

## Chapter 1 - Introductory Module

### Clive Wearing

- developed a rare condition in which the herpes simplex virus invaded his brain.
  - Clive survived, which is also rare, his brain tissue swelled, crushing against the confines of his skull.
  - He can recognize his wife, but cannot recall their wedding. He lost the past and the present.
  - He cannot form a temporary memory, always living "in the moment".
  - Emotional memory, such as that he know he loved his wife survived when almost everything else is gone, and he can also play musical instruments just like a normal person.
  - He was unable to consciously learn new facts, he could acquire some new habits through repeated practice.
1. The unrivaled importance of learning and memory to our lives.
  2. Memory as if it were a single, cohesive process is misleading, memory consists of different kinds, some can be damaged while others are spared in Clive's case.

### 1.1 From Philosophy to Psychology

#### Top Ten Tips on improving one's memory

1. Pay attention
2. Create associations
3. A picture is worth a thousand words
4. Practice makes perfect
5. Use multiple senses
6. Reduce overload
7. Time travel
8. Get some sleep
9. Try a rhyme
10. Relax

#### The Empiricism and Associationism of Aristotle

- Aristotle(384-322 BC), Greek philosopher and teacher, one of the earliest thinkers to write about memory.
- Collected data to form theories.
- Associationism: memory depends on the formation of linkages between pairs of events, sensations, or ideas, so that recalling or experiencing one member of the pair elicits a memory or anticipation of the other. (e.g., hot associated with cold, table with chair)
  - A. Contiguity: or nearness in time and space, events experienced at the same time (temporal contiguity) or place (spatial contiguity) tend to be associated.
    - a. Table and chair
  - B. Frequency: The more we experience events that are contiguous, the more strongly we associate them.
    - a. The more often we see table and chair together, the stronger they are linked.
  - C. Similarity: if two things are similar, the thought or sensation of one will tend to trigger a thought of the other.
    - a. Table and chairs are often made of wood, both are found in kitchens, and both have the function associated with eating meals.
- Aristotle: provided foundations for modern theories of learning in both psychology and neuroscience.
  - His view was that knowledge emerges from experience. Which identifies him with a philosophical thought of empiricism.
  - All the ideas we have are the result of experience. The new born child is like a blank slate, not yet written on.

- Plato, Aristotle's teacher, differed from him in thought. Plato believed in nativism.
  - Our knowledge is inborn (or native), acquired during the past lifetimes of our eternal souls.
  - His book "The Republic", an idealized society in which people's innate differences in skills, abilities, and talents, form the basis of their fixed roles in life, some rule while others serve.
- Nature vs. Nurture
  - Nature - including genes
  - Nurture - including upbringing and environment
  - Which one has a greater influence on our learning and memory abilities.
- Nativism: knowledge is inborn

#### Rene Descartes (1596 - 1650) - Nativist

- The minds and the body are distinct entities, governed by different laws. The body functions as a machine with innate and fixed responses to stimuli.
- Deep doubts about the existence of everything, including God. He concluded that the only evidence that he himself even existed was his ability to think: "I think, therefore I am".
- Firm believer in Dualism
  - The principle that the mind and body exist as separate entities, each with different characteristics, governed by its own laws.
  - The body functions like a self-regulating machines, much like the clockwork statues and fountains in Renaissance.
- Descartes' reflex
  - Begins when a stimulus, a sensory event from the outside world enters the system.
    - Light reflected off a bird enters the eye as a visual stimulus.
  - The stimulus causes fluids to flow through hollow tubes from the eyes to the brain and then to be "reflected" back as an outgoing response.
  - Such a pathway from sensory stimulus to motor response is called a reflex arc.
- Borrowed ideas from Hydraulic engineering

#### John Locke and His Reliance on Empiricism

- Inspired by Newton's work that coloured prism lens recombined together to produce white light, Locke hope to show that the mind could also be broken down into elements that when combined produced the whole of consciousness.
- Complex ideas are similarly formed from the combination of more elementary ideas that we passively acquire through our senses.
- "Red" and "sweet" are acquired automatically by our senses of sight and taste, and more complex ideas such as "cherry" are acquired by combining these simpler components.
- All knowledge is derived from experience alone.
- A man's worth cannot be determined at birth, all men are born equal with same potential for knowledge, success, and leadership.
- Access to a good education is critical for all.
- Locke's ideas influences Thomas Jefferson when he drafted the Declaration of Independence.

#### William James and Associationism

- He gave the first lecture of Psychology in America.
- The soldier's response to command is so deeply ingrained as a reflex that it is still affective after leaving the army for years.
- Believed that most abilities and habits were similarly formed by our experiences, especially early in life.
- Tension between "new learning" and "old memories"
- Activation of the memory for the dinner party, with all of its components, could in turn activate the memory for a second event that shared some related elements - such as visit to a dance hall with the same lady on the next night.

- The two events would be associated by a linkage between their common or related components (the sight of the lady and the smell of her perfume).
- Believed that the associations it described would eventually be mapped directly onto physical connections in the brain.

## 1.2 Evolution and Natural Selection

Evolution (Erasmus Darwin): the theory that species change over time, with new traits or characteristics emerging and being passed from one generation to the next. With sufficient time, one species could evolve so far that it becomes an entirely different species from its ancestor.

### Charles Darwin and the Theory of Natural Selection

- Studies bird's finches, "one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends".
- Darwin's three criteria for traits to evolve through natural selection
  - Inheritable trait
  - Natural variability
  - Relevance to survival
- Natural selection: a mechanism for how evolution occurs, species evolve when they possess a trait that meets three conditions. Over time, natural selection means that the trait will spread through the population.
- Darwin argued that behavioural traits could evolve through the same process of natural selection as do physical traits. Which is known as evolutionary psychology today.
  - The basic premise is that learning has enormous value for survival, allowing organisms to adapt to a changing and variable world.
  - Organisms with more capacity for learning and memory has a better chance for survival, and is more likely to be able to breed and pass their inherited capacities on to offspring.
  - The content is not passed on, only the capacity or ability or learning and memory.

### Francis Galton and the Variability of Nature

- He travelled around the world, became fascinated with the variability of human characteristics, he began to measure them. Comparing mental power, physical size etc. Which showed as normal distribution on graph.
- Proposed that "a man's natural abilities are derived by inheritance".
- Statistical techniques, started with a hypothesis that prayers are beneficial for health, and designing a correlational study.
- Introduced the term "eugenics", a program for encouraging marriage and procreation among the most fittest man, while discouraging childbearing in the mentally or physically unfit.
- Contribution to understanding the role of inheritability in behavioural traits and the development of novel statistical and experimental methods for psychology.

## 1.3 The Birth of Experimental Psychology

### Hermann Ebbinghaus and Human Memory Experiments

- Experiments on forgetting
  - Used himself as participant, with three-letter nonsense words. He reads a list of 20 words from the original list, put it away for a while, then tried to remember as many words as possible. Then check how many words he missed afterwards. Then reviewed the list, and tried again.
  - Four stages: learning, delay, test, relearning
- Plotted a retention curve, which measures how much information is retained at each point in time following learning. Graphing the percentage savings in time for relearning the list at various delays between the initial learning and relearning.

- Strong time savings if the delay is short, nearly 100%, but as the delay grows longer, the saving declines to 25%.
- The most forgetting occurs early on, if a memory can survive the first few hours after learning, there is little additional forgetting.
- Independent variable was manipulated, and its effect on the dependent variable was measured.
- Major limitation is self-experimentation, subject bias, and experimenter bias. Encourage double-blind and the use of placebo to reduce bias.

#### Ivan Pavlov's Conditioning Studies

- He trained a dog to expect that the sound of a doorbell always preceded delivery of food, over many trials in which the two were paired. The dog then developed a stronger and stronger salivation response to the sound of the bell.
- This form of learning is called classical conditioning.
- Influenced by Darwin and the newly invented telephone.
- Extinction: the salivation to the bell gradually decreased as the animal learned that the bell no longer predicted food by pairing the bell with the absence of food.
- Generalization: the more dissimilar the new stimulus was to the original stimulus, the less intense was the dog's salivation response. The ability to transfer past learning to novel events and problems.

#### Edward Thorndike and the Law of Effect

- Instrumental conditioning (operant conditioning): organisms learn to make responses in order to obtain or avoid important consequences
- Law of effect: the probability of a particular behavioural response increased or decreased depending on the consequences that followed.
  - Desired outcome, increase, vice versa.
  - An animal has a range of behaviours, those that lead to positive consequences for the animal tend to persist, analogous to Darwin's idea of survival of the fittest.

### 1.4 The Region of Behaviourism

Behaviourism: psychology should restrict itself to the study of observable behaviours and avoid reference to unobservable, and often ill-defined, internal mental events.

#### John Watson's Behaviourism

- He went to grad school and conducted research on how rats learn. Watson placed a rat at the entrance to a maze, and rewarded it with food if it found its way to the exit.
- Initially the rat would spend half an hour wondering around the maze, after 30 training trials, the rat could traverse the maze in less than 10 seconds.
- He then surgically impaired the rats to become deaf, blind, and whisker-less, none of these affected the rat's performance. He even eliminated all odours in the maze.
- Only when the maze was rotated or when the corridors were made shorter or longer did the rats show a significant loss in their ability to navigate the maze.
- Watson argued that the rats had learned an automatic set of motor habits for moving through the maze and that these habits were largely independent of any external sensory cues.
- Faced questions from animal rights activists.
- Viewed psychology as a "purely objective experimental branch of natural science". And he was a strong empiricist. Everyone has an equal chance of success.

#### Clark Hull and Mathematical Models of Learning

- Pavlov and Watson -> S-R Learning
- Developed an equation, the variables that Hull entered into his equations included the

number of learning trials, the frequency of reward, the spacing between trials, the intensity of stimulus cues etc.

- Hull's models have been abandoned because modern psychologists have despaired of ever being able to reduce all the factors governing learning into a single equation.

#### B.F. Skinner's Radical Behaviourism

- "Skinner box"
- When trained with intermittent reinforcements, rats learn to respond as quickly and as frequently as when they are rewarded on every trial, sometimes even better.
- Extreme form of behaviourism, Radical Behaviourism.
  - he asserted that consciousness and free will are illusions.
- Promotes an utopian world.

#### The Neo-Behaviourism of Edward Tolman

- Believed in goals and intentions. Rats are intrinsically motivated to learn the general layout of mazes by forming what he called a cognitive map, an internal psychological representation of the spatial layout of the external world.
- Rats are able to find food in mazes by using alternative routes if their preferred routes are blocked.
- Cognitive maps can also be formed without any explicit reward.
- Latent learning: learning that takes place even when there is no specific motivation to obtain or avoid a specific consequence.
  - Part of our everyday lives.
- Tolman emphasizes the importance of internal representations of the environment and utilizing concepts such as purpose and intent that are not directly observable, only inferred.

### 1.5 The Cognitive Approach

#### Cognitive Psychology

- Many things such as language acquisition cannot be explained by behaviourism, by the mid-1900s, many people turned to a cognitive perspective.
- A new subfield of psychology that focused on human abilities such as thinking, language, and reasoning - the abilities not easily explained by a strictly behaviourist approach.

#### W.K. Estes and Mathematical Psychology

- Builds on Hull's modeling approach to develop new methods for interpreting a wide variety of learning behaviours.
- Stimulus sampling theory: a key principle is that random variation is essential for learning, much as it is essential for the adaptation of species in Charles Darwin's theory of evolution through natural selections.
  - Gave better account than other theories of the variability seen in both animal and human learning.
- Mathematical psychology: uses mathematical equations to describe the laws of learning and memory.

#### Gordon Bower: Learning by Insight

- The "ah-ha" moment in learning when you suddenly figure out the solution. A long period of 0% correct responding that transitions all at once into a period of 100% correct responding.
- But most psychologists report average learning curve for a group of people. It is important to study individual learning process than a massive group at once, because it is difficult to determine when each individual show the correct response, only a group result. Therefore, difficult to analyze the results.
- "one trial" experiment to illustrate how individual performance can look quite different from averaged group performance during learning.

### George Miller and Information Theory

- Information theory: a mathematical theory of communication that provides a precise measure of how much information is contained in a message, based not only on the message itself but also on the listener's prior knowledge.
- The average memory capacity for number seemed to be about 7 digits, plus or minus 2.
  - magnitude rating and digit span
  - used to understand memory's limits and mechanisms.

### The Connectionist Models of David Rumelhart

- Cognition was best understood as networks of connections between simple processing units that in their theory were called nodes. They called such networks "connectionist models".
- Distributed representation: information consists of the activation of many different nodes, "distributed" across many nodes rather than represented by only one.
- Inspired in part by ideas about how the brain is organized.

## **Chapter 2 - The Neuroscience of Learning and Memory**

### 2.1 A Quick Tour of the Brain

#### The Brain and the Nervous System

- Central nervous system: consists of the brain and the spinal cord. Where many of the events responsible for learning and memory take place.
- Peripheral nervous system: consists of motor and sensory neurons that connect the brain and the spinal cord to the rest of the body.
- The Brain
  - Cerebral cortex is the largest portion of brain. In each hemisphere, the cortex is divided into four lobes.
  - Four Lobes
    - Frontal lobe: Plan and perform actions, higher directions.
    - Parietal lobe: enable you to feel the differences between silk and sand paper
    - Temporal lobe: associated with hearing and remembering
    - Occipital lobe: sight
  - Cerebellum: contributes to the coordination of movement and is thus especially important for learning that involves physical action.
  - Brainstem: a collection of structures connecting the brain to the spinal cord and playing key roles in the regulation of automatic functions, such as breathing and regulation of body temperature.
  - Thalamus: a structure that receives sensory information from the peripheral nervous system and relays this information to other parts of the brain. Such as a gateway through which almost all sensory information enters the brain.
  - Basal Ganglia: a group of structures important for planning and producing skilled movements such as throwing a football or juggling.
  - Hippocampus: inside the temporal lobes, it is important for learning new information about facts or remembering autobiographical events.
  - Amygdala: important for adding emotional content to memories. Remembering the happiest or saddest day in your life.

#### Comparative Neuroanatomy

- The study of similarities and differences between organisms' brains.
- The brains of vertebrate species are similar in that all have a cerebral cortex, a cerebellum, and a brainstem. Their brain are also similarly organized into two hemispheres.
- In general, bigger animals have bigger brains.

- Size of frontal and parietal lobes in human can predict their performance on intelligence tests.
- Different species have different proportions of cerebral cortex. In human, it takes up a lot of brain portion, which is associated with language and complex thought.
- Only vertebrates have both CNS and PNS. Invertebrates' brain are much different, for example octopus has brain on its legs, yet it is a remarkable learner. Also, it shows signs of social learning.
- Worms and jellyfish have no recognizable brains at all.
- Studies of invertebrate NS have been particularly rewarding because of their simplicity

## Neurons

- Sensory fibers and motor detectors. In vertebrates, the vast majority of neurons are centralized in the brain. They are capable of changing their function and modifying the way they process information.
1. Dendrites: input areas that receive signals from other neurons.
  2. The cell body: integrates signals from other neurons.
  3. One or more axons: transmit information to other neurons.
    - Information flows in one direction, from dendrites to axons.
    - Interneurons: connects two or more neurons, have short axons or no axons at all.
    - Glia: outnumbers neurons in the brain, provide functional and structural support to neurons. Wraps the axon with myelin sheath to facilitate the information transmission process.

## Observing Learning-Related Changes in Brain Structure

- Phrenology: carefully measured the size and shape of many individuals' skull and compared those measurements with the individuals' personalities and abilities.
  - This is wrong, bumps on the skull do not imply bulges in the underlying brain.
  - Gall had no way to examine the brain of a living person.
- Structural neuroimaging: brain scanning
  - Computed tomography (CT): produce scans created by multiple x-ray images. 2-D, cannot show the depth of the broken bone. By taking multiple x-rays, it generates cross section through the body. But the soft tissues that make up the brain show much less clearly than bones and tumors.
  - Magnetic resonance imaging (MRI): changes in the magnetic fields generate images of internal structure. MRI employs an extremely powerful magnet, constructed like a giant tube. The patient lies on a pallet that slides into the tube.
  - Diffusion tensor imaging (DTI): a new form of MRI, which can measure the diffusion of water in brain tissue, permitting bundles of axons throughout the brain, white matter, to be imaged. Used to study how different regions in the brain interact, by studying the fiber pathways between them.

## 2.2 What Brains Do

### Information Pathways in the CNS

- Reflex: an involuntary and automatic response "hardwired" into an organism, cannot be learned.
  - Experiments that surgically disconnect the spinal cord from the brain, but they still show many basic reflexes, such as jerking their leg away from a painful stimulus.
  - Sensory neuron -> Spinal cord -> activate motor fibers traveling out of spinal cord.
- Spinal reflexes could be combined into complex sequences of movements and that these reflexes were the building blocks of all behaviour.
- Sensory fibers enters the spinal cord and connect to motor fibers there, but some fibers also travel up to the brain. The brain processes these inputs and produces its own outputs, some of which may travel back down the spinal cord and out to the muscles.

### Incoming Stimuli: Sensory Pathways into the Brain

- Most sensory information enters the brain through the thalamus, which then turns and distributes these inputs into cortical regions specialized for processing particular sensory stimuli.
  - Primary auditory cortex (A1) - temporal lobe, sound
  - Primary somatosensory cortex (S1) - parietal lobe, sensations from skin and internal organs
  - Primary visual cortex (V1) - occipital lobe, sight
- These are primary sensory cortices, they are the first stage of cortical processing for each type of sensory information. Then transmit outputs to surrounding cortical regions for further processing.

### Outgoing Responses: Motor Control

- Primary motor cortex (M1) generates coordinated movements. Located in the frontal lobe, it sends output to the brainstem, which in turn sends instructions down the spinal cord to activate motor fibers that control the muscles.
- Gets much of its input from the frontal lobes. Some inputs come from the basal ganglia and cerebellum, which help to translate the high-level plans into concrete sets of movements.
- All these inputs help determine the output that M1 sends to the brainstem.
- Other mentioned motor areas produce their own outputs as well, complex movements require interactions between all of these brain structures and the muscles they control.

### The Synapse: Where Neurons Connect

- Neurons transfer messages across the synapse. Most synapses are formed between the axon of the presynaptic neuron and a dendrite of the postsynaptic neuron.
- Neurotransmitters: chemical substances that can cross a synapse to carry a message to a postsynaptic neuron.
  - Kept in packets known as vesicles. To send a message, one or more vesicles of the presynaptic axon burst and spill neurotransmitter molecules into the synapse.
    - A. Glutamate
      - a. most prevalent excitatory neurotransmitter
    - B. Gamma-aminobutyric acid (GABA)
      - a. main inhibitory neurotransmitter
    - C. Acetylcholine
      - a. connects motor neurons and muscles, regulates attention and memory
    - D. Dopamine
      - a. associated with voluntary movement, regulates reward-seeking behaviour
    - E. Norepinephrine
      - a. increases arousal, contributes to long-lasting memories
    - F. Epinephrine
      - a. increases attention and concentration
    - G. Serotonin
      - a. regulates sleep, mood, appetite, and aggression
    - H. Histamine
      - a. regulates sleep and arousal
    - I. Glycine
      - a. decreases neural activity
- Next step is for the postsynaptic neurons to pick chemical signals up. Receptors are molecules embedded in the surface of the postsynaptic neuron that are specialized to bind with and respond to particular kinds of neurotransmitters.
- After the neuron fires, there is a refractory period.
- Neuromodulators: a neurotransmitter released by neurons in the brainstem when they fire, which alter how neurons exchange messages, although they themselves are not part of the message.

## Discovering How Different Brain Regions Function

- **Neuropsychology:** the branch of psychology that deals with the relation between brain function and behaviour.
- **Theory of Equipotentiality:** which states that memories are not stored in one area of the brain, rather, the brain operates as a whole to store memories.
  - based the concept of engram, he found that no matter which part of the cortex he lesioned, the rats kept performing the task.
- **Engram:** the supposed physical change in the brain that forms the basis of a memory.
  - train a group of rats to navigate a maze, then he remove 10% of the rat's cortex, once he'd found the lesion that erased the animal's memories of how to run through the maze, he would have located the site of the engram.

## 2.3 Measuring and Manipulating Brain Activity

### Functional Neuroimaging and Electroencephalography

- **functional neuroimaging:** allows researchers to look at the activity, or function, of a living brain. When a region becomes active, it required more oxygen, and vice versa.
  - First scan a baseline image, then compare with image when the person is performing experimental tasks. Creating a difference image.
1. **Positron emission tomography (PET):** measured brain activity by detecting radiation from the emission of subatomic particles are positrons, associated with the brain's use of glucose from the blood.
  2. **Functional magnetic resonance imaging (fMRI):** makes use of the same MRI technology, taking two MRIs, one at baseline and one during the experiment.
  3. **Electroencephalography (EEG):** technique for measuring electrical activity in the brain, using the same type of recording electrodes that are used in electrocardiograms.
    - averages over many repetitions of the same event are called event-related potentials (ERPs).
- fMRI allows images to be taken every few second, and PET every few minutes.

### Recording from Activating Neurons

- **Neurophysiology:** study of activity and function of neurons.
- **Single-cell recording:** microelectrodes that are used in this technique are similar in function to EEG electrodes, but they are shaped like a thin needle. Observe the behaviour resulted from single cell activation.
- **Transcranial magnetic stimulation (TMS):** allows researchers to stimulate parts of the human brain by generating strong magnetic pulses over the skull. Activates the entire brain, but takes no surgery.

### Observing the Effects of Drugs

1. Increase or decrease the ability of the presynaptic neuron to produce or release neurotransmitter.
2. Drugs can increase or decrease the ability of postsynaptic receptors to receive the chemical message.
3. Drugs can alter the mechanisms for clearing neurotransmitter molecules out of the synapse.

## 2.4 Neural Plasticity

**Synaptic plasticity:** the ability of synapses to change as a result of experience.

- "neurons that fire together, wire together."
- Strengthening or weakening the connections between neurons can influence when they fire.

### Long-term Potentiation and Depression

- LTP: when synaptic transmission becomes more effective as a result of recent activity
- LTD: occurs when synaptic transmission becomes less effective as a result of recent activity.

#### Experience-Dependent Neural Growth

- Housed rats in a enriched environment, where there was plenty of sensory stimulation and opportunity to explore and learn, which showed better maze learning than the rats kept in the standard laboratory housing.