05a | Introduction

In this module we're going to be talking about memory structures. Memory is probably one of the most studied areas in cognitive psychology, the reason being is that memory enters into almost every cognitive activity that we do. Memory is obviously involved when you're sitting in an exam and thinking hard and trying to recall that information that you studied for that test. However, other activities also involve memory. For example, if you're playing a game of Texas hold 'em poker, you need to remember all the rules of the game, you need to remember how much to bet if you're the small blind, or if you're the big blind, and which is the better hand to have, a full house or a straight. Even very simple tasks, like carrying on a conversation with someone, are highly dependant on memory. When someone speaks a sentence to us, we have to keep in mind the beginning of that sentence while we process its middle and end. Furthermore, we have to remember what they said maybe one or two minutes before, in order to understand the context of what is being said now. As you can see from these examples, memory is central to pretty much every cognitive activity that we have.

What researches have found over the years is that memory can actually be broken down into many small subcomponents, each with its own abilities and capacities. How these subcomponents operate is what we're going to focus on in this module. We're going to begin this module by talking about different memory stores, that is, places in our mind that store information for a specific amount of time. We're going to start off by talking about sensory memory – that is, the briefest area of storage – then move on to short-term and long-term memory. We're then going to talk about working memory, which is just simply a more expanded version of short-term memory, and then move on to episodic and semantic memory – and here, episodic and semantic memory is just another way of actually further breaking down the types of information that are stored in long-term memory. And then we're going to finish off this module by talking about neurological studies of memory, as neurological studies of memory have been very useful in helping researches not only understand the human mind in general, but memory in particular.

Even though we're not going to get into neurological studies of memory until later on in this module, I think it's worthwhile to expose you briefly to the case of Clive Wearing, an individual who, after a bout with encephalitis has experienced profound memory deficits. When you watch the video of Clive Wearing, think about those things that seem to be spared, and those things that seem to be particularly affected. For example: he can still play the piano beautifully, he can still conduct the choir, he can still sing – those abilities obviously rely on some form of memory. However, he can't remember what happened five minutes ago, and he can't go outside alone, because he would quickly become lost and unable to find his way home. You see, every time he sees his wife, it's as though it's for the very first time. In this module, we'll try to explain some of these phenomena. We'll try to explain how you can have different types of memory, and some things can be affected by certain types of deficits, where as others will not –

they can be spared. So, before we go on with the rest of the sections of this module, and before we begin talking about the different sub-components of memory, do take a look at that Clive Wearing video, as it will help you gain some insights into the different types of memories that we have. We will be referring to this case of Clive Wearing throughout this module.

05b | Sensory Memory

Before we talk about the different types of memory we need to go through a couple important terms. These terms are relavent for all the different types of memory that we're going to be talking about. First off, when we talk about memory, we're going to be talking about the encoding of information and the retrieval of information. Encoding simply refers to how information is acquired, and it occurs when information is first translated into a form that other cognitive processes can use – that is, how is it that you get information into your mind. Retrieval, on the other hand, is simply calling to mind previously stored information, that is, once you have information stored in memory, after you've encoded it, how is it that you bring this information to mind? We will also be talking about storage, that is, how information is stored in memory and how it is coded in memory. And finally, we'll be talking about forgetting, which is simply when we cannot retrieve previously stored information. And again, how information is stored and how information is forgot from memory will be different depending on the type of memory structure that we're referring to.

Let's move on now and talk about memory structures. Perhaps one of the most influential models of memory, and actually referring to memory in terms of different structures or different stores, comes from Atkinson and Shiffrin in 1968. They came up with a very influential model, called the "Modal model" of memory. This Modal model of memory is represented in the following figure. You'll notice in this model that there are a number of different modules, or places where information can be encoded, stored, and retrieved from. Just to orient you to the figure, if you look to the far left side, where it has some information, and that's Jane's phone number, 751-0579, that is some information out there in the world. Now if you just simply view this information or hear this information it will be imprinted very briefly in the sensory memory system. If this is a phone number that you wish to remember, what you might do is you might rehearse it over and over again. Well, that act of conscious rehearsal of information happens within short-term memory. And, if you give enough attention to it, and if you try to rehearse it over and over again, and perhaps try to encode it into a more meaningful fashion, that information will get stored into long-term memory. Once it gets stored into long-term memory, it will basically be stored there indefinitely. This basic model, this Modal model of memory, has stood the test of time, that is, I think it's fair to say that the majority of researchers in cognitive psychology to this day believe that memory is broken up, at least loosely, into these different storage systems. In the remainder of this module, we're just going to focus on sensory memory. Then, in later sections of the module, what we're going to do is we're going to talk about short-term and long-term memory.

Now, sensory memory refers to the initial, brief storage of sensory information. For example, if you hear a telephone number, or see a telephone number, that brief instant where that information is imprinted on your mind. Now, if this sounds like what we talked about before, in perception, well that's a good thing, because a lot of researchers argue that sensory memory is just simply another form of perception. In addition, many cognitive psychologists believe that we have different types of sensory memories. Specifically, they argue that we have a different type of sensory memory for each of the sensory modalities – that is, researches believe that we may have a separate visual sensory memory, an auditory sensory memory, an olfactory sensory memory, a tactile sensory memory. However, the vast majority of research in cognitive psychology has focussed on visual and auditory sensory memory, and here, what we're going to refer to it as is iconic memory, for visual, and echoic memory, for auditory.

We're going to spend the majority of our time talking about iconic memory. A good real-world example of iconic memory is when you view a lightning strike. When you see and experience a lightning strike bolting across the sky, it feels like that actually lasts a fair amount of time. In fact, it seems to linger in our perception for a second or so. In reality, however, that lightning strike is occurring very briefly, on the order of a couple hundred milliseconds. The same thing happens when you, perhaps, write your name in the air with a sparkler, or with a burning ember from a fire. When you actually have a burning ember and you shake it in the air and write your name, it feels like you can actually see your name hanging in the air for a second or so. Of course, your name isn't floating there in the air – it's just your perceptual system. What's happening is that your sensory memory, your iconic memory, is storing ever-briefly an imprint of that image which is occurring in front of you. It's basically freezing reality for a split second. This fascinating phenomenon has intrigued cognitive psychologists for decades. When it comes to memory, however, two main questions pop up. How much information can be stored, so the amount of information that can be stored, and how long does it persist. Those central questions will come up again and again as we talk about different types of memories. So how is it that you go about testing the length of time information can be stored and the quantity of information that can be stored in iconic memory?

Well, Sperling in 1960 came up with a brilliant experiment, and we're going to walk through this experiment in some detail. So, what Sperling did is he presented participants with a brief, very brief display of a three by four matrix of letters. So, for example, in this matrix we have the letters going across the top in rows: S, D, F, G - P, W, H, J – X, C, V, and N. So what he would do is he would present displays like this very briefly, for around 50 milliseconds. Now, 50 milliseconds is fast enough that you can barely just see a flash. And then what he did is he asked participants to report just how many letters they could actually see. And what he found was is that participants could report, on average, about four or five of the letters, so four or five out of twelve. So, what you would take from this at this point is, well, sensory memory can only hold about four or five pieces of information. Well, that's not necessarily the case. When Sperling spoke to his participants afterwards, many said that they had seen all the stimuli quite clearly, but, once they started to report them, they forgot the rest. So, once the participants started to report them, it would take a couple of seconds for participants to be able to report a couple of letters, and once they had actually reported those couple of letters, they had forgotten what the whole display was. Sperling came up with a very clever condition to test to see if there was more information stored than could actually be reported in that brief amount of time. What he did is he came up with a partial report condition. The previous condition we talked about is called the whole report, where participants just had to report all of the stimuli that they had actually seen. In the partial report condition, however, participants were given a cue to report only a single row. What would happen was, was that the three by four matrix of letters was presented to participants, very briefly, again, and then it was taken away, followed by either a low, medium, or high pitched tone. If they heard a low pitched tone, they were supposed to report only the top row, if they heard a medium pitched tone they were supposed to report back the medium row, and if they heard a high pitched tone, they were supposed to report back the bottom row. Using this method, that is, when receiving a cue to only report a single row after the whole display was removed, participants could reliably report either three or four of the four letters in that row. Therefore, what Sperling showed was, was that regardless of which tone sounded, participants' reports indicated they had roughly nine out of twelve letters available in sensory memory.

Now, you might want to stop the lecture here, just to think about that for a bit. It's a bit of a complicated point, but the main idea is, is that once the display was presented and taken of the screen, if a participant can be cued on any one of those rows, and still show around three out of four average recall of the information in that cued row, necessarily, they had to have held all that information about all three rows in their sensory memory. So, we now know how much information can be stored in sensory memory. At least, when it's concerned with letters, we know that sensory memory can hold anywhere between nine and twelve letters.

So how long does information last in sensory memory? Again, we all pretty much have that subjective experience, as when we actually look at a lightning strike, we actually get this very brief imprint in our minds, in our visual perception, for a very brief moment of time. Well, sensory memory as experimentally examined in the laboratory operates on a very similar level. What Sperling did in the follow-up experiment is actually insert a delay between the time that the stimulus was presented, and the time at which participants could report, or could report back and retrieve the information that was in their sensory memories. And what he found was, was that after a delay of about one second, they partial delay advantage, that's the advantage of being cued for a single line, completely disappeared. This information is all portrayed in the following figure. In this figure, what we have here is the average number of letters recalled by a participant as a function of the delay between the presentation of the letters and the tone signalling when to recall the letters aloud. As you can see, if they were cued immediately, they'd recall between nine and ten letters. That is what was originally found in Sperling's earlier experiments. However, if they were delayed by about one second, all of a sudden their recall advantage by using this partial recall technique was down to around between five and six letters. So, after that much of a delay, after a second delay, participants were no better at reporting in the partial report technique than the full report technique. This was taken as evidence that visual sensory memory, or iconic memory, only lasts around one second. If you aren't allowed to rehearse that information or de any more meaningful encoding of that information, it will delay and it will fade away in that very brief amount of time.

Now, as I mentioned previously, there has been a fair amount of research conducted on other sensory modalities as well, such as auditory sensory memory, or echoic memory. I'm not going to go into the details of the research conducted on echoic memory, however, I will just say that it does seem to behave in a similar fashion to iconic memory, except, of course, that it's dealing with auditory stimuli and not visual stimuli.

When I introduced this module I said that we were going to be talking about different types of memory structures, and it's important to keep in mind when we talk about these things what role they all play. So, let's think about sensory memory, here. Why is it that we have sensory memory? Well, when we get into talking about short term and long term memory later on, what you're going to find out is, is that information stored in short term memory and rehearsed in short-term memory, and information that gets stored and moved into long-term memory seems to require our attention to it, that is, it doesn't just passively happen. Information doesn't just passively get processed in working memory and passively move on into long-term memory – while there are some exceptions to this rule, of course. But typically it takes our active participation, our active rehearsal, while sensory memory, on the other hand, doesn't require that, it just needs your visual system. So, you can see from this how sensory memory is useful from a cognitive perspective, in that in the real world it guarantees a minimum amount of time during which information given to us is available for processing, that is, this information will hit our perceptual system, and we can choose to attend to it and to have it then flow through and be processed more and more into later cognitive systems like short-term memory or long-term memory, or we can ignore it, and it will just passively fade away.

05c | Short-Term Memory

Before we begin talking about the specifics of short-term and long-term memory, I want you to participate in a small experiment. Now, in this experiment, I'm just going to simply read to you twenty words, and after I've finished reading the twenty words I want you to recall, just by writing them down on a piece of paper, as many of the words as you can. Alrighty, so here we go, lets begin: table, candle, maple, subway, pencil, coffee, towel, softball, curtain, player, kitten, doorknob, folder, concrete, railroad, doctor, sunshine, letter, turkey, hammer. Okay, press pause here for a second, and write down as many of the words as you can, in about a minute or two.

Welcome back. So what I'm going to do now is I'm going to talk about typical responses to that task. Now, I don't know how you responded, but you can look at your own sheet of paper, and you can map on how you responded to typical finds in an experiment just like this. So what happened was is I presented you twenty words, and by asking you to freely recall them, you probably showed a tendency to respond better on some words than the other. Specifically, you were probably more likely to remember words that were presented at the beginning and end of the list, rather than those that were presented at the middle of the list. So, if you look at the following figure, this is called a serial position effect. On the X axis is the serial position, for example, the first word in the list would be "table," and the twentieth word in the list would be "hammer," and the tenth word in the list would be "player." And on the Y axis is the probability of correct recall. So, why am I showing you this, now? Well, the reason is that the serial position effect has been taken as evidence for separate short-term and long-term memory systems. Specifically, the finding that people are typically better able to remember the last few items in a list, also referred to as the recency effect, is thought to reflect short-term memory processes. The reason being is that people typically try to off-load those items form short-term memory first. After you've off-loaded the contents of short-term memory, then you try to drudge through and get that information that made it into long-term memory, and that is typically items that were first presented in the list, and that is the primacy effect. So, to understand how this works, think about how you might have done this task. Typically what happens is, when the experimenter is reading the words, the participant begins rehearsing them right away. So, for example, when you hear "table, candle, maple, subway," you're likely to encode those words and rehearse them over and over again in short-term memory, and since you're giving a lot of attention to them, you're liable to get them into long-term memory. However, what happens is as more and more words come in, you're not able to do that for all of them. So, the first few words get into long-term memory, and then, once you get to the end of the list, since you can recall right away, what happens is that you're able to off-load those last few items like "letter," "turkey," and "hammer" right away, and actually write those ones right away before they actually fade out or decay from short-term memory. And then after you do that you go back through and think through what were the original ones in the list – and to do that you need to search long-term memory.

So now that I hopefully have you convinced there are separate short-term and long-term memory systems, let's talk about the both of them in detail. First, let's talk about short-term memory, and to start this off I want to read a quote to you. This quote is from George Miller's article from 1956, published in *Psycological Review*: "My problem is that I have been persecuted by an integer. For seven years this number has followed me around, intruding into my most private data, and has assaulted me from the pages of our most public journals. This number assumes a variety if disguises, being somewhat a little smaller than usual, but never changing as much as to be unrecognizable. The persistence with which this number plagues me is far more than a random accident, there is, to quote a famous senator, "a design behind it," some pattern governing its appearances. Either there really is something unusual about the number, or else, I'm suffering from delusions of persecution." Now, what George Miller is referring to in this beautiful quote is called the "magic number seven." and what that simply is, is the maximum number of information that can be correctly recalled from short-term memory. And through a variety of experiments – doesn't matter is it's letters, digit spans, spatial discrimination, tone discrimination – what has typically been found is that people can remember, on average, around seven, plus or minus two, bits of information. Importantly, this amount of information, this seven, plus or minus two, bits of information, can be increased dramatically by what is referred to as "chunking." So, for example, try to recall the following items, in order: F, B, I, P, H, D, C, F, L, I, B, M. Chances are, when you try to recall those items, you could probably remember around six or seven of them. Now, try to recall the following items: F B I, P H D, C F L, I B M. Now here, chances are, you're probably able to remember all of them, even though they have the same number of letters: twelve letters. However, in this case, they were organized into meaningful chunks. These acronyms, FBI, PHD, CFL, and IBM, allow you to meaningfully group, chunk, or code this information, so that you can move past the typical limitations of short-term memory. This linguistic recoding of information requires the use of long-term memory in conjunction with short-term memory. So, what happens here, is you make use of what you know in long-term memory, to organize and structure information so that it can be more efficiently coded and stored and rehearsed within short-term memory. So, what happens then is no longer does the letter become the unit of storage and representation, but because it is grouped into a meaningful chunk, that new chunk becomes the unit of information to be stored.

So, so far we have established that there are separate short-term memory and long-term memory stores. And we've talked a little bit about, now, how much information can be stored in short-term memory, that is, around seven, plus or minus two, bits or chunks of information. Now we're going to spend a little bit of time talking about how information is thought to be forgotten in short-term memory. Now, when we talk about forgetting, whether it be in short-term memory, or in long-term memory, for that matter, there are two main theoretical approaches. One is trace decay, and that is the automatic fading of the memory trace, and the second is interference, and that is the disruption of the memory trace by other traces, where the degree of interference depends upon the similarity of the two memory traces. We're going to focus predominately on interference theory, as that, is seems, is the most predominate view of how forgetting happens in short-term memory, and again, we talk about long-term memory later on. So, when we talk about interference, there are two different types of interference. There can be proactive interference, where old information makes it difficult for you to acquire new information, and there is retroactive interference, where new information makes it difficult for you to recall old information.

So, let's just put this into some real-world terms. So, imagine the case where you just got a new phone number, and you're trying to remember your new phone number, trying to give it to other people, but every time you try to remember your new phone number, your old phone number just pops into your mind. Well this is proactive interference, that old information is making it difficult for you to recall new information, or to learn new information. After a while, however, once you've efficiently encoded your new telephone number, it would become difficult for you to remember your old telephone number. That is retroactive interference, where that new information, that new phone number, makes it difficult for you to recall that old information, or that old telephone number. When it comes to short-term memory, it seems that both trace decay and interference likely play a role. The experiments that have been used to support this have typically involved what is referred to as the "Brown-Peterson paradigm." Here, participants are presented with a three-consonant trigram, such as the letters HLM, and then they are given a number, such as 492, and asked to count backward, out loud, by three's for a fixed rate of time. The purpose of the counting task is to prevent participants from rehearsing the trigram, and thus preventing them from getting it into long-term memory. That way, it gives a better assessment of what is going on within short-term memory. What has been shown using this task is that information decays from short-term memory very quickly. That is, if you're asked to count backwards for only three seconds, roughly 80% of participants can recall the trigram. However, if you're asked to count for around eighteen seconds, this drops way down to around 7%. That is, after only eighteen seconds of counting backwards by threes, if you cannot get that information out of short-term memory, it's gone.

However, shortly after this original work, a lot of researchers challenged the idea that forgetting in short-term memory was just due to trace decay. They argued, rather, that you could account for forgetting in the Brown-Peterson paradigm with interference. They just argued, however, that the task that the original authors used wasn't deigned efficiently enough to tap into that interference. Now, recall when we introduced the idea of interference, that the degree of interference depends entirely on how overlapping, or how close, the two different pieces of information are. If the two pieces of information are very similar to each other, they're more likely to interfere with each other. So, for example, an old phone number is going to make it difficult for you to learn a new phone number, however, it's not going to make it difficult for you to learn a new postal code. What Wickens, Born, and Allen did is they designed a modified Brown-Peterson paradigm that switched categories after a few trials. The idea being is that if you switch categories what you can find is something called release from proactive interference. So, the study was conducted as follows. So, recall in the original Brown-Peterson paradigm, participants were simply given a three-letter trigram and then had to count backward from a specified number by three. What Wickens, Born, and Allen did, is they extended this paradigm by having participants repeat this over and over again. Critically, however, when they received repeated trials, sometimes the trials were of a different category type. So, for example, in the control condition, all the participants had to do was either remember letter trigrams or number trigrams. In the experimental group, however, the categories would switch. So, for example, they may receive a letter trigram for the first couple, and then it would switch after either four, seven, or ten trials, to a number trigram.

So, let's look at the data here. What was found? So, if you look at the Y axis, what we have there is percent correct recall, and if you look at the X axis, we have the number of trials. The solid lines represent the control condition, that is whether they just received letters or just received numbers. And, what you see in both of these conditions is that there is a significant drop off, from around 70% down to around 10% for letters and down to around 40% for numbers, and then it pretty much levels off. The dash lines, however, represent the experimental conditions when that information was changed. So, for example, if you received numbers first, the category would have been changed to letters, or if you received letters first, the category would be changed to numbers. And what you can see here, right off the bat, is when participants' categories were changed, in this very simple Brown-Peterson paradigm, performance went right back up to ceiling again. That is, even though they were previously exposed to a trigram, because that trigram was categorically different, it did not interfere with their ability to learn that new trigram. As you can see, this is a very complicated study, and what I'd do is I would recommend that you go through this in the text a couple of times, just to make sure you understand the details.

05d | Long-Term Memory

Okay, let's move on to long-term memory. So, we'll return to the Modal model here and what we see is that we've already talked about sensory memory, and that is the very brief, kind of perceptual experience that is when you first experience some stimulus in the environment. Then, if you attend to that information, it goes into short-term memory. And here, short-term memory, again, is a very short term store where you can hold about seven, plus or minus two bits or chunks of information, and if you do anything further, if you encode that information any further, or rehearse it over and over again, it can get into long-term memory, and long-term memory is this relatively permanent storage facility for all information. We're only going to briefly talk about long-term memory, here. We're going to talk about the capacity of it, the coding, how information is coded in long-term memory, how long it might last in long-term memory, how forgetting is thought to happen, and then encoding and retrieval processes. We're going to return to long-term memory in later modules of this course.

So, first let's talk about the capacity of long-term memory. Well, it's hard to guess how much information can be stored in long-term memory. In fact, it could store a potentially infinite amount of information. For example, every experience you've ever had is somewhere, stored in long-term memory. Every word that you know, and the associated meaning with that word, is stored in long-term memory. The important thing about all this is that not every bit of information in long-term memory can be easily retrieved at any given time. That is, there's information stored in long-term memory that we have long lost easy access to. However, just because we can't easily access or retrieve that information doesn't mean that it's not there. We're going to talk more about this a little bit later on, as well, too, when we talk about different encoding and retrieval strategies.

So, moving on, now – how is long-term memory coded? Well, researchers have discovered that long-term memory is likely coded in terms of semantics – that is, in terms of meaning – and this is one way in which long-term memory is different than short-term memory. Short-term memory is thought to be based on, or is thought to code information based on, acoustic properties or visual properties – that is, very superficial or low-level features – whereas long-term memory codes information based on deeper semantic, or meaningful, features. So, how long can information last in long-term memory? Well, researchers think that some information might be able to stay in long-term memory relatively permanently. As you can imagine, it's very difficult to conduct a study where you test the duration of long-term memory, of course, because it's going to last a very, very long time. Bahrick, in 1984, did conduct such a study. Now, what he looked at was the retention of Spanish language information from 733 adults who had taken or were taking, a high school or university course in Spanish, and he looked at the retention of this information for up to fifty years. What Bahrick found is pretty startling, and it's highlighted in the following figure. On the Y axis it shows the percent of original score, that is, it's a measure of their Spanish language knowledge. On the X axis, it's the measure of the lag time, or the duration, and it goes from right from when they finished taking the class, and all the way up to 49 years and 8 months. Now, the important thing to look at here is not what each of the different lines represents, but the fact that they all pretty much follow the similar pattern. There's a significant drop from around 100% to around 40% after the first 2 years, 2 months, and then it pretty much levels off and remains flat – that is, there really is not much forgetting after the first initial couple years. Because of this, Bahrick coined the term "permastore" for long-term memory, and that is because large portions of this originally acquired information remained accessible for over 50 years, in spite of the fact that it was not used or rehearsed. This study by Bahrick also demonstrates a well-known phenomenon about forgetting in general, that is, initially, forgetting seems to happen relatively rapidly, but then it tapers off.

So, what causes forgetting in long-term memory? Well, again, we can bring back those same two things that we talked about before when we talked about short-term memory: trace decay and interference. And likely, both of those things have something to play in long-term memory as well, however, the vast majority of research has focussed on interference theory. And specifically, with the case of long-term memory, on the use of retrieval cues, and what a retrieval cue is, is it's a point to recover a target memory. And we use these all the time. They're kind of like putting a sticky note on your computer monitor, as a reminder to do something. The more unique retrieval cues you have for a given target memory, the more memorable that item will be. However, if you have retrieval cues that are associated with multiple memories, then that item will be less memorable, and the reason it's less memorable is because of interference, that is, interference among multiple targets being associated with a single retrieval cue. That is highlighted in the following figure, taken from the textbook. In this figure, it shows an episode of you trying to find your car, parked in a parking lot. However, the problem is that you have a single retrieval cue, that is, you sitting in this familiar parking lot on a Thursday at noon, however, since you often come to this parking lot on a Thursday at noon, that retrieval cue is not very good discriminating cue, and as such, it activates multiple parking locations. This association between a retrieval cue and a target memory highlights a very important concept about long-term memory – that is, in order to correctly recall information from long-term memory, you need to have a very powerful and uniquely associated retrieval cue.

So, what makes a good retrieval cue? This brings us to the encoding and specificity principle – probably one of the most important principles in cognitive psychology – and what this states is that recollection of an event or a certain aspect occurs if, and only if, properties of the trace of the event are sufficiently similar to the retrieval information. What this basically means is that recollecting information, or retrieving information, is kind of like reliving that original encoding experience: you bring yourself back into when you originally experienced the event at retrieval. The power of the encoding specificity principle can be demonstrated in a number of ways. One such way is by looking at context-dependent memory, that is, information learned in a particular context is better recalled if recall takes place in that same context. This brings me to one of my favourite studies. Gaudin and Baddeley wanted to look at the effect of encoding specificity in general, and context-dependent memory in particular, in the context of a very powerful cue, a very salient cue, that is, environment. So what they did was they took a bunch of professional scuba divers, and asked them to learn lists of words either on land – on the shore – or underwater. Then, after they encoded this information, they gave them a memory test, and they either did this memory test on land or underwater. What they can do, then, is they can cross these conditions – they can look to see whether having a test and the study in the same location is beneficial. And the following figure clearly shows that it is. What we have here is a perfect double dissociation. On the Y axis we have the percentage of words recalled correctly, and on the X axis we have recalled on land vs recalled underwater, the solid lines represent those words that were learned on land, and the dash line represents those that were learned underwater. So, first let's look down at the X axis there, and let's focus on the "recalled on land" words. What you can see here is that those words that were studied on land were much better recalled on land. And then we'll move over on the X axis to "recalled underwater," and what you can see here is that those words that were studied underwater, or learned underwater, were recalled better than those that were learned on land. So, in summary, the best recall happened when the encoding conditions mapped onto the retrieval conditions. Put another way, the environment, or the location, served as an appropriate retrieval cue for that retrieval of information from long-term memory, and, relating this to the encoding specificity principle, likely what is going on here is that by reinstating that individual into the same experience where they encoded that information, all those retrieval cues surrounding that original encoding of information are there, available to be used, at retrieval. If, on the other hand, the encoding and retrieval conditions don't match up, so, for example, if a participant learned the words on land and were tested underwater, then the appropriate retrieval cues just simply aren't present, and thus, memory for those words is less accurate.

05e | Working Memory

In the previous sections of this module, we discussed the characteristics of short and long-term memory. We're now going to unpack short-term memory a little bit more, and what we're going to see here is that short-term memory is a little bit more complex than what we originally thought. In the original formulation of short-term memory, which we talked about previously, by Miller, is that short-term memory was simply a short-term storage device, and that it could hold around seven, plus or minus two, bits of information. Since the time of Atkinson and Shiffrin, though, in 1968, with their Modal model, what we've discovered is that short-term memory can do much more than that. For example, it's been equated with consciousness, that is, any piece of information that you hold in your mind at any given time, can be thought to reside within short-term memory. In addition, it is also thought to be the place where various cognitive control processes happen, that is, it's the place that governs the flow of information into, and out of, consciousness. One of the first key studies that showed that short-term memory was more than just a temporary storage facility, that is, an area that can only hold seven, plus or minus two, bits of information, was conducted by Baddeley and Hitch in 1974. The general idea of this study was that they had participants perform two tasks at the same time, and I'll walk you through what these two different tasks were. So, in one task, what they did is they had participants hold in their mind either zero, two, four, six, or eight digits. So, for example, in the six digit condition, they could be given the following numbers: 4, 8, 5, 3, 7, 2, and were told to hold that in their mind. Now, importantly, based on what we think that we've known about short-term memory, before this time, was that that should pretty much tie up all the short-term memory resources, and not leave anything left over for any other sort of other processing that might require short-term memory. Now, what Baddeley and Hitch did, however, was that they had participants also do what is known as a syntactic verification task, that is, participants were also presented with a very brief statement, and asked to verify whether it was true or false. So, for example, they could be given "A follows B," and then shown "AB," and what the participant's task was was to judge whether the answer "AB" was correct, given the preceding statement. In the example I gave you, that would be false, because, for example, in the statement "A follows B," "AB" is not correct, it should be "BA." Then, after they verified that statement, then what participants needed to do was to recall the numbers that were presented beforehand. So, to reiterate, in this experiment participants were first given a series of numbers, and this series of numbers would range from zero to eight, and this is called the concurrent digit load, and then, while they're holding those digits in memory, they had to judge whether a given answer necessarily followed from a given statement. Then, after they judged whether the answer was correct or not, they had to recall the numbers.

So let's look at what they found. So, if you look at the following figure, on the X axis what we see is the concurrent digit load, that is, how much information, or how many digits, the participants had to hold in mind when judging the statements. On the Y axis to the left we have reasoning time in seconds, and that is how long it took participants to answer that syntactic verification question, and on the right we have percentage errors, that is, how many errors did they make in that syntactic verification task. The line with the open circles shows us their reaction times, and the line with the closed circles shows us their error rates, as a function of concurrent digit load. And what we can see here is that although it took people longer to respond to the syntactic verification task as a function of increasing concurrent digit load, percentage of errors remained flat, that is, whether participants had a zero digit load, or a digit load as big as eight, it did not increase the number of errors people made in the syntactic verification task, although it did slow them down. Now, these findings are really important, because what they show to us is that that previous conception of short-term memory as just the storage receptacle for seven, plus or minus two, bits of information is not entirely correct. If that was correct, participants, while holding that digit load in mind, should not be able to do the syntactic verification task – that is, errors in the task should have raised dramatically. However, what we see is that participants can quite easily actually carry on these two different tasks at the very same time. So, why is that the case? Well, researchers now think that that old idea of short-term memory – that it's just a very small storage receptacle for a very limited amount of information, that is, seven, plus or minus two bits of information – is incomplete. Rather, researchers have argued that we have what is called a "working memory." This working memory system is thought to consist of a limited capacity workspace that can be divided between storage and control processing. Specifically, Allan Baddeley, in a series of papers, conceived of working memory as consisting of three components. The first is the central executive. The central executive can be thought of more as an attentional system, rather than a memory system, per se, and what it does is it directs information to and from the two different sub-systems. These are the phonological loop and the visual-spatial sketchpad. The phonological loop is thought to carry out sub-vocal rehearsal and maintain verbal information, while the visual-spatial sketchpad is thought to retain visual material, through visualization. Importantly, these two sub-systems, the phonological loop and the visual-spatial sketchpad, can function relatively independently, that is, you can carry out a task that uses resources in the phonological loop and it won't really impact processing that's going on in the visual-spatial sketchpad, and vice-versa. Let's think about, now, those results of Baddeley and Hitch that we talked about previously, in terms of this more complex working memory model. You'll recall, in that experiment, holding on to these digits in mind didn't really impact the participant's ability to carry out that syntactic verification task. Granted, it slowed them down, but they didn't produce any more errors whatsoever, so they were able to do it. Well, holding those digits in mind would take resources in the phonological loop, that is, you'd have to take those numbers, store them, and likely rehearse them sub-vocally over and over again in your mind. Now, consider the syntactic verification task. In that task, participants are given a statement, such as "A follows B," ad then an answer, "AB," and then simply asked if that answer was correct given the preceding statement. Arguably, a portion of this task does require verbal information, and likely does tax, to some degree, the phonological loop. However, the majority of resources to solve this task likely require some form of visual-spatial processing. You have to look at the letters and decide if they are in the correct spatial orientation, given the preceding sentence. Judging whether they are in the correct spatial orientation would likely tax resources in the visual-spatial sketchpad. So, as the concurrent digit load likely taxes resources in the phonological loop, and the syntactic verification task likely taxes resources in the visual-spatial sketchpad predominately, these two tasks can be carried on relatively independently and do not interfere with each other to a great degree.

Now, as we leave this discussion of working memory, it's probably a good idea to stop and spend some time thinking about some daily mental activities that you might do that take resources from the phonological loop versus those that might take resources from the visual-spatial sketchpad. For example, reading a book or talking on the phone utilizes resources from the phonological loop, whereas, trying to picture in your mind what you had for dinner last night, or simply doodling a picture in your notebook, requires resources from the visual-spatial sketchpad. Given that, you can probably, without too much interference, talk on the phone while doodling a picture in your notebook. Rather, if you try to talk on the phone while reading a book, it may prove highly difficult, because those two tasks will compete for the same resources in the phonological loop.

05f | The Semantic/Episodic Distinction

In this final section of the module we're going to talk about episodic and semantic memory, as well as neurological studies of memory. And the reason we're going to be talking about them together is that a lot of the evidence for episodic and semantic memory comes from neurological studies of memory. So, in the previous section we talked a bit about working memory, and that helped us understand a little bit about how information is stored for very brief amount of time, and how it is that we can store multiple different types of information. Well, researcher have found out that long-term memory works in very similar ways, that is, we can store multiple different types of information in long-term memory. Now, a lot of this work really was pioneered by Endel Tulving in the seventies, and what he found was one of the biggest distinctions in long-term memory, was that it contained two distinctive, yet interactive systems, called episodic and semantic memory. Episodic memory contains information about one's personal experience, and memories here are a specific time and date attached to them, or they are temporally organized. For example, if you look back and think about what you were doing on your last birthday, or, even a more traumatic and significant event, like, perhaps what you were doing on September 11th in 2001. When you attempt to remember those things it's like you are actually going back in time and reliving those original experiences again, and again, that is the defining feature of what is episodic, or autobiographical, memory. Now, to be contrasted with this, is semantic memory. Now semantic memory is just our general knowledge base, that is, information about language and the world. It seems to be organized around meanings – for example, facts, concepts – rather than temporally organized. So, for example, knowing that Paris is the capital of France doesn't require you to actually go back in time and relive the original encoding experience of when you actually learned that fact. However, you can retrieve that fact from memory without having any sort of episodic or autobiographical recall. Rather, it just simply comes to mind.

05g | Neurological Studies of Memory

Now, some of the most powerful evidence for these two different memory systems comes from neurological studies of memory, and when we talk about neurological studies of memory what we're really talking about is patients who have suffered damage to the hippocampal system, and that is the hippocampus and amygdala, and related nesial structures around those areas, due to head Injury, stroke, brain tumour, or disease. And what these studies have shown is that patients may show very selective impairments in memory. For example, Dan Schacter talks about the case of Jean, who had a motorcycle accident at the age of thirty, and because of this accident he suffered damage to his frontal and temporal lobes, including the hippocampus. And what he found was that Jean has preserved intellectual functioning, so, for example, average intelligence, average memory span, language, and normal vocabulary – these are all things that would be subsumed under semantic memory. Critically, however, he seems to have lost his episodic memory. He doesn't remember his brother's death, which would have been a very traumatic event for him, years before. He doesn't know how he broke his arm, etcetera. He can't remember critical life events that have happened to him – that is, any sort of information that has a time stamped to it, information that would require him to go back and re-live that original encoding experience to recall it, can't be done. However, his knowledge of facts, that is, information that is stored in semantic memory, seems to be relatively intact. The case of Jean can be contrasted with another case than Dan Schacter talks about, of a woman who, because of encephalitis, suffered damage to the front temporal lobes of her brain, and because of this damage to the temporal lobes, she lost semantic memory. She forgot meanings of common words, cannot recall basic attributes of objects. However, she seems to have completely intact episodic memory. For example, she remembers her wedding, her honeymoon, her father's death, and, importantly, she can produce lots of verifiable details about these events. So these are two examples of patients that both have had damage done to the brain, damage to areas known to affect memory, that show completely dissociable disorders of memory, that is, one patient can show intact semantic memory but damaged episodic memory, and another patient could show damaged episodic memory and intact semantic memory.

This brings us now to two general classes of amnesia that I'd like to talk about. These are anterograde amnesia versus retrograde amnesia. Now these two amnesias are not to be dissociated from episodic and semantic memory deficits we just previously talked about – that is, you can have an episodic memory deficit that is anterograde in nature, or, you could have an episodic memory deficit that is retrograde in nature. So let's first talk about anterograde amnesia. Now, anterograde amnesia is the inability to form new memories, that is, after you have an event – now this could be a traumatic brain injury, disease due to encephalitis, a stroke, or anything like that – so you have a traumatic event and you're unable to learn new information. Typically, this anterograde amnesia affects episodic memory, but not semantic memory, that is, your memory for general knowledge typically remains intact, so does your skill performance. So, for example, if you knew how to ride a bike before, after a traumatic event that caused brain damage to, typically, the hippocampus region in the temporal lobes, what you would find is that you can still ride a bike after that. It only affects the formation of new, explicit, episodic memories. So, recall in the beginning of this module, when I talked about the case of Clive Wearing. Well, hopefully you watched the videos of Clive Wearing, and what you would see n those movies is that every day to Clive is like a new experience. If you walk out of the room and come back a couple of minutes later he will forget that he had any interaction with you at all previously. However, his skill set remained unaffected. He could still play the piano beautifully, he could still conduct a choir – all those things, again, which of course require lots and lots of exposure to information to learn that, remained intact. This form of amnesia can be contrasted with retrograde amnesia. In retrograde amnesia you have loss of memory for past events. So, for example, after a traumatic head injury, what you could experience is loss of memory for past events prior to that injury. However, you would still be able to learn and encode new autobiographical events post-injury. And just like anterograde amnesia, it doesn't affect overlearned skills, such as general social skills, or language, and procedural knowledge. That type of information remains intact. And, when comparing anterograde with retrograde, typically what you can find is that patients might experience retrograde without anterograde amnesia, however, if they have anterograde amnesia, they likely will have retrograde as well.

05h | Summary

In summary, we began this module on memory structures talking about Atkinson and Shiffrin's modal model of memory. And what they propose is that we have separate sensory short-term and long-term memory storage systems. We then moved on and talked about the characteristics of each of these systems. We began by talking about sensory memory, and what we learned there is that sensory memory is a modality-specific, brief-duration storage facility for visual, auditory, and other basic modalities of information. If that information in sensory memory is attended to, it then may pass on to short-term memory. Short-term memory has been likened to our conscious experience, that is, any information that we are thinking about at any given time is arguably within short-term memory. Originally, based on the work of George Miller, it was thought that we could hold around seven, plus or minus two, pieces of information in short-term memory, and it would remain there for around 20 seconds unless any sort of deeper rehearsal was done on that information. However, years later, work by Allen Baddeley showed that short-term memory wasn't that simple. In fact, it could be further sub-divided into three components – that is, the central executive, the phonological loop, and the visual-spatial sketchpad – in a more complex working memory model. And here we learned that the two sub-systems of the working memory model, the visual-spatial sketchpad and the phonological loop – could carry on relatively independently. We then talked about the many characteristics of long-term memory, and I'm only going to focus on one in this review, because I think it's the most important one, and that was the encoding specificity principle, and what we learned here was that recall of information will be made easier if the recall context is the same as the learning context. And then, in the final sections of this module, we further broke down long-term memory, and talked about neurological studies that supported these distinctions. For example, we talked about episodic and semantic memory, where episodic memory is memory for information about one's personal experience, and semantic memory is memory for general-knowledge-based information, such as facts and concepts. Evidence for these two different types of memory systems comes from neurological studies, which has shown that you can have a patient that has selective brain trauma that can show a deficit in episodic, and not semantic, and vice-versa.