Neuroscience

• is the scientific **study** of the nervous system (NS)

• structure, organization, function of its parts and its functioning as a whole unit

• traditionally: branch of biology

• an interdisciplinary science

• collaborates with other fields such as chemistry, medicine and allied disciplines, linguistics, mathematics, philosophy, physics, psychology, computer science, engineering.
“Whether judged in molecular, cellular, systemic, behavioral, or cognitive terms, the human nervous system is a stupendous piece of biological machinery. Given its accomplishments — all the artifacts of human culture, for instance — there is good reason for wanting to understand how the brain and the rest of the nervous system works.”

Mind-body problem

Phrenology (Gall, 19th century)
Experimental Approaches to Brain Function

- brain damage and its consequence
- experiments on animals
- functional brain imaging techniques
- methods that can reversibly disable particular brain area
Localization and Lateralization of Language

Paul Broca (1824–1880):

1) a behavior, such as language, is controlled by a specific brain area
2) destroying the area selectively destroys the behavior

Broca’s aphasia – inability to produce speech
Experimental Approaches to Brain Function

• brain damage and its consequence
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single-cell recording

(A) A single action potential occurs in 1 millisecond.

(B) Two action potentials occur in 3 milliseconds.

(C) A changing pattern of activity can be seen with the occurrence of many action potentials in a 40-millisecond period.
Simple cells in primary visual cortex

- Hubel a Wiesel, 1968
- 1981 Nobel prize
Experimental Approaches to Brain Function

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Brain Imaging Techniques

• Structural
  – CT
  – MRI

• functional
  – fMRI
  – PET
  – EEG
CT – computerized tomography

- narrow X-ray beam is detected by sensitive detector
- CT scanner rotates (from 0° to 180°)
- Computer then calculate the radiodensity of each point within the slice plane, producing a tomographic image
MRI – magnetic resonance imaging

1. The subject is placed in a long metal cylinder containing two sets of magnetic coils arranged at right angles to each other.

2. A radiofrequency coil (not shown) surrounds the head and is designed to perturb the static magnetic fields that produce MRI.

3. The resulting MRI is a horizontal slice through the head.

Protons have different relaxation rates in different types of tissue.

Relaxation is more rapid in brain tissue...

(A) $T_1$ Time constant
- Brain tissue
- CSF

...than in CSF.

(B) MRI
- CSF-filled ventricle
- Brain tissue
- Skull
MRI – magnetic resonance imaging

Each proton of a hydrogen atom rotates about its axis, acting as a small magnet with its own dipole. Normally the protons of hydrogen atoms are randomly positioned so that the tissue has no net charge.

When placed in a magnetic field the protons become aligned in parallel.

A radiofrequency pulse applied to the tissue pushes the protons to their sides, causing them to wobble about their axes.

This wobbling, called precession, produces two components of the magnetic field; a vertical component and a horizontal component.

When the horizontal radiofrequency pulse is turned off,...</ndocument
fMRI – functional magnetic resonance imaging

• variant of MRI allowing to see changes of activity in time

• detects differences in the level of oxyhaemoglobin vs. deoxyhaemoglobin, (resulting from neuronal activity)

Blood oxygen-level-dependent signal (BOLD) haemodynamic response function
PET – positron-emission tomography

(A) A positron released by an unstable nucleus of $^{15}$O meets an electron and their mass is converted to two annihilation photons traveling at 180 degrees from each other.

(B) Multiple radiation detectors are arranged about the subject's head.

(C) As many as 63 images are recorded simultaneously, in parallel horizontal slices.
Electroencephalography
EEG activity in different states of vigilance

(A) Excited
(B) Relaxed, eyes closed
(C) Drowsy
(D) Asleep
(E) Deep sleep
(F) Coma

Epileptic EEG activity

1 Normal
2 Onset
3 Clonic phase
4 Coma after seizure

LT
RT
LF
RF
LD
RO

source localization

inverse problem
forward problem
Evoked potentials
Experimental Approaches to Brain Function

• brain damage and its consequence

• experiments on animals

• functional brain imaging techniques

• methods that can reversibly excite or disable particular brain area
TMS – transcranial magnetic stimulation

A transcranial magnetic stimulator (TMS) is placed over a region of the cortex.

The TMS coil, shown here in composite MRI/PET scan photograph, interferes with brain function in the adjacent area, indicated by the dotted line.

https://www.youtube.com/watch?v=FMR_T0mM7Pc
Time and space resolution
We may believe that we see, hear, touch, and taste real things in a real world. In fact, the only input that our brains receive from the “real” world is a series of action potentials passed along the neurons of our various sensory pathways.

Kolb and Whishaw (2016) An Introduction to Brain and Behavior, 5th Edition Ch. 9: How Do We Sense, Perceive, and See the World?, Worth Publishers
Transduction of energy

- **Vision**: light energy is converted into chemical energy (in the receptors of the retina) and this chemical energy is in turn converted into neural activity.

- **Auditory system**: air pressure waves are converted into a number of forms of mechanical energy, the last of which eventually activates the receptors, which then produce a neural discharge.

- **Somatosensory system**: mechanical energy activates mechanoreceptors, which in turn generate neural activity.

- **Taste and olfaction**: various molecules carried by the air or contained in food fit themselves into receptors of various shapes to activate neural activity.

- **Pain sensation**: tissue damage releases a chemical that acts like a neurotransmitter to activate pain fibers and thus produce a nerve impulse.
Electromagnetic spectrum

wavelength in nm
• For audition: the receptors of the human ear respond to sound waves **between 20 and 20,000 Hz**.

• Elephants can hear and produce sounds that are **less than 20 Hz**, and bats can hear and produce sounds that are **as high as 120,000 Hz**.

• Dogs can hear the ultrasounds emitted by rodents and bats, they can hear the low-range sounds of elephants, they can detect odors that we cannot detect and they can see in the dark. (We can hold up only our superior color vision.)

• **Different species have different sets of sensory system filters**; each set produces an idiosyncratic representation of reality.
Perception

• How do we perceive senses like sound, smell, touch as different from each other?

• Partial explanations:
  – different senses are processed in different cortical areas
  – we learn from our experience
  – each Ss has preferential connection to a specific type of reflex behaviour

  SYNNESTHESIA
  0123456789

  – mixing of senses
  [seeing sound, hearing smell]
Vision
Sensory subsystems

Frontal eye fields control voluntary eye movements.

Pretectum produces changes in pupil size in response to light-intensity changes.

Pineal body controls long-term circadian rhythms.

Superior colliculus controls head orienting, particularly to objects in peripheral visual fields.

Visual cortex controls pattern perception, depth perception, color vision, and tracking of moving objects.

Suprachiasmatic nucleus controls daily rhythms (sleep, feeding, etc.) in response to day-night cycles.

Accessory optic nucleus moves eyes to compensate for head movement.
Topographic organization of retina
Retina
**Rods**

- scotopic vision = vision under low light conditions (confer achromatic vision)
- the highest density on the periphery of the retina

**Cones**

- photopic vision = vision under high light conditions (confer color vision)
- the highest density in the fovea

3 types of cones (photopigments):
- red, 560 nm
- green, 530 nm
- blue, 430 nm

**Fovea**
- sharp central vision
- composed of closely packed cones

Rodes and cones contain visual pigments, that changes after absorbing light.
Density of retinal cells
Lateral inhibition

real color intensity

perceived color intensity
Retina

retinale Ganglienzellen
amakrine Zellen
Bipolarzellen
Horizontalzellen
Zapfen
Stäbchen

Licht

3rd neuron  2nd neuron  1st neuron
Lateral inhibition
Visual Pathway

Photoreceptive cell
→
Bipolar cell
→
Ganglion cell

=> OPTIC NERVE
Retinal ganglion cells

**on – cells**
• respond to the appearance of the light spot in their receptive field

**off – cells**
• react to the disappearance of the light spot in their receptive field

*Stephen Kuffler, 1950s*
Retinal ganglion cells II.
Retinal ganglion cells III.

Responses of a hypothetical population of on-center ganglion cells whose receptive fields (A–E) are distributed across a light-dark edge. Those cells whose activity is most affected have receptive fields that lie along the light-dark edge.
Before entering the brain, the two optic nerves meet and form the optic chiasm (about half the optic fibers cross)

→ corpus geniculatum laterale (CGL)
→ primary visual cortex (V1, Brodmann area 17)
Magno- a parvo-cellular cell

• Ganglion cells have 2 types of nuclei:
  – cells with small nucleus (parvo), foveal area
  – cells with large nucleus (magno), periphery

• Magno and parvo system in CGL
  – Magno system – fast processing, changes in contrast, movement perception
  – Parvo system – informations about color, shape, slow processing, high resolution
Visual cortex: occipital lobe

- below the occipital bone of skull

Subdivisions
- Brodmann (on monkeys): BA 17, 18, 19
- nowadays (imaging methods):
  - finer division: V1, V2, V2, VP, V3a, V4d, V4v, MT (V5)
Simple cells in primary visual cortex

- Columnar arrangement – vertically adjacent neurons respond to the same orientation

- Hubel & Wiesel, 1968
- 1981 Nobel prize
Primary visual cortex

• **Simple cells**
  – respond to stationary linear stimuli.
  – sensitive to orientation

• **Complex cells**
  – respond to moving stimuli
  – sensitive to direction and orientation

• **Hypercomplex cells**
  – “all cells that exceed complex cells in intricacy of behavior”

double opponent orientation and directionally selective hypercomplex cell characteristically failing to respond if the red bar is elongated

https://www.youtube.com/watch?v=jw6nBWo21Zk
Color constancy

real color
Color constancy

https://www.youtube.com/watch?v=z9Sen1HTu5o
Subsequent processing

- **Dorsal stream** (ends in dorsal parietal cortex)
  - „Where it is?“
  - localization, spatial vision, movement control

- **Ventral stream** (ends in ventral temporal cortex)
  - „What it is?“
  - object recognition, identification
Thank you for your attention