SPECIAL TIME EDITION

THE SCIENCE OF MEMORY

The Story of Our Lives

Build a Sharper Mind • Erase Bad Memories • What Animals Recall

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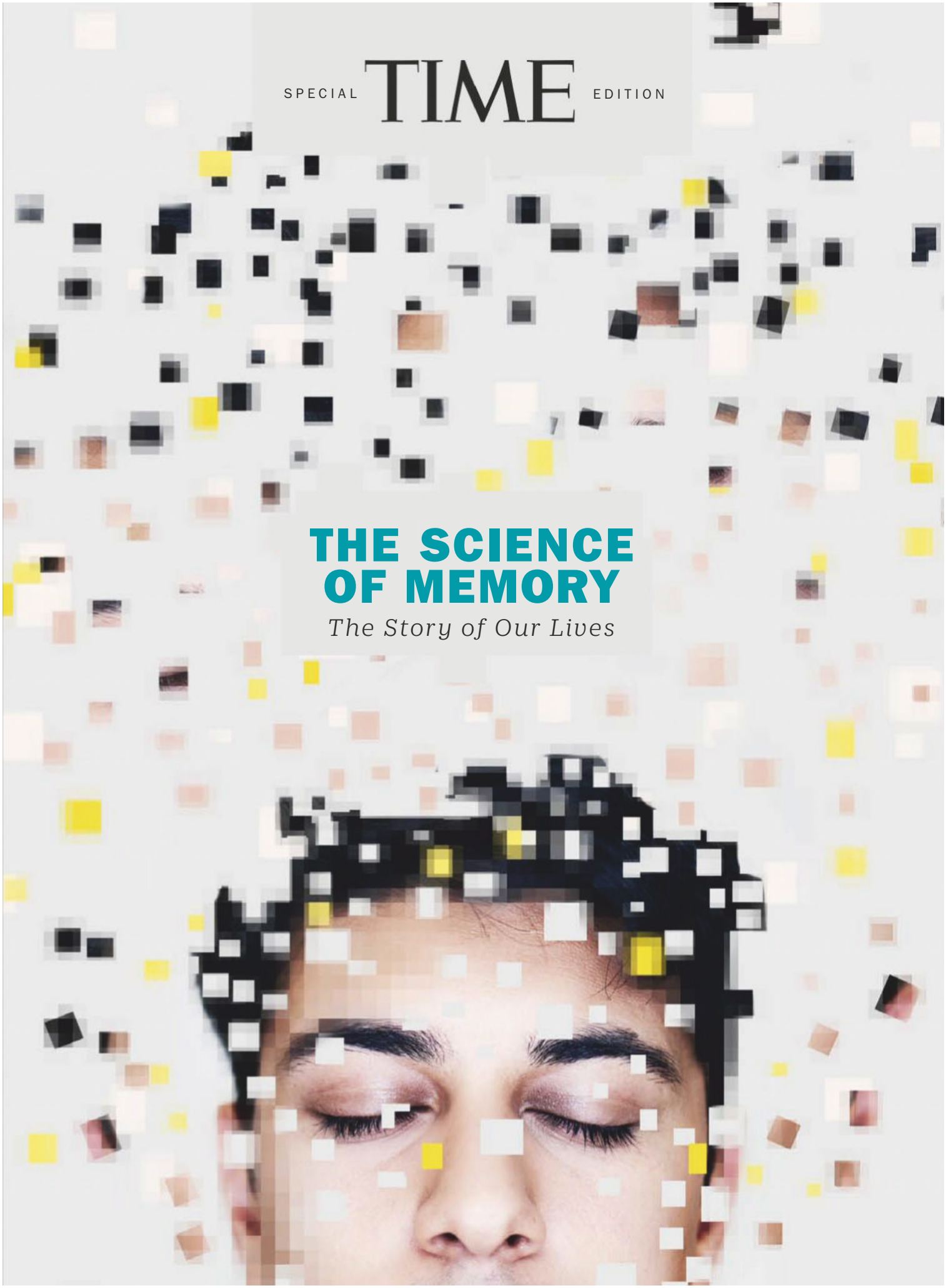

Memories are often compared to simple snapshots, but memory itself is complicated, and researchers don't fully know how it works physiologically.

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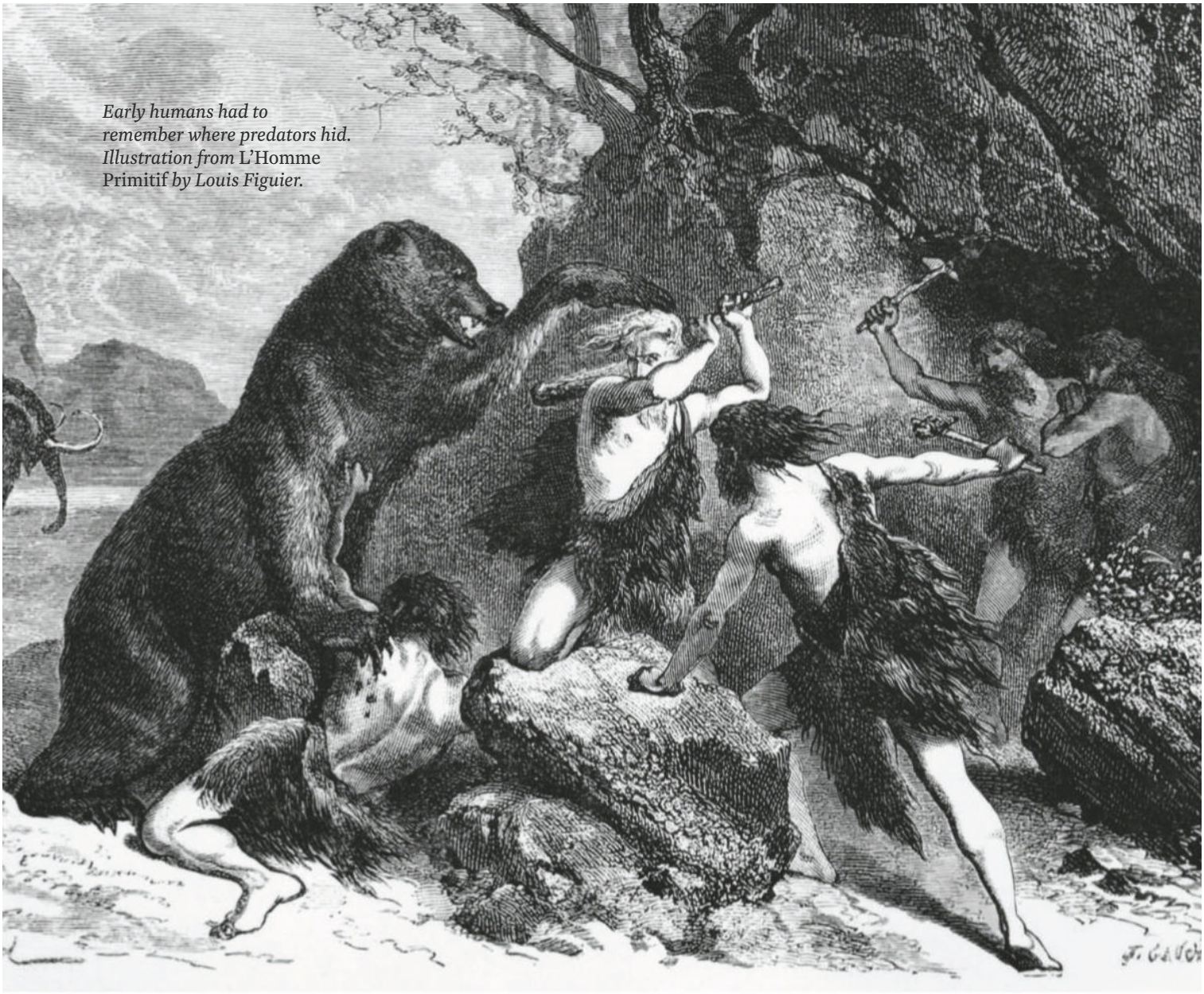


Early humans had to remember where predators hid. Illustration from L'Homme Primitif *by Louis Figuier.*

INTRODUCTION

WHY WE REMEMBER

From an evolutionary point of view, it comes down to survival of the fittest. He who endures remembers where the food is and where the predators lurk

By Eileen Daspin

For an experiment on navigational skills and natural selection, the setting—a Santa Barbara, Calif., farmers market on a Saturday morning—could not have been more Darwinian. So was the question at hand: How would spatial memory and adaptive behavior play out for a modern hunter-gatherer?

To find out, a group of psychology professors posted themselves at the market's entrance and enlisted shoppers as foragers. Eighty-six subjects were led along intentionally circuitous routes to pre-selected food stalls. There, they tasted the farmers' goods, were guided to the center of the market and finally were given a special device to indicate the locations of the foods they had sampled. True to Paleolithic form, the shoppers easily identified the locations that provided goods with the most energy—olive oil, avocados and nuts—but struggled to place booths stocking calorie-light leafy greens.

"I was surprised at how cleanly the results came out," says psychology professor Joshua New, one of the designers of the study, who now teaches at Columbia University. "People hadn't thought about encoding landmarks like that. But if you eat at a subpar restaurant, you're not going to commit memory to learning how to get back there."

From an evolutionary point of view, the reason we remember, like pretty much all human activity, comes down to survival of the fittest. He who is going to make it out alive remembers where the food is. And what the bad guys look like. And the best place to hide from predators. What scientists call adaptive memory—which is always functioning to figure out new solutions to problems—is key to nearly everything we do. We have to remember to physically navigate the world, to reproduce, to interact with others, to recognize kin, to know the truth of a situation. Memory is what allows us to learn, to acquire, to store and retrieve information.

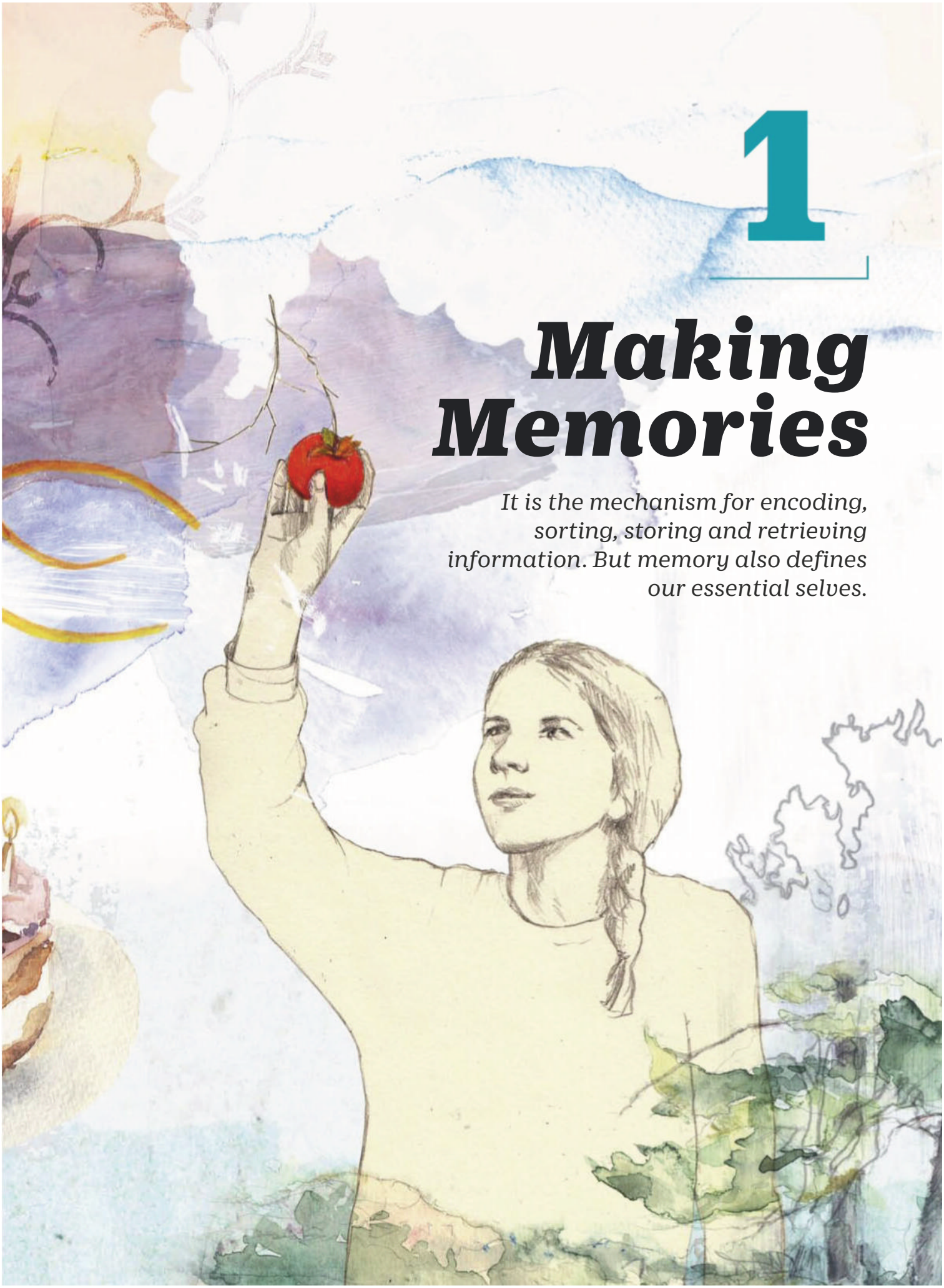
As machines, our memories are amazing, able to store long-term some 2.5 petabytes of data, by one professor's calculation. That's the equivalent of 300 million hours of television programming. The catch is that memories are as faulty as they are essential. No two people remember the same event the same way, a fact famously illustrated in the Japanese crime drama *Rashomon*, in which four people each remembered killing the same samurai—including the samurai himself, who returned from the dead to testify that he had committed hara-kiri.

Memory is so crucial, we even forget to remember, with the brain pushing out less-important memories to make room for the more-important ones. This is a phenomenon that Friedrich Nietzsche called "active forgetfulness," by his lights, an important component of happiness. The German philosopher's argument wasn't that you should be pleased you forgot where you parked your car, but rather that not remembering paves the way for peace of mind. "To shut the doors and windows of consciousness for a while . . ." Nietzsche wrote in *On the Genealogy of Morals/Ecce Homo*, allows for "a little tabula rasa of consciousness to make room for something new . . . like a doorkeeper or guardian of mental order, rest and etiquette."

Our memories are amazing, able to store long-term some 2.5 petabytes of data—about 300 million hours of television programming.

Research suggests that memory literally starts in utero. When Dutch professors put a honking, vibrating device on the abdomens of women in their 30th to 38th weeks of pregnancy, they found that the fetuses quickly recalled the noise, so that when the device was sounded 10 minutes later, they didn't squirm and their heartbeats remained stable. The 34-week-olds even remembered the noise four weeks later. "It's like getting used to a New York train station," lead author J.G. Nijhuis told *Scientific American*. "It is a learning capability to distinguish safe from unsafe stimuli. It is a primitive form of memory."

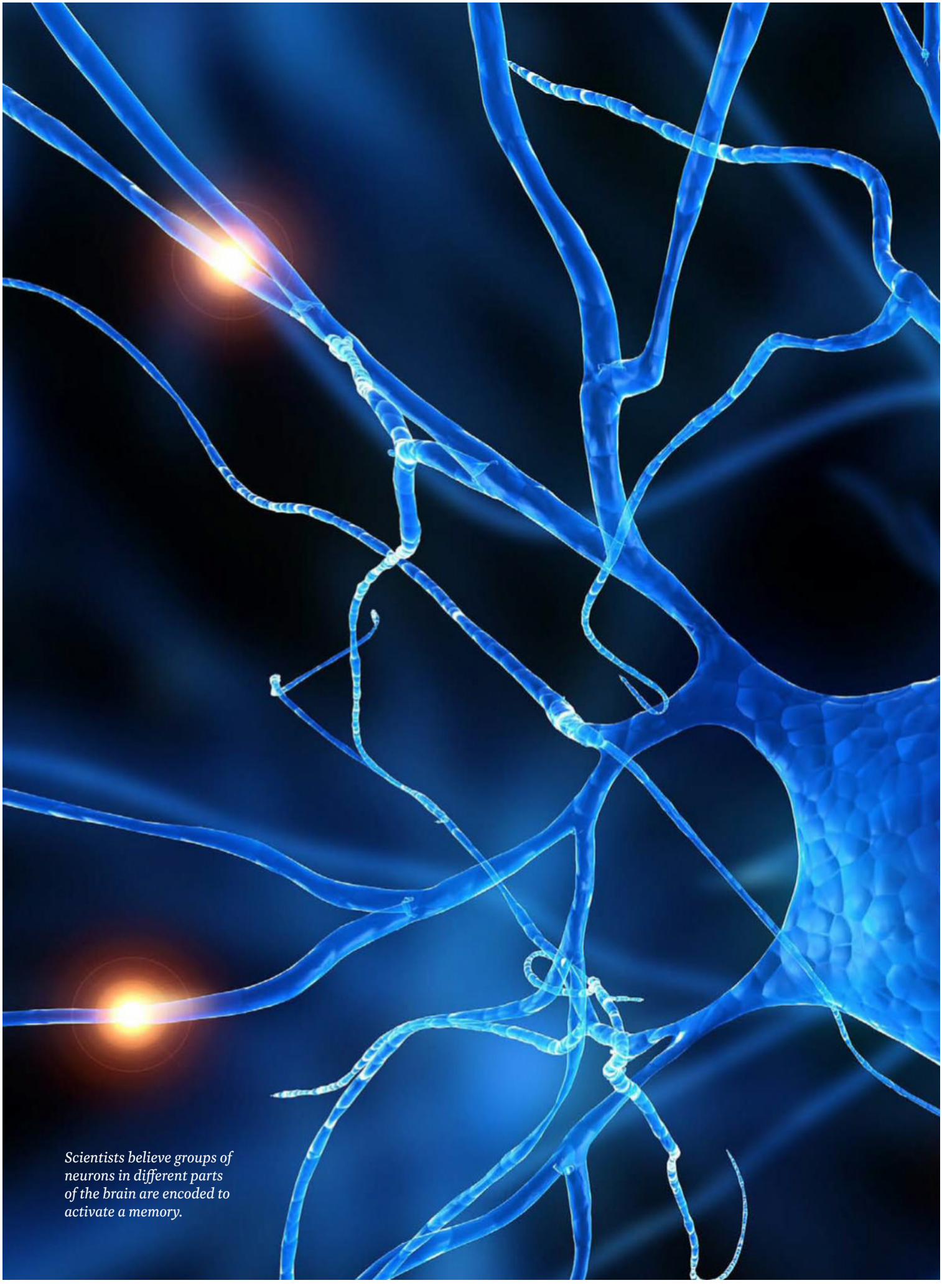
Then it gets a little more complicated. Infants and toddlers remember, but by about age 7, the first three years of memories are almost entirely erased from the conscious memory and overlaid with new ones. From there, our memories shift and evolve, colored constantly by our experiences. Why do we remember? As Oscar Wilde once suggested, to fill in "the diary we all carry about with us." ☐



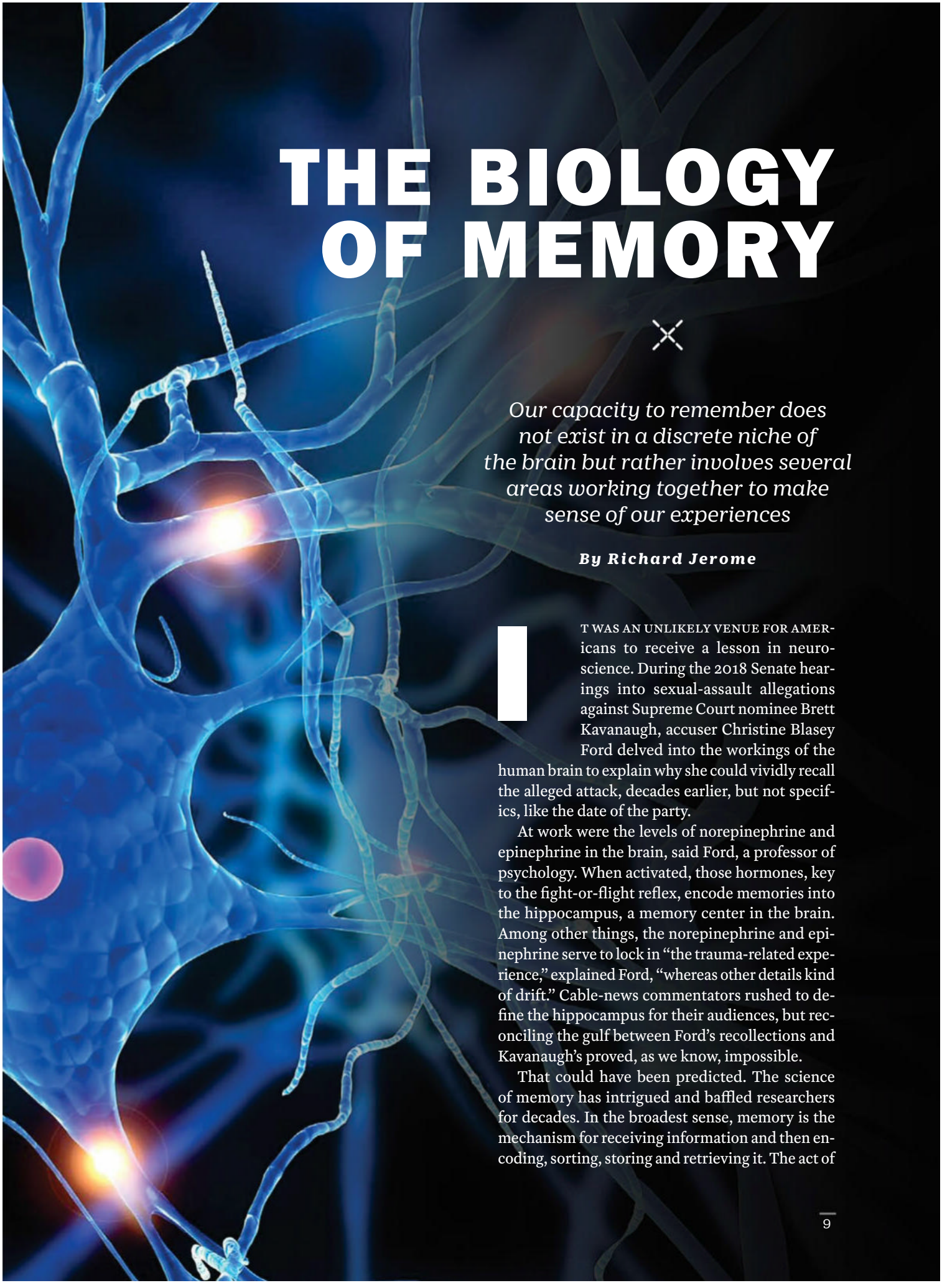
1

Making Memories

It is the mechanism for encoding, sorting, storing and retrieving information. But memory also defines our essential selves.



Scientists believe groups of neurons in different parts of the brain are encoded to activate a memory.



THE BIOLOGY OF MEMORY

Our capacity to remember does not exist in a discrete niche of the brain but rather involves several areas working together to make sense of our experiences

By Richard Jerome

IT WAS AN UNLIKELY VENUE FOR AMERicans to receive a lesson in neuroscience. During the 2018 Senate hearings into sexual-assault allegations against Supreme Court nominee Brett Kavanaugh, accuser Christine Blasey Ford delved into the workings of the human brain to explain why she could vividly recall the alleged attack, decades earlier, but not specifics, like the date of the party.

At work were the levels of norepinephrine and epinephrine in the brain, said Ford, a professor of psychology. When activated, those hormones, key to the fight-or-flight reflex, encode memories into the hippocampus, a memory center in the brain. Among other things, the norepinephrine and epinephrine serve to lock in "the trauma-related experience," explained Ford, "whereas other details kind of drift." Cable-news commentators rushed to define the hippocampus for their audiences, but reconciling the gulf between Ford's recollections and Kavanaugh's proved, as we know, impossible.

That could have been predicted. The science of memory has intrigued and baffled researchers for decades. In the broadest sense, memory is the mechanism for receiving information and then encoding, sorting, storing and retrieving it. The act of

Researchers at the University of Oxford study postmortem brain samples.

remembering is absolutely essential to our survival. We could not carry out the basic functions of living unassisted without our powers of recall. Learning would be impossible; nothing in the world would have context. We would have no sense of self—indeed, we wouldn't know what we'd done five seconds ago. Only within the past 50 years or so have researchers begun to understand the neurological and physiological operations that make this enigmatic but indispensable faculty possible. What's clear is that the human memory doesn't reside in one corner of the brain that scarfs up stimuli and records them for later retrieval. Rather, it's a complex system, involving several areas of the brain, working to make sense of life's experiences. And a great deal about it remains to be understood.

Neurobiologists have identified two main classes of long-term memory at work in the brain. Explicit (or declarative) memory, which is processed in the hippocampus and medial temporal lobe, is conscious recollection for names, dates, events, people, places and objects; it includes two subcategories: episodic memory, which logs one's personal experiences—say, the coffee date you had last week or your first kiss; and semantic memory, which stores factual information. The second major class of recall is implicit memory, which encompasses unconscious, procedural or motor tasks: walking, tying your shoe—things we do routinely, without conscious thought. Implicit memory calls on other brain systems, such as the cerebellum (which regulates muscle activity) and the striatum (a cluster of neurons that regulate voluntary movement).

When a memory forms, the first, crucial step is encoding. For example, when meeting a person for the first time, our various senses take in their looks, the sound of their voice, the smell of their breath or body, the feel of their handshake. All that sensory input gets stored and analyzed in the hippocampus. The information gets evaluated—graded, in a way, to determine whether it's worth retaining as part of your long-term memory. In a process known as con-

solidation—a window of a few hours that is enhanced by sleeping—memories deemed worthy of retention are stabilized, and then associated neurons are transferred to the neocortex, the wrinkly sheet of neural tissue that forms the outside surface of the brain. Another key cog in the brain's memory-retention complex is the amygdala, an almond-shaped structure in the temporal lobe that imbues recollections with emotional significance, associating them with shame, joy, love, grief or fear. Emotionally charged events are generally much harder to forget—they're sometimes referred to as "flashbulb memories" because they stand out so vividly.

We know the brain's major memory centers, but what goes on there, exactly? How are memories encoded and stored? Through a complicated interplay of electricity and chemicals. Nerve cells—or neurons—connect with other cells at a gap known as a synapse. That's where electrical pulses fire up, triggering the exchange of messengers called neurotransmitters. When we recall a memory, the same neurons from the original experience are reactivated and duplicate the moment.

To give an idea of the scope of these operations, your typical human brain has about 100 billion neurons, passing signals to one another via well over 100 trillion synapses. As one brain cell sends signals to another, it strengthens the synapse between them—a process known as potentiation—creating a bond that grows more powerful as the signals multiply. When we study a textbook in school, for example, drumming it into our heads by marking key passages in highlighter, it stokes potentiation. And so, with each new experience, or repetition of a previous one, the brain rewires itself—a phenomenon scientists call neuroplasticity. Indeed, some areas of the brain can actually grow with repeated use. In a study of London cabbies, for instance, magnetic imaging tests showed that the drivers' hippocampi—which are heavily involved in spatial memory—became larger the longer they were on the job, navigating the city's streets.

These are the broad outlines of neuroscientists' understanding of memory, which was essentially a black box until the mid-20th century. A huge breakthrough came in 1957 when McGill University neuropsychologist Brenda Milner published a landmark paper based on the case study of Henry Molaison, a former assembly-line worker from Connecticut. Molaison had undergone brain surgery to relieve severe epileptic seizures—specifically, doctors had removed a portion of his medial temporal lobes from both sides of his brain. On one level, the operation was a success—the seizures subsided. But in another sense, Molaison's life, which lasted another half-century, was altered disastrously: his surgery had left him with anterograde amnesia, an inability to form new memories.

Molaison's surgeon consulted Milner and her colleagues at the Montreal Neurological Institute, who made a detailed study of the case. What they determined was that the operation had cut out much of the patient's hippocampus—the first evidence to suggest that the brain structure was critical to the formation of memories. On the other hand, tests showed that Molaison's implicit memory was undimmed. For instance, he was shown how to draw the image of a star by tracing its reflection in a mirror. Molaison could perform that task repeatedly but had no memory whatsoever of being taught how to do it. The result demonstrated that there are at least two separate areas of the brain involved with memory processing—the hippocampus and medial temporal lobe deal with explicit memories, and a different part of the brain (later discovered to be the basal ganglia and cerebellum) handles implicit, automatic tasks.

Surgery on a man who suffered epileptic seizures left him unable to form new memories but revealed that brain structure was key to recall.

WHILE RESEARCHERS WERE identifying the "where" of memory in the brain, the question of "how" remained mysterious—and still does, to a significant extent. Around the time Milner was publishing her findings, the neuroscientist Eric Kandel, now at Columbia University, began a decades-long quest to understand the biochemical mechanisms of memory storage, work that would earn him a Nobel Prize in Physiology or Medicine in 2000.

Kandel has probed the molecular underpinnings of short-term and long-term memory, including genetic changes that take place and help build new connections in the brain. He started out by picking up on Milner's work and studying the human hippocampus—how memories might be processed and stored there. But Kandel and his partner, W. Alden Spencer, found that analyzing such a complex structure in such a complex animal wasn't conducive to determining memory's basic essentials.

"In the 1960s, we went to a more reductionist approach," Kandel told the *New York Times* in 2012. "Instead of studying complicated mammalian brain cells, we studied the neural system of a simple animal, *Aplysia*, a snail with a very large nerve cell." Kandel subjected the foot-long mollusks to reflex tests, stimulating their nerve cells with electrodes to gauge the response. "We discovered that the snail's reflexes could be modified by several forms of learning, and that learning involved alterations in how nerve cells communicated with one another."

Kandel then studied the conversion of short-term memories into long-term ones—essentially the act of learning—and found that learning itself strengthened the brain. To illustrate: Short-term memory can hold about seven digits for about 20 or 30 seconds. The common example given is a 10-digit telephone number you don't have a chance to jot down; you try to keep it in your head just long enough to dial. What Kandel discovered was that when you actually learned the number, the synaptic connections involved strengthened. "It was astonishing!" Kandel recalled. "You could double the number of synaptic connections in a very simple neurocircuit as a result of experience and learning."

Kandel and colleagues found that, unlike short-term memory, long-term memory requires the synthesis of new proteins. In the early 1970s, they found evidence to suggest that the neurotransmitter serotonin activates a messenger molecule crucial to memory known as cyclic AMP (cAMP). During the 1990s Kandel's lab identified the protein CREB as playing a key role in long-term memory storage by spurring synaptic connections. Meanwhile, other researchers had learned more about the alphabet soup that powers memory. For instance, two receptors, AMPA and NMDA, also play crucial roles inside the hippocampus, enabling learning and the synapse potentiation needed for long-term information storage.

Then in the early 2000s, Kandel and a member of his lab, Kausik Si, made what was considered a remarkable discovery: that another protein, CPEB, may be responsible for creating stable long-term memories. The surprise was that CPEB resembled a prion—which in its usual form is a toxic, self-perpetuating protein that may play a role in mad cow disease and Alzheimer's. CPEB, however, appeared to be a mutation that helps stabilize memories for the long term. Although other nonpathogenic prion-like proteins have been discovered in recent years, at that time, the idea that anything like a prion, one of the most malevolent actors in the body, could do something beneficial was "nothing less than extraordinary," Rockefeller University's Robert Darnell wrote when Kandel and Si published their work.

In studying the conversion of short-term memories into long-term ones, Kandel found that learning strengthened the brain.

When activated by a clue—say, a snippet of a song—our brains can retrieve a memory within a millisecond, but precisely how isn't known. Although imaging techniques show that the retrieval network involves interconnected areas of the medial temporal lobe, the specifics remain to be seen. Another of many other open areas of memory research is the role of the amygdala and emotion in making some emotionally charged memories more vivid; or, as some studies suggest, whether a strong emotion such as fear can actually have the opposite effect, altering or clouding memories we believe to be sharp and accurate.

As scientists follow these and other complicated threads of human memory, they are unraveling the tapestry of life itself. In Kandel's book *In Search of Memory*, he quotes Tennessee Williams's play *The Milk Train Doesn't Stop Here Anymore*: "Has it ever struck you . . . that life is all memory, except for the one present moment that goes by you so quickly you hardly catch it going? It's really all memory." ◻

Know Your Terms: A Memory Glossary

BY EMILY JOSHU

Sorting out the different types of memories can be confusing, but they all essentially fall into one of two categories: either declarative or implicit. Within those classifications, memories are deemed either short-term or long-term. Short-term memories last only up to about 30 seconds, while long-term memories can theoretically last forever, but they aren't all created equal.

DECLARATIVE MEMORY

Also known as explicit memory. This is a system of conscious memories requiring effort, such as being able to tick off all the items on a grocery list, recalling material you've read in a book or article, or remembering a friend's face or a phone number. There are three subsets:

1. Working memory
A short-term system for storing and processing limited amounts of information for 15 to 30 seconds; after that, the memory begins to decay. Tasks that function under working memory include calculating a tip, listening to a newscast or remembering lecture material for a test. Storage capacity is between four and seven items at a time. These could be four chunks of information, five words, six letters or seven numbers.

2. Episodic memory
A type of long-term memory for recalling past events, such as a road trip with a friend, a family reunion or an episode of a TV show you watched the other night.

3. Semantic memory
A type of long-term memory for recalling general knowledge, such as knowing that 2+3=5, that George Washington was the first president or what the capital of your home state is.

IMPLICIT MEMORY

Also known as non-declarative memory, this long-term memory system unconsciously influences our current perceptions and behavior without effort or awareness. There are three subsets:

1. Procedural memory
The memory of motor skills allows us to complete tasks we have previously learned and know how to do without trying, such as typing or riding a bike.

2. Priming
In this process, exposure to a stimulus triggers associated concepts that help us recall an answer. Our brains are continuously forming associations between memories and ideas, such as the color yellow, a banana and a monkey. You're faster and more likely to come up with the word "banana" after reading the word "yellow."

3. Conditioning
Unconscious memory makes associations between two stimuli in this process. The classic example is Russian physiologist Ivan Pavlov's conditioning experiments with dogs. Before showing a canine a bowl of food, Pavlov rang a bell. Eventually, the animal salivated at the sound of a bell, knowing it was time to eat.

UNDERSTANDING THE LIMBIC SYSTEM

Memories and emotions are linked through important brain structures

By Emily Joshu

Memory is often described with evocative, romantic terms, as sepia-tinted snapshots or as a scrapbook. But this vital function is not something you can tuck under your arm like a diary. Instead, it comes to life inside the limbic system, an umbrella of brain structures controlling emotions, drives and learning processes. How do we remember where we left our keys, how to hit a baseball, or when to eat or sleep? Here is a look at some key areas and what each does.

1 / HIPPOCAMPUS

The hippocampus is a seahorse-shaped structure, embedded in the temporal lobe. This is where all conscious memories begin and where long-term memories are processed. According to Anthony Wagner, director of the Memory Lab at Stanford University, the parts of the brain that process the senses—taste, smell, sight, sound, touch—communicate with the hippocampus. "The hippocampus is positioned at the top of this information flow in the brain," he says. What we remember about an event, in effect, comes from a competition between typical memory traces. So when we touch something or see someone's face, the hippocampus helps us associate the sense with a memory.

2 / AMYGDALA

An almond-shaped structure of gray matter, the amygdala, nestled close to the hippocampus, controls emotional processing, memory and responses. It works in tandem with the hippocampus to connect memories with emotions such as fear. The amygdala activates when we're afraid of something, but the connection between the amygdala and the prefrontal cortex also helps to mediate the alarm by providing reasoning and context to control it or work through it. When this connection is damaged, it is more difficult to overcome fear or resolve disturbing recollections, a condition often seen in post-traumatic stress disorder patients.

3 / PREFRONTAL CORTEX

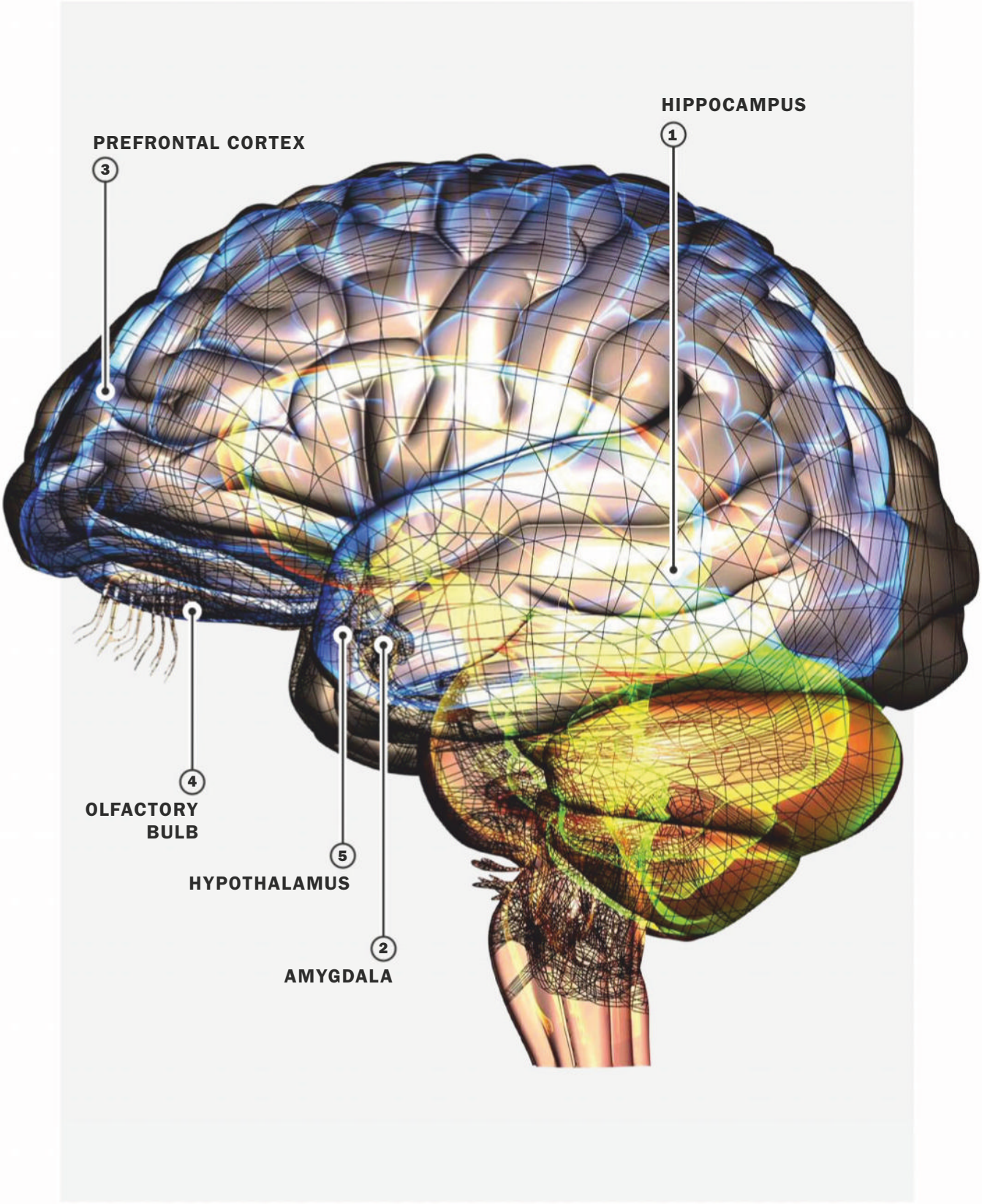
In the frontal lobe, the prefrontal cortex is responsible for working memory, the ability to remember and use information for reasoning and activities during a specific moment in time. These could include doing your taxes, baking a cake or even writing this article. The interaction between it and the hippocampus can be compared to a railroad: the hippocampus lays down new tracks—forming and retrieving memories—while the prefrontal cortex switches between tracks, gathering related memories to form context for an experience. The resulting memory is brief, staying in the back of your mind like a sticky note with a password on it.

4 / OLFACTORY BULB

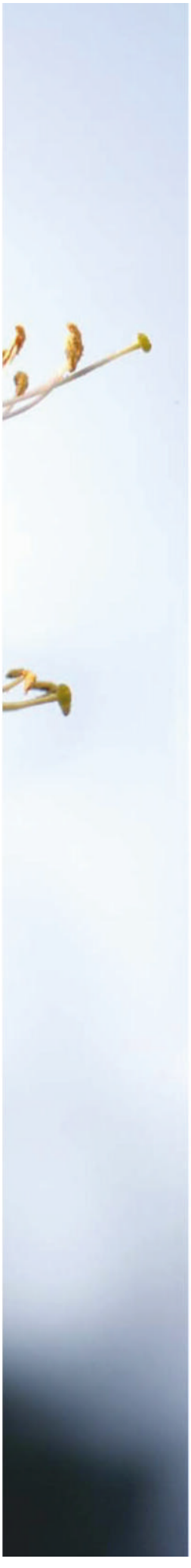
The olfactory bulb is composed of receptors that send signals to the hippocampus. The receptors hang off a thin membrane, almost resembling a toothbrush grazing the nasal passage. This is the primary limbic structure for processing smell. When you walk into a room and detect something familiar, like your grandfather's cologne, that smell projects from the olfactory receptors into the hippocampus and amygdala. There are few memories that have smells strongly bound to them, so odor-related cues are powerful compared to visual or auditory cues, says Wagner. "We're not a very olfactory organism. We're very much a visual and auditory sort of species," he adds. Smell is atypical, so it's easier to recall odor-related memories.

5 / HYPOTHALAMUS

How is it that you know it is time to feed yourself, sleep or drink? Thank your hypothalamus, which controls involuntary functions like hunger, body temperature, fear, sexual responses and hormonal balances that keep us alive. However, sometimes the hypothalamus malfunctions and your body forgets to tell you when to stop doing these things. People with Prader-Willi syndrome are examples of this, their hunger insatiable because their bodies never remember to feel full. Even though these are not functions that we actively think about, they still are a part of memory.


HIPPOCAMPUS
1
PREFRONTAL CORTEX
3
4
OLFACTORY BULB
5
HYPOTHALAMUS
2
AMYGDALA

The 20th-century British homeopath Dr. Edward Bach prescribed honeysuckle to remedy nostalgia and longing for the past.



THE TIME-BENDING MAGIC OF SMELL

Odor-evoked autobiographical memories derive their power from the way they are processed in the brain

By Richard Jerome

In the shadow of the grand apartment houses along Central Park West, an aroma of honeysuckle wafts through the thick summer air and suddenly I'm a boy again in our New Jersey backyard, where a cluster of white petals surrounds the grave of our fox terrier, who died when I was 10. A garlic breeze from a local restaurant carries me miles and years away to Boston's North End, dining with my wife-to-be at an Italian place where the owners lived in back and they served up the best chicken parm ever; a cinnamon stick conjures the late, lamented Café Figaro in the Village, where I've grabbed a window table overlooking Bleecker Street, watching till she rounds the corner from dance class and we sip cappuccinos into the night.

We've all had the experience, a scent that evokes vivid, visceral memories, as if an internal time machine were transporting us back to events and places in our deepest past, recalling them to life with profound urgency and immediacy. It's a phenomenon

that inspired one of the most celebrated passages in Western literature, the scene early in Marcel Proust's seven-volume masterpiece, *In Search of Lost Time* [see excerpt on page 23], when the narrator bites into a madeleine biscuit dipped in Linden tea and the taste and aroma unleash a sudden flood of reminiscence that carries him back to early childhood. He remembers the aunt who used to fix him madeleines the same way; the old, gray house where she roomed; flowers in the garden and water lilies on the river Vivonne; the parish church, modest homes and people of Combray, the fictional village where the narrator grew up. Proust's observations were so compelling, they inspired a cottage industry of psychological research into what is referred to as the Proust phenomenon—the ability of odors to cue vivid autobiographical memories.

Why do scents work such time-bending magic, peeling away decades instantaneously as no other human sense can? The sight of fall foliage, the sound of a train whistle, the feel of Silly Putty—all, to varying degrees, can spark remembrance of things past. But it seems that only our noses allow us to relive events, however remote or ordinary, in the moment. These recollections do indeed hold a unique place in our psyches, writes cognitive neuroscientist Rachel Herz, an expert on the psychology of smell. They extend deeper into our past "specifically clustered in the first decade," Herz notes, and also pack a more potent emotional wallop than recollections triggered by sights, sounds and other sensory cues.

On the flip side, potent odors can revive incidents we'd rather forget, in the worst cases inducing severe distress and even all-too-vivid flashbacks, particularly in people who already suffer from posttraumatic stress disorder. For instance, the smell of alcohol on a man's breath or a particular aftershave might cause the survivor of a sexual assault to relive the horrific experience. A widely cited series of case studies published in 2003 by PTSD researchers Eric Vermetten and J. Douglas Bremner found in one patient that the scent of diesel from a neighborhood fire sparked intense feelings of guilt and nausea. As it turned out, the man had served in Vietnam and witnessed a vehicle accident in which fellow soldiers had died in a burst of flames.

"Odor-evoked autobiographical memories," as scientists refer to them, derive their special power from the particular way they're processed in the brain. The olfactory system is the only sensory apparatus that does not feed its incoming signals through the thalamus—one of the brain's major relay stations. Rather, scents and tastes are directly connected to the limbic system, a collection of brain structures important for emotion, behavior, motivation and memory. Specifically, when you smell something, the odor gets routed through the olfactory bulb, a neural structure that analyzes scent.

Scent memories pack a more potent emotional wallop than recollections triggered by sights, sounds and other sensory cues.

Beginning inside the nose and running along the bottom of the brain, the olfactory bulb is closely connected with two other limbic-system sites—the hippocampus, the seahorse-shaped part of the forebrain responsible for the functions of memory and learning as well as the perception of space and time; and the amygdalae, two small masses of gray matter, resembling almonds, that, among other things, are involved in the experience of emotions. It's this unique proximity and access to the limbic system that underlies the particularly evocative ability of odors to generate memory and emotion. While the human body has just two receptors for sight and four for touch, it has about 350 for scent, allowing it to detect a trillion different smells.

All in all, then, smell is a formidable capacity, albeit one we tend to underestimate. "Humans are visual creatures—our external environment is predominantly represented by brilliant and colorful scenes acquired through our eyes," says Afif Aqrabawi, a researcher in neuroscience and biology at the University of Toronto who specializes in the link between scent and memory. "This makes it difficult for us to appreciate the importance of our other senses. Nevertheless, the majority of the animal kingdom must rely on the sense of smell to navigate their surroundings. Olfaction is essential for

Researchers at the European Centre for Taste Sciences examine a newborn to see if it remembers strong tastes such as anise and curry that were part of the mother's diet.

most organisms to find food, predators and mates." Indeed, adds Aqrabawi, "chemosensation"—the capacity to sense chemical substances, an evolutionary precursor to olfaction—"serves as the primary means of external experience and communication for even the most elementary forms of life, such as bacteria and protozoans."

A growing insight into the scent-memory connection has great potential for enhancing human health, opening the door for new therapies and cures. For example, a large body of work has shown that one of the first signs of Alzheimer's and Parkinson's is that patients suddenly find themselves unable to identify odors or pinpoint when and where they smelled them. Researchers believe that finding the roots of that olfactory deficit may hold a key to treating those afflictions.

There are also possible psychic benefits. In one promising study, neuroscientist Artin Arshamian of the Donders Institute in the Netherlands found in a survey of young adults that autobiographical memories cued by odors tended to be not only more intense but also more positive than recollections cued by verbal labels for the same odors. A 2013 study led by Japanese researcher Masahiro Matsunaga found that when men and women were exposed to a particular perfume they associated with a pleasant memory, the fragrance gave them an elevated sense of comfort and happiness and a decrease in anxiety.

EXCERPT

The Power of a Madeleine

In one of literature's most famous passages linking smell, taste and memory, Marcel Proust's hero bites into a cookie and is transported to his childhood in Combray, France

No sooner had the warm liquid, and the crumbs with it, touched my palate than a shudder ran through my whole body, and I stopped, intent upon the extraordinary changes that were taking place. An exquisite pleasure had invaded my senses, but individual, detached, with no suggestion of its origin. . . . Whence could it have come to me, this all-powerful joy? I was conscious that it was connected with the taste of tea and cake, but that it infinitely transcended those savours, could not, indeed, be of the same nature as theirs. Whence did it come? What did it signify? How could I seize upon and define it?

And I begin again to ask myself what it could have been, this unremembered state which brought with it no logical proof of its existence, but only the sense that it was a happy, that it was a real state in whose presence other states of consciousness melted and vanished.

▲ *The madeleine story appears in* Swann's Way, *the first volume of* Remembrance of Things Past, *published in 1913.*

I decide to attempt to make it reappear. I retrace my thoughts to the moment at which I drank the first spoonful of tea.

And suddenly the memory returns. The taste was that of the little crumb of madeleine which on Sunday mornings at Combray (because on those mornings I did not go out before church-time), when I went to say good day to her in her bedroom, my aunt Léonie used to give me, dipping it first in her own cup of real or of lime-flower tea. The sight of the little madeleine had recalled nothing to my mind before I tasted it; perhaps because of those memories, so long abandoned and put out of mind, nothing now survived, everything was scattered; the forms of things, including that of the little scallop-shell of pastry, so richly sensual under its severe, religious folds, were either obliterated or had been so long dormant as to have lost the power of expansion which would have allowed them to resume their place in my consciousness.

And once I had recognized the taste of the crumb of madeleine soaked in her decoction of lime-flowers which my aunt used to give me immediately the old grey

With this in mind, Herz suggests that the evocative power of odor could make it a valuable clinical tool. "Many people intuitively note that odors have the potential to elicit comfort," writes Herz in the journal *Brain Sciences*, such as when a person "sniffs a garment worn by a loved one they are separated from." She adds that "nostalgia—reflecting upon one's personal past—has been shown to have many beneficial psychological consequences." Substantial research has demonstrated that this kind of thoughtful reminiscence "increases positive affect, bolsters self-esteem, strengthens the connection between one's past and present, produces feelings of social connectedness, elevates optimism and infuses life with meaning."

Who can argue with that? Interestingly, the Matsunaga study determined that whereas one usually associates nostalgic feelings with music—the tune that takes you back to childhood, your first love or whatever you consider the good old days—odors

When odors trigger strong autobiographical memories, scientists call it the Proust effect. Here, the novelist circa 1900.

house upon the street, where her room was, rose up like the scenery of a theatre to attach itself to the little pavilion, opening on to the garden, which had been built out behind it for my parents; and with the house the town, from morning to night and in all weathers, the Square where I was sent before luncheon, the streets along which I used to run errands, the country roads we took when it was fine. And just as the Japanese amuse themselves by filling a porcelain bowl with water and steeping in it little crumbs of paper which until then are without character or form, but, the moment they become wet, stretch themselves and bend, take on colour and distinctive shape, become flowers or houses or people, so in that moment all the flowers in our garden and in M. Swann's park, and the water-lilies on the Vivonne and the good folk of the village and their little dwellings and the parish church and the whole of Combray and of its surroundings, taking their proper shapes and growing solid, sprang into being, town and gardens alike, from my cup of tea.

actually inspired more than twice as many happy reveries as did musical excerpts. The effects are physiological as well. When a smell triggers an exhilarating or exciting memory, it can make the heart race and spark a rush of adrenaline. Another research survey found that when men and women from ages 29 to 50 self-selected a scent that elicited a pleasant, soothing autobiographical memory—say, a particular flower—their breathing grew slower and more relaxed. The remarkable implication: to feel better, happier, more exhilarated, it may literally be as simple as stopping to smell the roses—or the pine or freshly cut grass or whatever scent evokes your satisfying autobiographical memories.

For me, it's a certain perfume that transforms me once again into a toddler playing with the vintage atomizer on Mother's vanity. She's gone more than 30 years now, but that scent brings Mom back, if only for a fleeting, fragrant moment. ◻

AN ELEPHANT NEVE

Averaging about 10½ pounds, the pachyderm brain is the largest among all land animals, with a memory that rivals those of apes and dolphins

By Courtney Mifsud

SHIRLEY AND JENNY HAD NOT laid eyes on each other for more than two decades, but when the old friends were brought together for a surprise reunion in Hohenwald, Tenn., the moment was beyond dramatic. It was earsplitting. First Shirley started bellowing, then Jenny. Carol, who witnessed the moment, described the sounds as "roars."

No, Jenny and Shirley weren't long-lost girlfriends. They were retired circus elephants who had worked together briefly, been separated and suffered abuse. Now, they were side by side again at an animal sanctuary and overjoyed. "They were trying to climb in with each other and frantically touching through the bars," wrote Carol (Buckley), founder of the refuge, at the time. "I have never experienced anything even close to this depth of emotion," she said.

It turns out that what they say about elephants is true. Not only do they have better long-term memories than their four-footed peers, an elephant's brain—at 10½ pounds of matter—is the largest among all the land animals. Some elephants remember injuries and hold grudges against whoever hurts them. They recognize their reflections in a mirror, suggesting self-awareness, and some even know their handlers by sight after being separated for years. In terms of sheer intelligence, pachyderms

R FORGETS

Elephants understand basic math and can keep track of relative sums.

Bottlenose dolphins have procedural memories that last for years.

are up there with dolphins, apes and people, perhaps because inside their craniums sit 257 billion neurons, about three times the number contained within the human skull.

Granted, elephant brains are organized in a different way than those of their smaller hominid friends, which is why they aren't actually smarter than people. But they are humanlike in many respects. Elephants adapted to life in African forests and on savannas about the same time humans did, immigrated to Europe and Asia and evolved to live long and often migratory lives in complex societies. They also developed a sophisticated communication system and experienced a dramatic increase in brain size for the same reason as people—they live a very long time, normally 60 to 70 years. Before embarking on a group outing, they even debate which direction to take, according to Phyllis Lee, author of a study of elephants in Kenya's Amboseli National Park. "It's wonderful to watch," she told a newspaper, "a real process of negotiation."

Elephants are of course not the only brainiacs of the animal kingdom. Dolphins communicate through distinct whistles and clicks that may serve as names or a type of language. Adolescent chimpanzees have outperformed humans on certain memory tests. A few years ago, a group of goats figured out how to operate a lever to reach a piece of fruit—and remembered the task 10 months later.

But elephant intelligence awes us uniquely, perhaps because they display such humanlike emotions as empathy, grief, humor and compassion, and they behave like us in many situations. Elephants have been seen using heavy branches to weigh down fences so they can climb over them. They've brandished sticks to ward off attackers.

Legends of elephant memory and intelligence date back thousands of years, and scientists have long observed just how clever the animals can be in their natural habitat. But until the past 15 years or so, there were few carefully controlled experiments to compare the memory of elephants to their

animal-kingdom peers'. Now, in addition to probing how elephants use their smarts during droughts and to protect themselves when threatened by enemy agents, researchers are designing studies to evaluate how the animals use their memories to learn to use tools, to work as a group and to problem-solve.

In a 2011 study of Kandula, an elephant at the National Zoo in Washington, D.C., researchers hung fruit-dipped bamboo branches within and just out of trunk reach to see if he could learn how to access them. This was a test other elephants had failed, in part because researchers had given their subjects sticks to nab the fruity bamboo. The problem: when the elephants curled their trunks around the sticks, their sense of smell was compromised. Earlier participants could not smell the snack to find it. Kandula, however, aced the trial, moving a large cube in his yard to use as a stepping stool to reach the bamboo. He learned to do the same with a tractor tire and giant blocks.

Such research builds on traditional studies that have established how elephants' memories help them navigate climate events and other hardships. For example, in 1958 a severe drought ravaged Tanzania's Tarangire National Park, home to a large elephant population. Almost 40 years later, when drought conditions returned, the Wildlife Conservation Society of London studied the migration patterns of three herds in the park. Among other findings, the researchers noted that the herd with the youngest matriarch, age 33, remained in the northern area of the park, where there was little water or food, and two thirds of the calves died.

But the older matriarchs, ages 45 and 38, who had survived the trauma of the 1958 drought, fared much better. They led their packs out of the northern portion of the park, theoretically to food and water elsewhere. Fewer than 10% of these calves died, prompting researchers to hypothesize that the older elephants remembered the location of resources from decades earlier.

The matriarchal structure of elephant society is, in fact, crucial to the herd's survival. Though males leave the group when they reach sexual maturity, between 12 and 15, related elephant mothers and their offspring stay together for life. They form a tight-knit unit, communicating with chirps and rumbles and caring for one another's calves. Members look to the matriarch, typically the largest female in the herd, for guidance, and she may oversee anywhere from 12 to 100 elephants over the course of a day, depending on the availability of water and food.

The matriarch not only knows each elephant; she keeps tabs on them as the herd travels, according to research conducted by Scottish psychologist Richard Byrne. After collecting urine samples from elephants living in a park in Kenya, Byrne placed them in front of the matriarchs. The females examined the samples with their trunks and started acting up when the urine did not come from their herd. The elephants also reacted when the urine was from a family member they thought was far away. "Imagine taking your family to a crowded department store and the Christmas sales are on," Byrne told *Scientific American*. "What a job to keep track of . . . four or five family members. These elephants are doing it with 30 traveling-mates."

Imagine taking your family to a busy store at Christmas and keeping track of four or five kids. The elephants do it with 30 travel mates.

Which raises the inevitable: Can elephants sometimes best us at problem-solving? The answer appears to be a qualified "yes"—as illustrated by Neua Un, a Thai elephant who participated in a 2011 test of memory and cooperation. One of a dozen pachyderms at a conservation center, Neua Un was to pair up with another elephant and pull a table toward them with ropes. The animals had to learn to perform the task as a team; otherwise, the rope would unravel. Neua Un, however, figured out she could use her foot to hold the rope so that her partner had to do all the work. The shortcut, which spoke to the idea that animals with a great capacity for memory also seem to be astute in terms of ingenuity, hadn't occurred to lead researcher Joshua Plotnik. While he suspects Neua Un discovered the cheat by accident, Plotnik told NBC he was impressed nevertheless. "It speaks volumes to the flexibility of elephant behavior that she was able to figure this out and stick to it," he said. ◻

Forget-me-nots symbolize remembering during partings or after death and a connection that lasts through time.

THE ESSENTIAL ACT OF BEING HUMAN

The paradox of memory is that we can summon it, but it can control us. It is exquisite and it hurts

By Steve Leder

BECAUSE I AM A RABBI, I HAVE BEEN visiting people in hospitals for more than 30 years. One of the best techniques I learned long ago to help someone who is suffering terribly is to take that person on a sort of mental vacation back to happier times. "When was your first kiss?" I might ask. "Who was she? Do you know where he is now? What was the greatest vacation you ever took? Do you remember the first time you ever laid eyes on your wife? What went through your mind? Best meal you ever ate? Funniest thing you ever did? Take me back. . . ." It is amazing to watch how memories lift people above their current sorrow into the transcendent meaning embedded in reminiscing. And it works every time.

On the holiest day of the year, during a service devoted to remembering loved ones who have died (it's called *Yizkor*), I tried something similar to my hospital mental vacation exercise, but this time from the pulpit. "Close your eyes," I said to the congregation of 2,000 people seated in the quiet beauty of the sanctuary. "Close your eyes and breathe in deeply. Breathe out and relax. Breathe in deeply again. Breathe in peace. Breathe in quiet. Now, place yourself in a comfortable room in your home or wherever you choose and invite into that room a loved one who has died. Bring him to life again in your mind. Bring her to life again in your mind—in your memory. See her. See her skin, her hair. Feel his whiskers against your cheek. See his smile and his eyes. Be with her. Speak to her. Tell her what you wish for her. Give her your blessing. Now allow her to leave the room. Be with him. Speak to him. Tell him what you wish for him. Give him your blessing. Now allow him to leave the room. Breathe deeply—and when you are ready, open your eyes." Halfway through this visualization, the room was awash in tears, hundreds of grown men and women, weeping, longing . . . remembering.

To remember is the quintessential act of being human. Not in the instinctual, mindless way of salmon swimming upstream to spawn or squirrels finding their long-ago-hidden acorns, but to use

memory in a way that summons the past into the present and brings the dead back to life—willfully, specifically, tearfully.

MY FATHER DIED peacefully in his sleep after a 10-year battle with Alzheimer's. It is a disease that kills people twice: once when the mind is lost and once when the body mercifully wears out. Both deaths are painful, but each in its unique way. The first caused my dad to forget who he was and who everyone who loved him was. In a sense, that forgetting meant that for him, neither he nor we existed any longer. There was a new he and a new we created in the vacuum of his mind; no one and nothing was the same.

That is, unless and until I chose to make use of the most precious of all gifts—my memories. In order to bring my father back to life, I merely had to remember all those simple things that he loved: A slice from a perfect avocado. A sunny day. Hank Williams and Johnny Cash. A joke—the dirtier, the better. Watching *All in the Family* in his vibrating Naugahyde chair, peeling an orange into a perfect spiral before handing out slices to each one of his five children as if we were a nest of hungry birds.

He didn't know or care about sports or hobbies or new gadgets like other dads. But he could back up a semi and operate a crane. My dad taught me to love nature, fishing, pancakes, corned beef hash and Mom's soups. Mostly Dad taught me to enjoy a moment during that moment. So many times when he was eating something delicious and plenty of it, or when we were walking in the sunshine somewhere beautiful, he would just look around and ask rhetorically, "Are we livin'?"

The last real conversation I remember having with my dad before thinking became hard work and confusing for him was about my fundraising for the temple. Mom was there too. We were sitting around that Formica table in the Palm Springs kitchen where they had sat together all those years drinking pots of tea from the stainless-steel thermal container and playing countless rounds of Rummikub.

So many times my dad would be walking in the sunshine somewhere beautiful, and he would look around and ask, "Are we livin'?"

It was at that table Dad asked, "How's work going?" And I told him, feeling a little sorry for myself, that it was really hard to raise all the money we needed, and I wasn't sure I could do it. He looked at me, smiled and said, "*Az m'schtuptis, gatis*—If you push, it goes." Almost everything Dad said was a double entendre and dirty. So he wasn't just talking about fundraising. That was him: simple, funny and right. Whatever your goal, just keep pushing. He was crude—and hilarious. And when I remember it all, he is those things again.

But there is more to memory than laughter and love. Weeks after viewing him in a plain pine casket—vacuous, cold and dead—I want to forget that image of my dad. I can't. Weeks after shoveling earth onto that same casket with a thunk, I want to forget that sound. I can't. *I don't want to remember. I don't want to remember. I don't want to remember*, I tell myself. Yet I cannot forget the ugliness or the surreal power of his death.

And if Freud was even partially right, there is a world of memories not about my dad's death but about his life that, try as I may, I can only sort of forget. Harsh memories of discipline and anger, anxiety and fear repressed and banished to the basement of my subconscious are constantly pounding on that same basement ceiling with a broomstick, reverberating in ways mysterious and dark in the core of my conscious life, animating my own flaws, dysfunction and vulnerabilities. That is the secret truth of memory: we summon it, yet it controls us, it is exquisite, and it hurts—like being caressed and spat on at the same time.

WHENEVER A VILLAIN is mentioned in classical rabbinic literature, his name is followed by an acronym for the words "May his name be blotted out." In the minds of the ancient rabbis, the worst thing one could wish upon another, the curse of curses, was that he or she be forgotten. And yet within that very curse the name of the villain is nevertheless perpetuated. We can wish that evil, sadness and ugliness be forgotten, but saying "don't think about it" is to

think about it—an attempt at squaring a circle; a fruitless, impossible denial of the constant that is memory itself. When Santayana said, "Those who forget the past are doomed to repeat it," he was only half right. For it is also true that those who only remember the past are also doomed to repeat it. This is the trap of memory that causes so much pain in so many families.

I often counsel people to forgive the sins of others who are truly sorry for what they have done. More times than not, people know they should forgive but say they just can't. "Rabbi, maybe she's sorry now, but you have no idea what she did. How she hurt me. How he cut me down. How he turned his back on me when I needed him most. I want to forgive, but it's too hard."

Long ago I learned that what the unforgiving are often really saying is not that it is impossible to forgive but that it is impossible to forget. We have no choice but to remember pain, the same way we have no choice when asked not to think about a pink elephant, but far worse. Such is the grip of memory. It is a force unlike any other in our lives.

When a non-villainous person dies, a different wish is suggested when his or her name is mentioned; a beautiful wish: "May his memory be a blessing." Seemingly different, these two aphorisms, "May his name be blotted out" and "May his memory be a blessing," speak the same truth—to be remembered is to live beyond the grave in ways sublime and terrible. Of course, sooner or later we are all "blotted out." Kafka said, "The meaning of life is that it ends," and that is no less true of memory. When it is gone, we are gone. We don't like to think about it, but eventually, in a generation or two or three or four or five, there will not be a single person left on earth who remembers us. When that day comes, we are truly dead.

In the meantime, how else can we hold on to the people we love, to the past that defines us, the offenses that wound us, or the laughter and the love that warm us? How else can we hold on to anything in a world whose centrifuge of speed and stress tries to whirl us all apart? What else can I do when I miss my dad so much? Nothing, other than embrace this blessing, this curse, this imperfect gift, this burden, this holy vessel: memory.

Steve Leder is the author of More Beautiful Than Before: How Suffering Transforms Us.

THE UPS AND DOWNS OF A PERFECT MEMORY

A small number of people can remember every day of their respective lives. For them, it's a good thing. Or is it?

By Amanda MacMillan

JOEY DEGRANDIS WAS ABOUT 10 YEARS old when his parents first realized there was something special about his memory. "Someone would mention an event from years ago that we'd done as a family, and I'd casually say, 'Oh, that was a Monday,' or 'That happened on June 20,' " says DeGrandis, who is now 34. "My mom would cross-reference it with old calendars she'd kept, and they were a little dumbfounded at how accurate I was."

DeGrandis showed off his skill that year at a magic show at school, wowing his audience by correctly identifying the day of the week for any given date in recent history. And for the next 15 years or so, DeGrandis thought of his talent mostly as a neat party trick: not something everyone could do, but not something with much significance, either. He would later find that there are upsides—and surprising downsides—to an almost perfect memory.

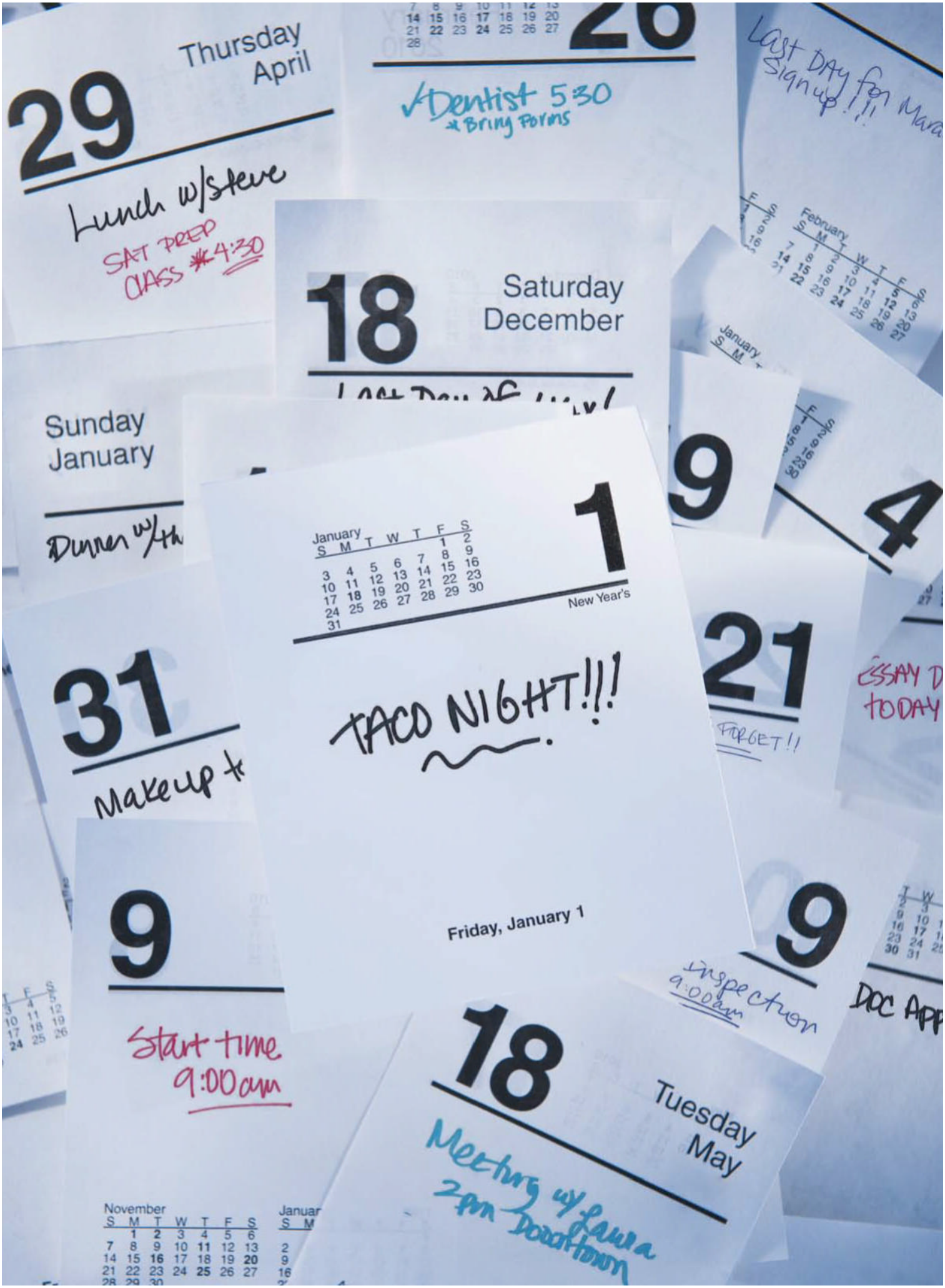
In 2010, when DeGrandis was 26, he saw a segment on *60 Minutes* featuring a handful of people with a similar ability: a condition now known as highly superior autobiographical memory, or HSAM. "I was on a road trip with a friend and ended up in California, and I decided to go visit this doctor who was studying these people who seemed to be like me," he says.

That doctor was James McGaugh, a research professor in neurobiology and behavior at the University of California, Irvine. McGaugh began studying HSAM in 2000, after a young woman named Jill Price contacted him about her memory "problem."

Price, who would later become the first person to be diagnosed with HSAM, had complained that her extraordinary memory was a burden. "Whenever I see a date flash on the television (or anywhere else for that matter) I automatically go back to that day and remember where I was, what I was doing, what day it fell on and on and on and on and on," she had written in an email to McGaugh. "It is non-stop, uncontrollable, and totally exhausting."

By 2010, McGaugh and his colleagues had identified a few others with an uncanny ability to link calendar dates with events, both major news and mundane personal details. After appearing on *60 Minutes*, McGaugh received more than 600 emails and phone calls from people—like DeGrandis—who thought they might also have this ability.

Ultimately, only about 60 of those people were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Fewer than 100 people have been diagnosed with HSAM, including Joey DeGrandis, left; Aureliaen Hayman, who was featured in the documentary The Boy Who Can't Forget, *center at left, with psychology professor Giuliana Mazzoni, who tested his memory; and Jake Hausier, a teen from St. Louis.*

identified by McGaugh as actually having HSAM, including DeGrandis, and opted to participate in the researchers' ongoing studies. (In his everyday life, DeGrandis works in marketing—in a job that has nothing to do with his special ability, he says.) He has enjoyed meeting others with HSAM and has been struck by the things they have in common.

DeGrandis says he's struggled from depression and anxiety, which he believes may be linked to his inability to let certain things go—a common theme with HSAM study participants. "I do tend to dwell on things longer than the average person," he says, "and when something painful does happen, like a breakup or the loss of a family member, I don't forget those feelings."

Research also suggests that people with HSAM tend to have obsessive traits. "Some subjects, like Price, focused on orderliness," McGaugh wrote in *Learning and Memory: A Comprehensive Reference*. "Some were germ-avoidant, and some had hobbies that involved intense, focused and sustained efforts," he added. It's not known yet whether these traits are the result of their superior memory or if both are caused by another underlying factor.

And while people with superior memories have an uncanny talent for linking dates and events, they do occasionally make mistakes. "Their memories are much more detailed than ours and last for a longer period of time, but they're still not video recordings," says McGaugh. "Memory is a distracting process, and what we pull from our brains isn't always entirely accurate."

People with HSAM are also no better than normal when it comes to remembering things such as faces or phone numbers. The ability is not the same as a so-called photographic memory, which allows people to vividly recall details from a scene they've observed for only a short time; nor is it the same as a talent held by "memory athletes" who use mnemonic devices to remember long strings of data.

"I'm not great with names or with mundane details like whether I brushed my teeth today or where I put my keys," says DeGrandis. "My mind is always moving and filled with so many other things, and maybe that contributes, ironically, to a poorer short-term memory."

Nearly two decades after the first case of HSAM was identified, there's still a lot we don't know about the condition. The UC Irvine researchers, for instance, plan to conduct functional MRI scans on people in the HSAM study to see if their brains work differently while they are retrieving information. Understanding the neurobiology behind HSAM may provide insights into how the brain stores and retrieves memories, says McGaugh, and may even be useful in the fight against Alzheimer's disease and other forms of dementia.

As for DeGrandis, he's happy to lend his mind to science in the hopes that it will ultimately help people who have trouble remembering things—not forgetting them. And although he and others like him sometimes feel burdened by this special talent, DeGrandis is ultimately glad to have it. "It can be frustrating, but it's also really wonderful to have easy access to happy memories," he says. "I really try not to take that for granted." ◻

Why Anxious People May Have Better Recall

But at the same time, their memories may be negatively biased if they've had a bad day

BY AMANDA MACMILLAN

In a new situation, anxiety may help you remember the event more vividly. "It . . . makes you attuned to details you wouldn't be otherwise," says Myra Fernandes, a psychology professor at the University of Waterloo in Canada and co-author of a 2018 study, published in *Brain Sciences*, on anxiety and memory. "That's a plus if you're trying to remember something later."

In Fernandes's study, 80 undergraduate psychology students were screened for their levels of everyday anxiety—asked, for example, how often in the past week they'd experienced dryness of the mouth or feelings of shakiness. The students were then instructed to study a set of words as they flashed across a computer screen, and to answer simple questions about their spelling or meaning. Some of the words were overlaid onto negative images, like a picture of an automobile accident, and some were overlaid onto neutral images, like a boat or a house.

Later, the students were prompted to recall words. Overall, memory performance did not differ based on their anxiety levels: those with low anxiety were better at remembering some words, and those with high anxiety were better at remembering others.

There was one interesting difference. The study authors suspected that words displayed over negative images would be remembered more accurately than words displayed over neutral images, since previous research has indicated that emotional context can make memories stronger. In Fernandes's trial, the people with higher anxiety levels better remembered the words over negative images, suggesting that they're more susceptible to this type of influence.

Sounds like a win for anxiety, right? Yet the aptitude may come with a downside, Fernandes warns, with high-anxiety sufferers adopting a "negative retrieval mode" when recalling events, which could lead to biased memories.

Most people have probably experienced this type of memory bias, comments Fernandes's co-author Christopher Lee. "Say you're having the worst day possible—you slept through your alarm, you slipped and fell in mud—and then the barista at Starbucks asks you a totally neutral question, like if you want whipped cream on your mocha," he says. "Because you entered this situation in such a negative mindset, you may remember him being rude or hostile or horrible for some reason, even when he's not." The more anxious you are, the more vulnerable you may be to this effect, says Lee.

Still, a little bit of anxiety is probably better than none at all, especially before events, says Fernandes. "Having butterflies in your stomach might actually make that information more memorable to you later on."

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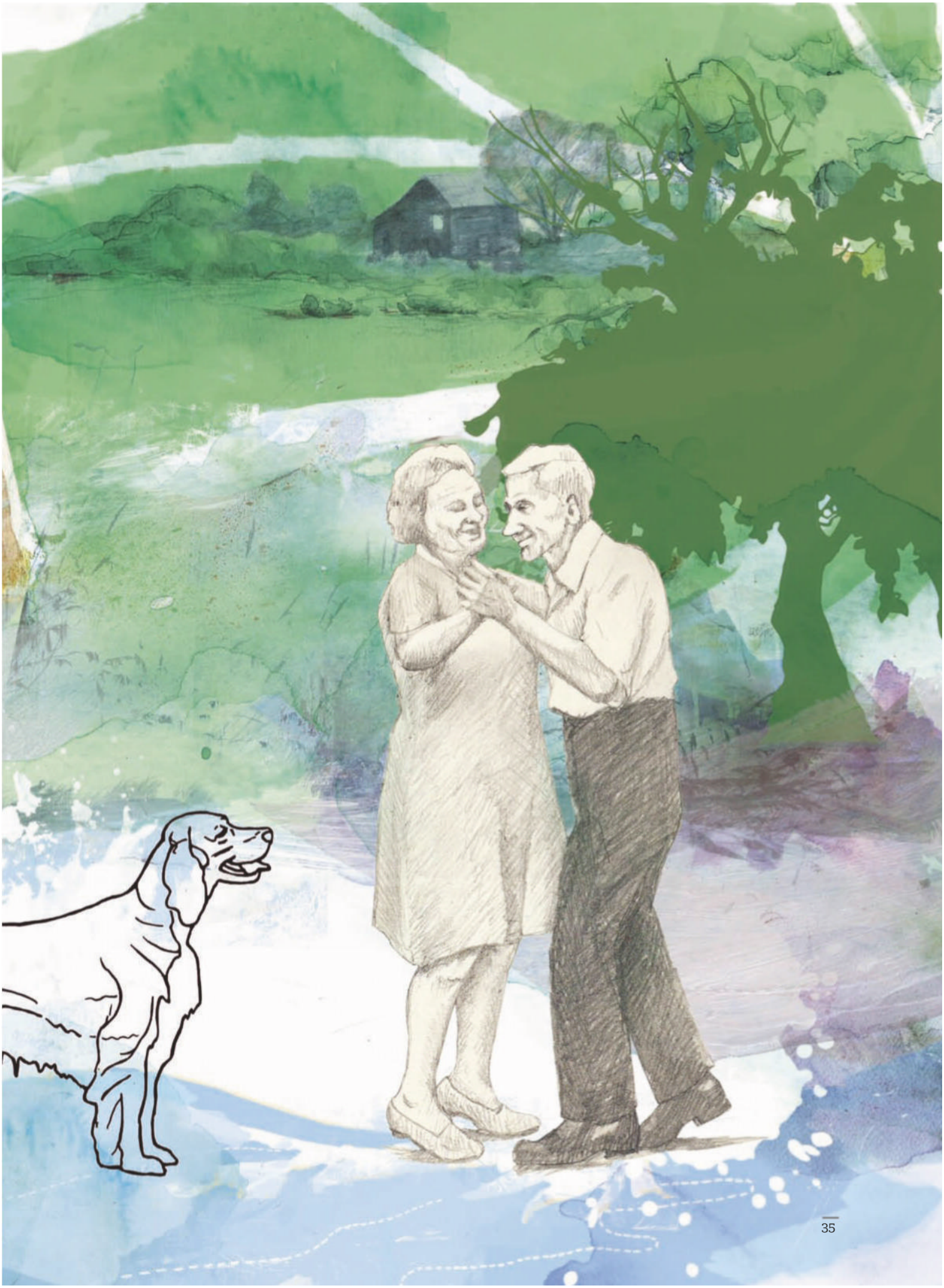
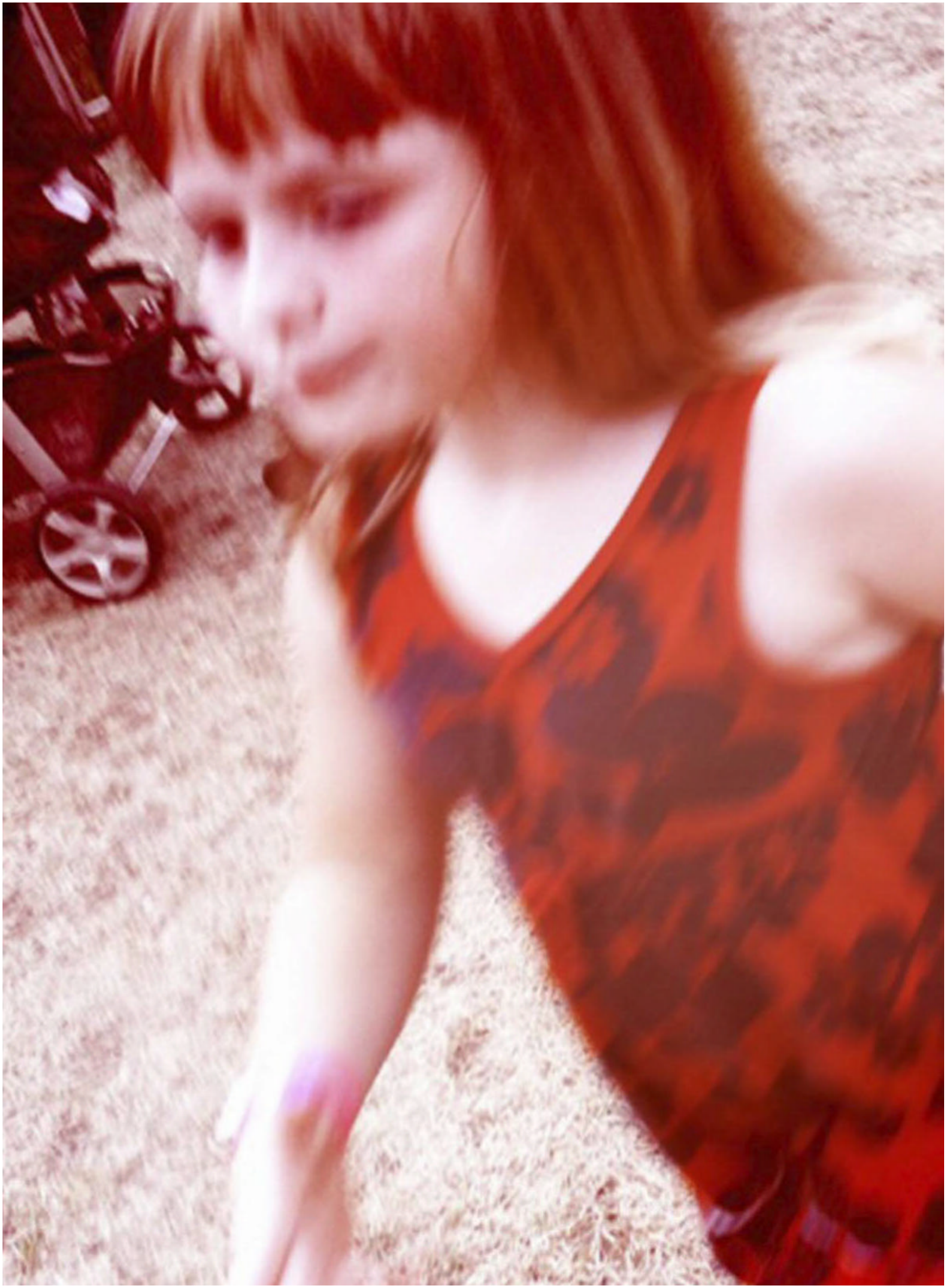
Why We Forget

Many of us are anxious about losing our memories, but letting go of certain information allows us to store what is important.