Introduction

I remember our garden when I was a child, the smells, the colours and the laughter as we played games near the big old tree. I remember when I fell off my bike and everyone from the neighbour's barbecue rushed over to see if I'd broken a bone.

Remember, remember... the verb itself is almost poetic. The notion of memory is so intriguing that it seems as though we have come up with more metaphors for it than for any other mental phenomenon. Early theories predicted a memory "engram", a literal text written by the body to describe past experiences. Freud popularised descriptions of repressed memories, experiences physically buried in the depths of the subconscious.

Modern descriptions are dominated by analogies to computers, in which the human brain is a hard disk that stores experience in electronic files and folders. Typical of biology, the truth is at once more complicated and more beautiful than any of these descriptions.

Connections Between Neurons

Fundamentally, memory represents a change in who we are: Our habits, our ideologies, our hopes and fears are all influenced by what we remember of our past. At the most basic level, we remember because the **connections** between our brains' neurons change; each experience primes the brain for the next experience, so that the physical stuff we're made of reflects our history like mountains reflect geological eras.

Memory also represents a change in who we are because it is predictive of who we will become. We remember things more easily if we have been exposed to similar things before, so what we remember from the past has a lot to do with what we can learn in the future.

An understanding of memory is an understanding of the role of experience in shaping our lives, a critical tool for effective learning. The way that we create and store memories can influence the way that we learn.

Immediate, Working, and Long-Term Memory

Scientists divide memory into categories based on the amount of time the memory lasts: the shortest memories lasting only milliseconds are called immediate memories, memories lasting about a minute are called working memories, and memories lasting anywhere from an hour to many years are called long-term memories.

Each type of memory is tied to a particular type of brain function.

> **Long-term memory**, the type that we are most familiar with, is used to store facts, observations, and the stories of our lives.
>
> **Working memory** is used to hold the same kind of information for a much shorter amount of time, often just long enough for the information to be useful; for

instance, working memory might hold the page number of a magazine article just long enough for you to turn to that page.

Immediate memory is typically so short-lived that we don't even think of it as memory; the brain uses immediate memory as a collecting bin, so that, for instance, when your eyes jump from point to point across a scene the individual snapshots are collected together into what seems like a smooth panorama.

Remembering Facts and How to do Things

Another way to categorise memory is to divide memories about what something is from memories about how something is done. Skills like catching a ball or riding a bicycle are called nondeclarative memories because we perform those activities automatically, with no conscious recollection of how we learned the skills. Declarative memories, on the other hand, are memories of facts and events that we can consciously recall and describe verbally.

Scientists have discovered that different brain structures specialise in processing each category of memory, suggesting that these categories are not merely convenient for discussion, but are based in the biology of how we remember. Understanding how memories are formed in each category and how some memories move amongst categories can help to focus strategies for improving memory and learning.

How Memories Are Made

Modern computers encode memory as a vast array of independent, digital bits of information that are "randomly accessible." Functionally, this means that your computer can bring up your best friend's phone number without accessing any information about what your best friend looks like or how you met.

The human brain stores memory in a very different way; recalling your best friend's phone number may very well bring to mind your friend's face, a pleasant conversation that you had, and the title of the movie that the two of you are going to see. While computer memories are discrete and rationally simple, human memories are tangled together and rationally complex.

Memories Formed Through Associations

Our memories are rich because they are formed through associations. When we experience an event, our brains tie the sights, smells, sounds, and our own impressions together into a relationship. That relationship itself is the memory of the event. Unlike computer memories, a human memory is not a discrete thing that exists at a particular location; instead, it is an abstract relationship amongst thoughts that arises out of **neural activity spread over the whole brain**.

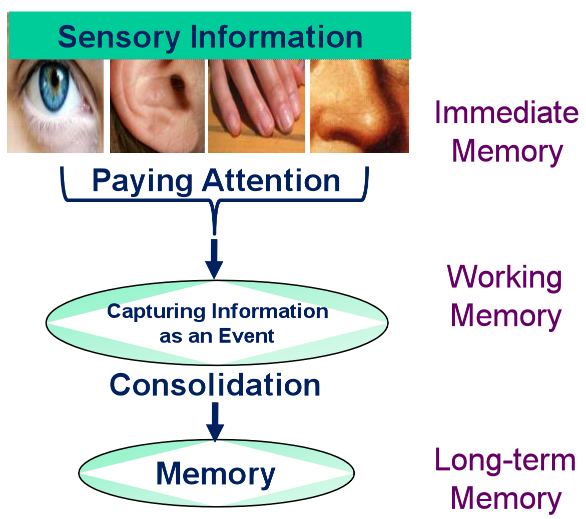
But how is the memory relationship actually made? The process from both a biological and a behavioural perspective is critically dependent on **reinforcement**. Reinforcement can come in the form of repetition or practice; we remember that two plus two equals four because we've heard it so many times. Reinforcement can also occur through emotional arousal; most people over a certain age can remember where they were when they heard that John F. Kennedy was shot or that Princess Diana had died because of the highly **emotional content** of that event. Arousal is also a product of **attention**, so memories can be reinforced independent of **context** by paying careful attention and consciously attempting to remember.

Remembering a New Face

Reinforcement is important in forming memories because it moves the memory relationship from short-lived categories to longer-lasting ones. For example, if you met a man called John Smith at a party, you would see his face, hear his name, and you would be aware of the social context of the event. At first this information is loosely held in immediate memory, just long enough for the event to play itself out. Immediate memories are held in various regions of the brain, meaning that immediate visual memory is probably held in visual parts of the brain, immediate auditory memory in auditory parts of the brain, and so on.

Figure 1. Making a memory

.



Sensory information like sight, sound, and touch are independently maintained in immediate memory. By attending to certain aspects of an experience, sensory information can be brought together into an event in working memory, where continued attention can maintain that information "online." Reinforcement and arousal allow events in working memory to be consolidated into long-term memory storage.

The relationship between sight, sound, and awareness is brought together into working memory, somewhere in the prefrontal lobe of the brain. When the event moves from immediate memory to working memory, certain features will be lost. You probably won't remember background conversations from the party and you may not remember the colour of the Mr. Smith's shoes. The loss of distracting information is an important feature of human memory, and is critical for efficient storage and recollection of experiences.

At this point you might rehearse the event by saying the name to yourself, or by making up a mnemonic (John Smith, who has a moustache and looks like Charles Bronson). The mnemonic and the rehearsal cause the memory to move from working memory into long-term memory, a change that starts in the brain's hippocampus.

The process of converting working memory into long-term memory is called **consolidation**, and again, it is characterised by the loss of distracting information. Several days after meeting Mr. Smith you may not be able to remember what colour his tie was or whether he wore a wristwatch, but you will still remember his face, his name, and the person who introduced you to him. The consolidation phase of memory formation is **sensitive to interruption**; if you are distracted just after meeting Mr. Smith, you may have trouble remembering his name later.

To recap, the event of meeting John Smith started out in immediate memory, spread out in various regions of the brain. Reinforcement through attention caused the relationship between sight, sound, and context to consolidate into working memory in the prefrontal lobe. Further reinforcement through practice caused more consolidation, and the most critical relationships in the event (the name, the face, and the context) were tied together in the hippocampus. From there, the memory relationship is probably stored diffusely across the cerebral cortex, but research on the actual location of memory relationships is still inconclusive.

Can Memory Be Improved?

The end result of all of this moving across categories is that humans are good at remembering a few complex chunks of information while computers are good at remembering many simple chunks of information. It is a lot easier for a person to remember four photographs in great detail than it is to remember a list of forty two-digit numbers; quite the opposite for a computer.

Also, because we form memories through consolidation, attention and emotional arousal work together to determine what features of an event are important, and therefore what features will be remembered.

From a practical perspective, that means that we can remember something best if we learn it in a context that we understand, or if it is emotionally important to us. It is a lot easier to remember that the hypophysial stalk connects the hypothalamus to the pituitary gland if you already know a lot about neurobiology. But it's also an easy fact to remember if you've ever had a loved one who suffered from a tumour near that part of the brain.

Mnemonic strategies, contextual learning, repetitive rehearsal, and emotional arousal are all good ways to ensure that we remember the things that are important to us. By focusing our learning strategies on the strengths of the brain's memory systems, we may be able to learn more information in a shorter amount of time in a way that is useful to our lives. This is referred to as accelerated learning.

This focus requires understanding the limitations of our memories; the human brain is not good at remembering long lists of unrelated numbers, dozens of nonsense words, or lengthy grocery lists. While the brain has an extraordinary ability to remember many events in rich detail, the neurologically appropriate strategy for life's most mundane memory tasks may require little more than pen and paper or, these days, computer and software.