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How Memory Works—and How to Make It Work for You, by Robert Madigan.
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Four Ways of Remembering

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Our modern understanding of memory began on August 25, 1953, when a reckless neurosurgeon performed a radical operation on a twenty-seven-year-old Connecticut man who suffered from epilepsy. The patient's name, Henry Molaison, wasn't made public until his death fifty-five years later, but his initials, H. M., were known by generations of memory researchers. He is one of the most famous medical patients of all time because the crippling effects of his operation led to revolutionary insights about the nature of human remembering.

H. M.'s epilepsy resulted from a childhood bicycle accident and gradually became worse so that by the time of the surgery he was enduring ten blackouts a week and occasional full seizures. His family doctor referred him to a hospital in Hartford, Connecticut, where he was seen by William Scoville, a well-known neurosurgeon.

Scoville's particular expertise was in lobotomies, a surgery that involved cutting nerve fibers to and from the front of the brain. He had performed more than 300 of these operations on patients with serious psychological disorders like schizophrenia. It is a controversial procedure, one long since abandoned. Although it sometimes calmed agitated patients, it could also leave them zombie-like and unable to carry out normal daily activities. As it happened, Scoville was trying out an alternative to the standard lobotomy when H. M. came under his care.

Scoville believed that surgery on a region of the brain called the limbic system might produce fewer side effects than traditional lobotomy, and he had special interest in a structure called the hippocampus. At the time its function was unclear—possibly something related to emotion or smell.

Based on little more than a guess, Scoville focused on the hippocampus for H. M.'s treatment. Surgical interventions for epilepsy remove or isolate specific brain areas to disrupt the uncontrolled neural signals that cause seizures. Following this approach, Scoville made plans to excise H. M.'s hippocampus. A colleague with experience in treating epilepsy warned Scoville that the operation was unlikely to help and carried significant risk for the patient. Scoville was undeterred.

Removing either of the two hippocampi—there is one on each side of the brain—would not have been disastrous, but inexplicably Scoville elected to excise both, along with surrounding tissue, thereby ensuring that the functions performed by these structures could no longer occur. A disastrous outcome became apparent as soon as H. M. arrived in the recovery room, where he immediately showed severe memory problems. And there was more bad news. The very next day, the seizures began again, although they were not as frequent.

To Scoville's credit, he didn't try to hide his error. He contacted Wilder Penfield, a neurologist renowned for his work on epilepsy, and told him about the operation. At first Penfield was furious, but he realized the important implications the case held for science. He passed word to the psychologist Brenda Milner, a researcher experienced in amnesia. She immediately made arrangements to study H. M.

The results of her tests were unambiguous: H. M. was unable to form new memories. As Milner told a reporter later, "this was an intelligent, kind, amusing man, but he couldn't acquire the slightest new piece of knowledge. He lives today chained to his past, a sort of childlike world. You can say his personal history stopped with the operation." The first detailed description of H. M.'s impairment appeared in a 1957 issue of the *Journal of Neurology, Neurosurgery and Psychiatry.* It provided an astonishing account of H. M.'s handicap.

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> This patient's memory defect has persisted without improvement to the present time, and numerous illustrations of its severity could be given. Ten months ago his family moved from their old house to a new one a few blocks away on the same street; he still has not learned the new address, though remembering the old one perfectly, nor can he be trusted to find his way home alone. Moreover, he does not know where objects in continual use are kept; for example, his mother still has to tell him where to find the lawn mower, even though he may have been using it only the day before. She also states that he

> will do the same jigsaw puzzles day after day without showing any practice effect and that he will read the same magazines over and over again without finding their contents familiar. This patient has even eaten lunch in front of one of us (B. M.) without being able to name, a mere half-hour later, a single item of food he had eaten; in fact, he could not remember having eaten at all.

Remarkably, though, Milner's careful testing showed that H. M.'s mental functions other than memory were unchanged. His IQ was 112, about the level of a typical college student. His memory for events prior to his surgery was vivid and intact, and he often talked about these earlier times. He showed no difficulties with comprehending abstract ideas, solving reasoning problems, and making arithmetic computations.

In addition, H. M.'s short-term memory—the ability to retain a phone number while dialing it or to remember a thought long enough to express it—was unharmed. This demonstrated to the researchers that the short-term memory system was separate from the one controlled by the hippocampus. His functioning short-term memory allowed H. M. to use language and converse normally except for his profound forgetfulness. It also allowed him, within limits, to be reflective and observant. He knew he had a memory disability due to an operation, and he was aware of the constant challenge to find clues in the environment to guess what was expected of him and what he needed to do next.

Milner's ongoing work with H. M. uncovered another surprising facet of his handicap. In the early 1960s she decided to find out if H. M. could learn new manual skills. She gave him the task of tracing over a geometric figure while he watched his hand in a mirror. This is tricky because the mirror image is left–right reversed, but with practice people learn how to do it. Milner reasoned that any improvement by H. M. would show that he remembered eye–hand motor skills. She gave him several opportunities to trace the figure on three different days.

The graph on the next page shows his progress.

Every day that he worked at this challenge, he improved, and after three days he was doing quite well, tracing the figure more accurately and doing it in much less time. Despite his growing skill, however, H. M. had no conscious memory of ever having done it; each day he approached the task as if he had never laid eyes on it before. His memory for life events was decimated, but his memory for eye–hand coordination was operating normally.

This experiment dramatically revealed the presence of separate

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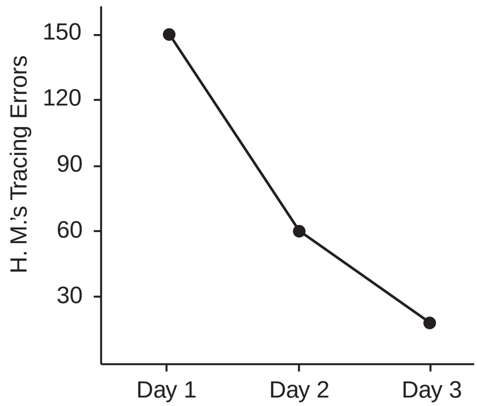

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memory systems for different kinds of human experience. The idea was not itself new; psychologists traditionally distinguished between short- and long-term memory. But beyond that there had been no compelling evidence for any other specific form of memory. Now there was.

At first the researchers believed that motor skill was a special case, a complement to a general long-term memory system assumed to store all other kinds of past experiences. However, as research efforts pressed on, study by study, decade by decade, a different picture emerged, one that now includes several forms of long-term memory that range from major systems visible in daily activities to subtle, esoteric systems handling specialized situations. Four of these systems are important players in the coming chapters, each a distinct form of long-term memory, a distinct way of retaining the past.

H. M.'s surgery affected two of the four memory systems: his "episodic memory," the ability to remember new "episodes" or life events like eating lunch or reading a magazine, and his "semantic memory," the ability to retain new facts about the world like the names of H. M.'s attendants or the layout of his living space.

Remembering Experiences and Remembering Facts

The distinction between these two systems was first made in the 1970s by the eminent memory researcher Endel Tulving; it has since become a foundation for modern views of human memory. Tulving proposed that episodic and semantic memory systems differ from one another not only in the information they retain but also in how we recall it.

In the case of episodic memory, remembering involves traveling back in time and reexperiencing what happened earlier. Think about the dinner you had last night. Can you go back to that time? Were you sitting at a table? What did you eat? Was it tasty? Did you get enough? Did you use a napkin? What happened with the dishes when you were finished? To answer these questions, you must access a specific episodic memory by mentally returning to the scene and finding remnants of the sights, sounds, tastes, and feelings from that time. Notice how readily you were able to retrieve aspects of the dinner as you focused on the table, the dishes, and the food, recapturing different parts of that experience. For Tulving, the sense of returning to an earlier event and reexperiencing it is the defining property of episodic memory, one that distinguishes it from semantic memory, our storehouse of facts.

Now try recalling a semantic memory by saying to yourself the name of the first president of the United States. Do you know the number of pennies in a dollar? The capital of France? The colors of the American flag? These facts probably came instantly to mind, appearing in consciousness more quickly than yesterday's meal. The retrieval was also a very different experience. This impersonal information—not linked to the specific place and time when you acquired it—lacks the sensory richness of episodic memories. Ask adult Americans just exactly how they learned that George Washington was the first president and you get blank looks. It's just something they know. We all have a rich store of semantic memories—facts, concepts, names, terms, and more—potentially useful bits and pieces of knowledge long separated from when and where we encountered them and ready to move into consciousness when needed.

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Time Traveling via Memory

It is mental time travel that gives episodic memory a qualitatively different feel from semantic memory. Locating a past experience in time is a sophisticated cognitive achievement. It starts with our sense of time, which itself is an advanced ability. Children are almost school age before they have a solid grasp of the present as a point in time flanked on one side by the past and on the other by the future. But episodic memory requires one more step, an even more impressive mental calculation: the ability to return to a moment in the past and reconstruct it from a personal perspective. This feat is important because it clarifies what in fact does the traveling in mental time travel. It is our sense of self that moves back on a timeline to the desired memory, and we accomplish this without losing the vantage point of the present. When you come across pictures of a trip you took last summer, you may pause for a moment to allow your episodic memory to take you back to the adventures of that time, remembering specific experiences, reliving what you did and felt, what you saw and heard, before returning to the present and going on with the day.

The self is not limited to traveling backward; it can also journey forward to the future. Indeed, in Tulving's view, the episodic memory system is as much about our projecting our imagination into the future as it is about reliving the past. Not only can we remember a previous trip; we can also plan a new one. Planning, anticipating, and daydreaming are similar to recalling, reviewing, and reminiscing. And the two faculties are linked. Children develop the ability to time travel in both directions at the same age, usually around five. Older adults who have trouble remembering recent happenings also have difficulty imagining the future.

Episodic memory is our most sophisticated memory system. Its intricate workings probably explain why it is the last memory system to appear in childhood, the first to decline in old age, and the one most vulnerable to disease, head trauma, and lack of oxygen. The complexity of episodic memory has led scientists to wonder whether other animals also experience it. Tulving believes that this kind of memory is fully developed only in humans and that other animals know the past in a more limited way.

Connecting Facts

The unique value of episodic memory in no way diminishes the contributions of semantic memory, which is our knowledge base, our dictionary, our own private Google. It is more than a storehouse of facts; it also creates connections among them, so that when we recall one fact or concept we also gain access to related information. Semantic memory is thought to start with recent experiences. During sleep, these new episodic memories are "replayed" in a process that both strengthens them and identifies the associations, relationships, and patterns that become semantic knowledge—like the association between George Washington and the first presidency. But

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that's not the end of it. A newly discovered fact is also linked to related information in our network of knowledge. Once you retrieve "George Washington," you can immediately access other facts you learned about him at different times. You know he was the American general in the Revolutionary War, the young boy who couldn't lie about the cherry tree, and the face on the dollar bill. This is the great contribution of semantic memory. It's not only about facts; it's also about connections among them.

Explicit Memory

When we speak of "memory," it is episodic and semantic memory we usually have in mind. Psychologists call these two ways of remembering "explicit memory" because we readily acknowledge them as memories—both are unmistakably information from the past. Other forms of long-term memory don't really seem like memories even though they are just as much reflections of the past. Consider the act of riding a bicycle. Although it is based on previous learning, it doesn't feel like a memory—it's just something you know how to do. Your body carries out the mechanics automatically as information about how to do it is retrieved and put into play behind the scenes. These skill memories have their roots in your first nervous bike ride, your mastery of turning and stopping, and the hours of practice before you rode well. But when you ride a bike now, you are not aware of remembering anything; you are just doing what comes naturally.

Scientists learn about this kind of memory by observing behavior rather than by asking a person to recount the memory. It was behavioral observation that led to the discovery that H. M. could learn a new motor skill. Such memories are called "implicit" because they are deduced from behavior. As we will see, two forms of implicit memory—skills and habits along with Pavlovian associations—are every bit as crucial in our lives as episodic and semantic memories. The diagram on the next page shows the explicit and implicit memory systems discussed in this chapter.

Implicit Memory: Skills and Habits

Much of what we do each day requires little explicit memory. We tie our shoes, cook, eat, drive, and avoid obstacles with hardly a thought about how we accomplish these tasks. These procedural skills and habits are based on

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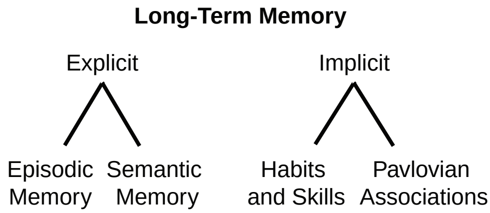

implicit memories built up over the years and then retrieved at just the right moment. They form slowly through trial and error as successes and failures refine behavior patterns and optimize them for efficiency.

This process was recently brought home to me when I bought a pair of shoes that were slightly longer than my old ones. I discovered how well tuned my stair-climbing movements were after I began stumbling when my toe caught on the stair. Apparently, I had learned to lift my leg no higher than required by my old shoes. But after a little experience, my system adjusted to a higher and safer movement. We see the same process whenever we drive a different car, use a new cell phone, or learn to cook a novel dish.

Because implicit skill memories are distinct from explicit memories, they remain intact in early dementia, which affects primarily episodic and semantic memory. This was evident in Ronald Reagan's struggle with Alzheimer's disease. The fortieth president disclosed his affliction in 1993, and within three years he was severely impaired—he couldn't recall what he had done each day, and he was unable to recognize people he had worked with for years. Despite these serious explicit memory problems, he played golf regularly, dressed himself in suit and tie, and displayed his characteristic gentlemanly behavior. When visitors arrived, he welcomed them warmly even though he didn't know who they were. When he entered an elevator, he would step back and, with a sweeping gesture, allow women to enter first. These well-practiced behavior patterns were still preserved.

Mental Skills

Many important skills are mental. An expert physician readily diagnoses a puzzling illness by drawing on years of practice that have taught her what to look for and what questions to ask. "Book learning" alone doesn't

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cut it in a practical situation like this. Mental skills like hers are learned through experience just as motor skills are. Experience provides practitioners with something more than facts, something they find hard to put into words, something about the way they approach problems. For example, expert radiologists differ from beginning ones in that they rapidly zero in on abnormalities in an x-ray, passing over normal-appearing parts of the film so that they can devote full attention to clinically significant areas. Similarly, experienced computer programmers have developed an intuitive ability to see solutions to software design problems that beginners must find by working in a linear, step-by-step manner. Successes and failures give experts a deep repertoire of implicit skills and procedures, which they seamlessly combine with explicit factual information. The hallmark of an expert is this amalgam of implicitly "knowing how" and explicitly "knowing that."

Implicit Memory: Pavlovian Associations

Another implicit memory system is the one famously investigated by the Russian physiologist Ivan Pavlov. The drawing on the next page illustrates the best-known psychology experiment of all time in which a bell is paired with food given to a hungry dog. After a few pairings, as everyone knows, the dog begins salivating when it hears the bell, a response implicitly demonstrating the animal's memory for the connection between the bell and the food. This is a primitive memory system found throughout the animal world, even in such biologically distant life forms as ants and clams. It allows creatures large and small to anticipate important events in their environments.

Like motor skills, Pavlovian associations can be acquired even when explicit memory is seriously impaired. An early example was reported in 1911 by the Swiss psychologist Eduarde Claparède. He described the curious case of an amnesic patient who could never remember Claparède from one appointment to the next. Each meeting required that the doctor introduce himself as if they had never met. The patient's memory problems were the result of chronic alcohol abuse, a condition known as Korsakoff's syndrome that can drastically undercut explicit memory. One day, after Claparède went through yet another round of introductions, he placed a pin between his fingers that pricked the patient as he touched her hand. Later,

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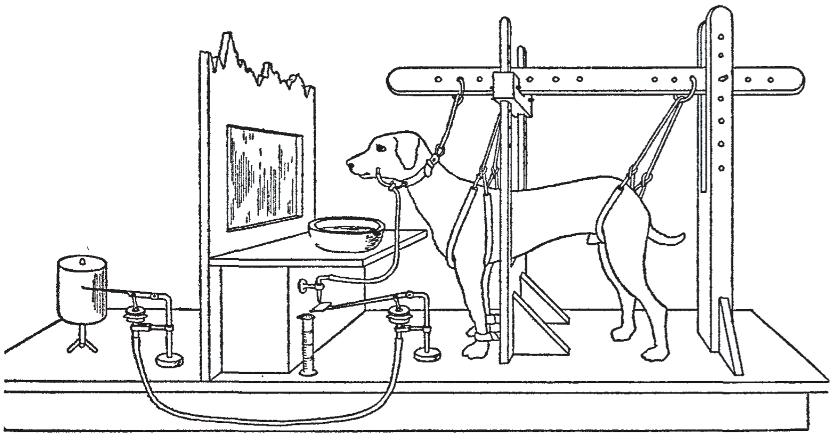

The testing apparatus Pavlov used to discover what came to be called Pavlovian associations.

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after she had forgotten that interaction, he reached to touch her hand again, and this time she pulled back. Her memory for the association between the pin prick and his touch was preserved, even though she didn't know why she was leery of his hand.

Pavlovian associations are often earthy, visceral, and primitive, strikingly different from the more factual, intellectual recollections of explicit memory. A person who has been in a serious automobile accident may later react to screeching brakes with a racing heart, sweaty palms, and a surge of adrenaline. These associations are implicit memories retrieved as involuntary, automatic reactions. Because Pavlovian associations normally occur along with explicit memories, the screeching brakes may also bring back the details of the accident as a conscious episodic memory. But in cases like this, it's helpful for us as students of memory to analyze the experience carefully and realize that the gut-level responses represent memory retrieval from a more primitive system. This type of memory was crucial for animals negotiating a complex and dangerous world long before conscious memory evolved, and this ancient memory system continues to play an important role in the lives of advanced creatures like ourselves. We flinch before the doctor inserts the needle, salivate as we study the menu at our favorite restaurant, smile at the sound of a friend's voice, or become apprehensive when we hear a siren. These automatic associations prepare us for important events in the offing.

Multiple Memory Systems: A Major Insight

The discovery of distinct long-term memory systems is a revolutionary scientific advance, one that is the foundation for the modern study of memory. It has allowed researchers to ask more refined questions and discover memory principles unique to the specific types of memory. Scientists now know that episodic memory for new experiences declines slowly over the lifespan, beginning in the thirties, but semantic memory for facts actually improves with age well into the sixties. And the best techniques for developing strong semantic memories are quite different from the best ways to develop good skill memories.

The new perspective has also provided a framework for viewing human memory that is consistent with an evolutionary view of mental abilities. Procedural memory and Pavlovian associations, for example, are based on primitive systems for retaining the past. Both are found throughout the animal world. Explicit memory, on the other hand, is more advanced. It depends on recently evolved neural capabilities and supports sophisticated forms of behavior such as language, reasoning, and problem solving.

The discovery of multiple memory systems helps us understand what it means to be human because it identifies the aspects of the past we are able to retain and use to further our interests. Each memory system captures a different kind of information for a different purpose. Some types of memory are conscious; others are not. Some preserve specific events; others blend them together. Some systems differ little from those found in most animals, while others appear to exist only in advanced creatures, and there is even one memory type that may be ours alone.

In the coming chapters you'll learn more about how these systems work and how to improve them. But long-term memory systems are only part of the picture. The topic of Chapter 2, short-term or "working" memory, allows us to juggle the information we need to deal with the activity of the moment, from expressing a thought to preparing a meal.

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Introduction to the Memory Lab: Two Types of Visual Mnemonics

The Memory Lab section at the end of each chapter gives you a chance to try out different mnemonic techniques. In this first installment I introduce visual mnemonics, which are memory aids based on visual imagery, and illustrate them with a way to remember the four long-term memory systems.

Visual mnemonics are a historically appropriate place to begin learning the memory arts. Ancient mnemonists knew their power and stressed their importance, so much so that most classic mnemonic techniques use visual imagery extensively. Cicero spoke for many ancients when he wrote in 55 B.C., "the keenest of all our senses is the sense of sight, and consequently perceptions received by the ears or from other sources can most easily be remembered if they are conveyed to our minds by the mediation of vision."

The first step in putting Cicero's advice into action is to identify the information needing memory support. I will focus on the diagram on page 16 showing the four memory systems organized as either explicit or implicit. That diagram itself could be enough to help you remember the systems, but I'm going to rework it using more graphic imagery so I can introduce two powerful ways to construct visual mnemonics.

A Mnemonic Based on Direct Visual Associations

The visual image below is a memory aid to help recall the two implicit memory systems. A dog is harnessed in a Pavlovian apparatus and is catching a Frisbee. The Frisbee is a cue for skill and habit memory, and the dog is a cue for Pavlovian associations. If you can remember this image, there is a good chance you can remember the two systems. This

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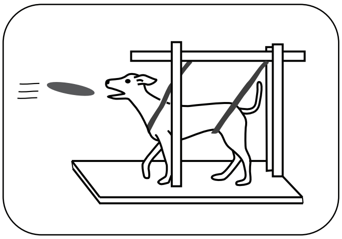

A visual mnemonic for skills and Pavlovian associations based on direct associations.

approach to creating a visual mnemonic is based on finding an image with a direct association to the content you are trying to remember.

A Mnemonic Based on Substitute Words

What about a visual memory aid for the two forms of explicit memory: episodic and semantic memory? Right away we can see a limitation of the direct approach. What possible image could be a cue for "episodic memory"? It's an abstract term, and visual mnemonics use concrete images.

This is a common problem when using visual imagery: not everything we want to remember can be visualized, and so a direct association just isn't always possible. However, there is a workaround, a strategy called the "substitute word technique" and also known as the "keyword mnemonic." It's an approach that has served mnemonists well for centuries. To apply it, we search for a concrete word that *sounds* like the abstract word, and then we create a visual cue for the concrete word. The visual image helps us remember the concrete word, and its sound helps us remember the abstract word. It works like this:

Remember visual image →
remember concrete word →
remember abstract word

To apply the strategy here, I chose "exotic salmon" as substitute words for "episodic" and "semantic" memory based on the fact that they sound somewhat similar. Then I created the image shown at the top of the next page. To remember the two explicit memory systems, you imagine the exotic salmon, and the sound of these words helps you remember "episodic" and "semantic."

Using the Mnemonics

I have combined the two images into a single mnemonic also shown on page 22. Take a good look at it because next I am going to ask you to re-create it in your imagination and use it to cue your memory.

When you're ready, close your eyes and retrieve the image. Start by visualizing it from afar so that you can see the full image, with its

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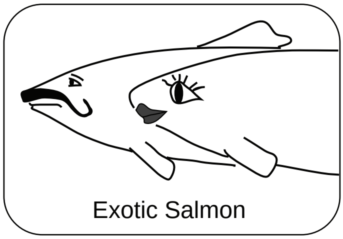

A visual mnemonic for episodic and semantic memory based on substitute words.

two components side by side. Then zoom in on the salmon and mentally inspect it. Recall the substitute words and use them to think of the two explicit memory systems. Give your associations free range so that you can review the characteristics of these two systems. Next, zoom out, move over to the dog image, and repeat the process. If you find your images are fragmented, weak, or fuzzy, that's OK. Just make them as distinct as you can. Expect to see improvements in your mental imagery as you continue to work at it in the coming chapters.

How much memory benefit will this mnemonic provide? That will depend on how well the visual cues work for you and how well you remember the mnemonic. I'll have more to say about both of these requirements in later chapters.

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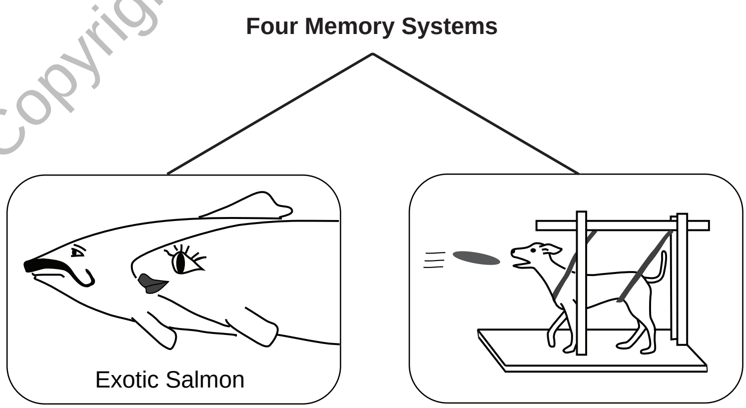

A composite visual mnemonic for the memory systems.

About Visual Images

People differ greatly in how vivid they report their mental images to be. Some describe highly detailed and brightly colored images, but for others, visual images appear washed out, broken up, and fleeting. Fortunately, research has shown that a high level of imagery skill isn't necessary for the visual techniques described in this book. You can expect to receive about as much memory enhancement from weak mental images as from vivid images. Moreover, you can expect your imagery skill to improve with practice. Keep in mind that when you visualize an image mentally you're drawing on the same brain machinery you use in actually seeing something. So the basic equipment is there; it's just a matter of learning to use it. And it's worth doing. Mental imagery not only provides a useful memory tool but is an enriching mental experience, one you may be missing.

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