Neuroscience Introductory Textbook

(An English Rendition)

Compiled by Ngawang Norbu and Lodoe Sangpo

Translated by Geshe Dadul Namgyal

CONTENT

1) A BRIEF HISTORY OF NEUROSCIENCE

Humans have long been interested in exploring the nature of mind. The long history of their enquiry into the relationship between mind and body is particularly marked by several twists and turns. However, brain is the last of the human organs to be studied in all seriousness, more particularly its relation with human mind.

Around 2000 BC and for long since that time the Egyptians did not think highly of the brain. They would take out the brain via the nostrils and discarded it away before mummifying the dead body. Instead, they would take great care of the heart and other internal organs. However, a few Egyptian physicians seemed to appreciate the significance of the brain early on. Certain written records have been found where Egyptian physicians had even identified parts and areas in the brain. Besides, Egyptian papyrus, believed to have been written around 1700 BC, carried careful description of the brain, suggesting the possibility of addressing mental disorders through treatment of the brain. That is the first record of its kind in the human history (Figure 1).

The Greek mathematician and philosopher, Plato (427-347) believed that the brain was the seat of mental processes such as memory and feelings (Figure 2). Later, another Greek physician and writer on medicine, Galen (130-200 AD) too, believed that brain disorders were responsible for mental illnesses. He also followed Plato in concluding that the mind or soul resided in the brain. However, Aristotle (384-322 BC), the great philosopher of Greece at that time, restated the ancient belief that the heart was the superior organ over the brain (Figure 3). In support of his belief, he stated that the brain was just like a radiator which stopped the body from becoming overheated, whereas the heart served as the seat of human intelligence, thought, and imagination, etc.

Medieval philosophers felt that the brain was constituted of fluid-filled spaces called ventricles where the ‘animal spirits’ circulated to form sensations, emotions, and memories. This viewpoint brought about a shift in the previously held views and also provided the scientists with the new idea of actually looking into the brains of the humans and animals. However, no such ventricles as claimed by them were found upon examination nor did the scientists find any specific location for the self or the soul in the brain.

In the seventeenth century, the French philosopher Rene Descartes (1596-1650) described mind and body as separate entities (Figure 4) yet they interacted with each other via the pineal gland, the only structure not duplicated on both sides of the brain. He maintained that the mind begins its journey from the pineal gland and circulates the rest of the body via the nerve vessels. His dualist view influenced the mind-body debate for the next two centuries. However, through the numerous experiments undertaken in the 19^{th} century, the scientists gathered evidences and findings which all emboldened the scientists to claim that the brain is the center of feelings, thoughts, self and behaviors. Just to give an example of the kind of experiments performed on a particular physical activity which pointed to the brain as the regulator of bodily actions, imagine activating a particular area of the brain through electrical stimulus, you would actually see it effectively impacting a corresponding body-part, say the legs by making them move. Through findings such as these as well as others, we have come of know also of the special activities of the electrical impulses and chemicals in the brain.

Explorations continued into the later centuries and, by the middle of 20^{th} century, human understanding of the brain and its activities have increased manifold. Particularly, towards the end of twentieth century, with further improvement in imaging technologies enabling the researchers to undertake investigation on functioning brains, the scientists were deeply convinced that the brain and the rest of the nervous systems monitored and regulated emotions and bodily behaviors (Figures 5 & 6). Since then, the brain together with the nervous system have become the center of attention as the basis of mental activities as well as physical behaviors, and gradually a separate branch of science called neuroscience focusing specifically on the nervous systems of the body has evolved in the last 40 so years.

To better understand modern neuroscience in its historical context, including why the brain and nervous system have become the center of attention in the scientific pursuit of understanding the mind, it is useful to first review some preliminary topics in the philosophy of science. Science is a method of inquiry that is grounded in empirical evidence. Questions about the unknown direct the path of science as a method. Each newly discovered answer opens the door to many new questions, and the curiosity of scientists motivates them to answer those unfolding questions. When a scientist encounters a question, she or he develops an explanatory hypothesis that has the potential to answer it. But it is not enough to simply invent an explanation. To know if an explanation is valid or not, a scientist must test the hypothesis by identifying and observing relevant, objectively measurable phenomena. Any hypothesis that cannot be tested in this way is not useful for science. A useful hypothesis must be falsifiable, meaning that it must be possible to ascertain, based on objective observations, whether the hypothesis is wrong and does not explain the phenomena in question. If a hypothesis is not falsifiable, it is impossible to know whether it is the correct explanation of a phenomenon because we cannot test the validity of the claim.

Why does the scientific method rely only on objective observations? Science is a team effort, conducted across communities and generations over space and time. For a hypothesis to be accepted as valid, it must be possible for any interested scientist to test it. For example, if we want to repeat an experiment that our colleague conducted last year, we need to test the hypothesis under the same conditions as the original experiment. This means it must be possible to recreate those conditions. The only way to do this in a precise and controlled manner is if the scientific method relies on empirical evidence.

Furthermore, conclusions in science are subject to peer review. This means that any scientist's colleagues must be able to review and even re-create the procedures, analyses, and conclusions made by that scientist before deciding if the evidence supports the conclusions. Because we don't have access to the subjective experiences of others, it is not possible to replicate experiments that are grounded in subjectivity because we cannot recreate the conditions of such an experiment, nor can we perform identical analyses of subjective phenomena across people. No matter how many words we use, we cannot describe a single subjective experience accurately enough to allow another person to experience it the same way. Consequently, we cannot have a replicable experiment if the evidence is not objective.

Therefore, two necessary features of a scientific hypothesis are the potentials to falsify and replicate it. And both of these requirements are dependent on objectively measurable evidence. This is why we began with the claim that science is a method of inquiry that is grounded in empirical evidence.

Neuroscience is a scientific discipline like any other, in that the focus of investigation is on objectively measurable phenomena. But unlike most other sciences, this poses a particularly challenging problem for neuroscience. How do we investigate the mind, which is subjective by nature, if empirical evidence is the only valid form of data to support a conclusion in science? The relationship between the mind and the body has become known as the "mind-body problem" in modern neuroscience and Western philosophy of mind, because there is a fundamental challenge to explain the mind in objective terms. Scientists view this relationship as a problem because their method of inquiry investigates phenomena from a third-person (he, she, it, they) perspective, while the subjective experience of the mind has a first-person (I, we) perspective. The mind-body problem has been a central, unresolved topic in Western philosophy of mind for centuries, and is a topic we will discuss in more detail in a later chapter of this textbook when we explore the neuroscience of consciousness.

For now we can start simply by stating that the majority of scientists, including neuroscientists, hold the philosophical view that all phenomena are caused by physical processes, including consciousness and its related mental phenomena. This view might be proven wrong as inquiry proceeds, but is taken as the most simple (or parsimonious) starting point. Science uses the principle of parsimony, of starting with simple rather than complex explanations, as a way to facilitate production of falsifiable hypotheses: more complex explanations are built up as evidence accumulates and more simple explanations are excluded. Modern neuroscience investigates the brain and nervous system based on the working assumption that the objective physical states of those biological systems are the cause of the subjective mental states of the organism that has those biological systems. In other words, when you smell a fresh flower, taste a cup of chai, listen to the birds, feel the wind on your cheek, and see the clouds in the sky, those subjective experiences are caused by the momentary physical processes in your body, nervous system, and brain interacting with the physical environment. Under this philosophical view, then, mental states correlate with physical states of the organism, and by investigating those physical states scientists can understand the nature of those mental states. So while this might seem counterintuitive based on the Buddhist method of inquiry, for a neuroscientist it is obvious to begin the investigation by focusing on physical phenomena; on the empirical evidence. Neuroscientists often equate the "neural correlates" of consciousness as consciousness itself. We will explore in more depth the relationship between form and function between the body and mind later in the textbook, as well as the philosophical view of materialism in neuroscience.

It will also be helpful to introduce some basic concepts in neuroscience before exploring topics in more detail. The primary goal in this year of the neuroscience curriculum is that you become familiar with the brain and nervous system. The human brain is the most complex and extraordinary object known to all of modern science. Because of this immense complexity, it can be very challenging to encounter neuroscience in an introductory course such as this one. So patience is an important part of the learning process. First, neuroscience is still very much in its infancy as a scientific discipline, and there are vastly more questions than there are answers. Second, it can be a challenge for new students of neuroscience to simultaneously learn the details of the basic concepts while understanding and appreciating the broader conclusions. It's like learning a language while also reading the literature of that language! Neuroscience is a scientific discipline with many different levels of exploration and explanation. Therefore, it is important for you to pay attention to the level at which are we speaking when you learn new concepts. For example, the brain and nervous system are made up of cells called neurons or nerve cells, which we will discuss in detail in Chapter 4. Neurons connect with each other to form complex networks, and from those different patterns of connection emerge different phenomena (such as a thought or a sensation) in the brain and ultimately in the mind. This may sound confusing at the moment, but we will explore these topics in more detail in later chapters. In neuroscience, levels of explanation can span from very low levels such as the molecular mechanisms involved in the neuron cells, to middle levels such as particular networks of neurons in the brain, to very high levels such as how humans engage in thoughts, speech, and purposeful actions.

The brain is the bodily organ that is the center of the nervous system. But it might surprise you to learn that not all animals that have neurons have a brain! For example, jellyfish have neurons, but they don't have a brain. Jellyfish are very simple organisms that live in the ocean, and their neurons allow them to sense some basic information about their environment. But because they don't have a brain to process that environmental information, they can only react to their immediate environment. Without a brain, jellyfish cannot think, make plans for the future, have memories of the past, or make decisions. Their behavior is limited to reactions and reflexes. Complex networks of neurons in the human brain are the physiological substrates that support what we experience as human beings. But we are not the only species with a brain. Later in this textbook we will explore the relationship between brain complexity and behavior across species.

For organisms that have a brain, information can flow along the complex networks of neurons in different ways. Some networks, also called pathways or systems, flow from the sensory organs to the brain, while others flow from the brain to the muscles of the body. Afferent neurons, also called sensory neurons or receptor neurons, communicate information from the sensory organs to the brain. Efferent neurons, also called motor neurons, communicate information from the brain to the muscles of the body. Interneurons, also called association neurons, communicate information between neurons in the central nervous system and brain. This allows for the sensory and motor systems to interact, facilitating complex behaviors and integrating across the different sensory modalities. For example, to be able to reach for an object such as a teacup, your brain needs to link together your ability to sense the presence and location of the cup with your ability to control the muscles in your arm to grasp the cup. Interneurons perform this function.

Finally, before starting your journey in learning about neuroscience, pause to contemplate some of the big questions and insights as they pertain to the Western science of the mind. As you go through this textbook and learn new concepts, it will be useful to think about them within the context of these big questions. For example, what is sentience? Is a brain required for sentience? The jellyfish we mentioned earlier can have basic sensations and react to the environment without a brain, but it cannot think or have memory. What are the necessary conditions to be sentient? What is the relationship between the mind and body? As a method of inquiry, can science directly investigate subjective experience? Or must we use alternative, and perhaps complementary methods of inquiry to achieve that? Do we perceive the physical world directly, or are our perceptions constructed? If the latter, how does that happen?

2) WHAT IS NEUROSCIENCE AND WHAT ARE ITS BRANCH SCIENCES?

In the case of humans, it is the branch of science that studies the brain, the spinal cord, the nerves extending from them, and the rest of the nervous systems including the synapses, etc. Recall that neurons, or nerve cells, are the biological cells that make up the nervous system, and the nervous system is the complex network of connections between those cells. In this connection, it may involve itself with the cellular and molecular bases of the nervous system as well as the systems responsible for sensory and motor activities of the body. It also deals with the physical bases of mental processes of all levels, including emotions and cognitive elements. Thus, it concerns itself with issues such as thoughts, mental activities, behaviors, the brain and the spinal cord, functions of nerves, neural disorders, etc. It wrestles with questions such as What is consciousness?, How and why do beings have mental activities?, What are the physical bases for the variety of neural and mental illnesses, etc.

In identifying the sub-branches within neuroscience, there are quite a few ways of doing so. However, here we will follow the lead of the Society for Neuroscience which identifies the following five branches: Neuro-anatomy, Developmental Neuroscience, Cognitive Neuroscience, Behavioral Neuroscience, and Neurology. Of these, neuroanatomy concerns itself mainly with the issue of structures and parts of the nervous system. In this discipline, the scientists employ special dyeing techniques in identifying neurotransmitters and in understanding the specific functions of the nerves and nerve centers. Neurotransmitters are chemicals released between neurons for transmission of signals. When a neuron communicates with its neighboring cells, it releases neurotransmitters and its neighbors receive them. In developmental neuroscience, the scientists look into the phases and processes of development of nervous system, the changes they undergo after they have matured, and their eventual degeneration. In this regard, the scientists also investigate the ways neurons go about seeking connection with other neurons, how they establish the connection, and how they maintain the connection and what chemical changes and processes they have to undergo for these activities. Neurons make connections to form networks, and the different patterns of connectivity support different functions. Patterns of connectivity can change over different time scales, such as developmental changes over a lifetime from infancy to old age, but also in the short term such as learning a new concept. Neuroplasticity is the term that describes the capacity of the brain to change in response to stimulation or even damage: it is not a static organ, but is highly adaptable. In cognitive neuroscience, they study the functions of behaviors, perceptions, and memories, etc. By making use of non-invasive methods such as the PTE and MRI technologies that allow us to take detailed pictures of the brain without opening the skull, they look into the neural pathways activated during engagement in language, solutions, and other activities. Cognitive neuroscience studies the mind-body relationship by discovering the neural correlates to mental and behavioral phenomena. Behavioral neuroscience looks into the underpinning processes of human and animal behaviors. Using electrodes, they measure the neural electrical activities occurring alongside our actions such as visual perception, language use, and generating memories. Through fMRI scan techniques, another technology that allows us to take detailed motion pictures of brain activity over time without opening the skull, they strive to arrive at closer understanding of the brain parts in real time. Finally, neurology makes use of the fundamental research findings of the other disciplines in understanding the neural and neuronal disorders and strives to explore new innovative ways of detecting, preventing, and treating these disorders.

3) THE SUBJECT MATTER OF NEUROSCIENCE: THE MAIN SYSTEMS AND THEIR PARTS

The field of neuroscience is the nervous system of animals in general and of humans in particular. In the case of humans, its nervous system has two main components: the central nervous system (CNS) and the peripheral nervous system (PNS) (Figure 7). The CNS comprises of the brain and the spinal cord. Their functions involve processing and interpreting the information received the senses, skin, muscles, etc. and giving responses that direct and dictate specific actions such as particular movements by different parts of the body.

The peripheral nervous system (PNS) includes all the rest of the nervous system aside from the central nervous system. This means that it comprises the 12 pairs of cranial nerves that originate directly from the brain and spread to different parts of the body bypassing the spinal cord, and the 31 pairs of spinal nerves that pass through the spinal cord and spread to different parts of the body. Thus, the PNS is mainly constituted of nerve. PNS is sometimes further classified into voluntary nervous system and the autonomic nervous system. This is based on the fact that the nerves in the former system are involved in making conscious movements, whereas those in the latter system make movements over which the person does not have control. Obviously, the former category of nerves includes those associated with the muscles of touch, smell, vision, and skeleton. The latter includes nerves spread over muscles attached with heart beats, blood pressure, glands, and smooth muscles.

4) AN EXCLUSIVE LOOK AT 'NEURONS', A FUNDAMENTAL UNIT OF THE BRAIN AND THE NERVOUS SYSTEM

Neurons

Neurons are the cellular units of the brain and nervous system, and are otherwise called nerve cells (Figure 8). Estimates of the number of brain neurons range from 50 billion to 500 billion, and they are not even the most numerous cells in the brain. Like hepatocyte cells in the liver, osteocytes in bone, or erythrocytes in blood, each neuron is a self-contained functioning unit. Its internal components, the organelles, include a nucleus harboring the genetic material (DNA), energy-providing mitochondria, and protein-making ribosomes. As in most other types of cells, the organelles are concentrated in the main cell body. In addition, characteristic features of neurons are neurites—long, thin, finger-like or threadlike extensions from the cell body (soma). The two main types are dendrites and axons. Usually, dendrites receive nerve signals, while axons send them onward. The cell body of a neuron is about 10-100 micrometers across, that is 1/100th to 1/10th of one millimeter. Also, the axon is 0.2-20 micrometers in diameter, dendrites are usually slimmer. In terms of length, dendrites are typically 10-50 micrometers long, while axons can be up a few centimeters (inches). This is mostly the case in the central nervous system (Figure 9).

Classification of neurons

There are numerous ways of classifying neurons among themselves. One of them is by the direction that they send information. On this basis, we can classify all neurons into the three: sensory neurons, motor neurons, and interneurons. The sensory neurons are those that send information received from sensory receptors toward the central nervous system, whereas the motor neurons send information away from the central nervous system to muscles or glands. The interneurons are those neurons that send information between sensory neurons and motor neurons. Here, the sensory neurons receive information from sensory receptors (e.g., in skin, eyes, nose, tongue, ears) and send them toward the central nervous system. Because of this, these neurons are also called afferent neurons as they bring informational input towards the central nervous system. Likewise, the motor neurons bring motor information away from the central nervous system to muscles or glands, and are thus called efferent neurons as they bring the output from the central nervous system to the muscles or glands. Since the interneurons send information between sensory neurons and motor neurons, thus serving as connecting links between them, they are sometimes called internuncial neurons. This third type of neurons is mostly found in the central nervous system.

Another way of classifying the neurons is by the number of extensions that extend from the neuron's cell body (soma) (Figure 10). In accordance with this system, we have unipolar, bipolar, and multipolar neurons. This classification takes into account the number of extensions extending initially from the cell body of the neuron, not the overall number of extensions. This is because there can be unipolar neurons which have more than one extensions in total. However, what the difference here is from the other two types of neurons is that these unipolar neurons shall have only one initial extension from the cell body. Most of the neurons are multipolar in nature.

Synapses

Synapses are communication sites where neurons pass nerve impulses among themselves. The cells are not usually in actual physical contact, but are separated by an incredibly thin gap, called the synaptic cleft. Microanatomically, synapses are divided into types according to the sites where the neurons almost touch. These sites include the soma, the dendrites, the axons, and tiny narrow projections called dendritic spines found on certain kinds of dendrites. Axospinodendrittic synapses form more than 50 percent of all synapses in the brain; axodendritic synapses constitute about 30 percent (Figure 11).

How signals are passed among neurons

Neurons send signals to each other across the synapses. Initially, signals enter into the cell body of a neuron through their dendrites, and they pass down the axon until their arrival at the axon terminals. From there, the signal is sent across to the next neuron. Starting from the time the signal passes along the dendrites and axon, eventually reaching the axon terminal, it consists of moving electrically charges ions, but at a synapse while making that transition, it relies more on the structural shape of the chemical neurotransmitters.

Every two neurons are separated by a gap, called synaptic cleft, at their synaptic site. The neuron preceding the synapse is known as pre-synaptic neuron and the one following the synapse is known as post-synaptic neuron. When the action potential of the pre-synaptic neuron is passed along its axon and reaches the other end of it, it causes synaptic vesicles to fuse or merge with the membrane. This releases the neurotransmitter molecules to pass or diffuse across the synaptic cleft to the post-synaptic membrane and slot into receptor sites (Figure 12).

Neurotransmitter molecules slot into the same-shaped receptor sites in the postsynaptic membrane. A particular neurotransmitter can either excite a receiving nerve cell and continue a nerve impulse, or inhibit it. Which of these occurs depends on the type of membrane channel on the receiving cell.

The interaction among neurons or between a neuron and another type of body cell, all occur due to the transfer of neurotransmitters. Thus, our body movements, mental thought processes, as well as feelings, etc. are all dependent on the transfer of neurotransmitters.

In particular, let's take a look into how the muscle movements happen due to the transfer of neurotransmitter. The axons of motor neurons extend from the spinal cord to the muscle fibers. For intending to perform any action, either of the speech or body, the command has to originate from the brain to the spinal cord. From the spinal cord, the command has to pass through motor neurons to the specific body parts, upon which the respective actions will be performed. The electrical impulse released along the axon of the motor neuron arrives at the axon terminal. Once they are there, then the neurotransmitters are secreted to carry the signals across the synapse. The receptors in the membrane of the muscles cells attach to the neurotransmitters and stimulate the electrically charged ions within the muscle cells. This leads to the contraction or extension of the respective muscles.

5) FACTS ABOUT HUMAN BRAIN

Brain is a complex organ generally found in vertebrates. Of all the brains, human brain is even more complex. On average, a human brain weighs about one and a half kilogram, and has over 100 billion neurons. Each of these neurons is connected with several other neurons and thus, just the number of synapses (nerve cell connections) exceeds 100 trillion. The sustenance required to keep these neurons alive is supplied by different parts of the body. For example, 25 percent of the body total oxygen consumption is used up by the brain. Likewise, 25 percent of the glucose produced by our food is used up by it. Of the total amount of blood pumped out by our heart, 15 percent goes to the brain. Thus, from among the different parts of the body, the brain is the single part that uses the most amount of energy. The reason for this is because the brain engages itself in unceasing activity, day and night, of interpreting data form the internal and external environment, and respond to them. To protect this important organ from harm, it is naturally enclosed in three layers of protection, with an additional cushioning fluid in between. These layers are, in turn, protected with the hard covering, the skull, which is once again wound around by the skin of the scalp (Figure 13).

The main function of the brain is to enhance the chance of survival of the person by proper regulation of the body conditions based on the brain's reading of the internal and external environment. The way it carries out this function is by first registering the information received and responding to them by undertaking several activities. The brain also gives rise to inner conscious awareness alongside performing those processes. When the data, released by the different body senses, in the form of electrical impulses uninterruptedly arrive at the brain, the brain first of all checks their importance. When it finds them to be either irrelevant or commonplace, then it makes them dissolve by themselves and the concerned person doesn't even generate an awareness of them. This is how only around 5 percent of the overall information received by the brain ever reaches our consciousness. For the rest of the information, the brain may process them, but they never become the subject of our consciousness. If, on the other hand, the information at hand is important or novel, the brain increases it impulses and allows it to active all over its parts. Remaining active for over a period of time, a conscious awareness unto this impulse is generated. Sometimes, in the wake of generating a conscious awareness, the brain sends commands to relevant muscles for either contraction or extension, thus making the body parts in question to engage in certain actions.

6) MAJOR PARTS OF HUMAN BRAIN

Human brain is enclosed within its natural enclosures. In its normal form, it is found to be composed of three major parts (Figure 14).

Cerebrum

Of the three parts mentioned above, cerebrum is located in the uppermost position and is also the largest in size. It takes up ¾ of the entire brain size. It is itself composed of two brain hemispheres—the right and the left hemispheres. The two hemispheres are held together by a bridge like part called corpus callosum, a large bundle of neurons. The covering layer of the hemispheres is constituted of the cortex of which the average thickness is between 2 to 4 millimeters. The higher centers of coordinating and regulating human physical activities are located in the cortex areas, such as the motor center, proprioception center (proprioception is the sense of the relative position of the body in space, for example being aware that your arm is extended when reaching for the doorknob), language center, visual center, and auditory center. The outer surface of the cortex is formed of grooves and bulges because of which, despite being quite expansive, the cortex is able to be contained in the relatively small area. In terms of its basic composition, the outer layer of cortex is mostly made of gray matter, which is mainly comprised of cell bodies and nerve tissues formed out of nerve fibers. This matter is gray with a slight reddish shade in color. In the layer below, the cortex is formed of the white matter, which is, as the name suggests, white in color and mainly comprised of nerve tissues formed out of nerve fibers wrapped around with myelin sheath. Some nerve fibers wrapped in myelin sheath bind together the right and left hemispheres of the cerebrum, while others connect it with cerebellum, brainstem, and the spinal cord. Most of the brain parts belong to cerebrum, such as amygdala and hippocampus, as well as thalamus, hypothalamus, and other associated regions. In short, of the division into forebrain, midbrain, and hindbrain—in which the entirety of brain is accounted for, the cerebrum contains the whole of forebrain (Figure 15).

The surface area of the cerebral cortex is actually quite large, and described above, it becomes folded to fit inside the skull. Humans are highly intelligent and creative animals not just because of the size of our brains, but also because of the complexity of the connections among our neurons. The folded nature of the human cortex promotes more complex connections between areas. For example, take a piece of blank paper, and draw five dots, one on each corner and one in the middle. Now draw lines from each dot to the other four dots. Imagine if these five dots were buildings, and the lines you drew were roads, then it would require more time to traverse from one corner to another corner than from one corner to the center. But what if you fold the four corners of the paper on top of the center of the page? Suddenly all five of those dots become immediate neighbors, and it becomes very easy to walk from one "building" to another. The folding of the cortex has a similar effect. Neurons make connections with their neighbors, and if folding the cortex increases the number of neighbors each neuron has, then it also increases the complexity of the networks that can be formed among those neurons.

Cerebellum

Cerebellum is located below the cerebrum and at the upper back of the brainstem. Its name connotes its small size. Its mass is 1/10 of the whole brain. However, in terms of the number of neurons it contains, it exceeds that of the remaining parts of the central nervous system combined. This lump of nerve tissues, bearing the look of something cut in half, covers most of the back of brainstem. With the help of three pairs of fibers, collectively called cerebral peduncles, the brainstem is bound to the cerebellum. Like the cerebrum, it also has a wrinkled surface, but its grooves and bulges are finer and organized into more regular patterns. In terms of its physical structure, this too has a long groove in the center, with two large lateral lobes, one on each side. These lobes are reminiscent of the two hemispheres of the cerebrum and are sometimes termed cerebellar hemispheres. The cerebellum has a similar layered microstructure to the cerebrum. The outer layer, or cerebellar cortex, is gray matter composed of nerve-cell bodies and their dendrite projections. Beneath this is a medullary area of white matter consisting largely of nerve fibers. As of now, it has been established that cerebellum's main function is in coordinating the body movement. Although, it may not initiate the movements, however it helps in the coordination and timely performance of movements, ensuring their integrated control. It receives data from spinal cord and other parts of the brain, and these data undergo integration and modification, contributing to the balance and smooth functioning of the movements, and thus helps in maintaining the equilibrium. Therefore, whenever this part of the brain is plagued by a disorder, the person may not lose total movement, but their ability of performing measured and steady movements is affected as also their ability to learn new movements. Within the division of entire brain into forebrain, midbrain, and hindbrain—cerebellum forms part of the hindbrain (Figure 16).

Brainstem

Brainstem is located below the cerebrum and in front of cerebellum. Its lower end connects with the spinal cord. It is perhaps misnamed. It is not a stem leading to a separate brain above, but an integral part of the brain itself. Its uppermost region is the midbrain comprising an upper "roof" incorporating the superior and inferior colliculi or bulges at the rear, and the tegmentum to the front. Below the midbrain is the hindbrain. At its front is the large bulge of the pons. Behind and below this is the medulla which narrows to merge with the uppermost end of the body's main nerve, the spinal cord. This part of the brain in associated with the middle and lower levels of consciousness. The eye movement involved in following a moving object in front of the eye is an example. The brainstem is highly involved in mid-to low-order mental activities, for example, the almost "automatic" scanning movements of the eyes as we watch something pass by. The gray and white matter composites of the brainstem are not as well defined as in other parts of the brain. The gray matter in this part of the brain possesses some of the crucial centers responsible for basic life functions. For example, the medulla houses groups of nuclei that are centers for respiratory (breathing), cardiac (heartbeat), and vasomotor (blood pressure) monitoring and control, as well as for vomiting, sneezing, swallowing, and coughing. When brainstem is damaged, that will immediately trigger danger to life by hindering heartbeat and respiratory processes (Figures 17 & 18).

7) WAYS OF ZONING AND SECTIONING THE HUMAN BRAIN FOR STUDY PURPOSES

The two hemispheres

Of the obviously so many different ways of zoning the human brain for study purposes, we will take up only a few of them as samples. As briefly mentioned before, a fully matured brain has three major parts. Of these the largest is the cerebrum. It covers around ¾ of the brain size. In terms of its outer structure, it is covered with numerous folds, and has a color of purple and gray blended. The cerebrum is formed by two cerebral hemispheres, accordingly called the right and the left hemisphere, that are separated by a groove, the medial longitudinal fissure. Between the two hemispheres, there is a bundle of nerve fibers that connects the two sides, almost serving like connecting rope holding the two in place. Called corpus callosum, if this were to be cut into two, the two hemispheres would virtually become two separate entities.

Just as there are two hemispheres, that look broadly like mirror images to each other, on the two sides, likewise many of the brain parts exist in pairs, one on each side. However, due to the technological advances in general, and that of the MRI, in particular, it has been shown that, on average, brains are not as symmetrical in their left-right structure as was once believed to be , almost like mirror images (Figure 19).

The two apparently symmetrical hemispheres and, within them, their other paired structures are also functionally not mirror images to each other. For example, for most people, speech and language, and stepwise reasoning and analysis and so on are based mainly on the left side. Meanwhile, the right hemisphere is more concerned with sensory inputs, auditory and visual awareness, creative abilities and spatial-temporal awareness (Figure 20).

The four or the six lobes

Cerebrum is covered with bulges and grooves on its surface. Based on these formations, the cerebrum is divided into the four lobes, using the anatomical system. The main and the deepest groove is the longitudinal fissure that separates the cerebral hemispheres. However, the division into the lobes is made overlooking this fissure, and thus each lobe is spread on both the hemispheres. Due to this, we often speak of the four pairs of lobes. These lobes are frontal lobes, parietal lobes, occipital lobes, and temporal lobes (Figure 21). The names of the lobes are partly related to the overlying bones of the skull such as frontal and occipital bones. In some naming systems, the limbic lobe and the insula, or central lobe, are distinguished as separate from other lobes.

Frontal lobes

Frontal lobes are located at the front of the two hemispheres. Of all the lobes, these are the biggest in size as well as the last to develop. In relation to the other lobes, this pair of lobes is at the front of the parietal lobes, and above the temporal lobes. Between these lobes and the parietal lobes lies the central sulcus, and between these lobes and the temporal lobes lies the lateral sulcus. Towards the end of these lobes, i. e. the site where the pre-central gyrus is located also happens to be the area of the primary motor cortex. Thus, this pair of lobes is clearly responsible for regulating the conscious movement of certain parts of the body. Besides, it is known that the cortex areas within these lobes hold the largest number of neurons that are very sensitive to the dopamine neurotransmitters. Granting this, these lobes should also be related with such mental activities as intention, short-term memory, attention, and hope. When the frontal lobes are damaged, the person lacks in ability to exercise counter measures against lapses and tend to engage in untoward behaviors. These days, neurologist can detect these disorders quite easily.

Parietal lobes

Parietal lobes are positioned behind (posterior to) the frontal lobes, and above (superior to) the occipital lobes. Using the anatomical system, the central sulcus divides the frontal and parietal lobes, as mentioned before. Between the parietal and the occipital lobes lies the parieto-occipital sulcus, whereas the lateral sulcus marks the dividing line between the parietal and temporal lobes. This pair of lobes integrates sensory information from different modalities, particularly determining spatial sense and navigation, and thus is significant for the acts of touching and holding objects. For example, it comprises somatosensory cortex, which is the area of the brain that processes the sense of touch, and the dorsal stream of the visual system, which supports knowing where objects are in space and guiding the body's actions in space. Several portions of the parietal lobe are important in language processing.

Occipital lobes

The two occipital lobes are the smallest of four paired lobes in the human cerebral cortex. They are located in the lower, rearmost portion of the skull. Included within the region of this pair of lobes are many areas especially associated with vision. Thus, this lobe holds special significance for vision. There are many extrastriate regions within this lobe. These regions are specialized for different visual tasks, such as visual, spatial processing, color discrimination, and motion perception. When this lobe is damaged, the patient may not be able to see part of their visual field, or may be subjected to visual illusions, or even go partial or full blind.

Temporal lobes

Temporal lobe is situated below the frontal and parietal lobes. It contains the hippocampus and plays a key role in the formation of explicit long-term memory modulated by the amygdala. This means that it is involved in attaching emotions to all the data received from all senses. Adjacent areas in the superior, posterior, and lateral part of the temporal lobes are involved in high-level auditory processing. The temporal lobe is involved in primary auditory perception, such as hearing, and holds the primary auditory cortex. The primary auditory cortex receives sensory information from the ears and secondary areas process the information into meaningful units such as speech and words. The ventral part of the temporal cortices appears to be involved in high-level visual processing of complex stimuli such as faces and scenes. Anterior parts of this ventral stream for visual processing are involved in object perception and recognition.

Limbic System

The structures of the limbic system are surrounded by an area of the cortex referred to as the limbic lobe. The lobe forms a collarlike or ringlike shape on the inner surfaces of the cerebral hemispheres, both above and below the corpus callosum. As such, the limbic lobe comprises the inward-facing parts of other cortical lobes, including the temporal, parietal, and frontal, where the left and right lobes curve around to face each other.

Important anatomical parts of this lobe are hippocampus and amygdala, associated with memory and emotions respectively.

Insular cortex (or insula)

Insular lobe is located between the frontal, parietal, and temporal lobes. As suggested by its name, it is almost hidden within the lateral sulcus, deep inside the core of the brain. It is believed to be associated with consciousness. Since data indicative of the inner status of the body, such as the heartbeat, body temperature, and pain assemble here, it is believed to impact the equilibrium of the body. Besides, it is also believed to be related with several aspects of the mind, such as the emotions. Among these are perception, motor regulation, self-awareness, cognition, and inter-personal emotions. Thus, insular lobe is considered to be highly related with mental instability.

The forebrain, the midbrain, and the hindbrain

The divisions of the brain so far, either into the two hemispheres or the four or six lobes are solely based on the cerebrum alone. None of the above divisions included any portion either of the cerebellum or the brainstem. Yet another way of dividing the portions of the brain is into the forebrain, the midbrain, and the hindbrain (Figure 22. This is the most comprehensive division of the brain, leaving no parts of it outside. There are two systems of presenting this division: one, on the basis of the portions of the brain during early development of the central nervous system, and the other, based on the full maturation of those early parts into their respective regions of an adult brain. Here, we follow the latter system.

The forebrain

The forebrain is so called because of its extension to the forefront of the brain. It is the largest among the three divisions. It even spreads to the top and back part of the brain. It houses both the hemispheres, as well as the entire portion of the part known as the diencephalon. Diencephalon comprises of the hippocampus, which is associated with memory, and the amygdala, which is associated with emotions. Besides them, the forebrain also includes both the thalamus and the hypothalamus, of which the former is the part of the brain that processes information received from other parts of the central nervous system and the peripheral nervous system into the brain, and the latter which is involved is several activities such as appetite, sexuality, body temperature, and hormones.

The midbrain

The midbrain is located below the forebrain and above the hindbrain. It resides in the core of the brain, almost like a link between the forebrain and the midbrain. It regulates several sensory processes such as that of the visual and auditory ones, as well as motor processes. This is also the region where several visual and auditory reflexive responses take place. These are involuntary reflexes in response to the external stimuli. Several of the masses of gray matter, composed mainly of the cell bodies, such as the basal ganglia linked with movement are also present in the midbrain. Of the above three major divisions of the brain, the midbrain belongs to the brainstem, and of the two main systems within the nervous system, it belongs to the central nervous system.

The hindbrain

The hindbrain is located below the end-tip of the forebrain, and at the exact back of the midbrain. It includes cerebellum, the pons, and the medulla, among others. Of these, the cerebellum has influence over body movement, equilibrium, and balance. The pons not only brings the motor information to the cerebellum, but is also related with the control over sleep and wakeful states. Finally, the medulla is responsible for involuntary processes of the nervous system associated with such activities as respiration and digestion. In terms of anatomy, pons is uppermost part, and beneath it the cerebellum and the medullae, which tapers to merge with the spinal cord.

Vertical organization of the brain

The organization of the brain layers can be said to represent a certain gradation of mental processes (Figure 23). The uppermost brain region, the cerebral cortex, is mostly involved in conscious sensations, abstract thought processes, reasoning, planning, working memory, and similar higher mental processes. The limbic areas on the brain's innermost sides, around the brainstem, deal largely with more emotional and instinctive behaviors and reactions, as well as long-term memory. The thalamus is a preprocessing and relay center, primarily for sensory information coming from lower in the brainstem, bound for the cerebral hemispheres above. Moving down the brainstem into the medulla are the so-called 'vegetative' centers of the brain, which sustain life even if the person has lost consciousness.

Anatomical directions and reference planes of the brain

To enable us to identify the precise location in the brain, both vertically and horizontally, it is important to be familiar with certain technical terms used by the neuroscientists. In terms of anatomy, the front of the brain, nearest the face, is referred to as the anterior end, and polar opposite to the anterior end is the posterior end, referring to the back of the head. Superior (sometimes called dorsal) refers to the direction toward the top of the head, and inferior (sometimes called ventral) refers to the direction toward the neck/body.

In terms of reference planes, the sagittal plane divides the brain into left and right portions, the coronal plane divides the brain into anterior and posterior portions, and the axial (sometimes called horizontal) plane divides the brain into superior and inferior portions (Figure 24).

In both the above contexts, we can further specify the location of a particular portion or plane in terms of its position, direction, and depth in relation to the whole brain. Likewise, for each of the planes themselves, we can further speak in terms of position, direction, and depth in relation to the whole brain as well as in relation to the individual planes.

Also, when representing brain parts and structures, a lateral view illustrates the section or lobes, etc. from the perspective of a whole brain, whereas a medial view illustrates the section in the dissected manner.

8) DIFFERENT TYPES OF BRAINS

In general, the number of living beings who possess brain is numerous. Their brains vary both in size and function. However, if you ask whether all brains completely differ from each other. Definitely not. There are features that are common to almost all brains, such as that all brains are composed mainly of neurons, and that they all have the function of protecting the individual being from internal and external dangers. So, although there are various types of brains, here we shall focus mainly on the differences in brain types between vertebrates and invertebrates in general, and the differences within the vertebrates in particular.

As you know, vertebrates are those animals who have backbone, and invertebrates do not have backbone. Most of the invertebrates do not have brain. However, those, among them, who do possess brain, theirs is usually a simple brain, composed of very few neurons. Note that majority of the animals on this earth are invertebrates. The vertebrates make up only two percent of the entire animal population. The unicellular organisms, because of practical existential reason, usually tend to be very sensitive to light. Organisms such as sea-urchins are slightly more complex and are multi-cellular. They have a few nerve cells that regulate the function of looking for sustenance and providing protection from possible dangers. Slightly more complex than the types of sea-urchins are earthworm and jellyfish, which have neurons that assist them in fighting hostile external environment (Figure 25). It is interesting to know that the neurons these simple organisms have are similar to the human neurons in terms of structure, function, as well as their neurotransmitters. If you ask, what is the difference then? There hardly is any connection between the nerves in the invertebrates. Besides that, the nerves almost cover their entire bodies. For example, among the invertebrates, earthworms (Figure 26) have one of the simplest types of brains, possessing only a few neurons. Their brains regulate only a few simple tasks such as eating food and doing a few simple body movements, not any higher actions. The network of neurons that process and interpret the information received from the earthworm's body parts is present in the earthworm's head. However, even if that network were to be removed from its body, no noticeable changes would be observe in its behavior.

Still, among the invertebrates, grasshoppers and bees have slightly more complex brains. Scientists have begun to understand the relation between their brains and the corresponding behaviors (Figure 27). The ants, also an invertebrate, have more complex behavior, but have a very tiny brain. Likewise, the mosquitoes perform the function of flying in the space, suck blood from others, etc. However, their brain size is still no more than a small dot.

Among the vertebrates, the mice are generally quite smart, yet have brains weighing no more than 2 grams. Their entire brain size is equivalent to that of the human hypothalamus. Though generally it is said the bigger the brain, the greater the intellect. However, in actuality it is the overall area of cortices, not just the overall bulk that determines the level of intellect.

Among the vertebrates, there are mammals and non-mammals. Birds and fish are examples of non-mammals. It is known that the brains of mammals and non-mammals differ greatly in terms of complexity in the areas of composition, neurons, synapses, etc. Though they still have the same basic parts and structures, they differ in the overall brain size in relation to their bodies. Besides that, depending on which parts play out more in their life, they differ in the relative size of specific parts of the brain and body. For example, birds and fish have relatively very small olfactory bulb. Also, these non-mammalian animals lack brain cortex. Cerebral cortex is a special brain part, quite prominent in primates including the humans. Not only this, human beings are known to have a disproportionately large cortex (Figures 28 & 29).

The average weight of human brain amounts to only one and a half percent of their body weight. However, it consumes 20 percent of the food required by the whole body. So, the larger the brain is the greater the amount of energy consumption. Therefore, bigger brain is not always a sign of boon to the individual species. This may be the reason why there are no many species with larger brains in the history of evolution.

Social animals that depend on their social community for survival are said to have larger brains. For example, dolphins, who hunt in groups, have fairly large brain. Although, the brains of elephants and whales are much bigger in size than that of the humans, but humans have the largest brains in proportionate to their body sizes.

9) FACTS ABOUT HUMAN SPINAL CORD

Spinal cord is located within the vertebrae of the backbone. It extends from brainstem down to the first lumbar vertebra. It is roughly the width of a conventional pencil, tapering at it base even thinner. It is comprised of a bundle of fibers, and the fibers are long projections of nerve cells, extending from the base of the brain to the lower region of the spine. The spinal cord carries information to and from the brain and all parts of the body except the head, which is served by the cranial nerves. The signals that travel along the spinal cord are known as nerve impulses. Data from the sensory organs in different parts of the body is collected via the spinal nerves and transmitted along the spinal cord to the brain. The spinal cord also sends motor information, such as movement commands, from the brain out to the body, again transmitted via the spinal nerve network.

In terms of its anatomy, the spinal cord (Figure 30) is constituted of what is known as white matter and gray matter. The gray matter, which forms the core of the spinal cord, is composed mainly of nerve cell bodies and forms an external look of a butterfly. The white matter surrounds the gray matter and its nerve fibers play a significant role of establishing connection between different parts of the spinal cord as well as between the brain and the spinal cord. The outer regions of white matter insulate the long projecting nerve fibers (axons) coming out from the neurons.

In the gray matter of the spinal cord, there are numerous low-key nerve centers that can perform certain fundamental movement responses. However, the nerve centers within the spinal cord are regulated by the brain. The ability of the humans in consciously controlling the bowl movement is an example in this regard. The fact that infants frequent to toilets more often than the adults and that many have bedwetting problem is due to the brain being not fully developed as well as lacking in control over urine. Thus, the spinal cord serves as a pathway of connection between the brain, the rest of the body, and internal organs. The spinal cord stays in contact with the majority of body organs through the medium of nerves.

10) PERIPHERAL NERVOUS SYSTEM

As discussed above, the whole of nervous system is divided into the central nervous system (CNS) and the peripheral nervous system (PNS). Of these two, we have already discussed the central nervous system constituted by the brain and the spinal cord. So here, we will take up the remaining part, i.e. the peripheral nervous system. The peripheral nervous system is a complex network of nerves extending across the body, branching out from 12 pairs of cranial nerves originating in the brain and 31 pairs of spinal nerves emanating from the spinal cord. It relays information between the body and the brain in the form of nerve impulses. It has an afferent division (through which messages are sent to the brain) and an efferent division (which carries messages from the brain to the body). Finally, there is the autonomic nervous system, which shares some nerve structures with both the CNS and PNS. It functions 'automatically' without conscious awareness, controlling basic functions, such as body temperature, blood pressure, and heart rate.

Sensory input travels quickly from receptor points throughout the body via the afferent networks of the PNS to the brain, which processes, coordinates, and interprets the data in just fractions of a second. The brain makes an executive decision that is conveyed via the efferent division of the PNS to muscles, which take the needed action.

The twelve pairs of cranial nerves

There are 12 pairs of cranial nerves (Figure 31). They are all linked directly to the brain and do not enter the spinal cord. They allow sensory information to pass from the organs of the head, such as the eyes and ears, to the brain and also convey motor information from the brain to these organs—for example, directions for moving the mouth and lips in speech. The cranial nerves are named for the body part they serve, such as the optic nerve for the eyes, and are also assigned Roman numerical, following anatomical convention. Of these, some are associated with sensory information and others with motor information, while some are associated with both the kinds of information.

How cranial nerves attach

The cranial nerves I and II connect to the cerebrum, while cranial nerves III to XII connect to the brainstem. The fibers of sensory cranial nerves each project from a cell body that is located outside the brain itself, in sensory ganglia or elsewhere along the trunks of sensory nerves.

The thirty-one pairs of spinal nerves

There are 31 pairs of spinal nerves (Figure 32). These branch out from the spinal cord, dividing and subdividing to form a network connecting the spinal cord to every part of the body. The spinal nerves carry information from receptors around the body to the spinal cord. From here the information passes to the brain for processing. Spinal nerves also transmit motor information from the brain to the body's muscles and glands so that the brain's instructions can be carried out swiftly. Each of the 31 pairs of spinal nerves belongs to one of the four spinal regions--- cervical, thoracic, lumbar, and sacral. Of them, the cervical region has eight pairs, the thoracic has twelve pairs, the lumbar has five, and finally, the sacral has six pairs.

How spinal nerves attach

As mentioned above, human spinal cord is located within the vertebrae of the backbone. So, one may wonder how the spinal nerves attach to the spinal cord. There are gaps in the vertebrae of the backbone through which spinal nerves enter the spinal cord (Figure 33). The nerves divide into spinal nerve roots, each made up of tiny rootlets that enter the back and front parts of the cord.

11) A SLIGHTLY DETAILED LOOK AT THE SENSES

How do our brain and the environment interact? Here is how. First the senses come in contact with the external stimuli such as light, sound wave, pressure, etc. to which the corresponding senses respond. Then those sense data are sent along the respective sensory nerves in the form of electrical signals which eventually reach their respective sites on the brain cortices. That is when we shall have the perception of the respective objects.

SEEING

Let's now take up each of the senses, one by one. First, we discuss the sense of vision. We shall look into the following topics surrounding the sense of vision: the structure of eye, its receptor cells, the visual pathway, and the range of light frequency different animals, including humans, have access to.

STRUCTURE OF EYE

The eyeball is a fluid-filled orb. It has a hole in the front called pupil. At the back of the eyeball, there is retina which is a sheet of nerve cells. Some of the retinal cells are light-sensitive (photoreceptive). In the center of the retina, there is a tiny pitted area called fovea, densely packed with cones which are color-picking, light-sensitive cells and are significant in detecting detailed, sensitive image of the object. Between the pupil and the retina is a lens that adjusts to help the light passing through pupil to focus on the surface of the retina. The pupil is surrounded by a muscular ring of pigmented fibers called iris. The iris is responsible for people having different eye colors, and it also controls the amount of light entering into the eye. The pupil is covered by a transparent layer of clear tissue called cornea which merges with the tough outer surface or the ‘white’ of the eye called sclera. In the back of the eye, there is a hole (optic disk) through which the optic nerves pass through to enter the brain (Figure 34).

LIGHT-RECEPTIVE CELLS

As mentioned before, retina is located at the back of the eye, and is composed of light-receptive cells (photoreceptors). There are, in the main, two types of photoreceptors in the retina: cone cells and rod cells. The cone cells detect the color components from amongst the visible light spectrum, and are also responsible for detecting fine detail. However, cone photoreceptors require a huge amount of light to perform its function well. Cone cells in the humans are of three types: red-, blue-, and green-sensing cones, each detecting the respective colors. They are all formed on the surface and around the fovea. On the other hand, the rod cells are formed on the periphery of retina. These cells can detect images even in dim light. However, these cells mainly detect shape and motion, not so much the color. Of these two types of photoreceptors, the rods are much more sensitive to light, so much so that even with just a few light particles, they can at least generate a faint image. Besides, the manner of concentration of these cells in and around fovea impacts greatly the sensitivity of the sensation of the object. The majority of the 6 million cone cells are concentrated in the fovea, whereas all of the more than 120 million rod cells are spread around the fovea. Since the rods are spread over a larger area of the retina, they are relatively less concentrated, and thus, when one sees objects, they are not seen that clearly and detailed.

VISUAL PATHWAYS

The light reflected from the visual objects first enters the pupil through cornea, and through pupil it enters deeper into the eyes. The iris that surrounds the pupil controls the amount of light entering the eyes by changing its shapes, due to which the pupil appears to contract when the light is bright and sharp, and expands when it is less bright. Afterwards, the light passes through the lens which bends (refracts) the light, making the light to converge on the retina. If focusing on a near object, the lens thickens to increase refraction, but if the object is distant, the lens needs to flatten. The light then hits the photoreceptors in the retina, some of which fire, sending electrical signals to the brain via the optic nerve.

Information received from the outer environment upon coming in contact with eyes has to travel right to the back of the brain where the relevant cortex (visual cortex) is, and only there it is turned into a conscious vision. Here is the pathway through which the information passes from the eyes to the optic nerves to the visual cortex: the signals from the eyes passes through the two optic nerves and converge at a crossover junction called the optic chiasm. The fibers carrying the signals continue on to form the optic tracts, one on each side, which end at the lateral geniculate nucleus, part of the thalamus. However, the signals continue to the visual cortex via bands of nerve fibers, called the optic radiation (Figure 35).

RANGE OF LIGHT WAVELENGTH THAT DIFFERENT ANIMALS, INCLUDING HUMANS, HAVE ACCESS TO

In the course of evolution, by means of natural selection, different species of organisms, including the humans, have evolved eyes with varying structures and functions. That range of electromagnetic spectrum visible to the human eyes is called the visible light, which range from 400 to 700 nanometers on the wavelength. That is, from the violet, with the shorter wavelengths, to red, with longer wavelengths. Lights with wavelengths outside of the above range are normally not visible to humans. This illustrates the difference in the structure of eyes among different species of organisms. For example, the vultures and rabbits have different eye from each other. Due to that, vultures can see much farther than the rabbits do, yet cannot see as widely as the rabbits do. Likewise, the infrared light that the humans cannot see is visible to some types of fish and birds. Some birds can tell a male bird from a female bird just by looking at the infrared light reflected from their wings.

Likewise, there are two main features distinct in the eyes of the bees that the humans do not have. First, their eyes can detect infrared light that the humans cannot. Second, their visual processing is five-fold speedier than that of the humans. For example, when the bees observe a normal moving object, they do not see that as moving. Rather, they are said to see that in the form of a series of distinct temporal instances.

What accounts for such a unique feature of the bees' eyes? Their eyes are composed of six-sided lens, covered with about 4500 circular discs. These lens let in just the lights reflected from the object they focus on and not from around it. Besides that, unlike human eyes, the eyes of the bees are said to have nine types of light receptors. Because of the speed of the visual processing that the bees possess, they have a advantage of being able to negotiate their movement so well even while moving with so much speed with the least incidents of ever bumping against objects, etc.

Also, often we wonder about the sharp lights reflected back from the eyes of cats and other animals of that family. That is now understood to be due to the fact that all the lights entering their eyes fail to be absorbed in the retina, and are thus reflected back by the membrane called the reflective white.

HEARING

The ear is divided into three sections: the outer ear, the middle ear, and the inner ear. The outer ear has three further sections: the visible part of the ear called the pinna, the auditory canal, and the eardrum. The middle ear has three tiny bone structures that help in our hearing process: malleus (hammer), incus (anvil), and stapes (stirrup). The inner ear has several parts, of which the important ones are oval window, cochlea, and auditory nerve. The outer ear funnels sound waves along the auditory canal to the eardrum which is situated towards the inner end of the air canal. Immediate after the eardrum, the three tiny bones of the middle ear are attached one after the other. The sound waves cause the eardrum to vibrate, which in turn causes this chain of bones to vibrate. The vibration eventually reaches a membrane known as the oval window, the start of the inner ear. The oval window is slightly smaller than the ear drum in diameter. Because of this, when the vibration enters from the middle ear into the inner ear, the vibration becomes more consolidated. Inner ear is situated deep under the skull. Commensurate with the force of sound waves striking the ear drum, the stapes will accordingly cause the oval window to vibrate. Due to this, the fluids filling the chambers of cochlea will move, causing basilar membrane to vibrate. This stimulates the sensory hair cells on the organ of corti transforming the pressure waves into electrical impulses. These impulses pass through auditory nerve to the temporal lobe and from there to the auditory cortex (Figure 36).

Because of the way human ear is structured, it has access to a limited range of sound frequency. That is between 20 and 20000 Hertz. Sounds beyond that range are not audible to the humans. Sounds vary in terms of their pitch, and the receptors corresponding to them are found in the various parts of the cochlea. The receptors for low pitch sounds are located in the front part of cochlea, whereas receptors for the higher and the highest pitch sounds are found in the middle and inner end, respectively, of the cochlea.

SMELL

The area within each nasal cavity that contains the olfactory receptor cells is known as the olfactory epithelium. A small amount of the air entering the nostrils will pass over the epithelium, which is covered in mucus. Smell molecules in the air dissolve in this mucus, bringing receptors into direct contact with the smell molecules. Three cell types are within the epithelium: in addition to the receptor cells, there are supporting cells which produce a constant supply of mucus and, basal cells, which produce new receptor cells every few weeks. The larger the epithelium is, the keener the sense of smell. Dogs, for example, have a considerably larger olfactory epithelium than humans.

Like the sense of taste, smell is a chemical sense. Specialized receptors in the nasal cavity detect incoming molecules, which enter the nose on air currents and bind to receptor cells. Sniffing sucks up more odor molecules into the nose, allowing you to ‘sample’ a smell. Olfactory receptors located high up in the nasal cavity send electrical impulses to the olfactory bulb, in the limbic area of the brain, for processing.

Odors are initially registered by receptor cells in the nasal cavity. These send electrical impulses along dedicated pathways to the olfactory bulb (each nostril connects to one olfactory bulb). The olfactory bulb is the smell gateway to the brain. It is part of the brain’s limbic system, the seat of our emotions, desires, and instincts, which is why smell can trigger strong emotional reactions. Once processed by the olfactory bulb, data is then sent to various areas of the brain, including the olfactory cortex adjacent to the hippocampus. Unlike data gathered by the other sense organs, odors are processed on the same side, not opposite, side of the brain as the nostril the sensory data was sent from (Figure 37).

How do the olfactory receptors detect the different odors? Different smells are produced from different molecular structures of smell. Research shows that each receptor has zones on it. Therefore, when a specific smell enters the nose, only the receptors forming a conforming pattern, not every receptor, is activated. That is how the specific smell is detected. So far the scientists have identified eight primary odors: camphorous, fishy, malty, minty, musky, spermatic, sweaty, and urinous.

TASTE

Taste and smell are both chemical senses. Therefore, tongue can detect taste only when the receptors in it bind to incoming molecules, generating electrical signals that pass through the related cranial nerves to the specific brain areas. Thus, the pathway of gustatory electrical impulses begins with mouth, going to medulla, continues to the thalamus, then to primary gustatory areas of the cerebral cortex.

A person can experience the basic five flavors (sweet, sour, salty, bitter, and umami) by merely activating the taste receptors on the tongue. However, the flavors produced from the combination of these can be detected by tongue only in interaction with the sense of smell. Compared with cold food, we experience the hot food to produce greater taste. This is because, during such time, smell particles rising from the hot food bind to and excite the smell receptors inside the nose, making us also to sense their smell. Before the smell particles and taste particles are detected by the smell receptors and taste receptors respectively, these particles have to dissolve in the liquid solvents in the nose and mouth respectively. So they are similar on that front. However, what is different between the two is that while the taste receptors are not actual neurons, but a special type of cells, the smell receptors are actual neurons. Due to this difference, we see a marked difference in the degree of sensitivity towards the chemical particles. The smell receptors are 300 hundred times more sensitive (Figure 38).

The tongue is the main sensory organ for taste detection. It is the body's most flexible muscular organ. It has three interior muscles and three pairs of muscles connecting it to the mouth and throat. Its surface is dotted with tiny, pimplelike structures called papillae. Papillae are easily visible to naked eyes. Within each papilla are hundreds of taste buds and they are distributed across the tongue. Four types of papillae have been distinguished---vallate, filiform, foliate, and fungiform. Each type bears a different amount of taste buds. A taste bud is composed of a group of about 25 receptor cells alongside supporting cells layered together. In general, humans have 5000 to 10,000 taste buds, and each bud may carry 25 to 100 taste receptor cells within it. At the tip of each cell, there is a hole through which taste chemical particles enter and come in contact with the receptor molecules. The tiny hair-like receptors inside these receptor cells can hold only particular taste particles. Earlier, scientists believed that different parts of the tongue are dedicated to detecting specific tastes. However, according to recent researches, all tastes are detected equally across the tongue, and the tongue is well supplied with nerves that carry taste-related data to the brain. Other parts of the mouth such as the palate, pharynx, and epiglottis can also detect taste stimuli.

TOUCH

There are many kinds of touch sensations. These include light touch, pressure, vibration, and temperature as well as pain, and awareness of the body position in space. The skin is the body's main sense organ for touch.

There are around 20 types of touch receptor that respond to various types of stimuli. For instance, light touch, a general category that covers sensations ranging from a tap on the arm to stroking a cat's fur, is detected by four different types of receptor cells: free nerve endings, found in the epidermis; Merkel's disks, found in deeper layers of the skin; Meissner's corpuscles, which are common in the palms, soles of the feet, eyelids, genitals, and nipples; and, finally, the root hair plexus, which responds when the hair moves. Pacinian and Ruffini corpuscles respond to more pressure. The sensation of itching is produced by repetitive low-level stimulation of nerve fibers in the skin, while feeling ticklish involves more intense stimulation of the same nerve endings when the stimulus moves over the skin (Figure 39).

As for the manner in which touch information finally makes its way to the brain, a sense receptor, when activated, sends information about touch stimuli as electrical impulses along a nerve fiber of the sensory nerve network to the nerve root on the spinal cord. The data enters the spinal cord and continues upward to the brain. The processing of sensory data is begun by the nuclei in the upper (dorsal) column of the spinal cord. From the brainstem, sensory data enters the thalamus, where processing continues. The data then travels to the postcentral gyrus of the cerebral cortex, the location of the somatosensory cortex. Here, it is finally translated into a touch perception. Somatosensory cerebral cortex curls around the brain like a horseshoe. Data from the right side of the body ends on the left side of the brain, and vice versa.

THE SIXTH SENSE

Proprioception is sometimes referred to as the sixth sense. It is our sense of how our bodies are positioned and moving in space. This 'awareness' is produced by part of the somatic sensing system, and involves structures called proprioceptors in the muscles, tendons, joints, and ligaments that monitor changes in their length, tension, and pressure linked to changes in position. Proprioceptors send impulses to the brain. Upon processing this information, a decision can be made—to change position or to stop moving. The brain then sends signals back to the muscles based on the input from the proprioceptors—

completing the feedback cycle. This information is not always made conscious. For example, keeping and adjusting balance is generally an unconscious process.

Conscious proprioception uses the dorsal column-medial lemniscus pathway, which passes through the thalamus, and ends in the parietal lobe of the cortex. Unconscious proprioception involves spinocerebellar tracts, and ends in the cerebellum. Proprioception is impaired when people are under the influence of alcohol or certain drugs. The degree of impairment can be tested by field sobriety tests, which have long been used by the police in cases of suspected drunk-driving. Typical tests include asking someone to touch their index finger to their nose with eyes closed, to stand on one leg for 30 seconds, or to walk heel-to-toe in a straight line for nine steps.

MIXED SENSES

Sensory neurons respond to data from specific sense organs. Visual cortical neurons, for example, are most sensitive to signals from the eyes. But this specialization is not rigid. Visual neurons have been found to respond more strongly to weak light signals if accompanied by sound, suggesting that they are activated by data from the ears as well as the eyes. Other studies show that in people who are blind or deaf, some neurons that would normally process visual or auditory stimuli are “hijacked” by the other senses. Hence, blind people hear better and deaf people see better.

SYNESTHESIA

Most people are aware of only a single sensation in response to one type of stimulus. For example, sound waves make noise. But some people experience more than one sensation in response to a single stimulus. They may “see” sounds as well as hear them, or “taste” images. Called synesthesia, this sensory duplication occurs when the neural pathway from a sense organ diverges and carries data on one type of stimulus to a part of the brain that normally processes another type (Figure 40).

PERCEPTION AS A CONSTRUCT

Do we perceive the external world directly, or do we perceive a constructed reality? Neuroscience finds that the latter is a more accurate description. When our sensory organs detect something in the environment, they are responding to a physical stimulus. For example, the photoreceptor cells in the retina of the eye respond to photon particles traveling through space. These photons stimulate the receptor neurons, and start a chain reaction of neural signals to the primary visual cortex in the brain, where it becomes a perception. While the visual perception correlates with the physical stimulus, they are not one and the same. It was described earlier that photons have a wavelength, and the wavelength can vary among photons. Each numerical difference in the wavelength of a photon correlates with a difference in the perception of color. That is, photons with a wavelength of around 500 nanometers correlate with perceiving the color blue, while a wavelength of around 700 nanometers correlates with perceiving the color red. While the physical property of wavelength exists objectively in the world, the perceived color only exists subjectively and depends on our ability to detect it. The colors we perceive are not physical properties, but rather the psychological correlates of the physical property of wavelength of light. Moreover, there are many wavelengths that we cannot detect, so our perceptions selectively represent the physical world.

The same principle applies to the other senses. Each sensory modality we have has two components: the physical stimulus that is detected by the sensory organ, and the psychological perception that results from it. We do not directly perceive the wavelength of light, rather we perceive the result of how the photon particles stimulate the visual pathway. Therefore, we can say that perception is a construction that is grounded in detecting physical phenomena, but we do not directly perceive those phenomena. Nor do we perceive all objective phenomena, only those that we are capable of detecting.

If perception is a construction and a limited representation of objective phenomena, why did it evolve that way? We need to be able to react to environmental circumstances to survive. To find food, to avoid predators, to meet mates, to care for offspring, to engage in social behavior, all of these actions require the ability to detect and respond to changes in the physical environment. But sensory systems can evolve to be simply good enough for survival. It is not necessary to have complete, direct perception to survive. In fact, recall the facts we discussed earlier about how the human brain is very demanding for the body's resources. More sophisticated sensory systems require more resources, and if those resource requirements are not of great utility to the organism, then evolution likely will not favor increasing the level of sophistication. In addition, there is often a trade-off between speed and accuracy in neural systems and resulting behaviors. When it comes to visual perception, seeing a danger with less accuracy and surviving is more important than seeing a danger directly and not surviving!

12) CONSCIOUSNESS AND THE BRAIN

WHAT IS CONSCIOUSNESS?

Consciousness is important as well as essential. Without it, life would have no meaning. However, once we embark on identifying its nature, it is certain to find it to be like nothing else. A thought, feeling, or idea seems to be a different kind of thing from the physical objects that make up the rest of the universe. The contents of our minds cannot be located in space or time. Although to the neuroscientists the contents of our minds appear to be produced by particular types of physical activity in the brain, it is not known if this activity itself forms consciousness or if brain activity correlates with a different thing altogether that we call “the mind” or consciousness (Figure 41). If consciousness is not simply brain activity, this suggests that the material universe is just one aspect of reality and that consciousness is part of a parallel reality in which entirely different rules apply.

MONISM AND DUALISM

The philosophical stands of those positing the relation between mind and body can be broadly brought under two divisions: monism and dualism. According to the former, every phenomenon in the universe can be ultimately reduced to a material thing. Consciousness too is identical to the brain activity that correlates with it. However, the fact that not every physical thing has consciousness is because only in those physical bodies where complex physical processes evolved over a long period of time did cognitive mechanism develop. Thus, consciousness never existed in parallel with the material universe as an independent entity of its own.

According to the latter, consciousness is not physical but exists in another dimension to the material universe. Certain brain processes are associated with the consciousness, but they are not identical to each other. Some dualists believe consciousness may even exist without the brain processes associated with it.

LOCATING CONSCIOUSNESS

Human consciousness arises from the interaction of every part of a person with their environment. We know that the brain plays the major role in producing conscious awareness but we do not know exactly how. Certain processes within the brain, and neuronal activity in particular areas, correlate reliably with conscious states, while others do not.

Different types of neuronal activity in the brain are associated with the emergence of conscious awareness. Neuronal activity in the cortex, and particularly in the frontal lobes, is associated with the arousal of conscious experience. It takes up to half a second for a stimulus to become conscious after it has first been registered in the brain. Initially, the neuronal activity triggered by the stimulus occurs in the “lower” areas of the brain, such as the amygdala and thalamus, and then in the “higher” brain, in the parts of the cortex that process sensations. The frontal cortex is activated usually only when an experience becomes conscious, suggesting that the involvement of this part of the brain may be an essential component of consciousness.

REQUIREMENTS OF CONSCIOUSNESS

Every state of conscious awareness has a specific pattern of brain activity associated with it. These are commonly referred to as the neural correlates of consciousness. For example, seeing a patch of yellow produces one pattern of brain activity, seeing grandparents, another. If the brain state changes from one pattern to another, so does the experience of consciousness. Consciousness arises only when brain cells fire at fairly high rates. So, neural activity must be complex for consciousness to occur, but not too complex. If all the neurons are firing, such as in an epileptic seizure, consciousness is lost. The processes relevant to consciousness are generally assumed to be found at the level of brain cells rather than at the level of individual molecules or atoms. Yet it is also possible that consciousness does arise at the far smaller atomic (quantum) level, and if so it may be subject to very different laws.

Many neuroscientists hold the philosophical view of materialism; that there is only one fundamental substance in the universe and that is physical material. How, then, is subjective experience of the mind explained? Through a process known as emergence. Emergence is a process described as the production of a phenomenon from the interactions or processes of several other phenomena. For example, the molecule that is water is composed of two hydrogen atoms and one oxygen atom. The hydrogen and oxygen atoms on their own do not have the quality of wetness that water has. But when you combine them to form the molecule, and you have enough water molecules, then the property of wetness emerges from those interactions. Neuroscientists use this as an analogy, and argue that when many neurons are combined, consciousness emerges from those interactions. This analogy serves as a useful description within the viewpoint of materialism, but it is not an explanation, as we have yet to demonstrate the mechanisms involved in such an emergence.

13) DEBATE EXERCISES RELATED TO INDIVIDUAL CHAPTER (appended at the end of respective chapters)