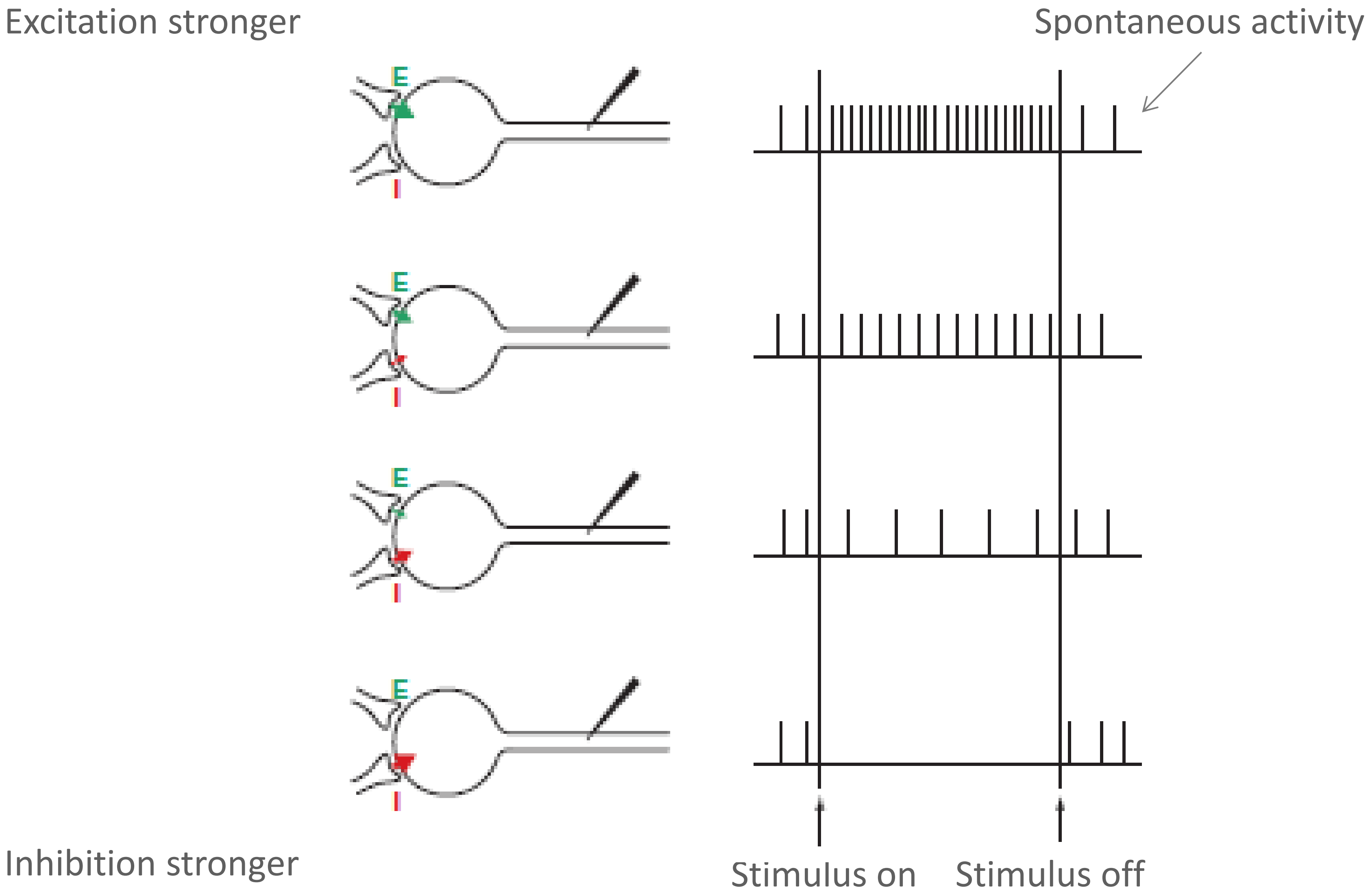


Depolarization
(Excitatory)

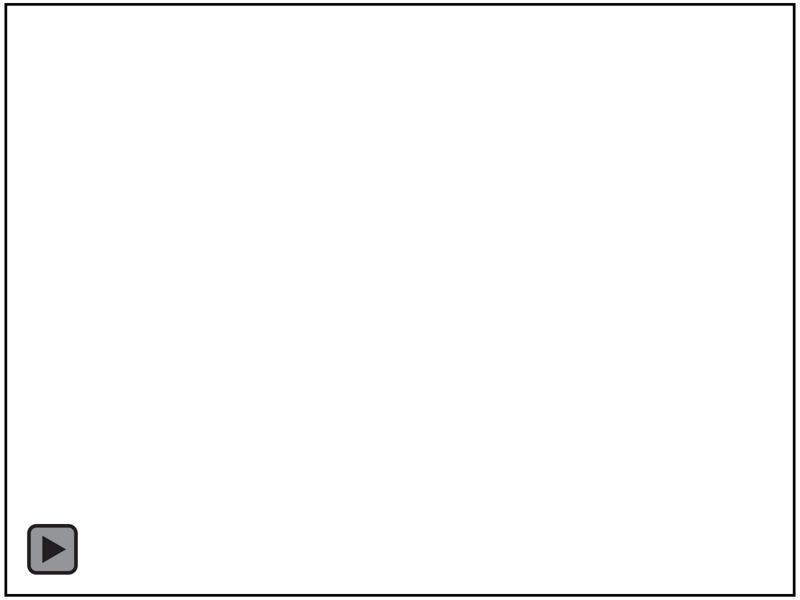


Hyperpolarization
(Inhibitory)

The effect of excitatory and inhibitory input



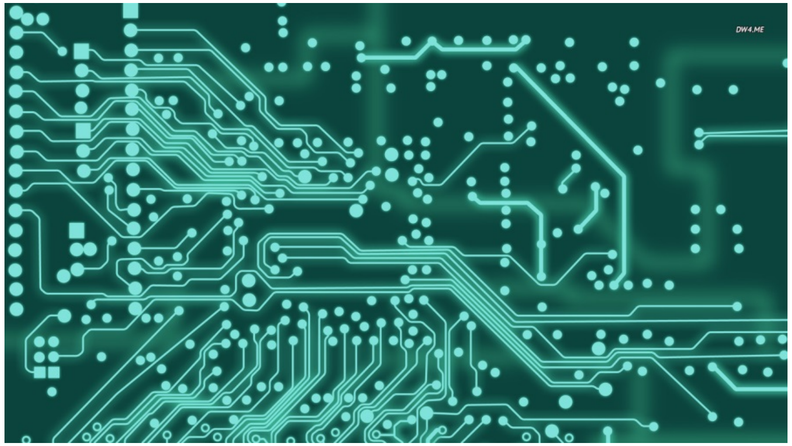
Synapse: animation



http://www.youtube.com/watch?v=HXx9qlJetSU

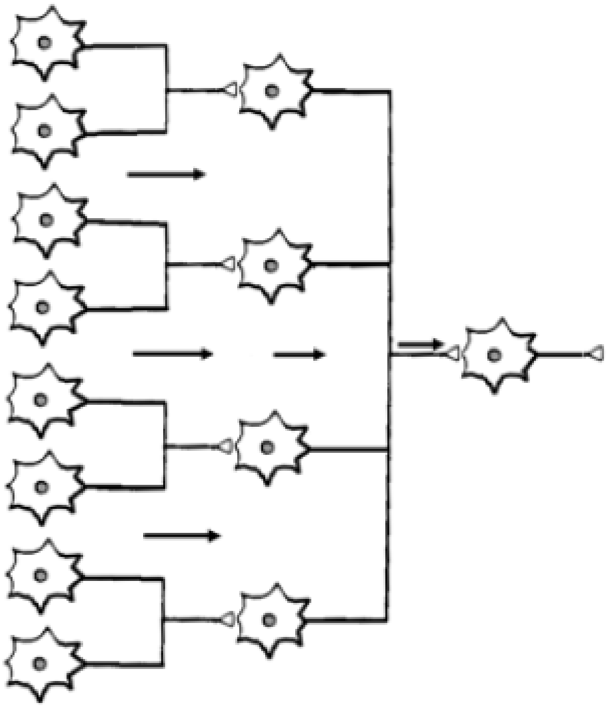
Neural circuit

- Neurons are interconnected with one another to form circuits, much as electronic components are wired together to form a functional circuit.



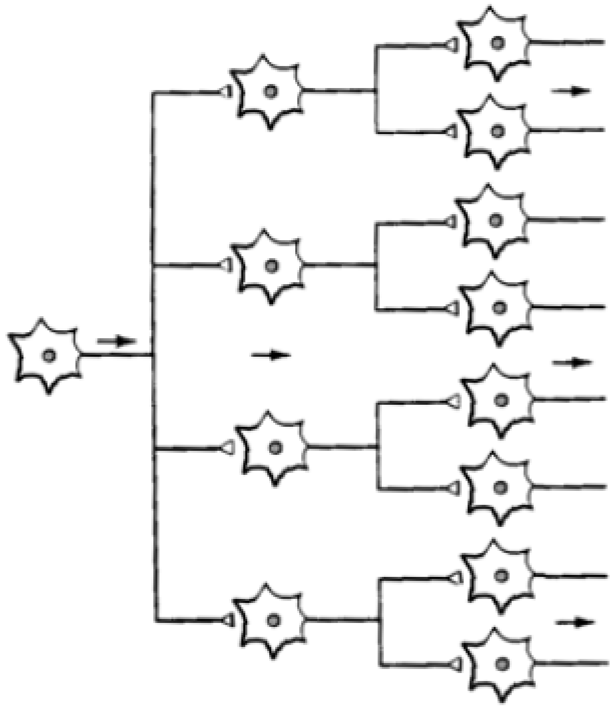
Convergence

- Output from many neurons onto one

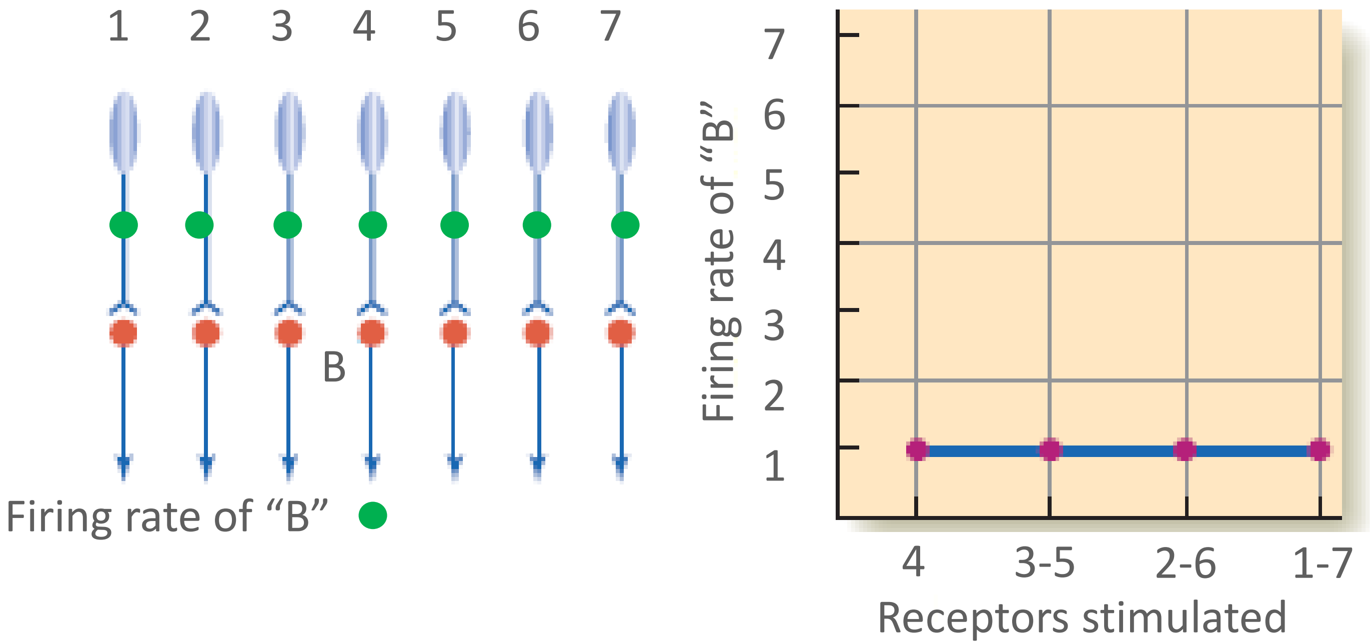


Divergence

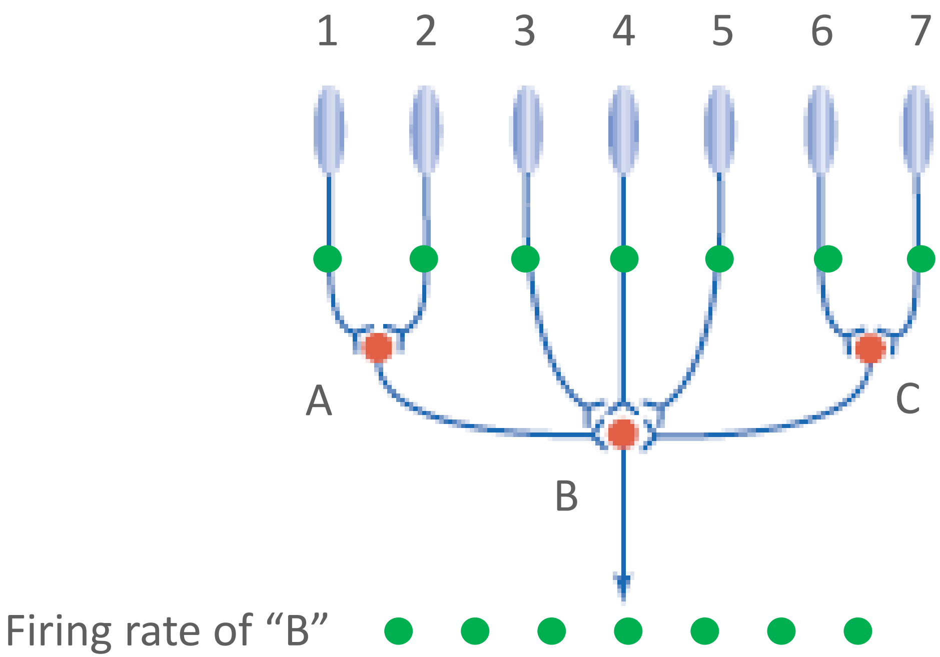
- Output from one neuron onto many

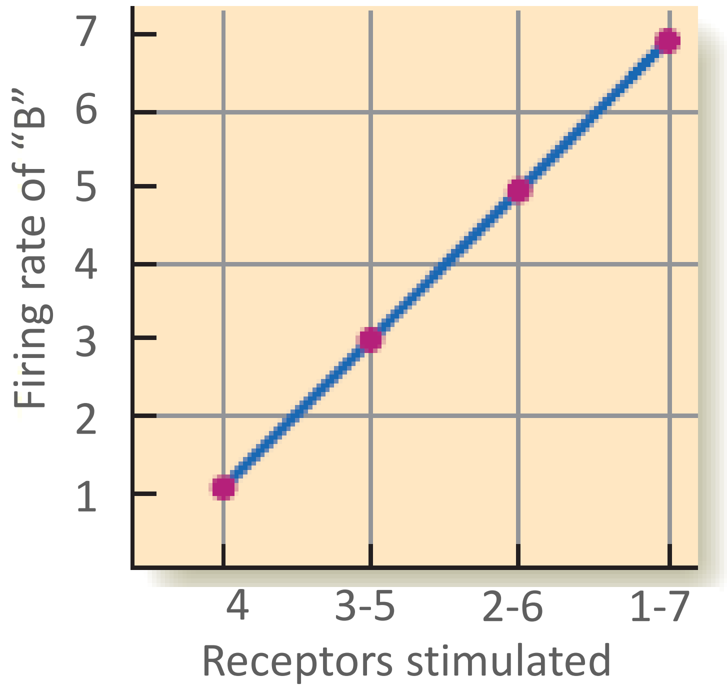


Neural circuits: no convergence

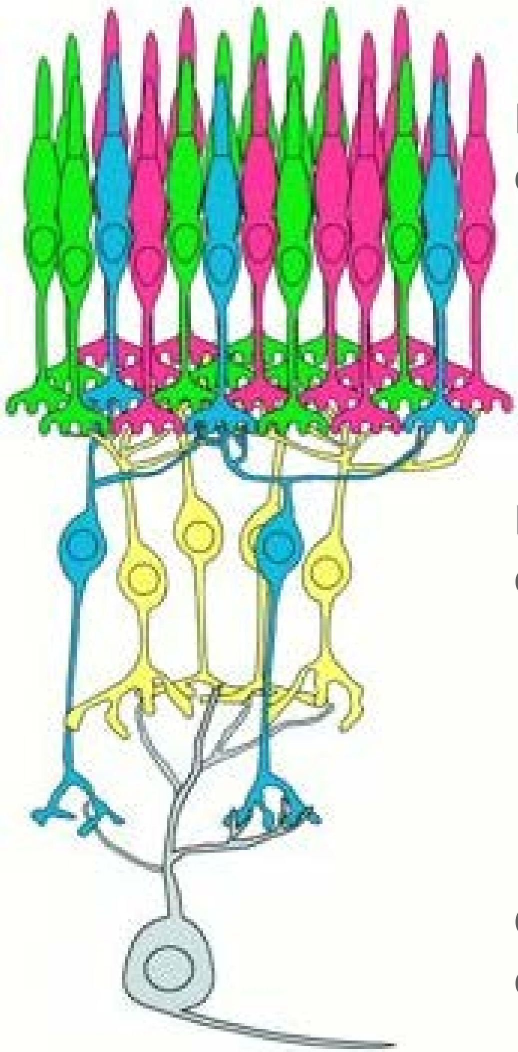


Neural circuits: Convergence





The eye, an example of convergence

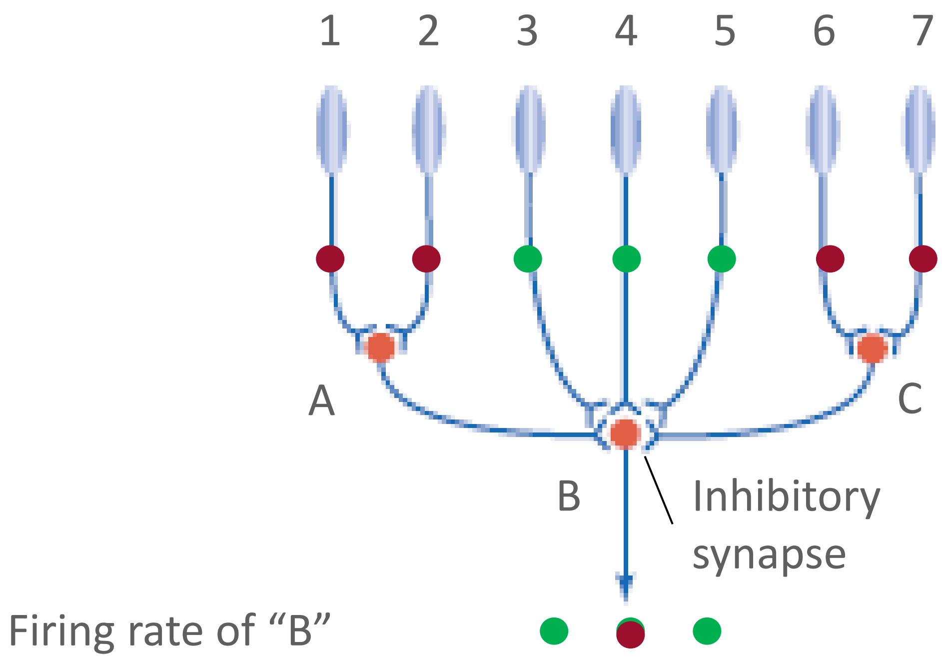


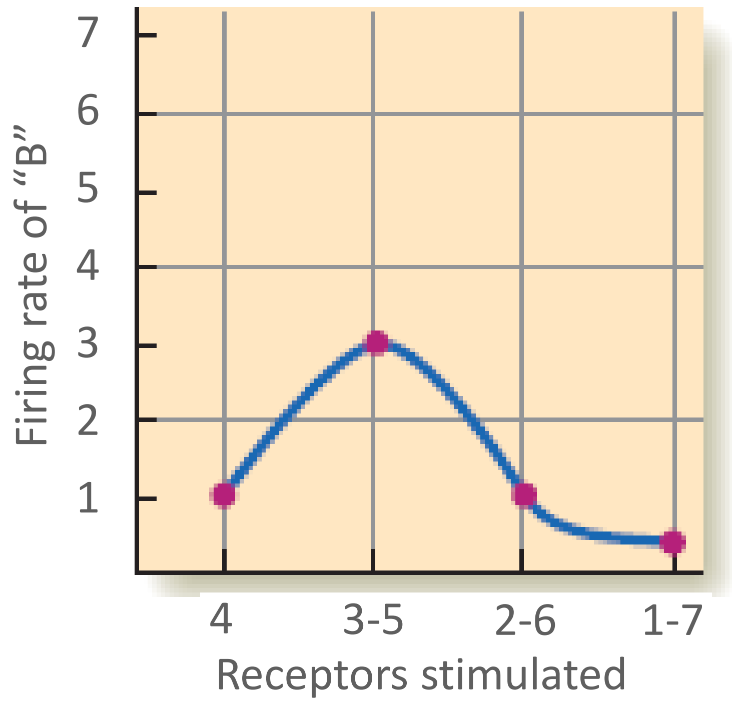
Rods and cones

Bipolar cells

Ganglion cells

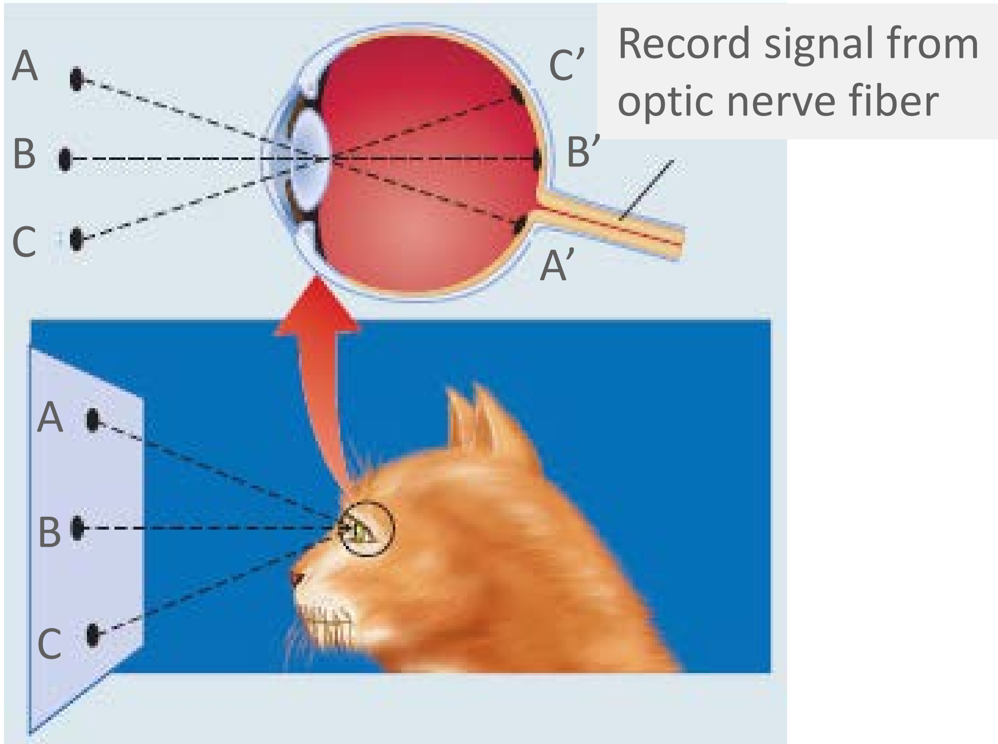
Neural circuits: Convergence and inhibition



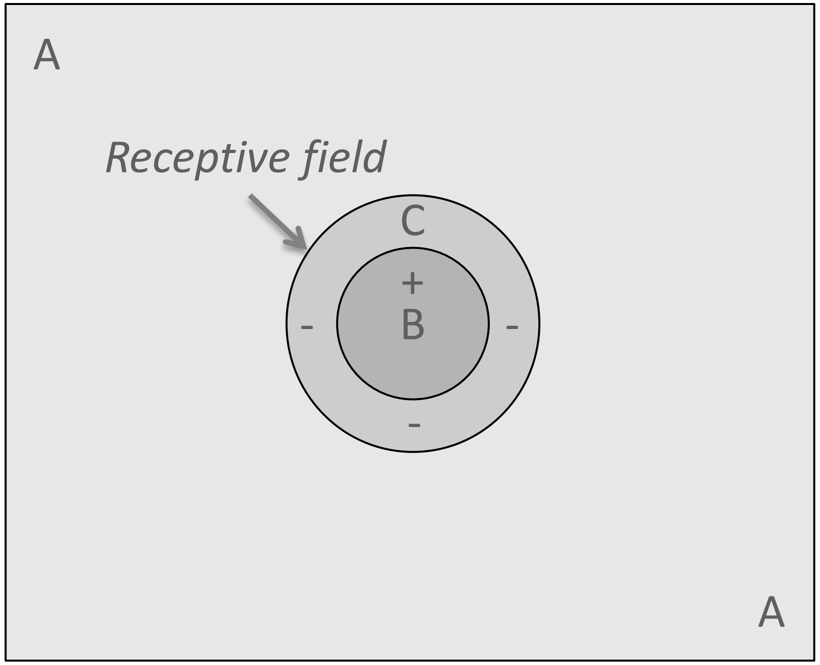


Receptive fields

- An area where stimulation leads to a response of a particular sensory neuron

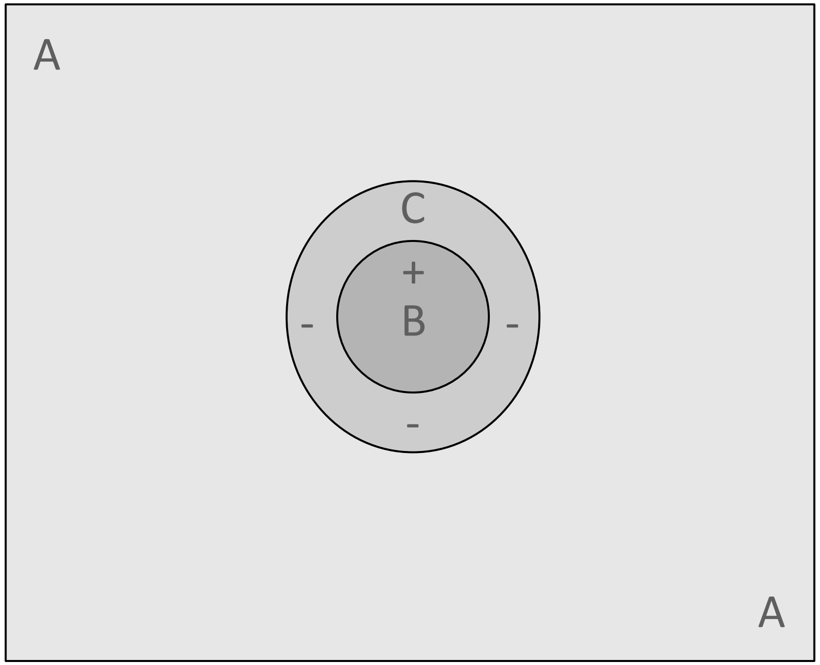


Receptive fields

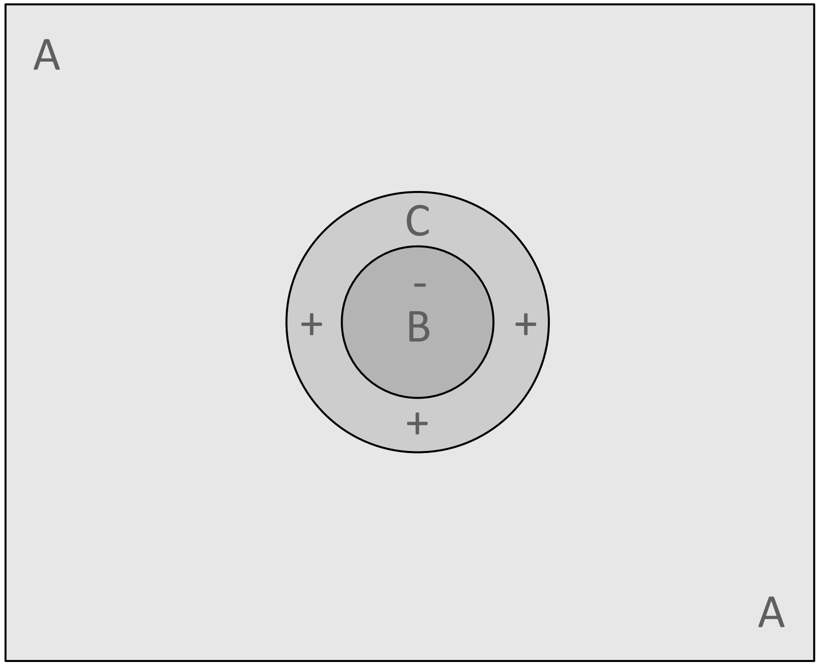


Receptive fields

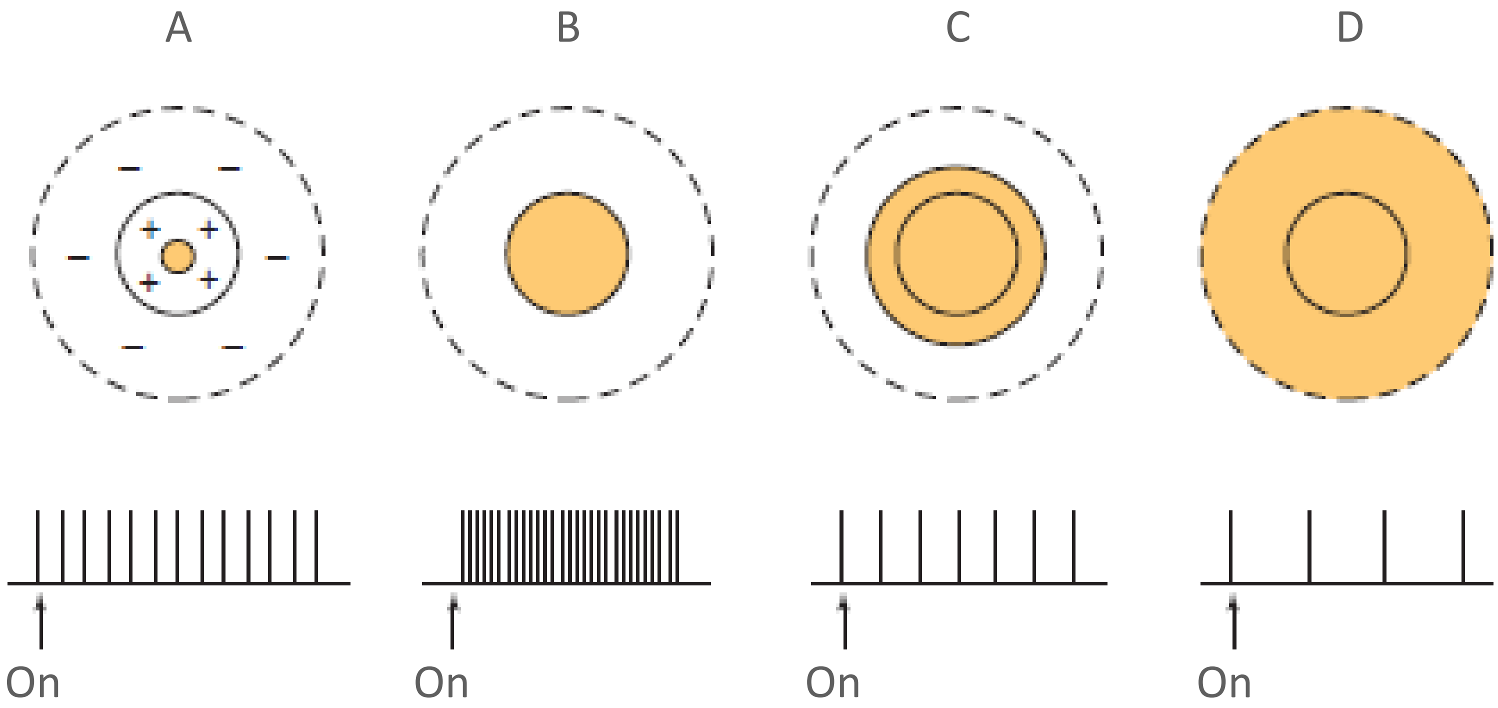
Excitatory-center-inhibitory-surround receptive field
"on center off surround"



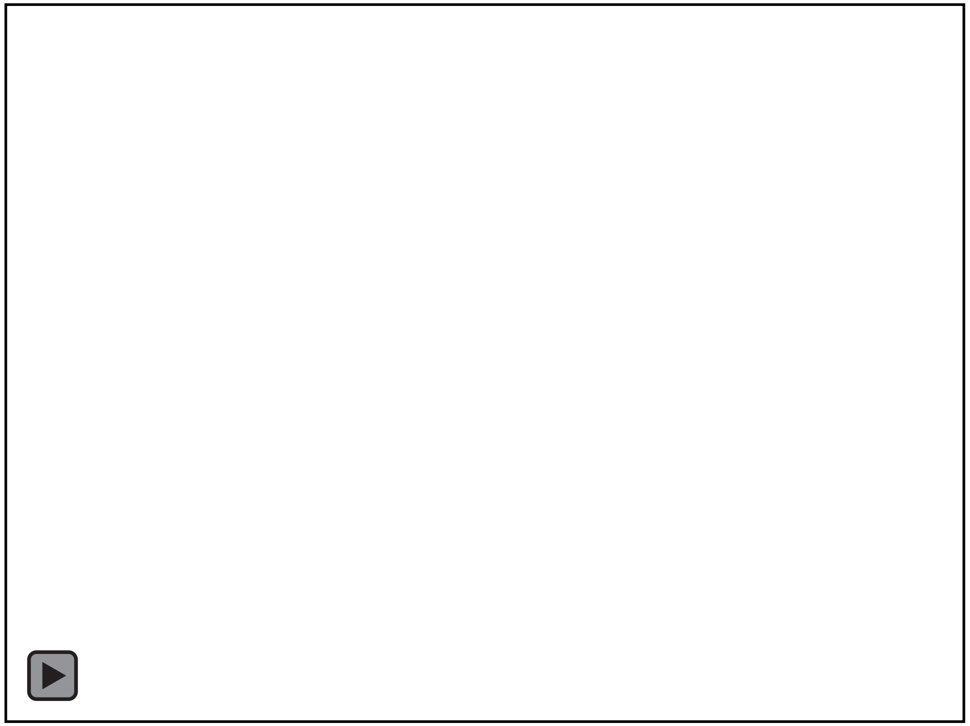
Inhibitory-center-exhibitory-surround receptive field
"off center on surround"



Center-surround antagonism



Simple Cell Receptive Field Mapping



http://www.youtube.com/watch?v=n31XBMSSSpI

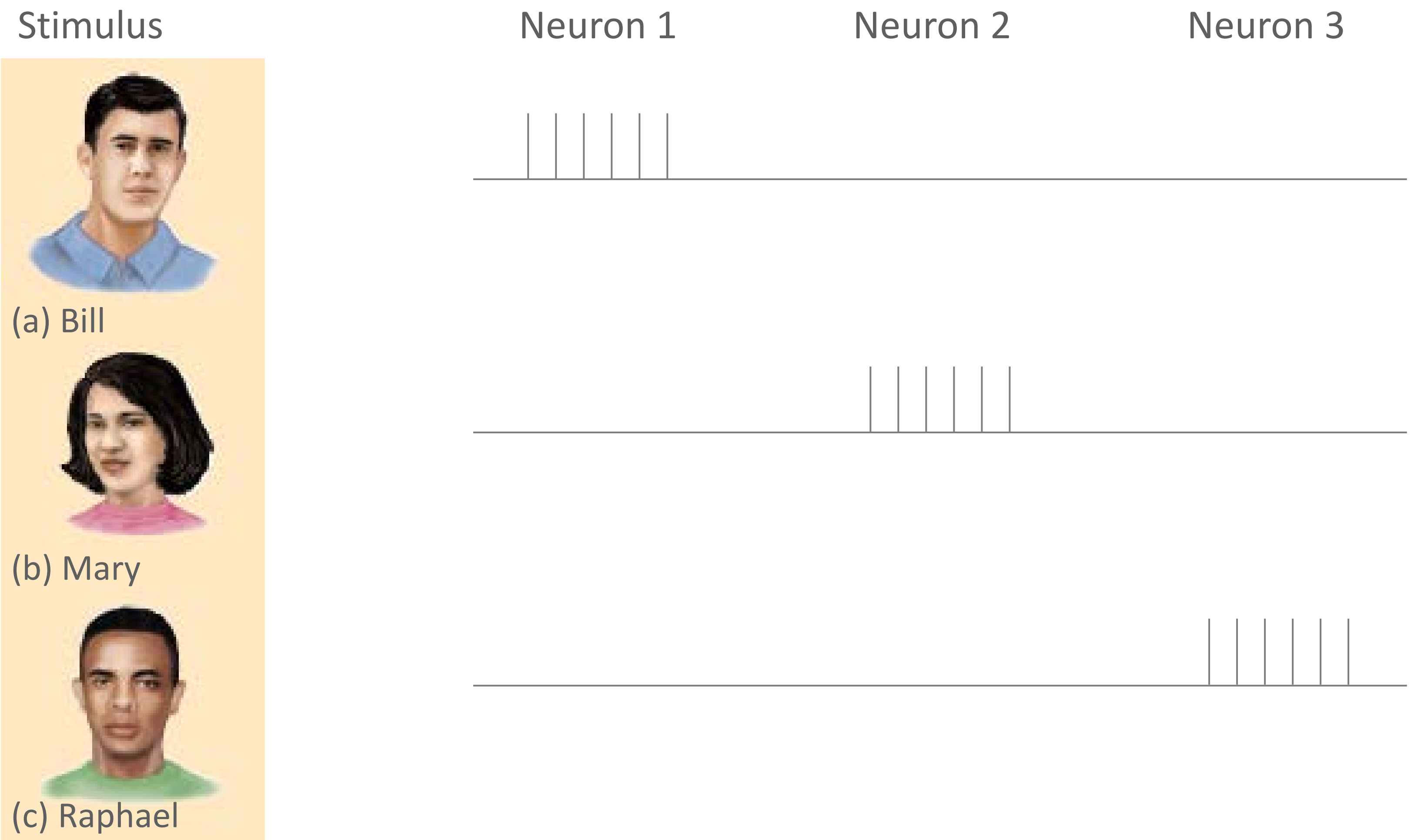
Summary receptive fields

- Studying a neuron’s receptive field:
  - Enables us to specify a neuron’s response
  - Indicates the area of the receptor surface that causes the neuron to respond
  - Indicates the size or shape of the stimulus that causes the neuron’s “best” (highest firing rate) response

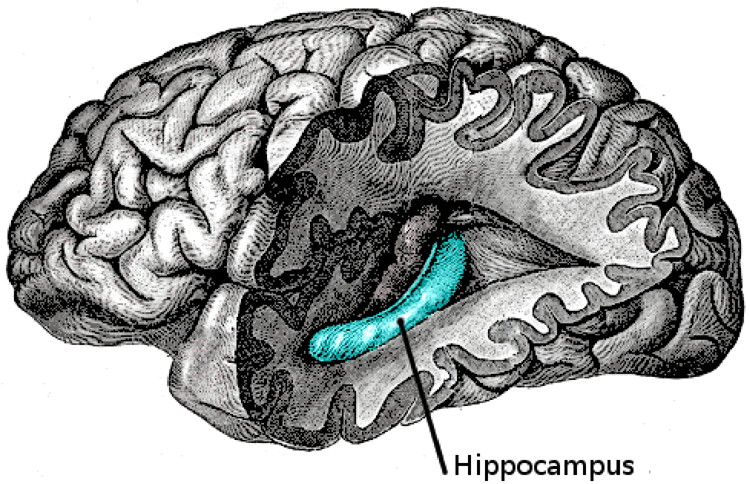
The problem of sensory coding

- We have now explored the electrical signals that are the link between the environment and perception.
- How does the firing of neurons represent various characteristics of our environment?
- Proposed answers:
  - *Specificity coding*
    - a concept is represented by the firing of a single neuron
  - *Distributed coding*
    - a concept is represented by the firing pattern of a large set of neurons
  - *Sparse coding*
    - a concept is represented by the firing pattern of a few neurons

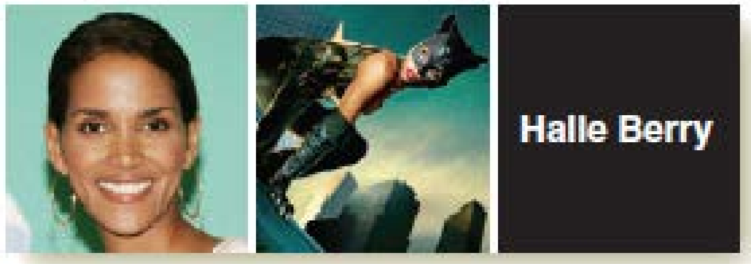
Specificity coding



Specificity coding

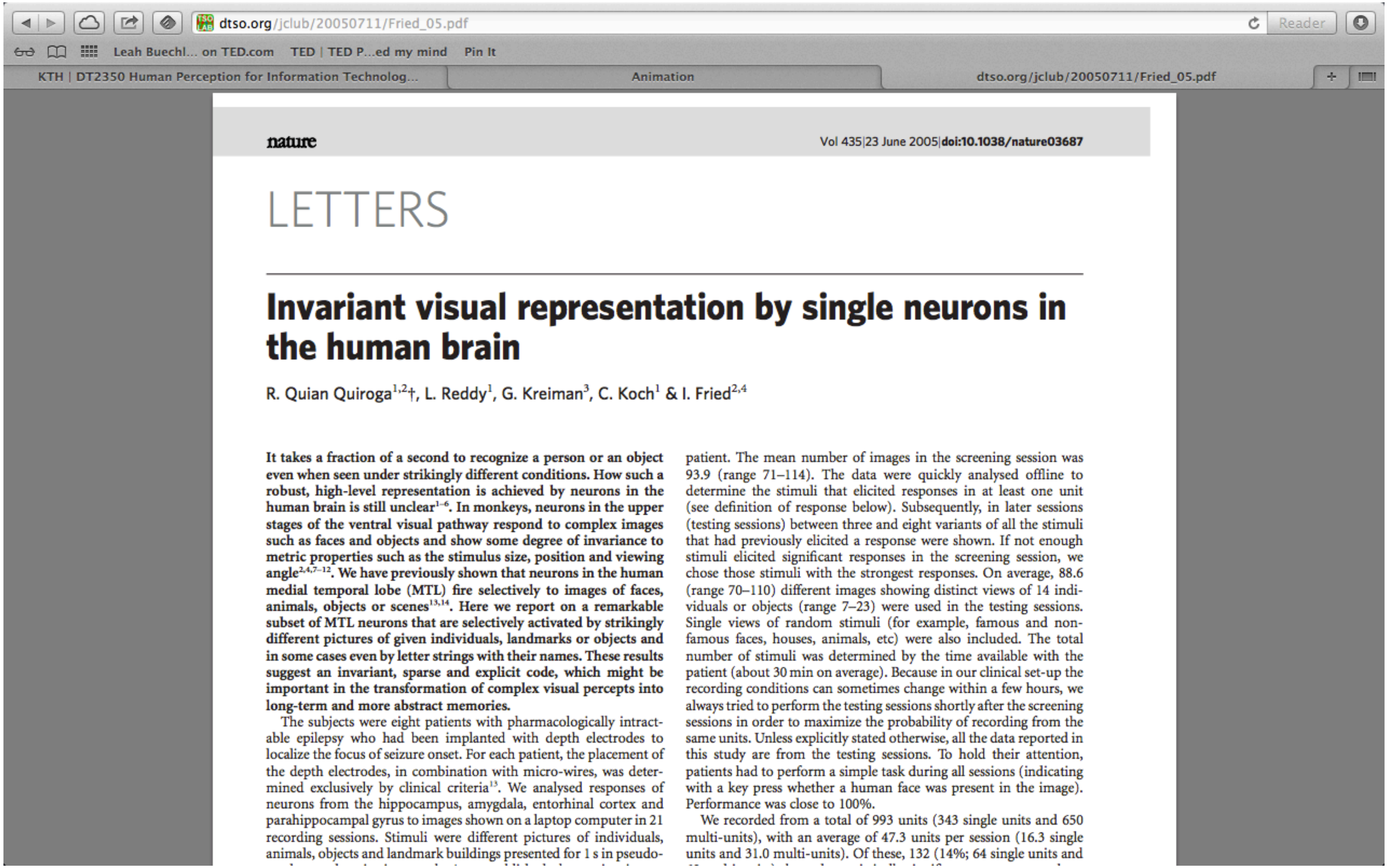


- Konoroski, 1967
  - “Gnostic units”
- Lettvin, 1969
  - “Grand mother cells”
- Quiroga, et al 2005
  - Studied the response in hippocampus in patients with epilepsy
  - Specific neurons that responded to Halle Berry alone, but not to other faces of other famous people



- Most researchers (including Quiroga et al. 2008) agree that specificity coding is unlikely

Assignment 1: Quiroga, et al 2005



nature Vol 435|23 June 2005|doi:10.1038/nature03687

LETTERS

Invariant visual representation by single neurons in the human brain

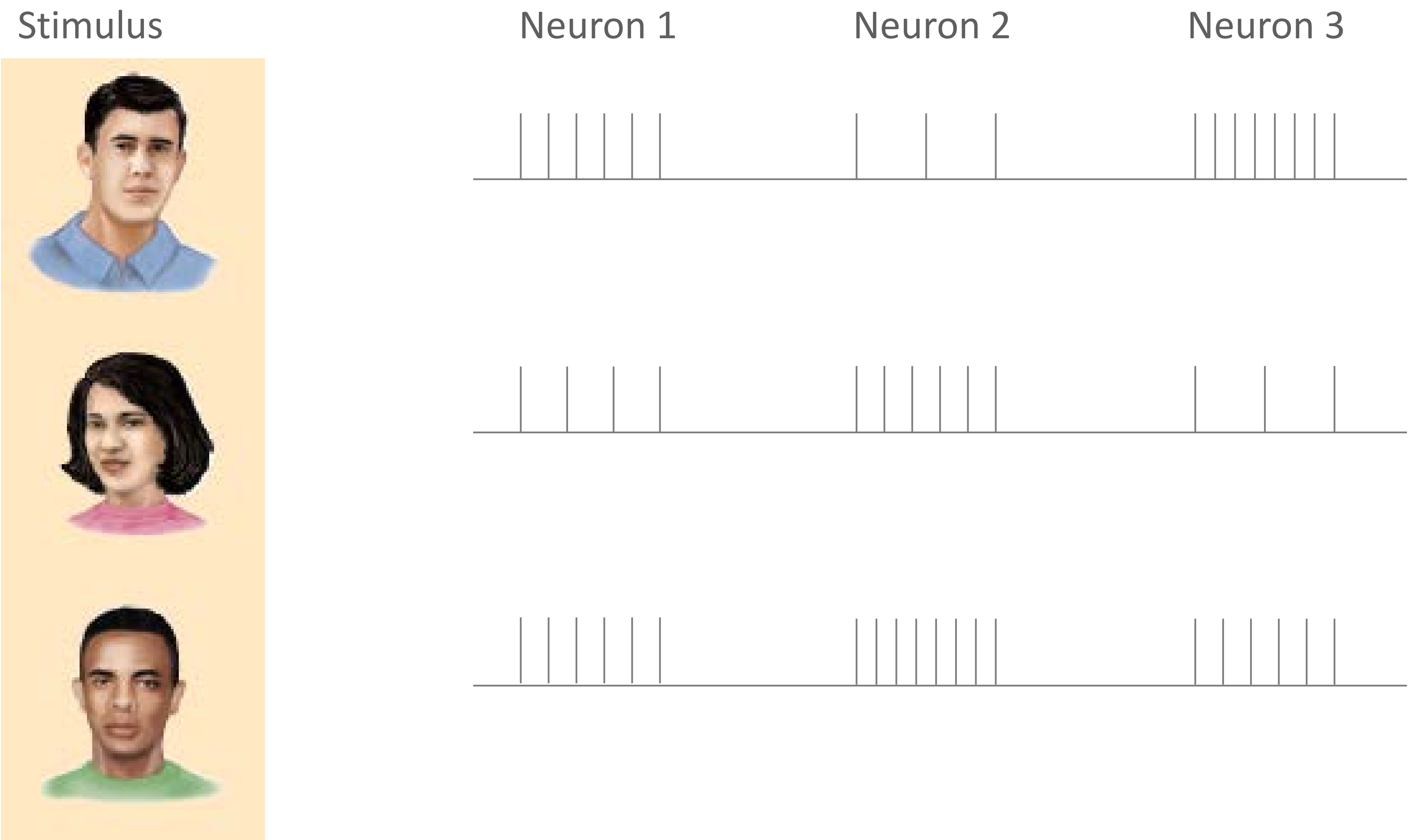
R. Quian Quiroga[1,2]†, L. Reddy[1], G. Kreiman[3], C. Koch[1] & I. Fried[2,4]

It takes a fraction of a second to recognize a person or an object even when seen under strikingly different conditions. How such a robust, high-level representation is achieved by neurons in the human brain is still unclear[1–6]. In monkeys, neurons in the upper stages of the ventral visual pathway respond to complex images such as faces and objects and show some degree of invariance to metric properties such as the stimulus size, position and viewing angle[2,4,7–12]. We have previously shown that neurons in the human medial temporal lobe (MTL) fire selectively to images of faces, animals, objects or scenes[13,14]. Here we report on a remarkable subset of MTL neurons that are selectively activated by strikingly different pictures of given individuals, landmarks or objects and in some cases even by letter strings with their names. These results suggest an invariant, sparse and explicit code, which might be important in the transformation of complex visual percepts into long-term and more abstract memories.

The subjects were eight patients with pharmacologically intractable epilepsy who had been implanted with depth electrodes to localize the focus of seizure onset. For each patient, the placement of the depth electrodes, in combination with micro-wires, was determined exclusively by clinical criteria[15]. We analysed responses of neurons from the hippocampus, amygdala, entorhinal cortex and parahippocampal gyrus to images shown on a laptop computer in 21 recording sessions. Stimuli were different pictures of individuals, animals, objects and landmark buildings presented for 1 s in pseudo- patient. The mean number of images in the screening session was 93.9 (range 71–114). The data were quickly analysed offline to determine the stimuli that elicited responses in at least one unit (see definition of response below). Subsequently, in later sessions (testing sessions) between three and eight variants of all the stimuli that had previously elicited a response were shown. If not enough stimuli elicited significant responses in the screening session, we chose those stimuli with the strongest responses. On average, 88.6 (range 70–110) different images showing distinct views of 14 individuals or objects (range 7–23) were used in the testing sessions. Single views of random stimuli (for example, famous and non-famous faces, houses, animals, etc) were also included. The total number of stimuli was determined by the time available with the patient (about 30 min on average). Because in our clinical set-up the recording conditions can sometimes change within a few hours, we always tried to perform the testing sessions shortly after the screening sessions in order to maximize the probability of recording from the same units. Unless explicitly stated otherwise, all the data reported in this study are from the testing sessions. To hold their attention, patients had to perform a simple task during all sessions (indicating with a key press whether a human face was present in the image). Performance was close to 100%.

We recorded from a total of 993 units (343 single units and 650 multi-units), with an average of 47.3 units per session (16.3 single units and 31.0 multi-units). Of these, 132 (14%; 64 single units and

Distributed coding

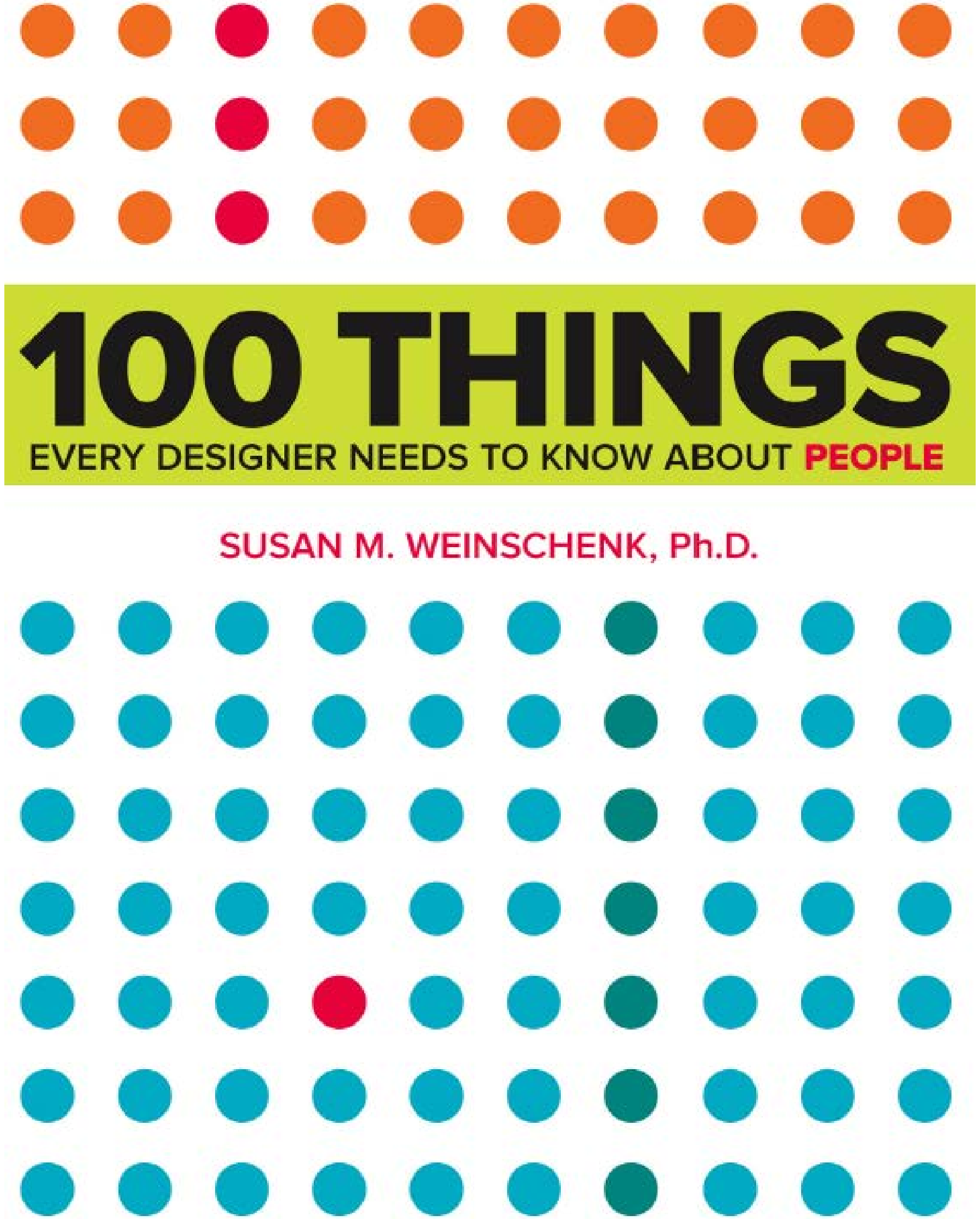


Distributed coding

- Instead of requiring a specific neuron for each concept in the environment, *distributed coding* allows the representation of a large number of stimuli by the firing of a *large* set of neurons

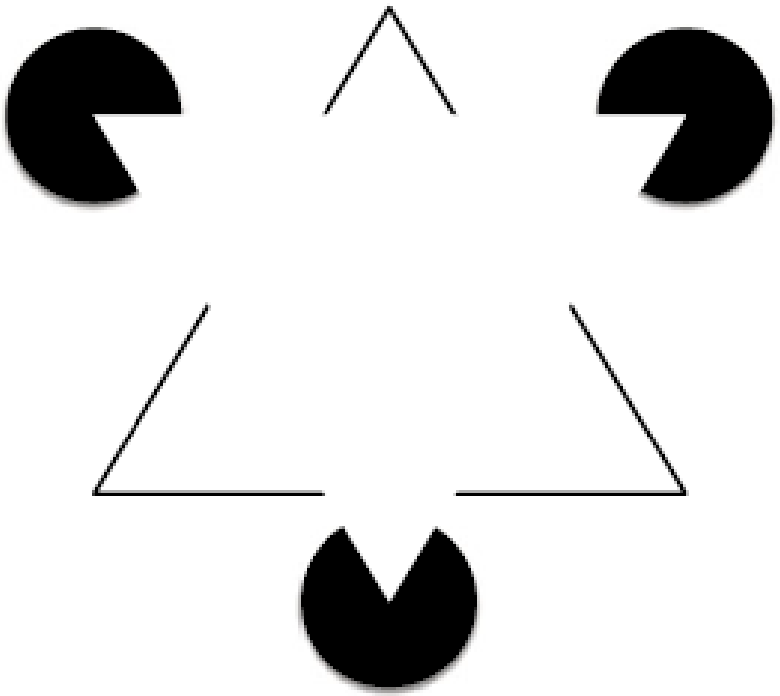
Sparse coding

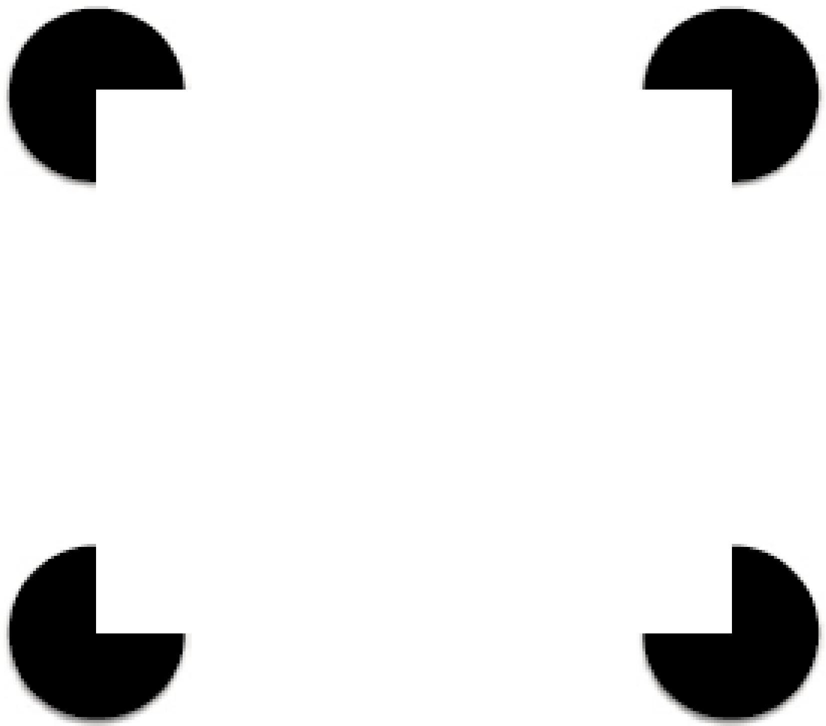
- Somewhere in-between distributed coding and specificity coding
- A concept is represented by the firing of a small number of neurons
- Quiroga, (2008) suggest that their results are probably an example of sparse coding.


100 THINGS
EVERY DESIGNER NEEDS TO KNOW ABOUT PEOPLE
SUSAN M. WEINSCHENK, Ph.D.

1. What you see isn’t what your brain gets

A Kanizsa triangle





An early optical illusion (Müller-Lyer, F.,1889)

Takeaways

- What you think people are going to see on your Web page may not be what they do see. It might depend on their background, knowledge, familiarity with what they are looking at, and expectations.
- You might be able to persuade people to see things in a certain way, depending on how they are presented.

Example: