Biophysical principles of sensory function

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Károly Liliom

From stimulus to sensation: parts of sensory function

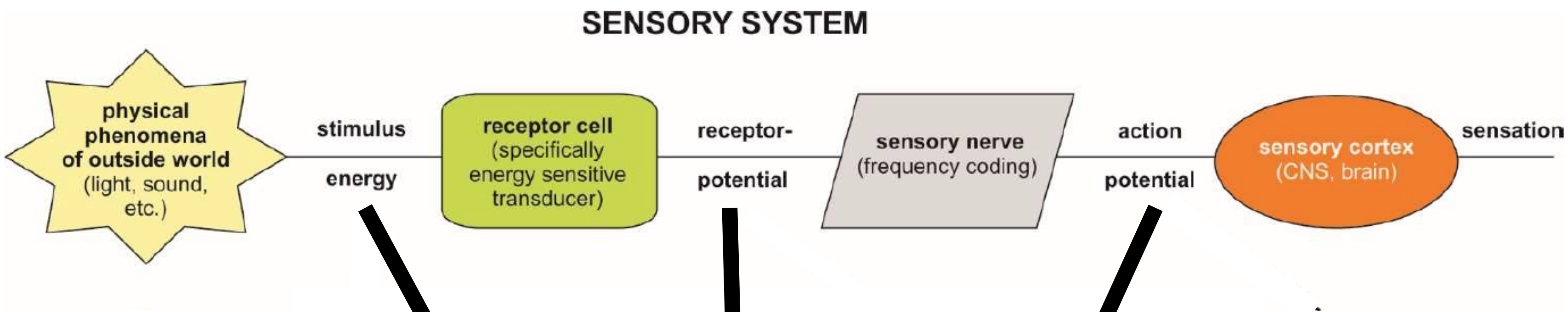
stimuli
from the external
or
internal environment

Specific transducers
(receptors)

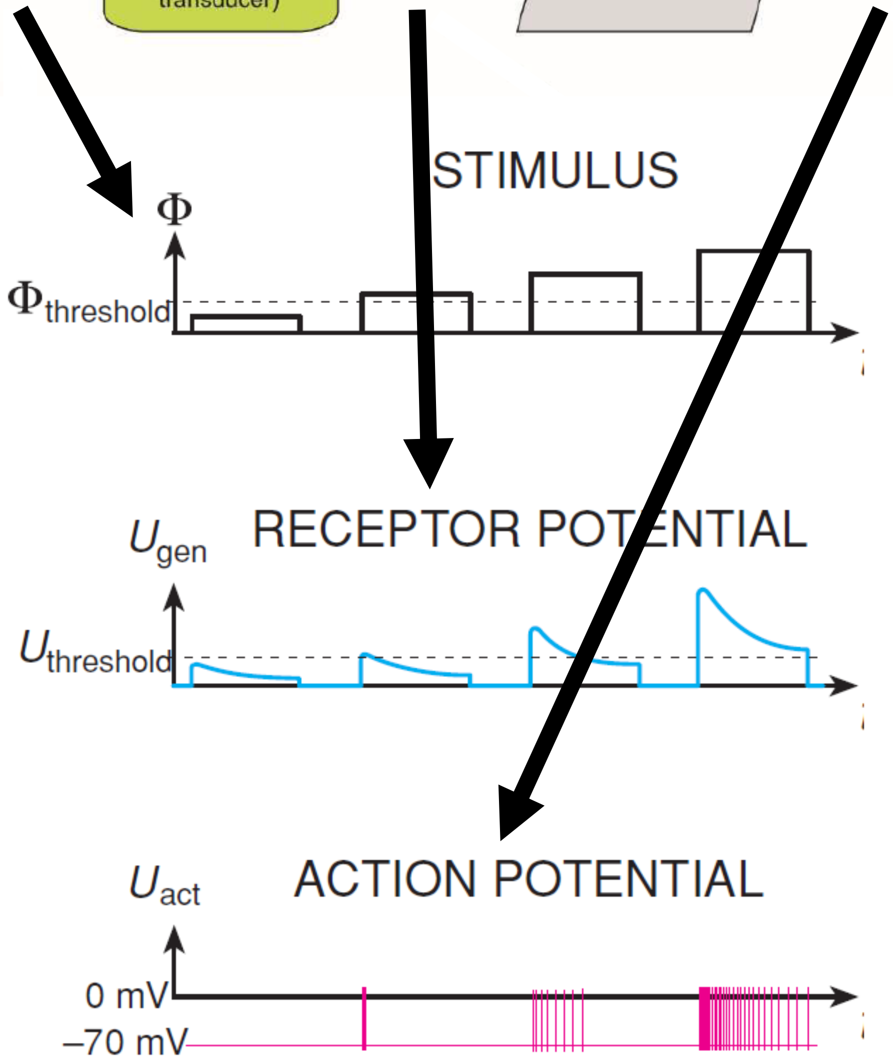
neurons

Central nervus system

Schematic structure of the sensory system



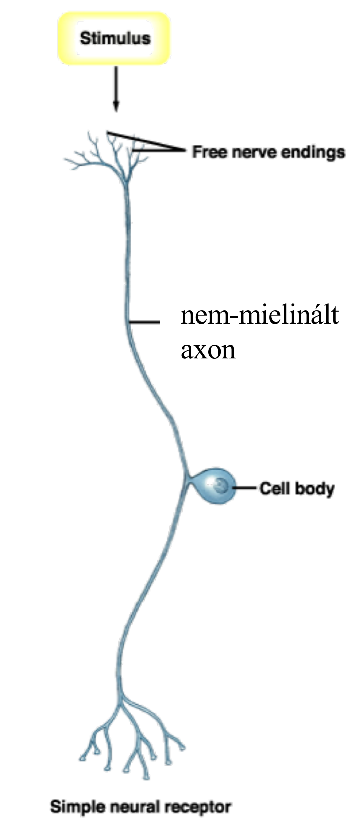
Features of stimulus: type, intensity, location, duration

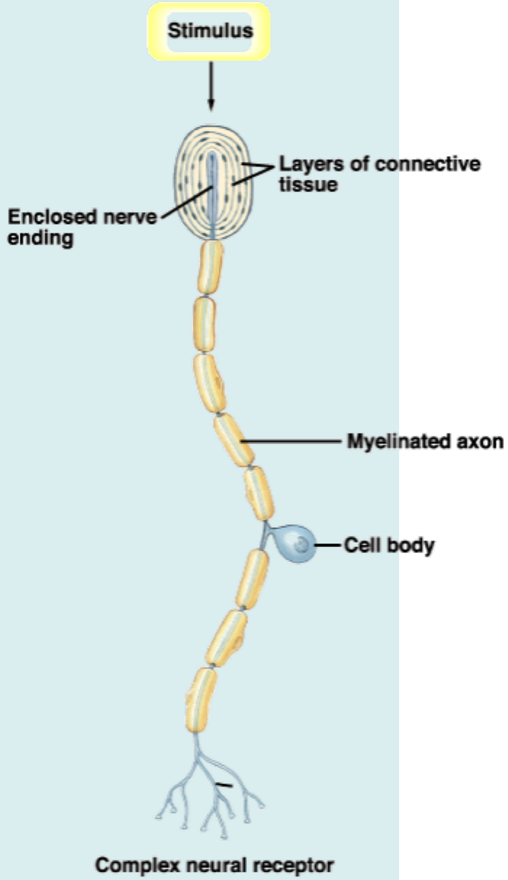


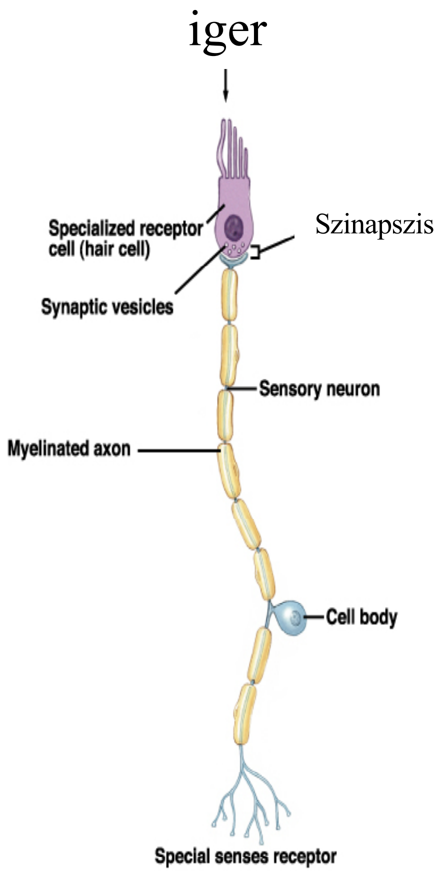
Types of sensory receptors

Primary receptors

Secunder receptor

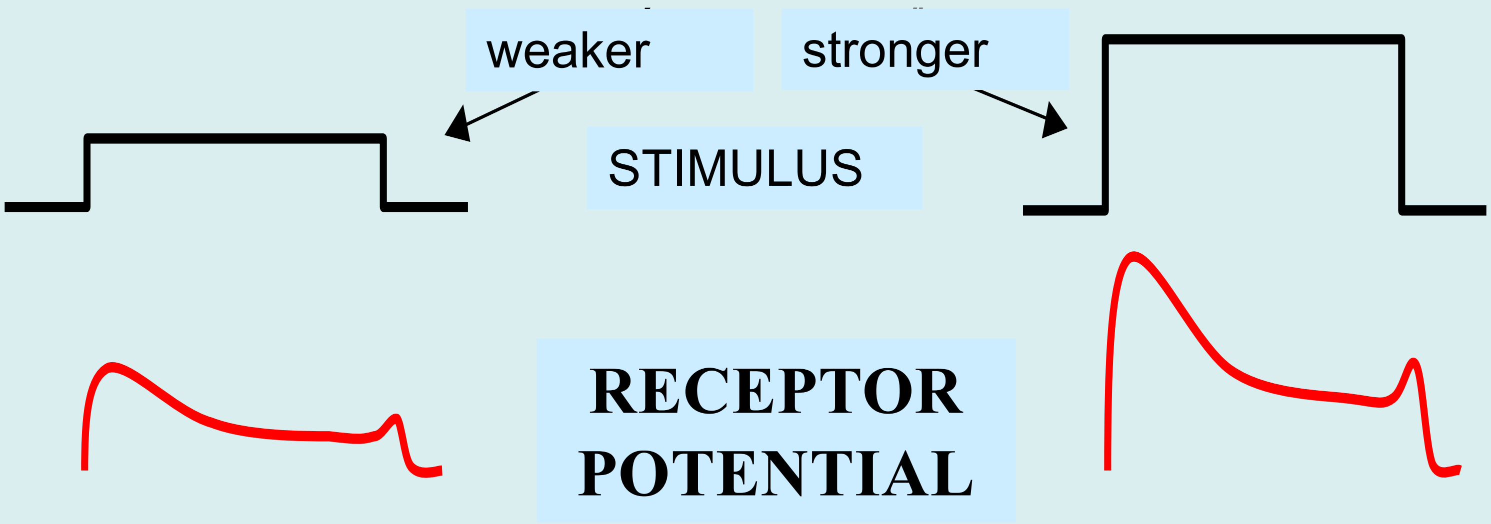






e.g. skin e.g. muscle e.g. vision, hearing

Reaction of receptor cells for specific stimuli

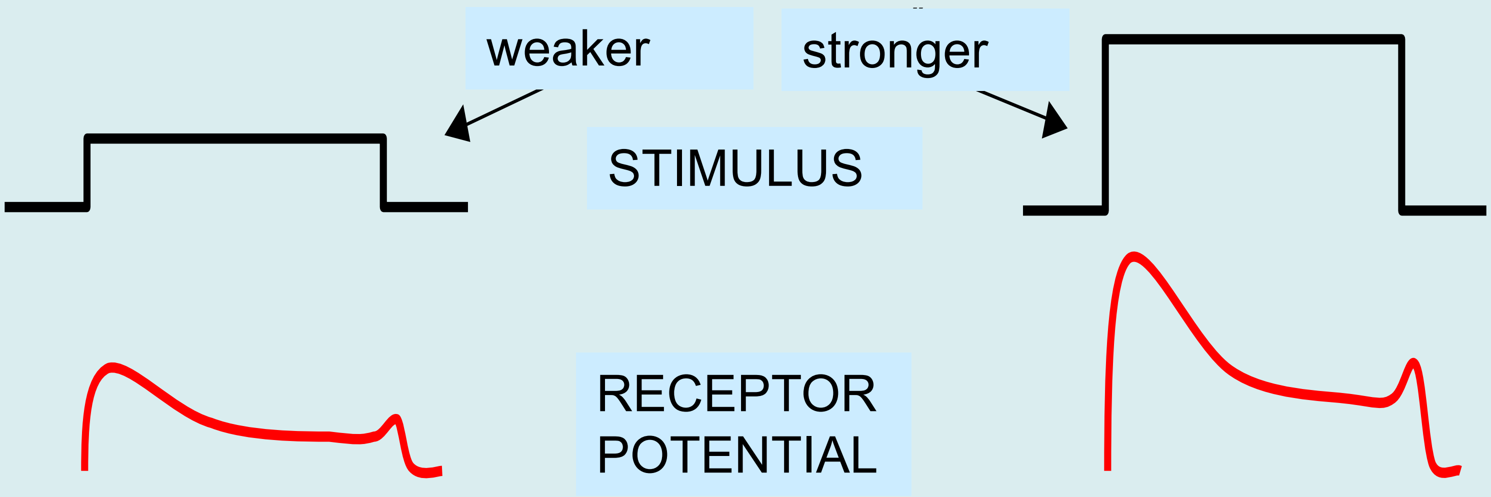


General response to different stimuli:

alteration of the membrane potential on receptor cell

RECEPTOR POTENTIAL

Analog signal conversion:
receptors are signal transducers



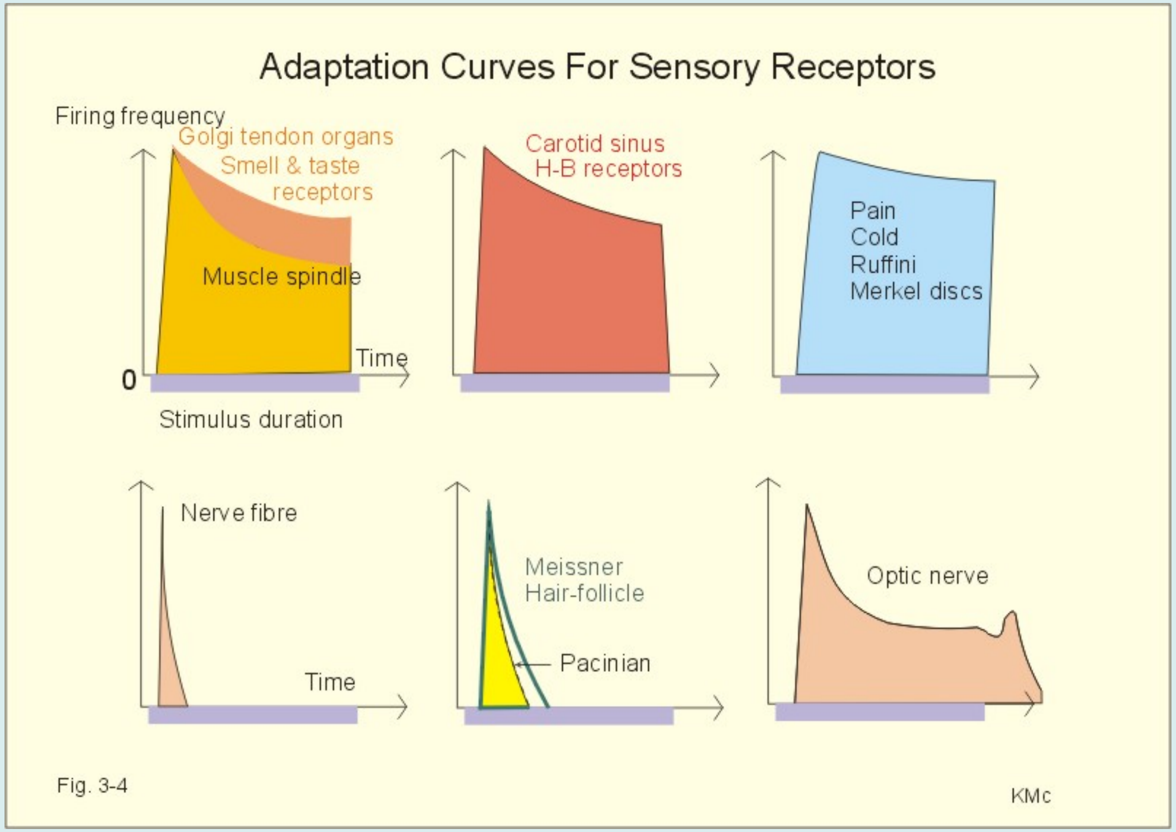
Its amplitude is proportional to the stimulus amplitude.

Its duration is identical to the stimulus duration.

It is a localized potential change.

Stimulus		Code
Which?	⟹	Type of receptor
Where?	⟹	Receptive field
How much?	⟹	Amplitude of receptor potential
How long?	⟹	Duration of receptor potential

Adaptation of Receptors

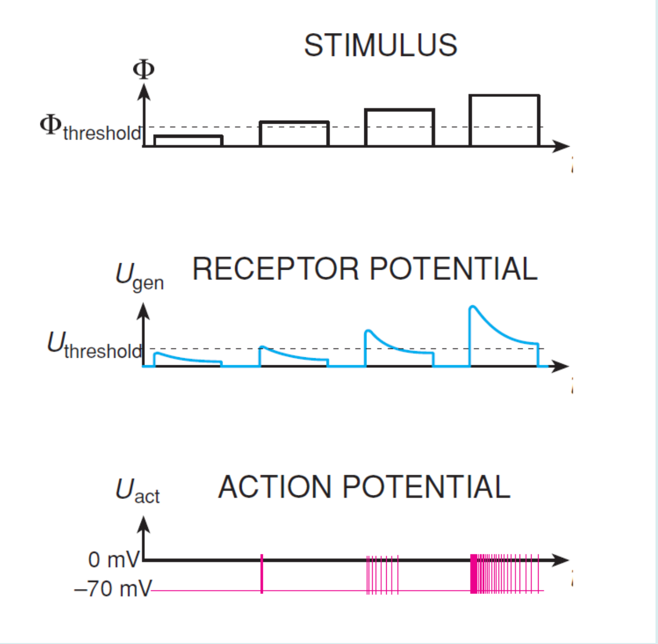


Rapidly adapting receptors (Rated receptors): e.g. pacinian and hair receptors detect the change in stimulus strength (detect movement)

Slowly adapting receptors (Tonic receptors): e.g. joint capsule, muscle spindle detect continuous stimulus strength (give report to the brain about the status of the body).

Non adapting receptors: pain receptors and chemoreceptor

Transition of information from receptor to neuron / axon



Secunder receptor ⟹ synapse ⟹ axon

receptor potential

neurotransmitter
quantity
quality

Primary receptors ⟹ local currents ⟹ axon

receptor potential

current intensity

Receptor potential acting on nerve cell membrane

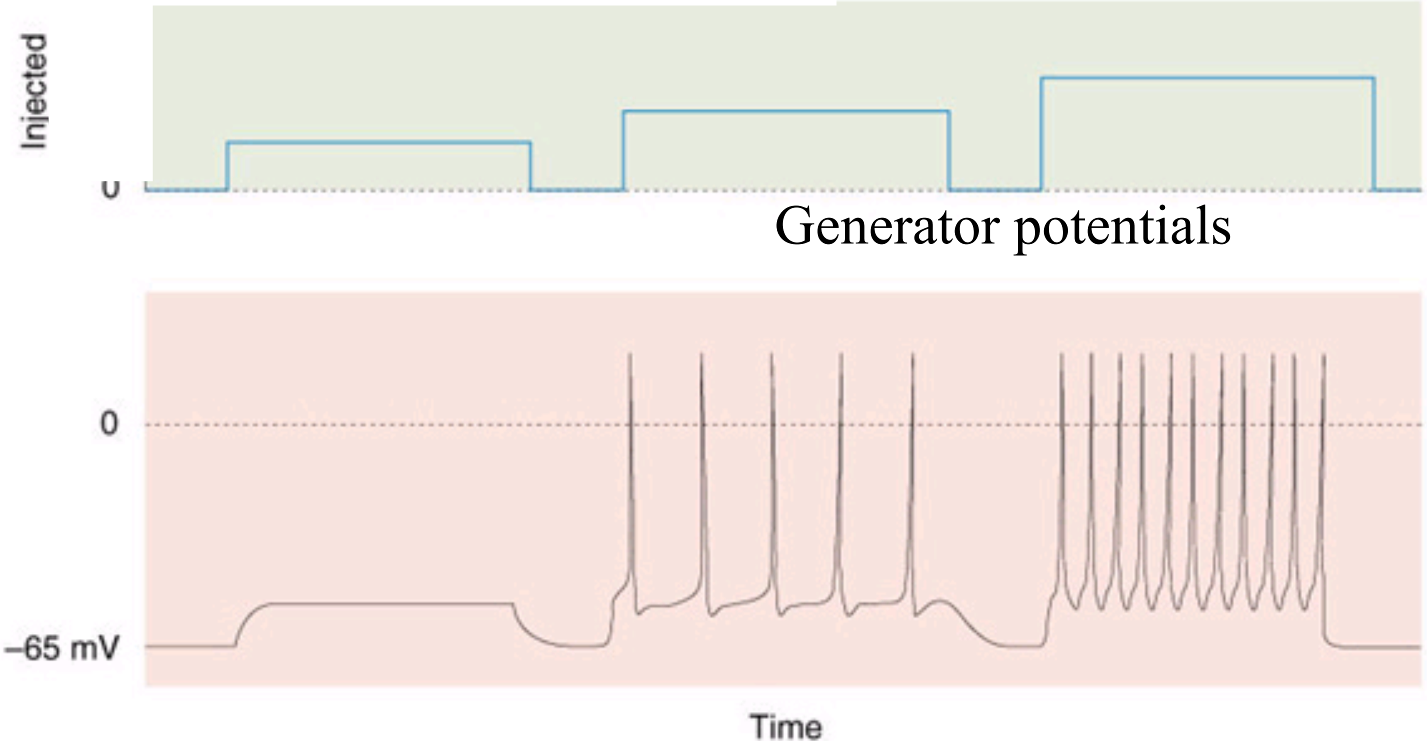
stimulus
below threshold

stimuli
above threshold

Receptor
potential

Generator potentials

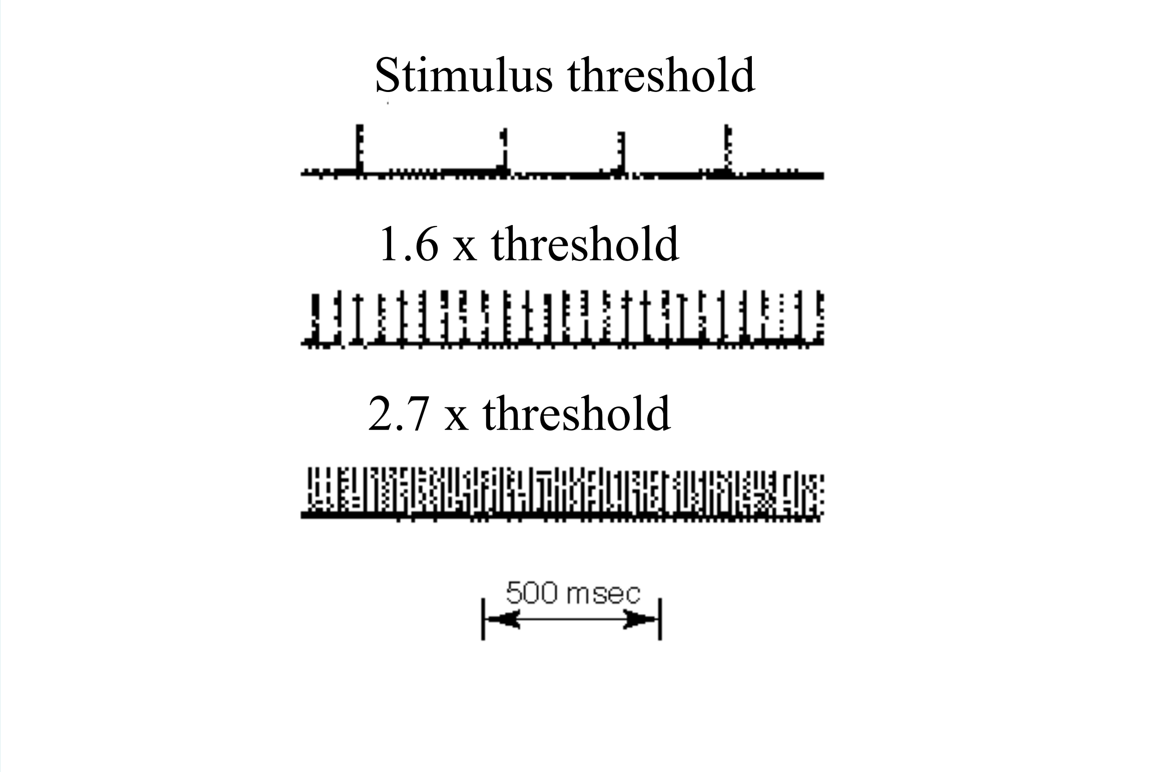
Axon
membrane
potential



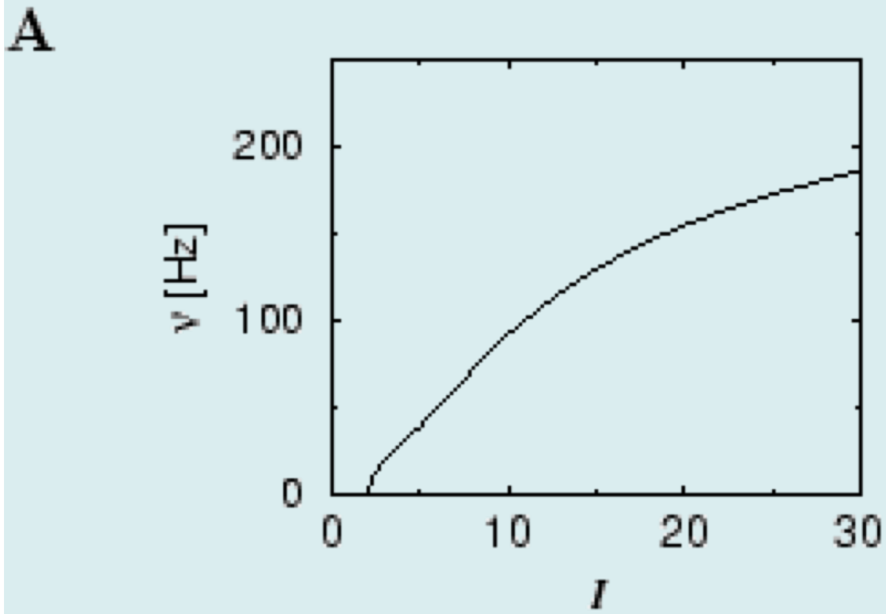
depolarization
(or hyperpolarization)

action potential

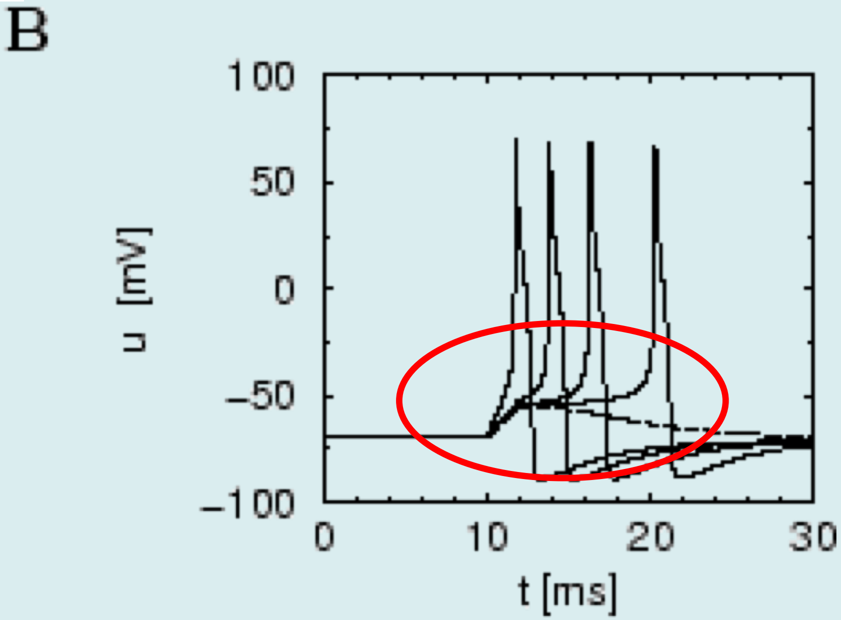
constant amplitude,
firing frequency modulated



Stimulus threshold
1.6 x threshold
2.7 x threshold
500 msec

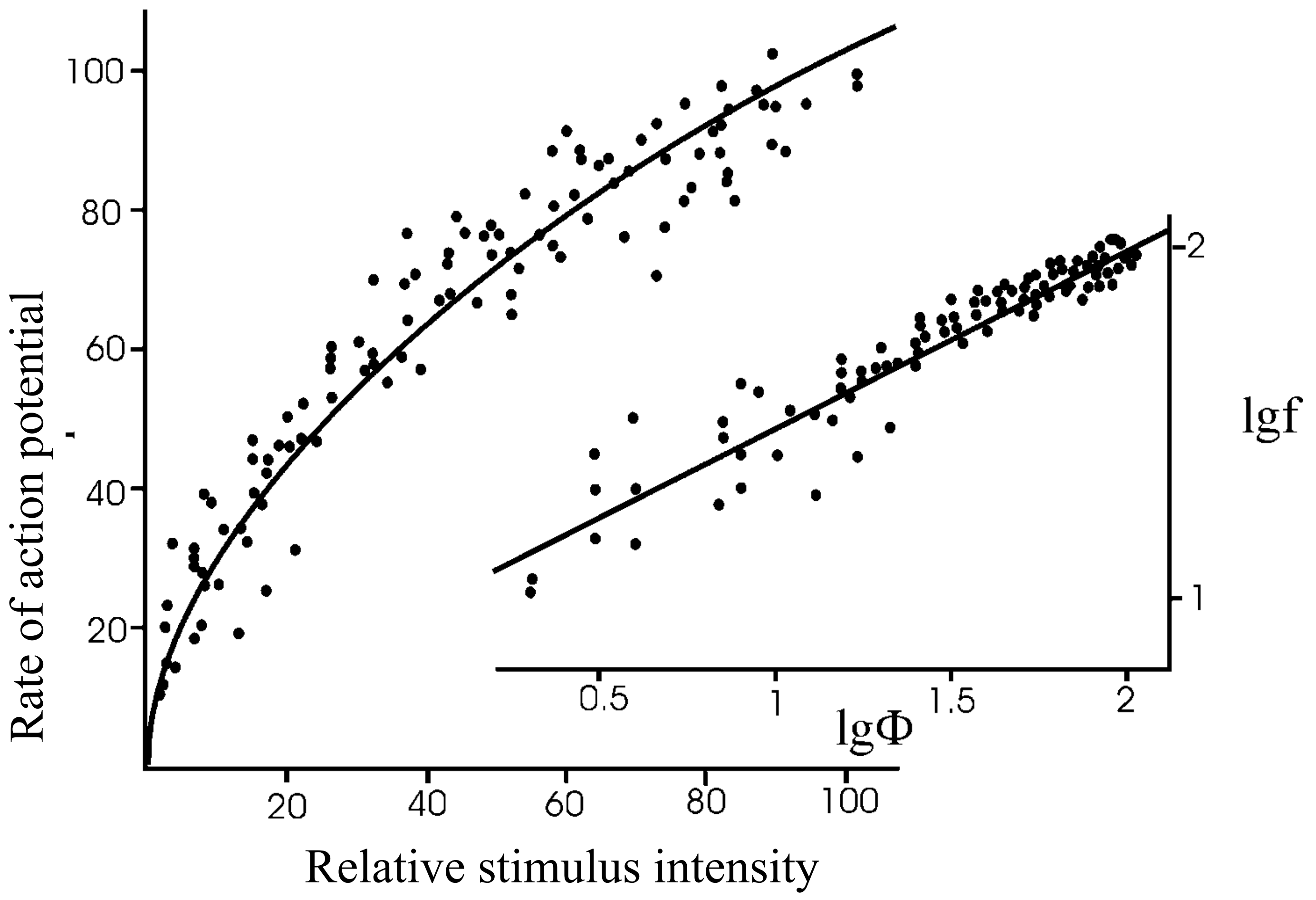


A
200
100
0
ν [Hz]
0
10
20
30
I

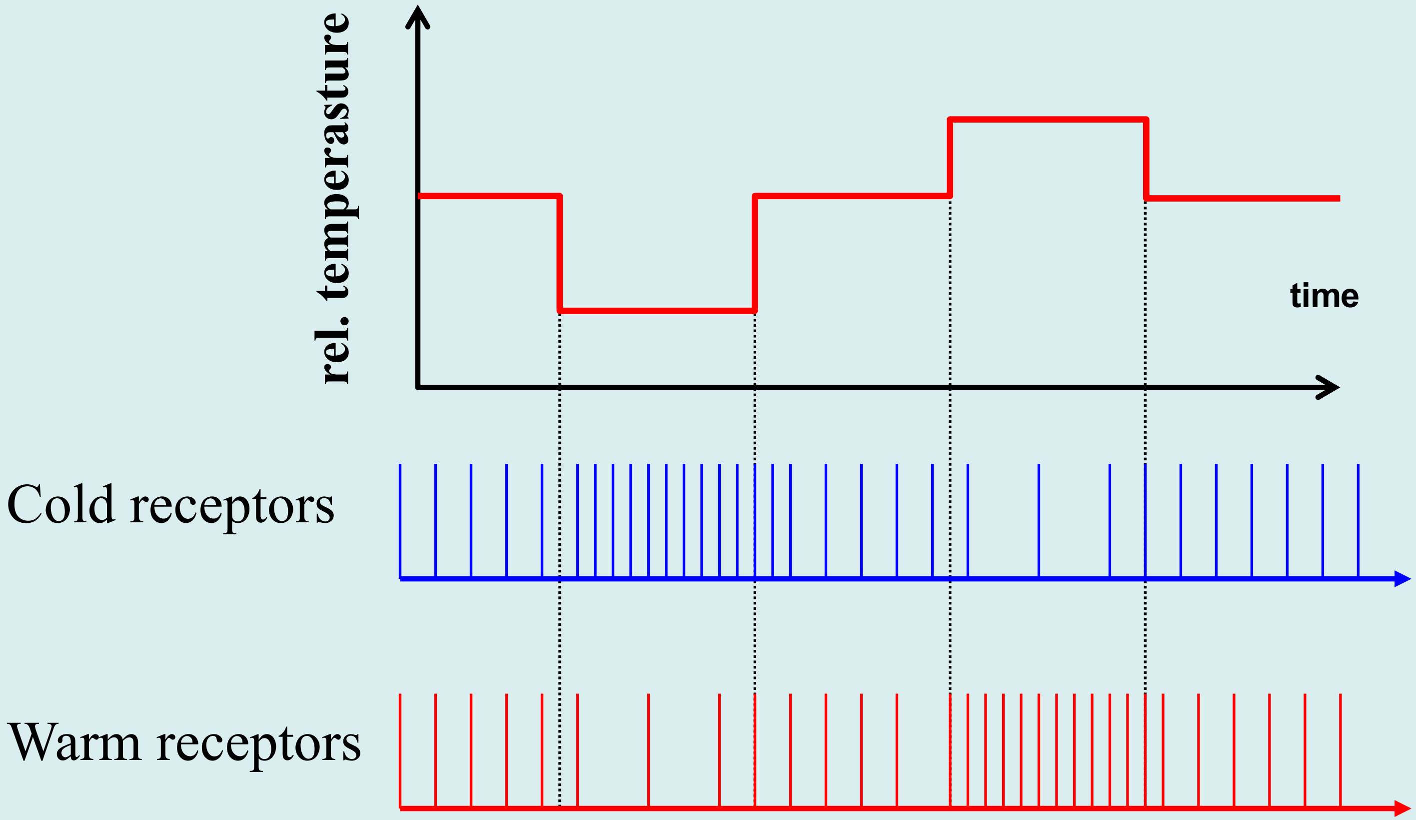


B
100
50
0
−50
−100
u [mV]
0
10
20
30
t [ms]

AP frequency and stimulus intensity



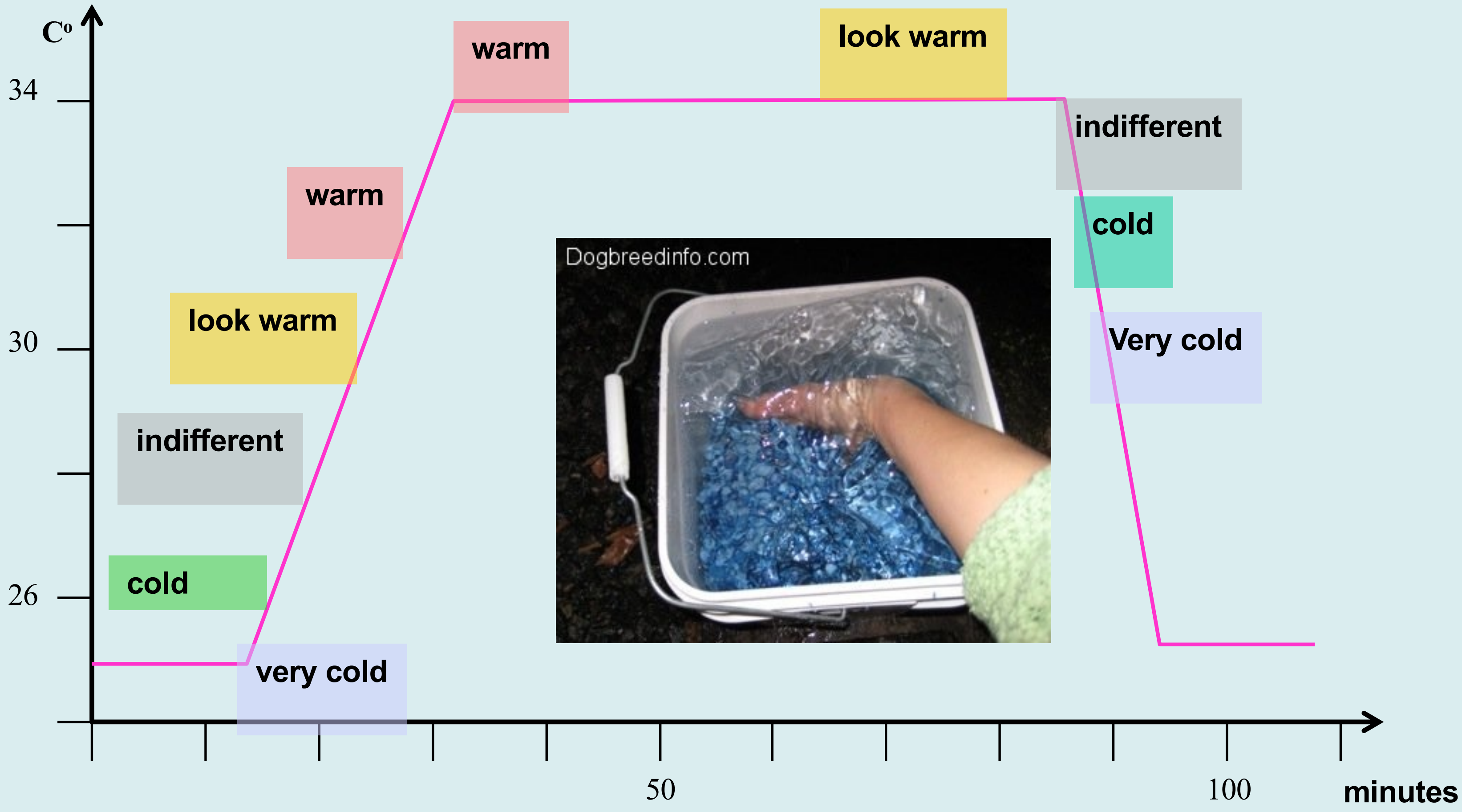
Persistent Action Potentials



For a warm receptor warming results in an increase in their action potential discharge rate, cooling results in a decrease in discharge rate. For cold receptors their firing rate increases during cooling and decreases during warming.
Some cold receptors also respond with a brief action potential discharge to high temperatures, i.e. typically above 45°C, and this is known as a paradoxical response to heat.

Thermal receptors

codes absolute and relative changes in temperature



CNS is composed of neuronal pools with **different mechanisms of signal processing.**

Excitation

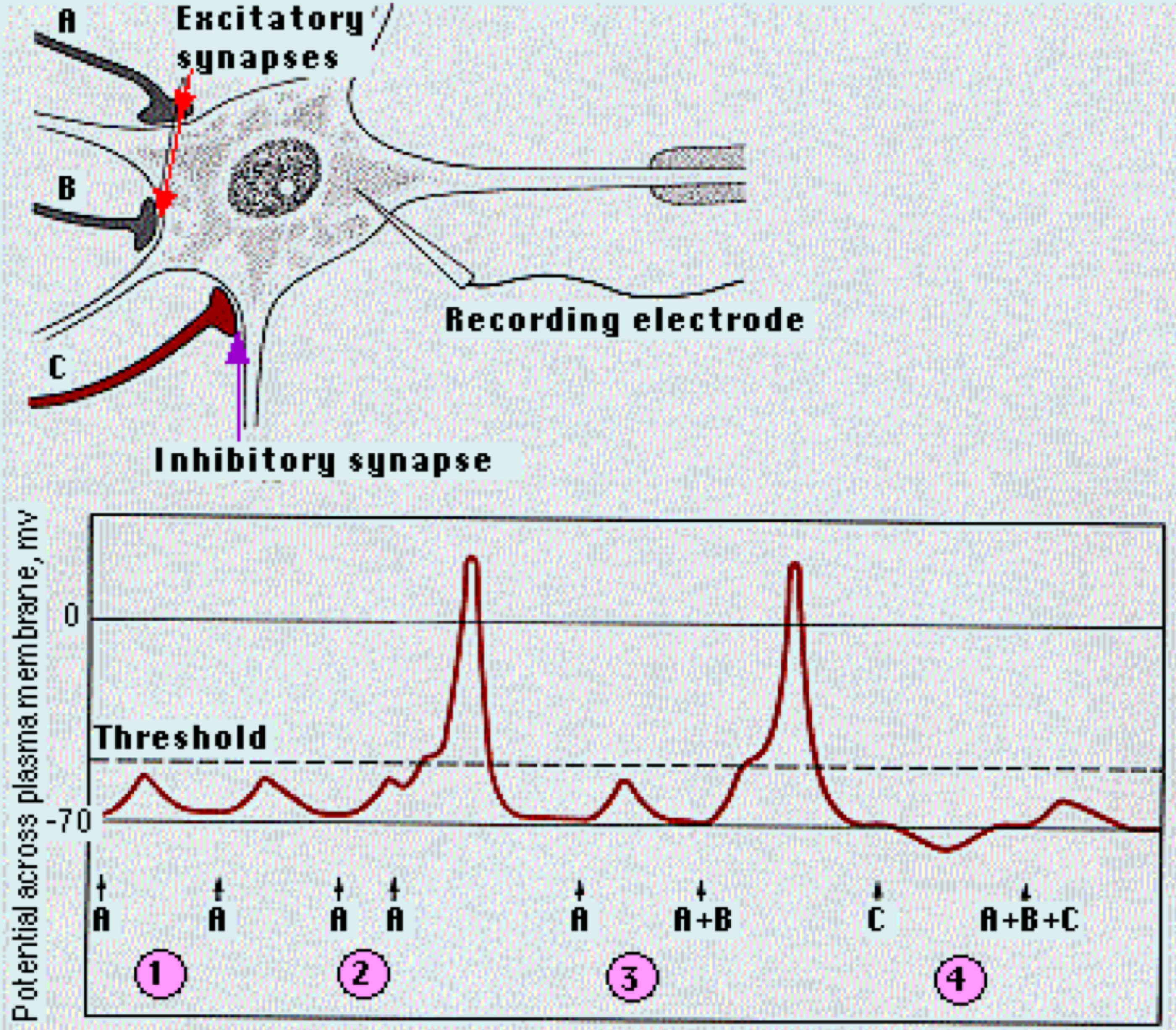
Facilitation

Inhibition

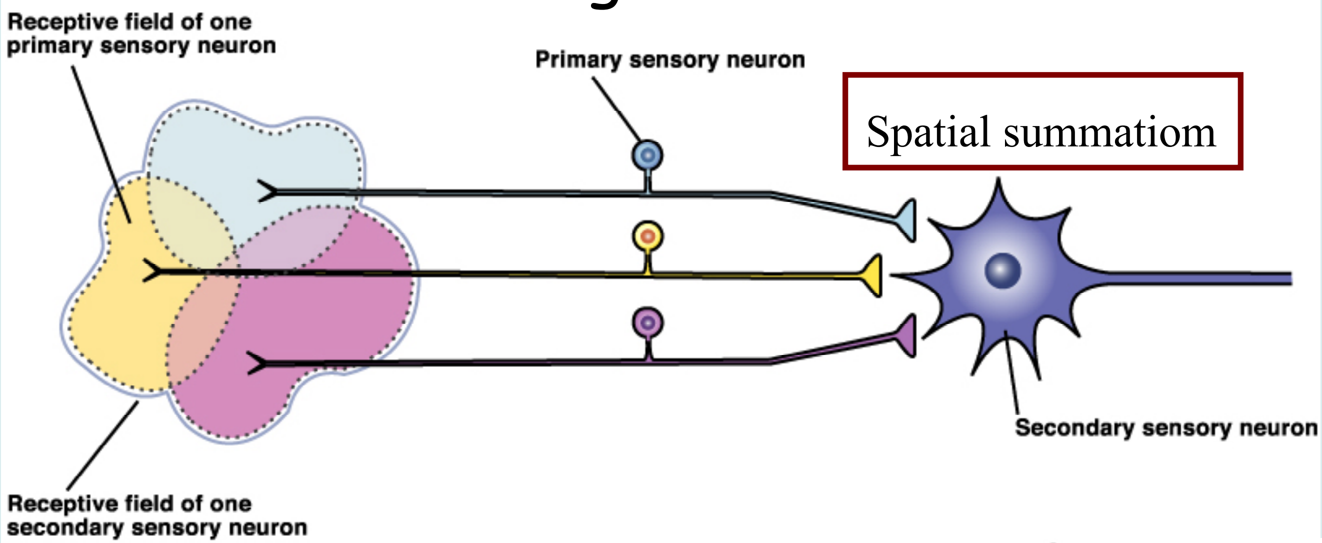
Convergence

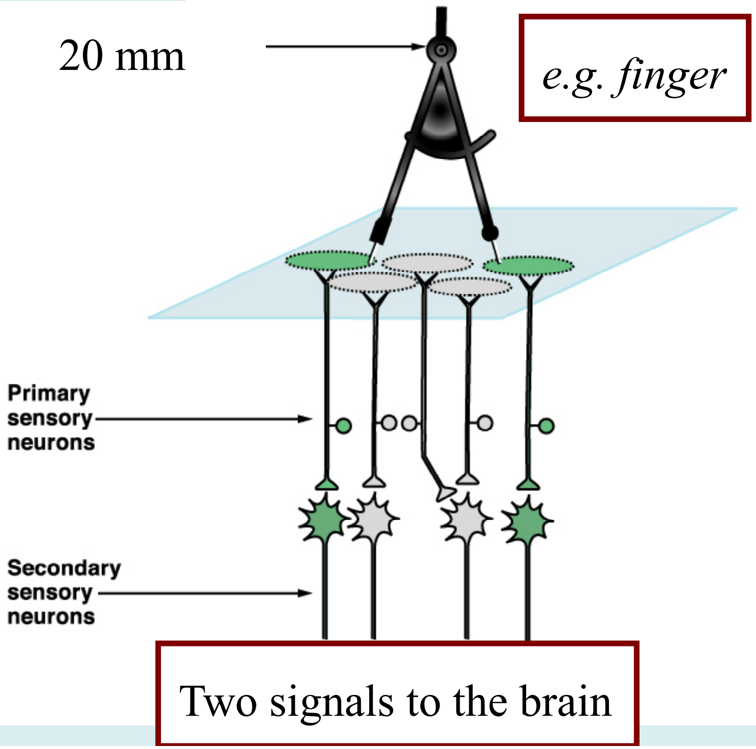
Divergence

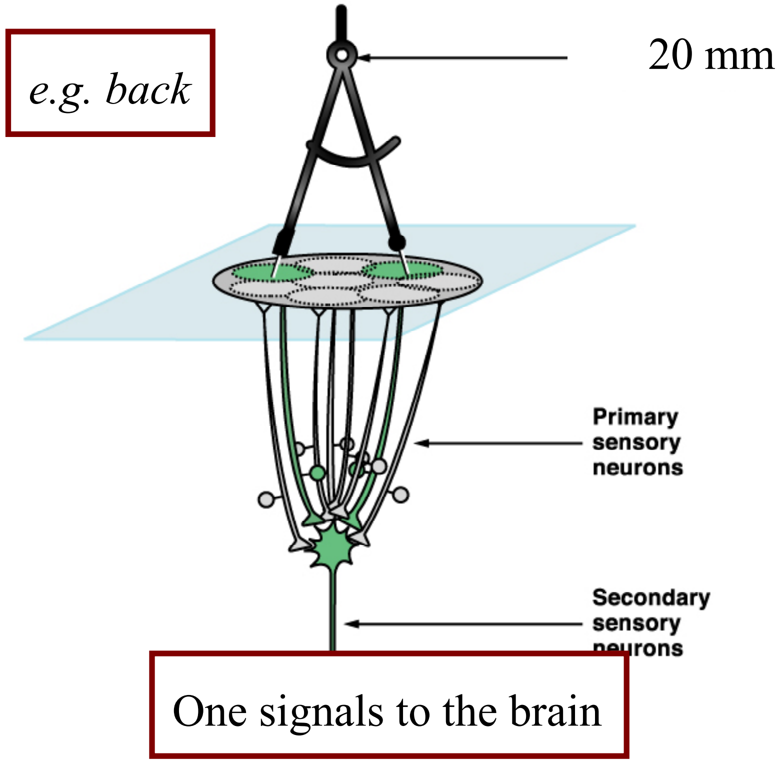
Temporal and spatial summation



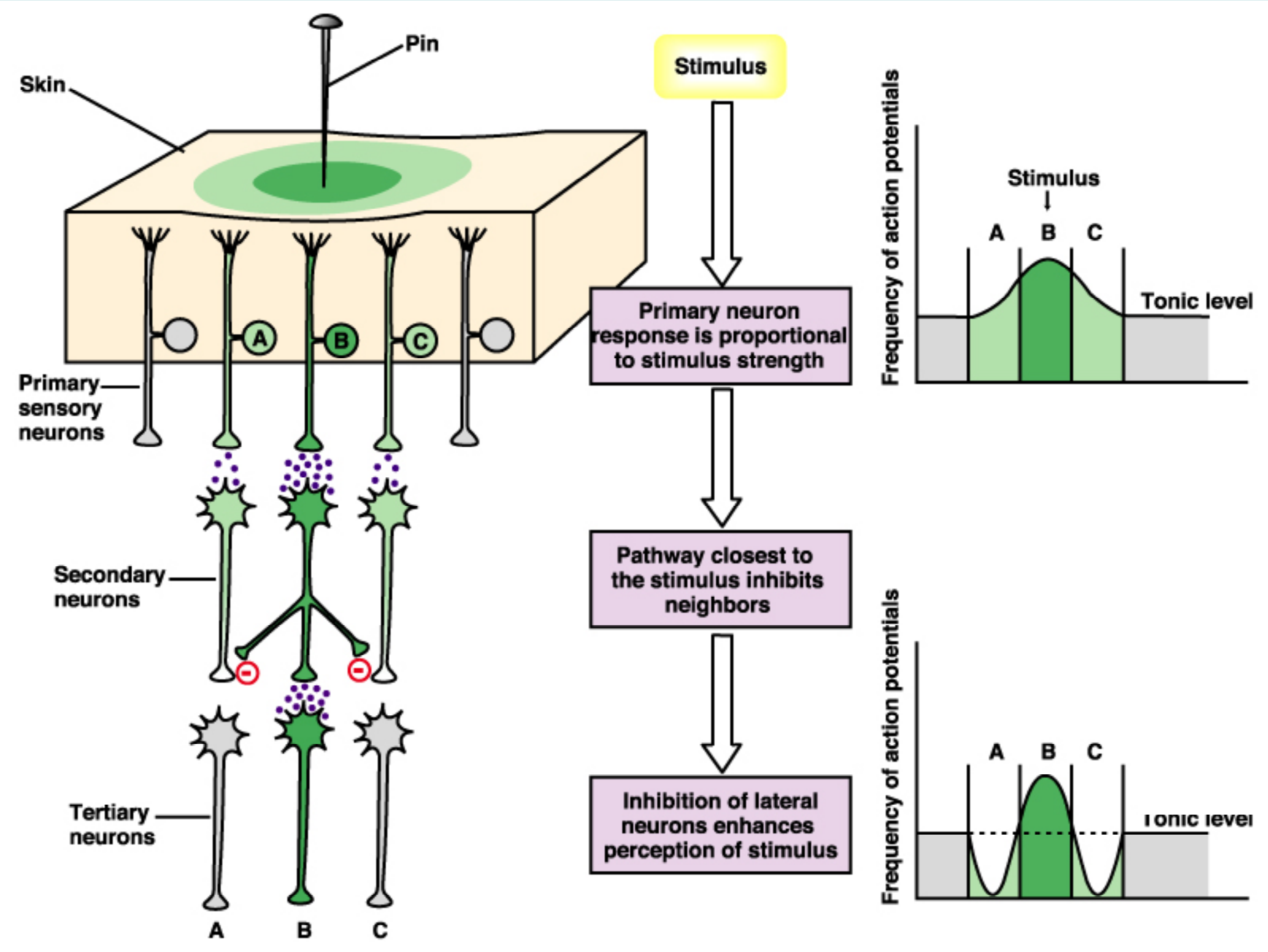
Convergence of Signals: multiple inputs uniting to excite a single neuron



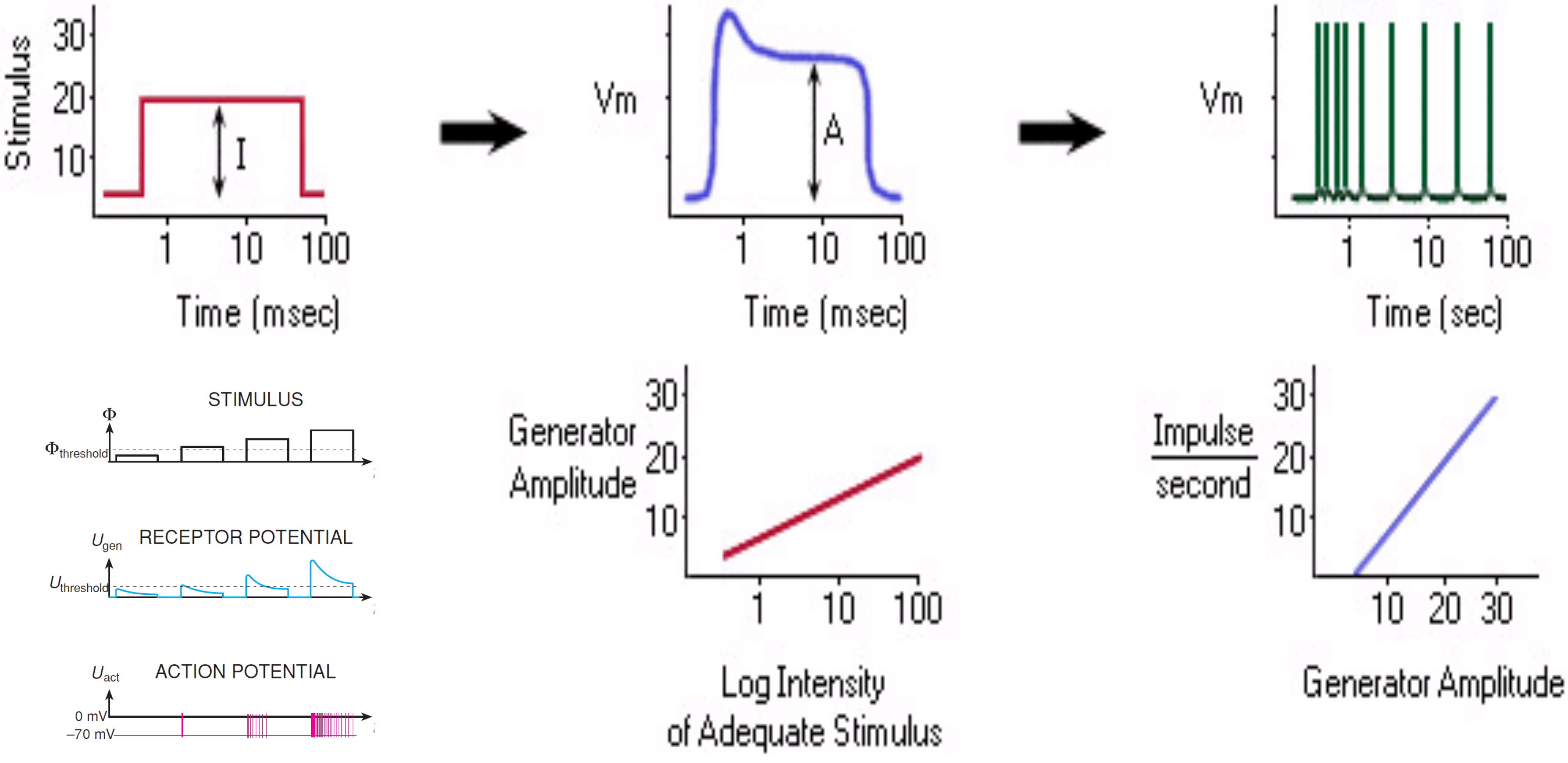




Divergence of Signals



Summary



Stimulus
30
20
10
I
1
10
100
Time (msec)
Vm
A
Time (msec)
Vm
Time (sec)
STIMULUS
Φ
Φthreshold
Ugen
RECEPTOR POTENTIAL
Uthreshold
Uact
ACTION POTENTIAL
0 mV
–70 mV
Generator Amplitude
Log Intensity of Adequate Stimulus
Impulse / second
Generator Amplitude

Psychophysics

Study the relationship between stimuli

&

our psychological response to them

Investigation of threshold stimulus

Absolute threshold

This is the minimum amount of a stimulus that is necessary for us to notice it 50% of the time

Decision method – yes - no

Determination of threshold by simple decision

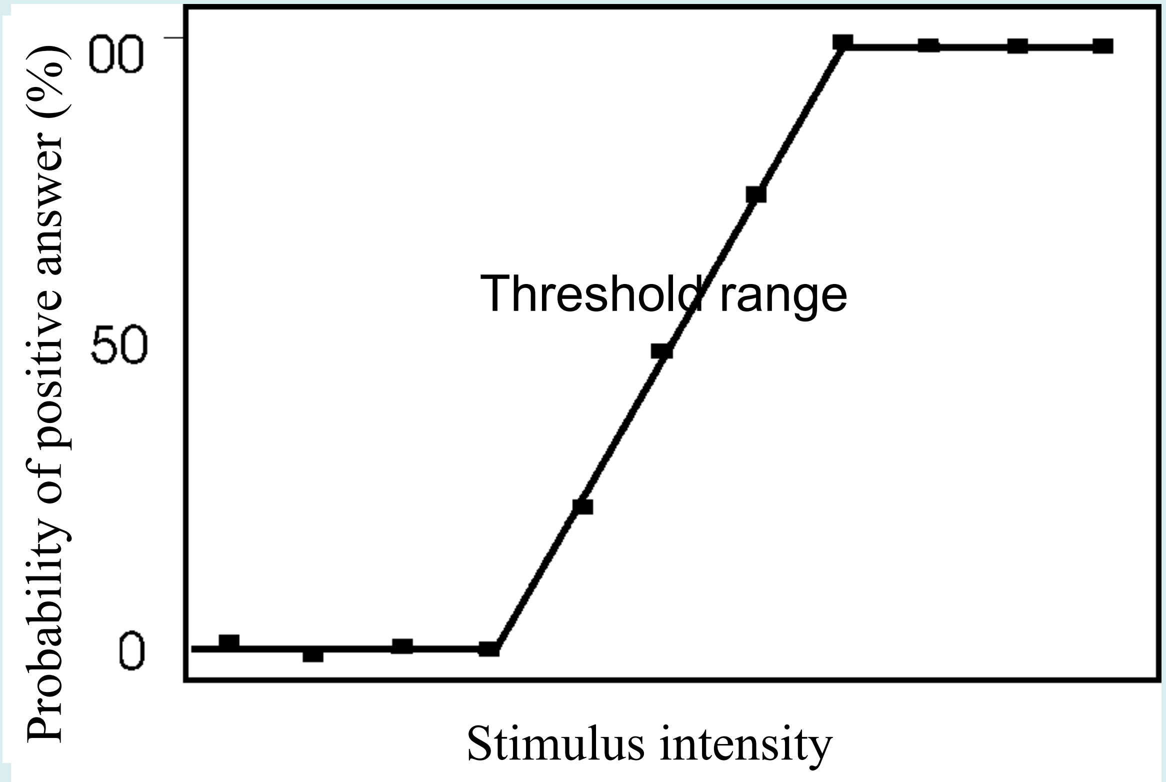
answer

Increasing intensity

stimulus	V1	V2	V3	V4	**YES (%)**
I1	NO	NO	NO	NO	**0 (0)**
I2	NO	NO	NO	NO	**0 (0)**
I3	NO	NO	NO	NO	**0 (0)**
I4	NO	NO	NO	NO	**0 (0)**
I5	NO	NO	NO	NO	**0 (0)**
I6	**YES**	NO	NO	NO	**1 (25)**
I7	**YES**	NO	**YES**	NO	**2 (50)**
I8	**YES**	NO	**YES**	**YES**	**3 (75)**
I9	**YES**	**YES**	**YES**	**YES**	**4 (100)**
I10	**YES**	**YES**	**YES**	**YES**	**4 (100)**
I11	**YES**	**YES**	**YES**	**YES**	**4 (100)**
I12	**YES**	**YES**	**YES**	**YES**	**4 (100)**

Determination of threshold by simple decision

Absolute threshold



Threshold is a variable

Threshold studies

Absolute threshold – the smallest intensity of stimulus to be recognized

Decision method – yes - no

Adjusting method – (see audiometry experiment)

Differential threshold : smallest difference between two intensities to be recognized as different

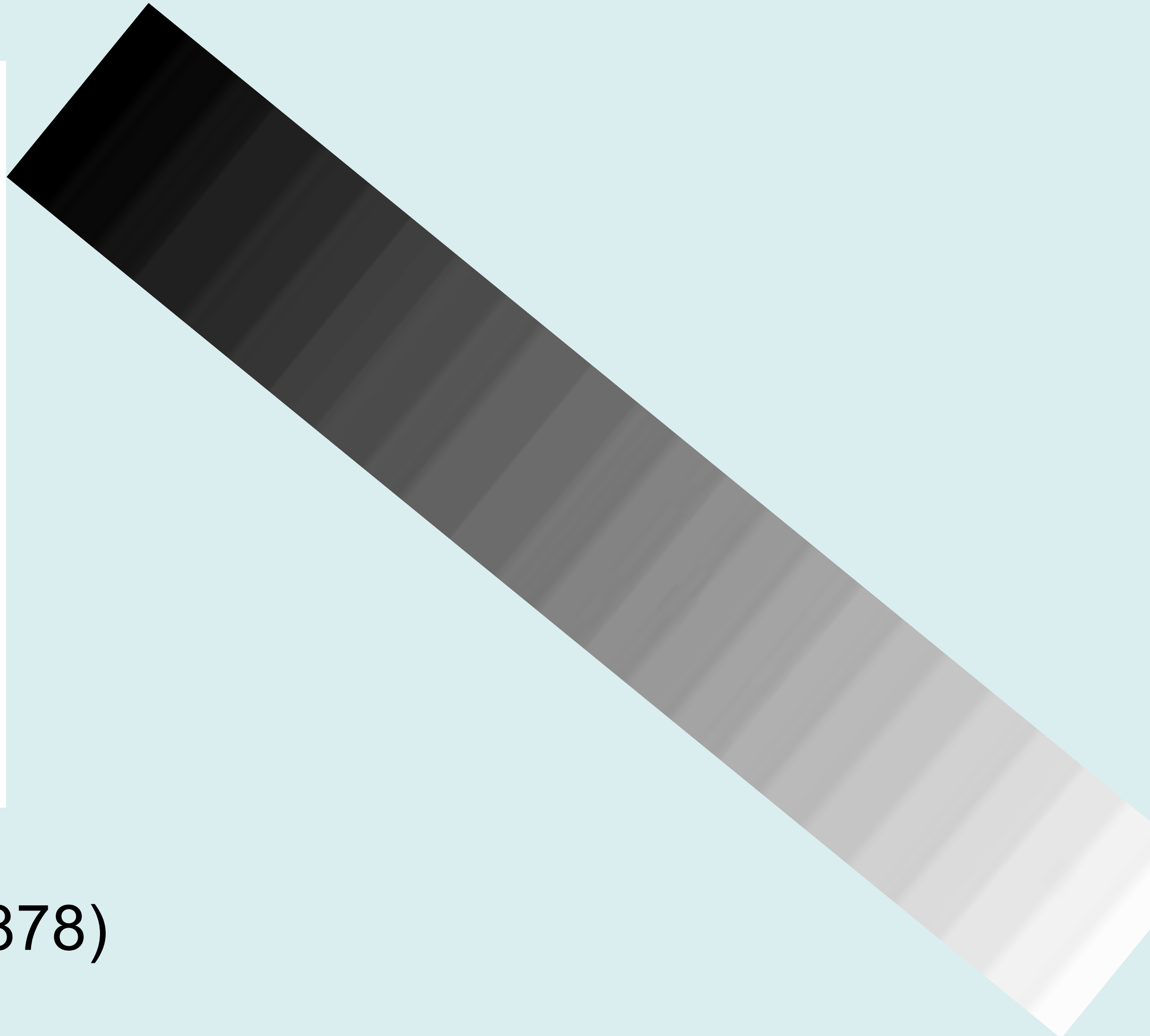
Forced decision method

Just Noticeable Difference: Smallest difference in amount of stimulation that a specific sense can detect

$$\textbf{Just Noticeable Difference} = I - I_0$$

Intensity recognised as different (I)

Reference intensity (I_0)



Ernst Weber (1795-1878)

"just-noticeable difference" (JND)

How much more you have to be offered to change your workplace?

50000 + 5000 ☑

500000 + 5000 ∅

JND= $I - I_0$

Higher initial stimulus – bigger JND

Weber's law

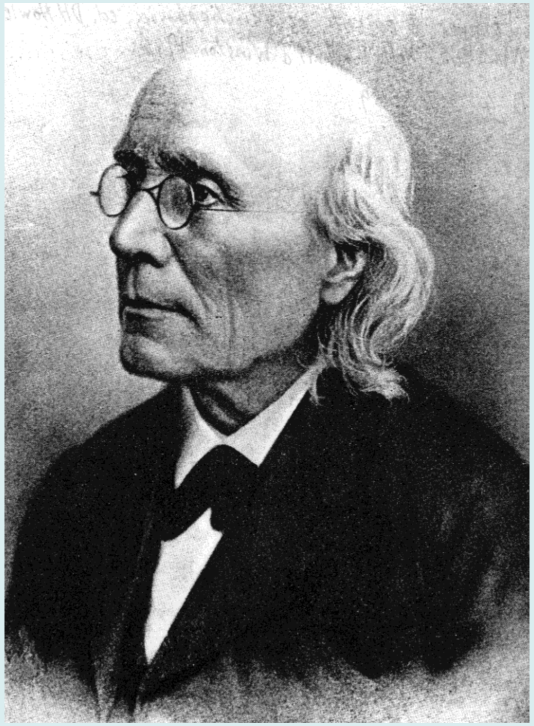
The size of the JND is a constant proportion of the initial stimulus. With other words the ratio of the increment threshold to the background intensity is a constant.

$$\frac{\Delta I}{I_0} = k$$

k: Weber ratio – can be determined by experiments

Each of the sensory perceptions has a consistent sensitivity to change.

stimulus	***Weber ratio***
brightness	0,079
loudness	0,048
touching	0,022
pressure	0,02
tasting (salt)	0,083
electric shock	0,013



Gustav Theodor Fechner
(1801-1887)

$$\Delta I = I - I_0$$

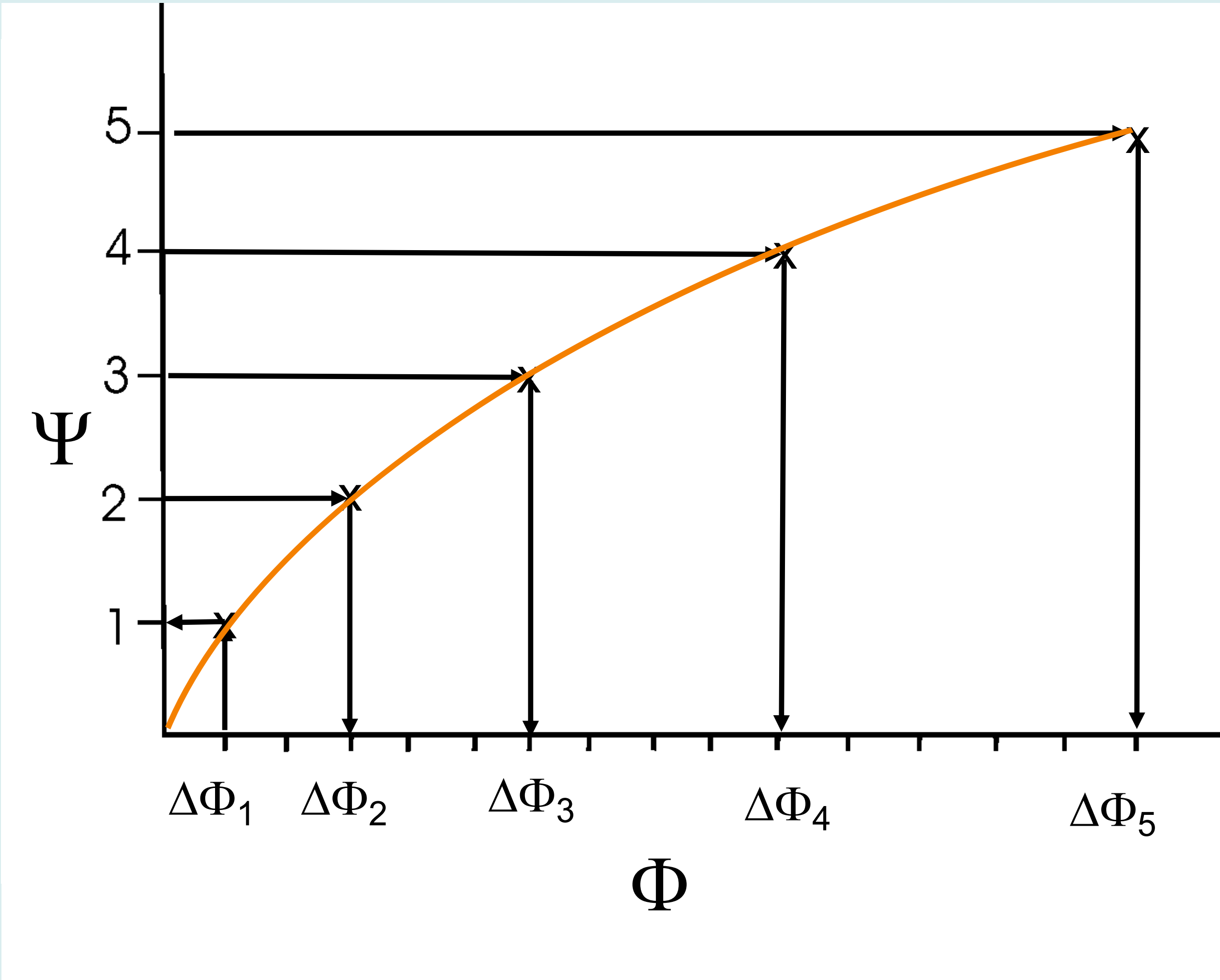
ΔI is a function

ΔI is the function of stimulus intensity

Fechner: what is the connection between stimulus intensity and sensation magnitude

Fechner assumed that the relative change of the stimulus is proportional to the change in the sensation magnitude

$$\Delta\Phi/\Phi \sim \Delta\Psi$$



$$\Psi \sim \lg\Phi$$

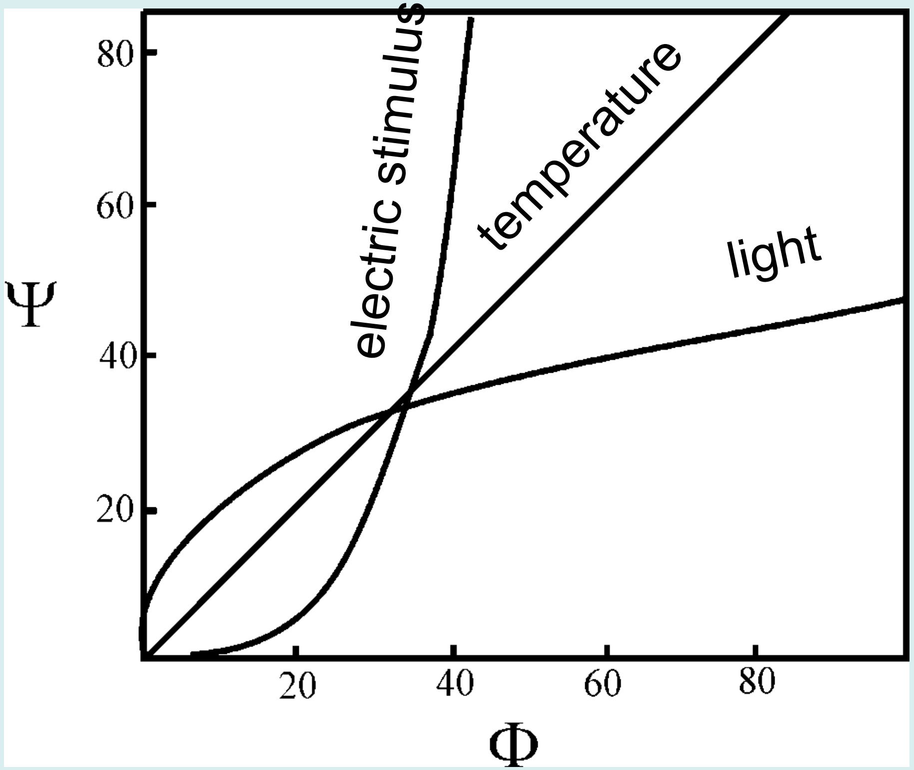
Established relationship between relative stimulus intensity (Φ/Φ_0) and psychological magnitude (Ψ).

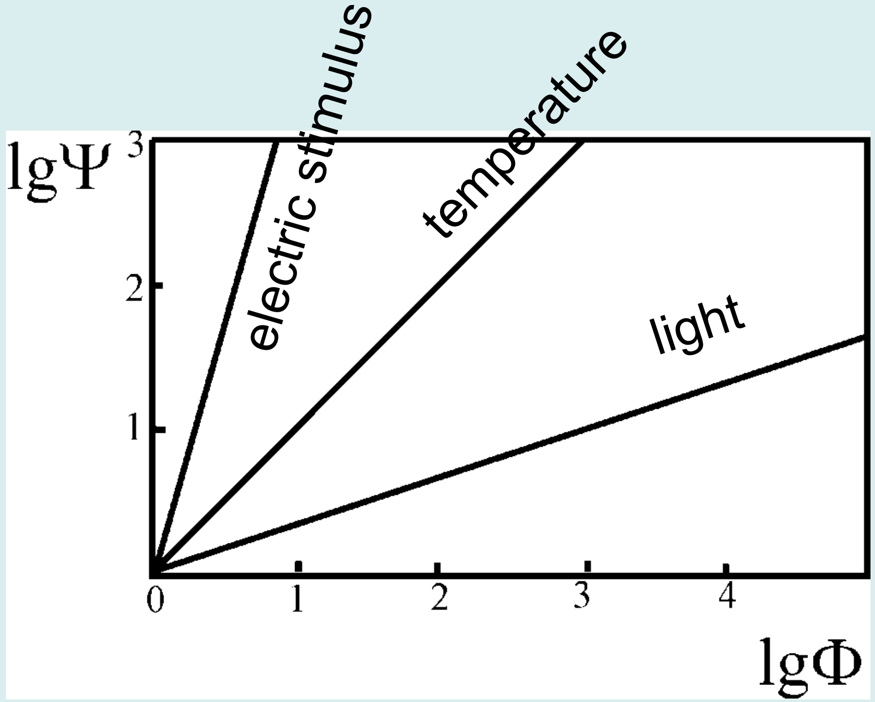
Performed measurements

Stanley Smith Stevens
(1906-1973)

sensation scale

Results of experiment





Sensation intensity increases with some expanding stimulus intensity. Equal stimulus ratios produce equal sensation ratios. This law is the power function

$$\Psi \approx \Phi^{n}$$

The exponent varies with the particular sensory modality, and also within a modality for different stimulus conditions, such as adaptation, inhibition, size, and duration of stimuli.

$$\Psi \approx \Phi^{n}$$

stimulus	***exponent***
short light pulses	0,5
smell (heptane)	0,6
loudness (1000 Hz)	0,3
ambient temperature	1,00
taste (salt)	1,30

Summary

Two different approaches:

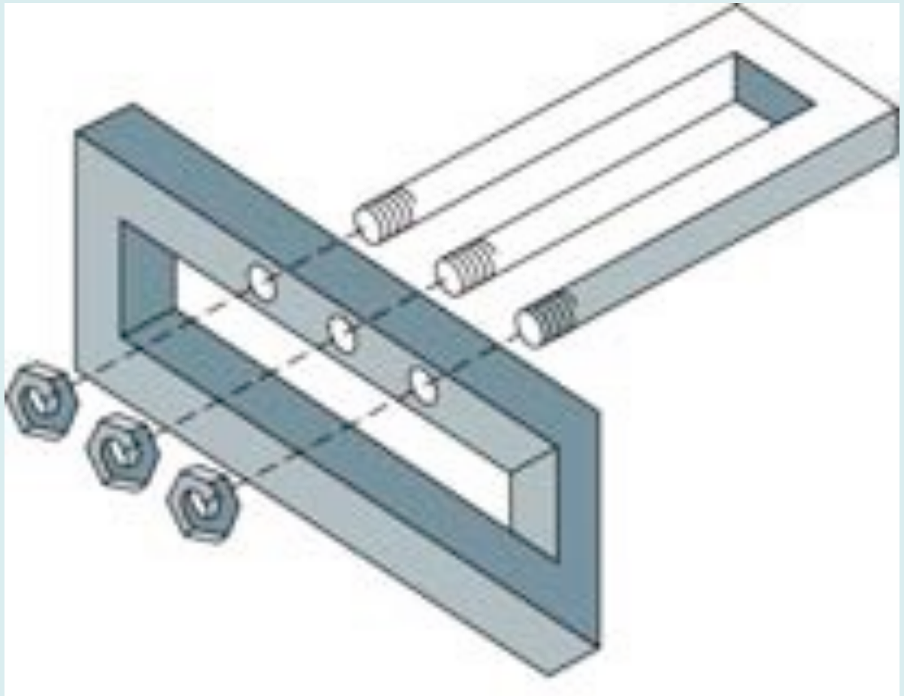
Weber – Fechner : $\Psi \sim \lg\Phi$

Stevens : $\Psi \approx \Phi^{n}$

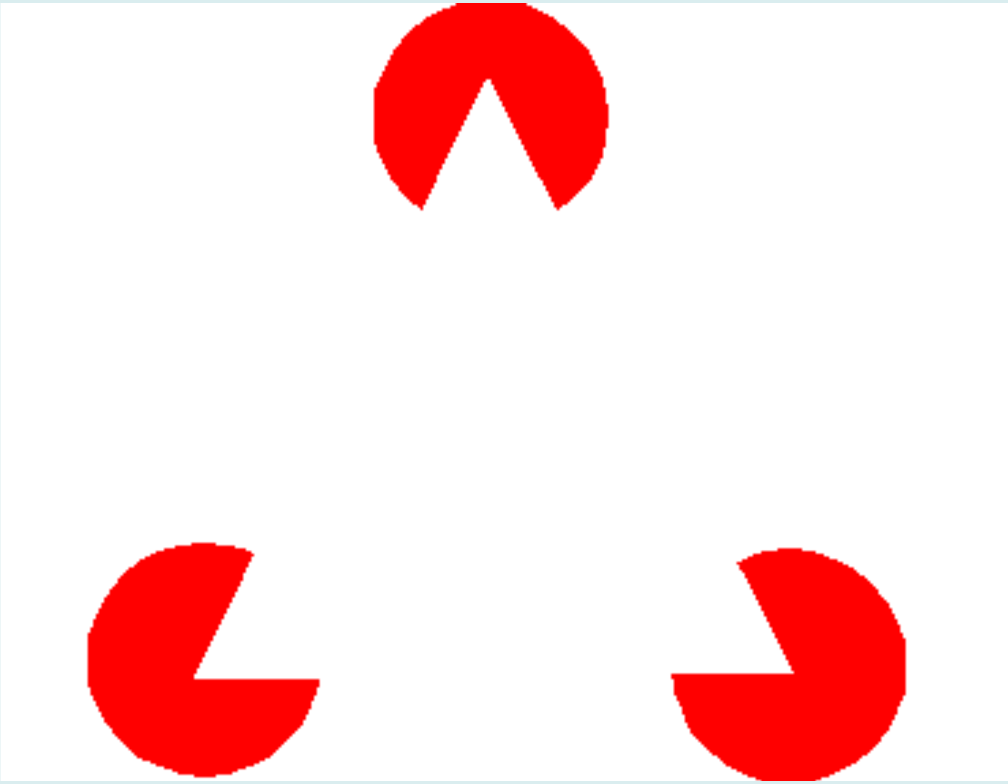
The second one received better experimental support.

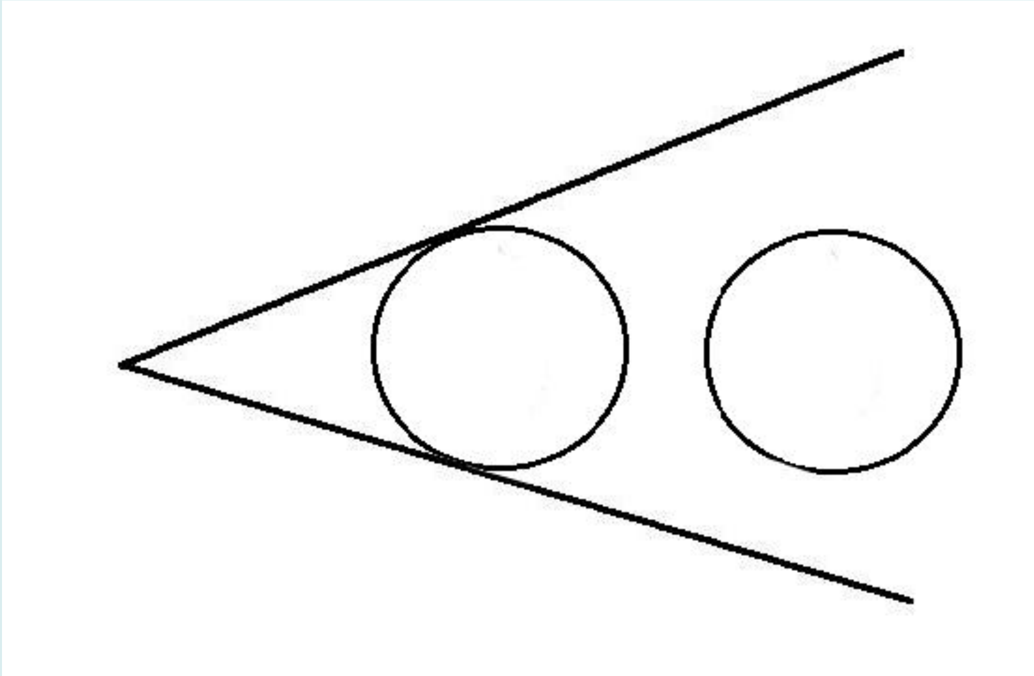
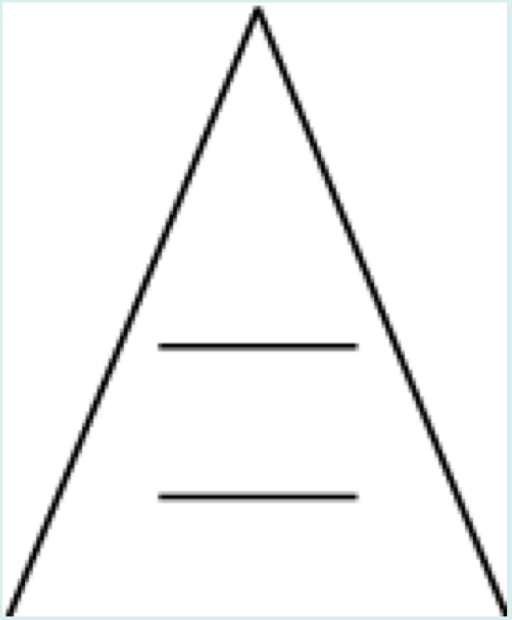
Perception - Organizing sensations into meaningful patterns

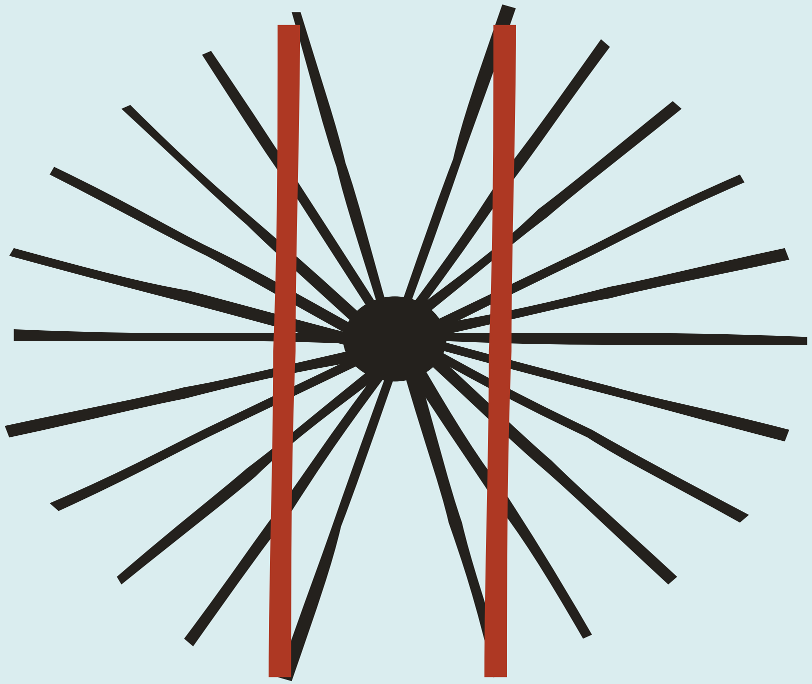
- analyzing
- organizing
- understanding

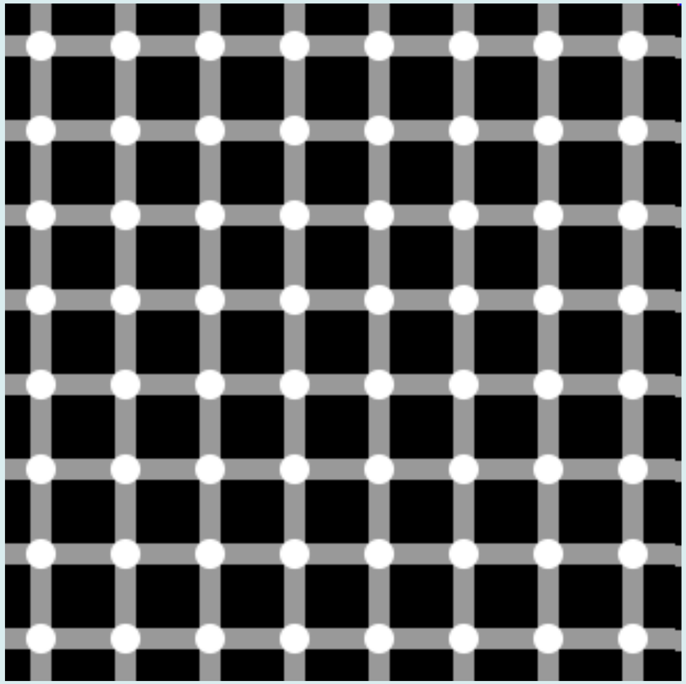


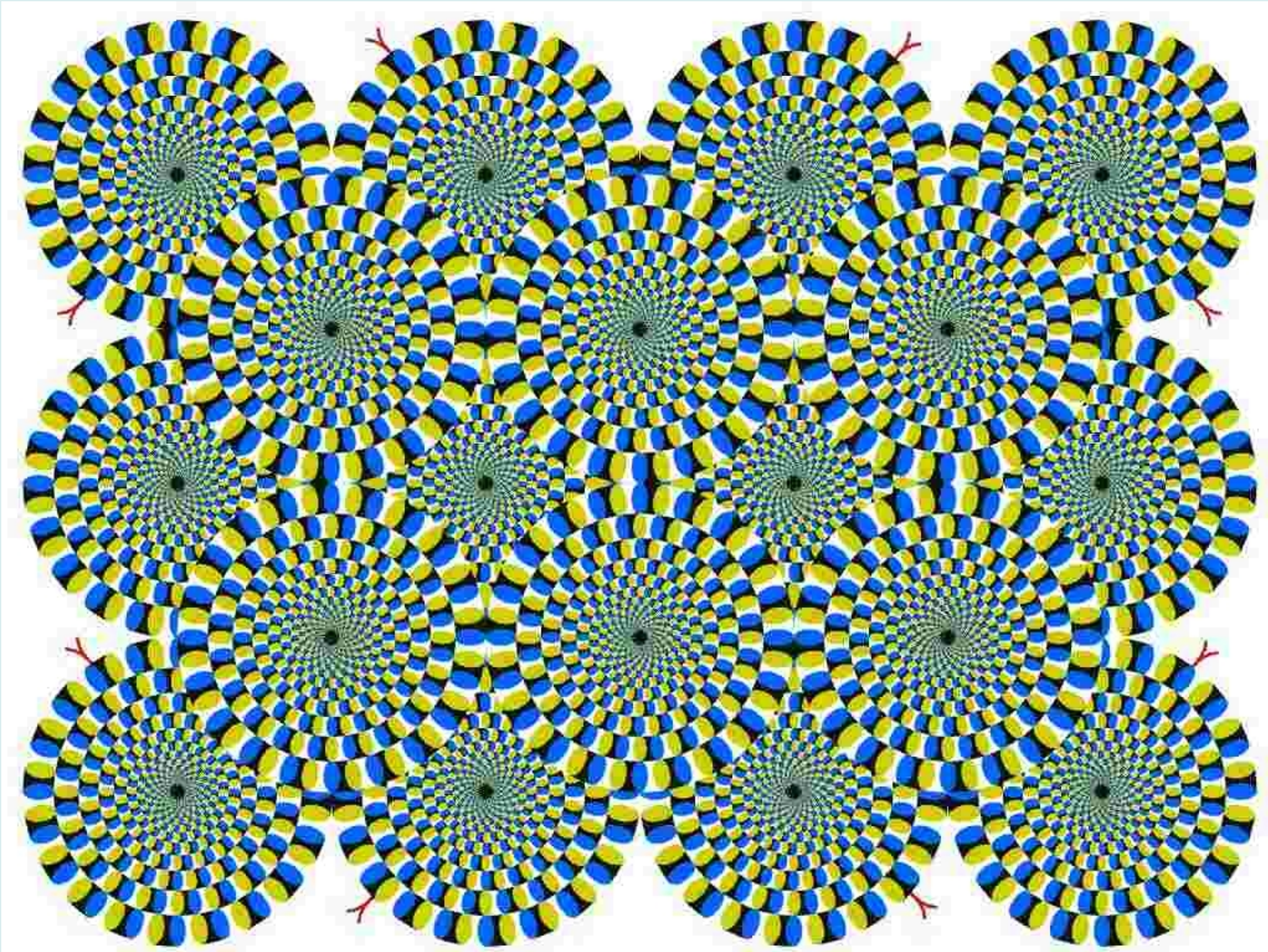
Perception might be correct or false.

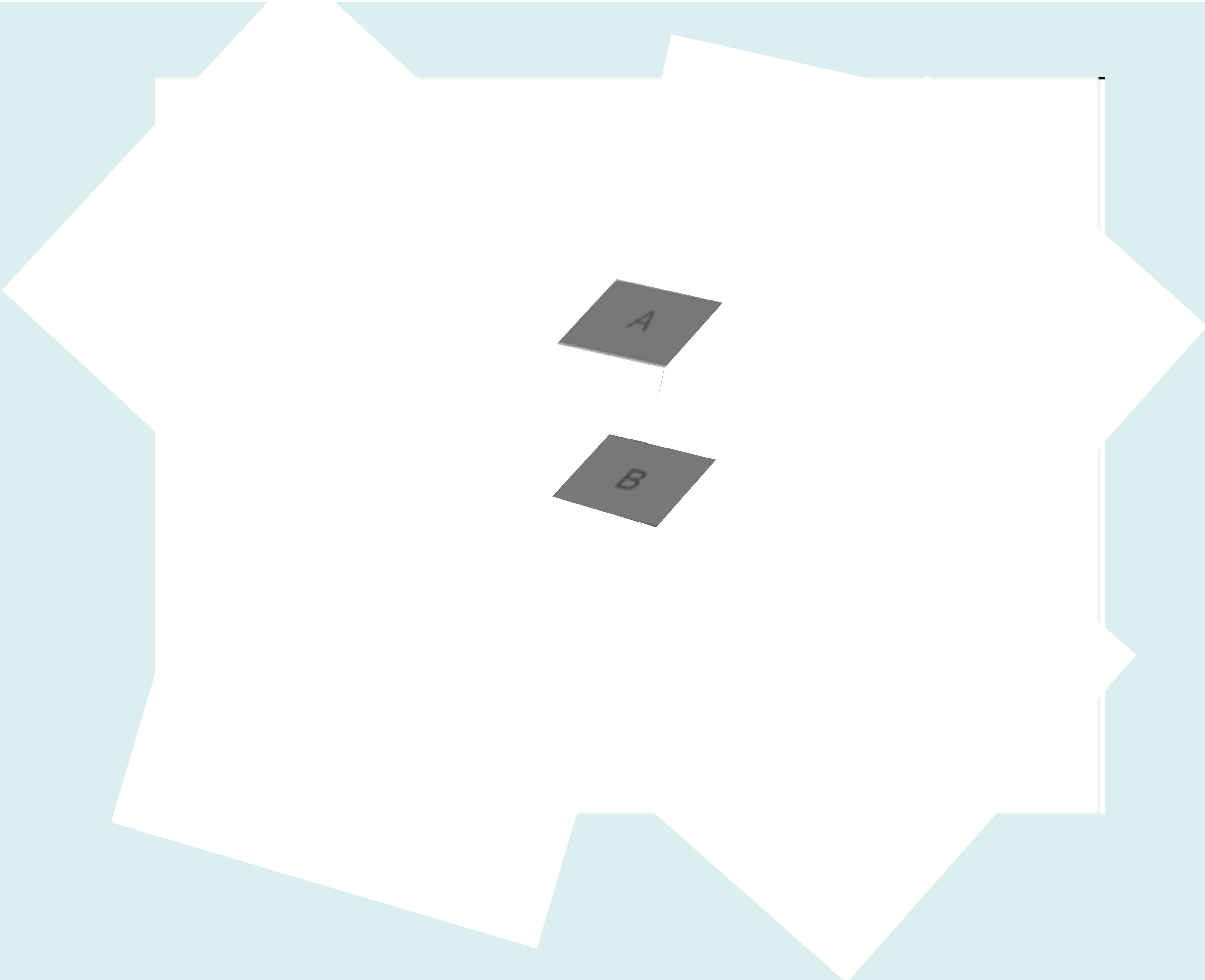









A
B

Damjanovich, Fidy, Szöllősi: Medical Biophysics

Ch. IV. 1.

Lab note: Sensor