19ECE431 : Neuroengineering
Unit 1

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April 29, 2023

0.1 Introduction

0.1.1 What is Neuroengineering?

Neuroengineering or neural-engineering is a field that combines neuroscience and engineering, as engineers the main focus of this field is to understand the biology of the functions of the nervous system and come up with engineering solutions that benefit people in a variety of applications, a famous application is the BMI(Brain Machine Interfacing) which is a device that enables to analyze brain signals and translates them into commands that can be used for electronic devices to interpret and display desired result. An interesting example is the wearable headgear by the Paris-based startup next mind, which collects brain activity from the occipital region of the brain (the visual cortex) and decodes its attentional focus, and generates desired outcomes. this can be used as a hand-less controller while playing games in virtual reality (Kind of like the anime sword art online).

Figure 1: Nextmind BMI

0.1.2 Different Approaches to Neuroscience

1. Evolution
2. Molecular genetics
3. Behavioral genetics
4. Ethology

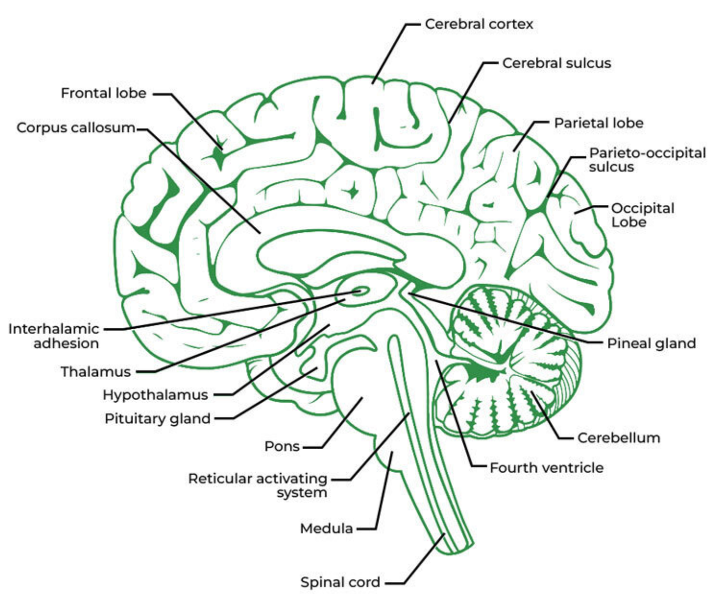
0.2 Neuroscience to brain circuits

0.2.1 What is neuroscience?

Neuroscience is the study of the nervous system (The brain, spinal cord, and peripheral nervous system), its functions, and disorders.

0.2.2 spinal cord and the brain system

The Brain



the brain is a complex organ that can operate complicated tasks such as the intake and transfer of information, emulate vision, generate thought, handle involuntary behaviors, and much more with just 20 watts of power. which is less than charging a small USB-powered fan or running a LED lamp.

This tells how optimized the brain is when it comes to processing information compared to a normal computer.

Emulating Brain Activity Using Von-Neumann computer

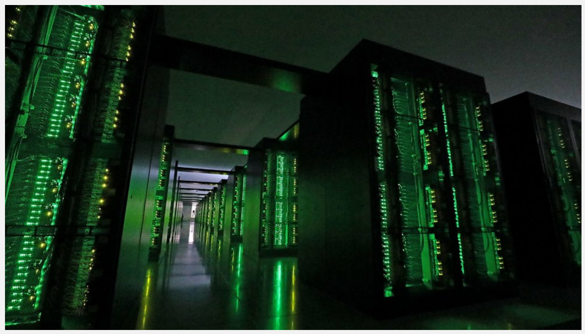
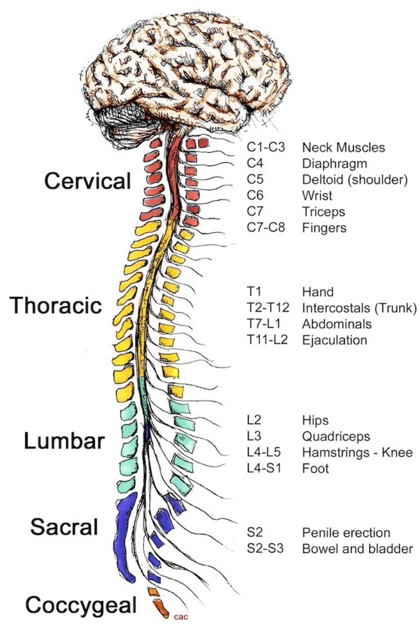


Figure 2: Supercomputer RIKEN

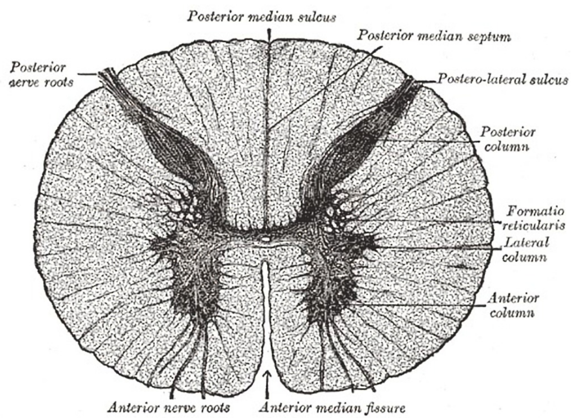
Traditional computers that everyone uses in today's generation works on Von-neumann's architecture where the memory and data are located in a different place and connected using a data bus this architecture is highly inefficient compared to the brain's processing.
A very famous example is the Japanese Supercomputer RIKEN which is termed one of the best Supercomputers in the works and of course, is a von-Neumann computer with 1.4 million GB RAM. But when it came to processing 1 percent of brain activity it took 40 minutes. so that means it would take 6.5 years to emulate a daily activity of the brain, that too not 100 percent of it just 1 percent !!. therefore we can tell how inefficient our new generation computers are, the brain compared to traditional computers process data and memory at the same time and they also process analog signals instead of digital ones. But researchers are trying to come up with processors that try to emulate brain functions that are still under development.

Parts of the brain

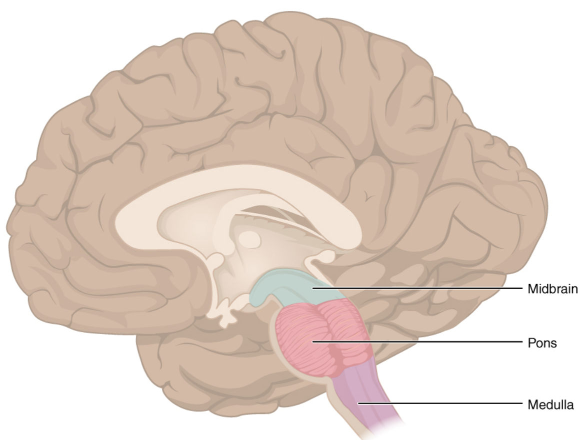
The brain consists of the following parts:
1. Spinal Chord
2. Medulla
3. Pons
4. Mid brain
5. Diencephalon
6. Cerebellum



The Spinal cord has three primary roles: 1. send motor commands from the brain to the body, send sensory information from the body to the brain, and coordinate reflexes due to the presence of several oscillators. The spinal cord has 62 spinal nerves (32 pairs) overall from the cervical, thoracic, lumbar, sacral, and Coccygeal regions.
if we take the cross-section of the spinal cord it consists of grey matter, white matter, and spinal fluid (which comes from the hole in the middle)



Brain-stem connects the brain to the spinal cord . it controls hunger and body functions such as body temperature regulation, blood pressure, and breathing which constitute the autonomic reflex center (also called the vital centers). below are the further components of the brain stem is -



- Medulla Oblangata.
- Pons.
- Mid brain.

the brain-stem is connected to the cerebellum with the **cerebellar-peduncles**.

cranial nerves

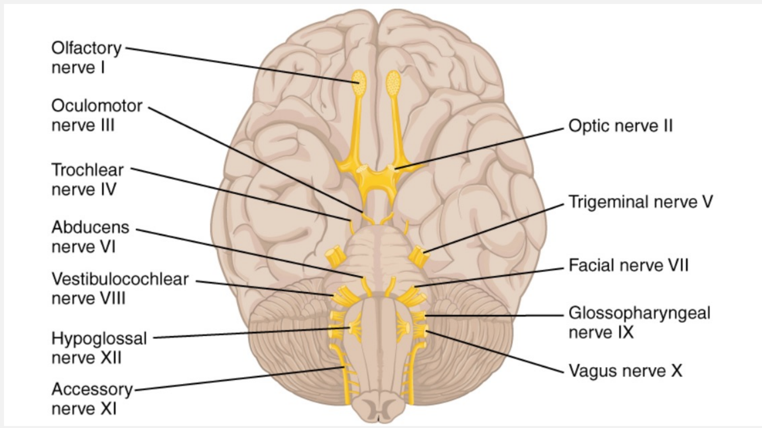


fig. a

cranial nerves supports in providing smell , taste , hearing and movement of facial muscles , sight, etc by acting as a medium of transportation of electrical signals between the brain and different parts of the neck , head and truck regions of the body.
These nerves start from the back of the brain and is a crucial part of the nervous system . There are total 12 cranial nerves in the body shown in Fig. a .
Olfactory nerve: Sense of smell.
Optic nerve: Ability to see.
Oculomotor nerve: Ability to move and blink your eyes.
Trochlear nerve: Ability to move your eyes up and down or back and forth.
Trigeminal nerve: Sensations in your face and cheeks, taste and jaw movements.
Abducens nerve: Ability to move your eyes.
Facial nerve: Facial expressions and sense of taste.
Auditory/vestibular nerve: Sense of hearing and balance.
Glossopharyngeal nerve: Ability to taste and swallow.
Vagus nerve: Digestion and heart rate.
Accessory nerve (or spinal accessory nerve): Shoulder and neck muscle movement.
Hypoglossal nerve: Ability to move your tongue.

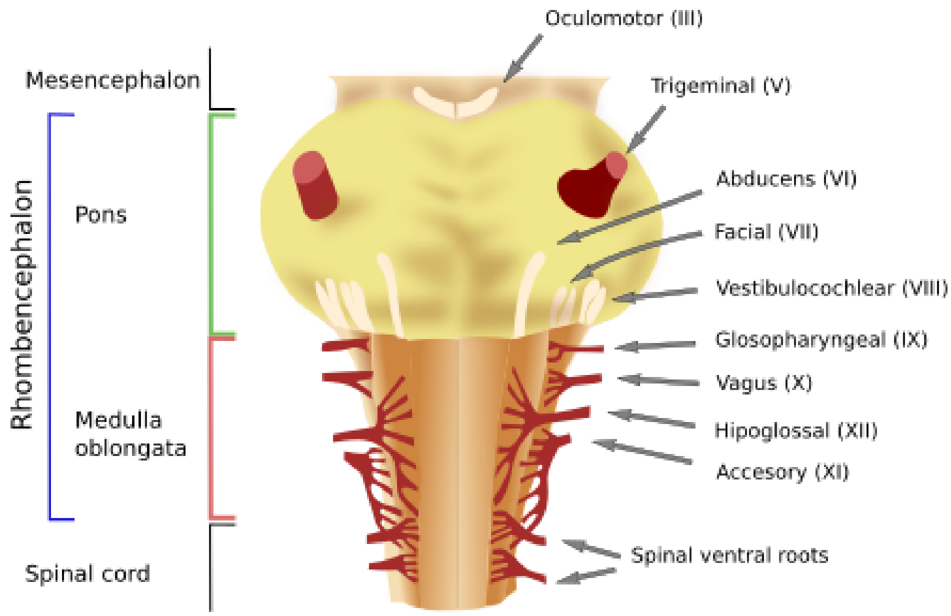


Figure 3: Cranial nerves by region

the brain stem has the most number of cranial nerves in the brain which is about 10 out of 12 cranial nerves (III - IX in Fig a).

Medulla Oblangata

The medulla Oblongata is the interconnection of the brainstem and the spinal cord. It is also called as bulb due to its shape . the medulla has access to the cranial nerves IX - XII therefore its vital centers is established as : -

- **Cardiac center** : Regulation of heart rate .
- **Vasomotor center** : Regulates blood flow in vessels.
- **Respiratory center** : Regulates respiratory movement.

Therefore a fatal blow in the **vital centers** can result to **serious respiratory failures and potential paralysis** in muscle movement due to the damage in the cranial nerves associated to the medulla.

Pons

pons is located in the between the medulla and the midbrain and has access to cranial nerves V - VIII , located in the posterior [1] cranial fossa [2] on the cilvus [3] and anterior [4] cerebellum. The cranial nerves in the Pons help in the movement of the eyeballs , sensations in the face and cheeks , creating facial expressions etc. The pons act as a bridge between the two cerebral hemispheres with its fibers in its front side region [Fig. 4]

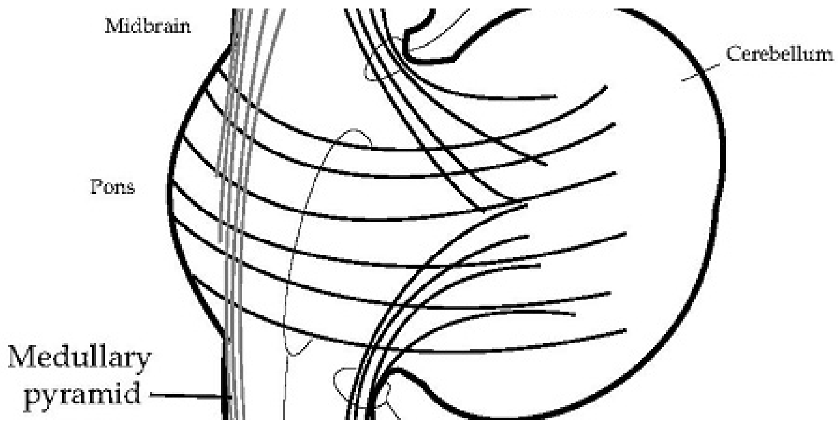


Figure 4: Pons Bridge

Mid-Brain

The **midbrain** is located at the topmost portion of the brain stem below the diencephalon, it has access to the cranial nerve III, also called the **mesencephalon** since it's from this region of the fetal brain that it's developed.
it has a huge contribution to the motor movement of the body as it's from this portion the portion closest to the brain and head movement in the body due to its Oculomotor nerve cranial nerve.
The midbrain has the following regions **Tectus** , **Tegmentum** , **crus cerebri**.

[1]Posterior : Back of the body
[2]cranial fossa : the floor of the cranial cavity of the skull
[3]cilvus : central portion at the floor of the skull
[4]Anterior : Front of the body

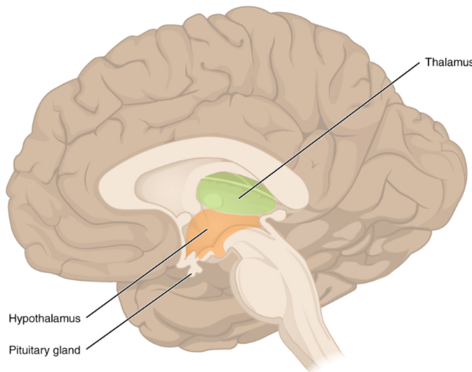


Figure 5: Diencephalon

Diencephalon

The **diencephalon** often refers to the interbrain of the fetus and it's from this region that the **thalamus** and **hypothalamus** are developed in the mature brain, which makes the diencephalon one of the crucial part of the brain that involves in transferring information chemically and electrically..

- **Thalamus :** acts as a relay signal for transferring electrical information to the different parts of the brain.
- **Hypothalamus :** handles the hormonal secretions from the pituitary gland and maintains homeostasis.

cerebellum

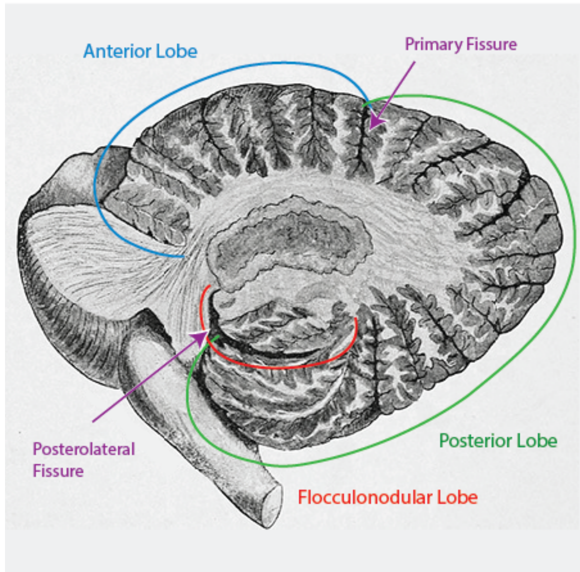


Figure 6: cerebellum

The cerebellum is a region of the brain located in the posterior part of the skull, below the cerebrum, and above the brainstem. It is responsible for coordinating and regulating muscular activity, maintaining posture and balance, and fine-tuning movements.

The main functions of the cerebellum include:

Coordination of voluntary movements: The cerebellum plays a crucial role in the coordination and timing of voluntary movements, including balance, posture, and skilled motor activities like playing an instrument or typing.

Maintenance of balance and posture: The cerebellum receives information from the inner ear, which helps it regulate balance and posture. It adjusts muscle tone and position to maintain stability.

Control of eye movements: The cerebellum helps control eye movements, including the ability to track moving objects and maintain gaze fixation.

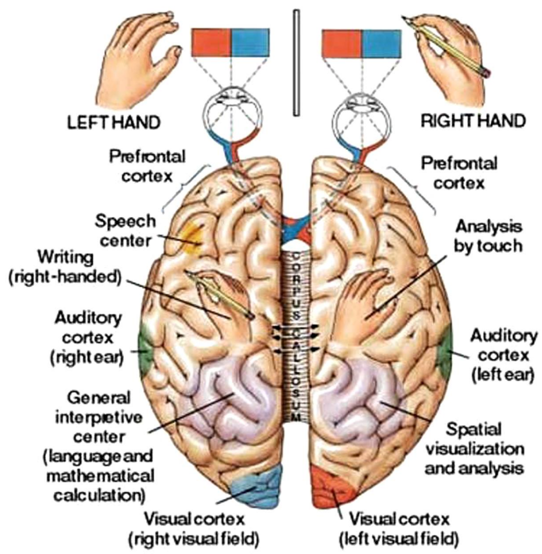


Figure 7: brain hemispheres and its control

Learning and motor memory: The cerebellum is involved in learning and storing motor patterns and motor memories, allowing for the development of automatic movements.

Cognitive functions: Recent research has suggested that the cerebellum also plays a role in higher-level cognitive functions, such as language, attention, and emotional regulation.

0.2.3 cerebral hemispheres

The brain is divided into two hemispheres the left and the right and each hemisphere and its connectives are built in such a way that , each hemisphere controls the opposite side of the body.
ex : the right hand is controlled by the right hemisphere and the left hand is controlled by the left hemisphere [Fig 7.]. The cerebral hemispheres consists of lobes (the grey matter) and the inner layer (the white matter).

The **cortex** consists of :

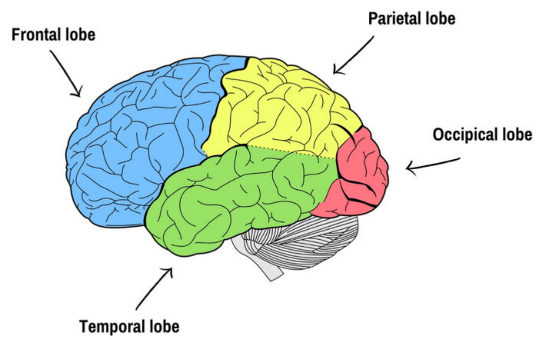


Figure 8: Cerebral lobes

- **Frontal Lobe:** The front of the brain and also the largest part of the brain which is locates right in front of the cortex. This is part of the brain that has involvement in intellect, muscle control, problem-solving, judgment, personality, mood, judgment, etc.
- **Pariental Lobe:** Located behind the frontal lobe, which makes it the middlemost region of the brain which helps in the analysis of languages and its interpretation and various sensations like pain, touch, and pressure.
- **Occipital Lobe:** The occipital lobe is the smallest of the four lobes of the cerebral hemisphere. It is present posterior to the parietal and temporal lobes. Thus, it forms the caudal part of the brain. Relative to the skull, the lobe lies underneath the occipital bone. It rests on the tentorium cerebelli, which separates it from the cerebellum. The paired occipital lobes are separated from each other by a cerebral fissure. The posteriormost part of the occipital lobe is known as the occipital pole.
- **Temporal Lobe:** The temporal lobes sit behind the ears and are the second largest lobe. They are most commonly associated with processing auditory information and with the encoding of memory.

the cerebrum has **Crests** and **Grooves** called the **Gyri** and **sulci** respectively as shown in fig 9.

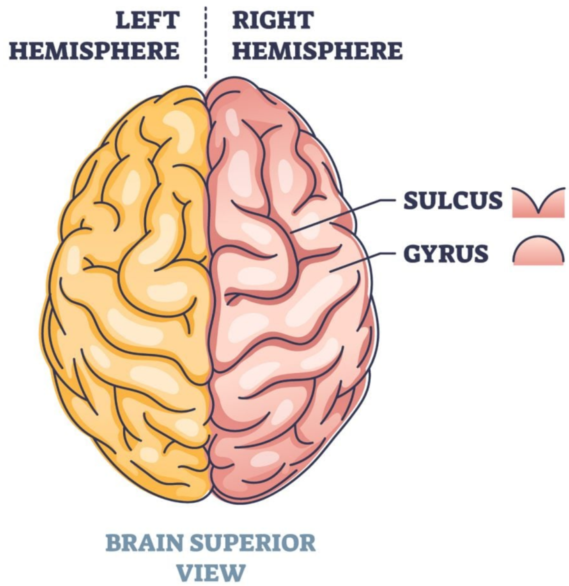


Figure 9: crests and grooves

Organization of cerebral cortex

Each hemisphere of the cerebral cortex is mapped to sensory and motor processes on the contra-lateral side of the body.
Hemispheres are similar in appearance but not symmetrical in function or structure.[Fig 7.]