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The **Eureka** Hunt; Why do good ideas come to us when they do?

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The summer of 1949 was long and dry in Montana. On the afternoon of August 5th-the hottest day ever recorded in the state-a lightning fire was spotted in a remote area of pine forest. A parachute brigade of fifteen firefighters known as smoke jumpers was dispatched to put out the blaze; the man in charge was named Wag Dodge. When the jumpers left Missoula, in a C-47 cargo plane, they were told that the fire was small, just a few burning acres in the Mann Gulch.

Mann Gulch, nearly three miles long, is a site of geological transition, where the Great Plains meet the Rocky Mountains, pine trees give way to tall grasses, and steep cliffs loom over the steppes of the Midwest. The fire began in the trees on one side of the gulch. By the time the firefighters arrived, the blaze was already out of control. Dodge moved his men along the other side of the gulch and told them to head downhill, toward the water.

When the smoke jumpers started down the gulch, a breeze was blowing the flames away from them. Suddenly, the wind reversed, and Dodge watched the fire leap across the gulch and spark the grass on his side. He and his men were only a quarter mile uphill. An updraft began, and fierce winds howled through the canyon as the fire sucked in the surrounding air. Dodge was suddenly staring at a wall of flame fifty feet tall and three hundred feet deep. In a matter of seconds, the fire began to devour the grass, hurtling toward the smoke jumpers at seven hundred feet a minute.

Dodge screamed at his men to retreat. They dropped their gear and started running up the steep canyon walls, trying to reach the top of the ridge. After a few minutes, Dodge glanced over his shoulder and saw that the fire was less than fifty yards away. He realized that the blaze couldn't be outrun; the gulch was too steep, the flames too fast.

So Dodge stopped running. The decision wasn't as suicidal as it appeared: in a moment of desperate insight, he had devised an escape plan. He lit a match and ignited the ground in front of him, the flames quickly moving up the grassy slope. Then Dodge stepped into the shadow of his fire, so that he was surrounded by a buffer of burned land. He wet his handkerchief with water from his canteen, clutched the cloth to his mouth, and lay down on the smoldering embers. He closed his eyes and tried to inhale the thin layer of oxygen clinging to the ground. Then he waited for the fire to pass over him.

Thirteen smoke jumpers died in the Mann Gulch fire. White crosses below the ridge still mark the spots where the men died. But after several terrifying minutes Dodge emerged from the ashes, virtually unscathed.

There is something inherently mysterious about moments of insight. Wag Dodge, for instance, could never explain where his idea for the escape fire came from. ("It just seemed the logical thing to do" was all he could muster.) His improbable survival has become one of those legendary stories of insight, like Archimedes shouting "**Eureka!**" when he saw his bathwater rise, or Isaac Newton watching an apple fall from a tree and then formulating his theory of gravity. Such tales all share a few essential features, which psychologists and neuroscientists use to define "the insight experience." The first of these is the impasse: before there can be a breakthrough, there has to be a mental block. Wag Dodge spent minutes running from the fire, although he was convinced that doing so was futile. Then, when the insight arrived, Dodge immediately realized that the problem was solved. This is another key feature of insight: the feeling of certainty that accompanies the idea. Dodge didn't have time to think about whether his plan would work. He simply knew that it would.

Mark Jung-Beeman, a cognitive neuroscientist at Northwestern University, has spent the past fifteen years trying to figure out what happens inside the brain when people have an insight. "It's one of those defining features of the human mind, and yet we have no idea how or why it happens," he told me. Insights have often been attributed to divine intervention, but, by mapping the epiphany as a journey between cortical circuits, Jung-Beeman wants to purge the insight experience of its mystery. Jung-Beeman has a tense smile, a receding hairline, and the wiry build of a long-distance runner. He qualified for the 1988 and 1992 Olympic trials in the fifteen hundred metres, although he gave up competitive running after, as he puts it, "everything below the hips started to fall apart." He now subsists on long walks and manic foot tapping. When Jung-Beeman gets excited about an idea-be it the cellular properties of pyramidal neurons or his new treadmill-his speech accelerates, and he starts to draw pictures on whatever paper is nearby. It's as if his mind were sprinting ahead of his mouth.

Jung-Beeman became interested in the nature of insight in the early nineteen-nineties, while researching the right hemisphere of the brain. At the time, he was studying patients who had peculiar patterns of brain damage. "We had a number of patients with impaired right hemispheres," he said. "And the doctors would always say, 'Wow, you're lucky-it got the right hemisphere. That's the minor hemisphere. It doesn't do much, and it doesn't do anything with language.'" But it gradually became clear to Jung-Beeman that these patients did have serious cognitive problems after all, particularly with understanding linguistic nuance, and he began to suspect that the talents of the right hemisphere had been overlooked. If the left hemisphere excelled at denotation-storing the primary meaning of a word-Jung-Beeman suspected that the right hemisphere dealt with connotation, everything that gets left out of a dictionary definition, such as the emotional charge in a sentence or a metaphor. "Language is so complex that the brain has to process it in two different ways at the same time," he said. "It needs to see the forest *and* the trees. The right hemisphere is what helps you see the forest."

It wasn't clear how to pinpoint these nuanced aspects of cognition, because the results of right-hemisphere damage were harder to spot than those of left-hemisphere damage. But in 1993 Jung-Beeman heard a talk by the psychologist Jonathan Schooler on moments of insight. Schooler had demonstrated that it was possible to interfere with insight by making people explain their thought process while trying to solve a puzzle-a phenomenon he called "verbal overshadowing." This made sense to Jung-Beeman, since the act of verbal explanation would naturally shift activity to the left hemisphere, causing people to ignore the more subtle associations coming from the right side of the brain. "That's when I realized that insight could be a really interesting way to look at all these skills the right hemisphere excelled at," he said. "I guess I had an insight about insight."

Jung-Beeman began searching in the right hemisphere for the source of insight in the brain. He decided to compare puzzles solved in moments of insight with those solved by methodical testing of potential solutions, in which people could accurately trace their thought process and had no sense of surprise when the answer came. Unfortunately, all the classic puzzles developed by scientists to study insight *required* insight; if subjects didn't solve them in a sudden "Aha!" moment, they didn't solve them at all. In a popular puzzle known as "the candle problem," for instance, subjects are

given a cardboard box containing a few thumbtacks, a book of matches, and a candle. They are told to attach the candle to a piece of corkboard so that it can burn properly. Nearly ninety per cent of people pursue the same two strategies. They try to tack the candle directly to the board, which causes the candle wax to shatter. Or they try melting the candle with the matches, so that it sticks to the board; but the wax doesn't hold and the candle falls. Only four per cent of people manage to come up with the solution, which involves attaching the candle to the cardboard box and tacking the cardboard box to the corkboard.

To isolate the brain activity that defined the insight process, Jung-Beeman needed to develop a set of puzzles that could be solved either by insight or by analysis. Doing so was a puzzle in itself. "It can get pretty frustrating trying to find an experimentally valid brainteaser," Jung-Beeman said. "The puzzles can't be too hard or too easy, and you need to be able to generate lots of them." He eventually settled on a series of verbal puzzles, based on ones used by a psychologist in the early nineteen-sixties, which he named the Compound Remote Associate Problems, or CRAP. (The joke is beginning to get old, and in his scientific papers Jung-Beeman decorously leaves off the final "P.")

In a C.R.A. word puzzle, a subject is given three words, such as "pine," "crab," and "sauce," and asked to think of a word that can be combined with all three—in this case, "apple" ("pineapple," "crab apple," "apple sauce"). The subjects have up to thirty seconds to solve the puzzle. If they come up with an answer, they press the space bar on the keyboard and say whether the answer arrived via insight or analysis. When I participated in the experiment in Jung-Beeman's lab, I found that it was surprisingly easy to differentiate between the two cognitive paths. When I solved puzzles with analysis, I tended to sound out each possible word combination, cycling through all the words that went with "pine" and then seeing if they also worked with "crab" or "sauce." If I worked toward a solution, I always double-checked it before pressing the space bar. An insight, on the other hand, felt instantaneous: the answer arrived like a revelation.

Jung-Beeman initially asked his subjects to solve the puzzles while inside an fMRI machine, a brain scanner that monitors neural activity by tracking changes in blood flow. But fMRI has a three-to-five-second delay, as the blood diffuses across the cortex. "Insights happen too fast for fMRI," Jung-Beeman said. "The data was just too messy." Around this time, he teamed up with John Kounios, a cognitive neuroscientist at Drexel University, who was interested in insight largely because it seemed to contradict the classic model of learning, in which the learning process was assumed to be gradual. Kounios, a man with a shock of unruly wavy hair and an affinity for rumpled button-up vests, had been working with electroencephalography, or EEG, which measures the waves of electricity produced by the brain by means of a nylon hat filled with greased electrodes. (The device looks like a bulky shower cap.) Because there is no time delay with EEG, Kounios thought it could be useful for investigating the fleeting process of insight. Unfortunately, the waves of electricity can't be traced back to their precise source, but Kounios and Jung-Beeman saw that combining EEG with fMRI might allow them to construct a precise map, both in time and space, of the insight process.

The resulting studies, published in 2004 and 2006, found that people who solved puzzles with insight activated a specific subset of cortical areas. Although the answer seemed to appear out of nowhere, the mind was carefully preparing itself for the breakthrough. The first areas activated during the problemsolving process were those involved with executive control, like the prefrontal cortex and the anterior cingulate cortex. The scientists refer to this as the "preparatory phase," since the brain is devoting its considerable computational power to the problem. The various sensory areas, like the visual cortex, go silent as the brain suppresses possible distractions. "The cortex does this for the same reason we close our eyes when we're trying to think," Jung-Beeman said. "Focus is all about blocking stuff out."

What happens next is the "search phase," as the brain starts looking for answers in all the relevant places. Because Jung-Beeman and Kounios were giving people word puzzles, they saw additional activity in areas related to speech and language. The search can quickly get frustrating, and it takes only a few seconds before people say that they've reached an impasse, that they can't think of the right word. "Almost all of the possibilities your brain comes up with are going to be wrong," Jung-Beeman said. "And it's up to the executive control areas to keep on searching or, if necessary, change strategies and start searching somewhere else."

But sometimes, just when the brain is about to give up, an insight appears. "You'll see people bolt up in their chair

and their eyes go all wide," Ezra Wegbreit, a graduate student in the Jung-Beeman lab who often administers the C.R.A. test, said. "Sometimes they even say 'Aha!' before they blurt out the answer." The suddenness of the insight comes with a burst of brain activity. Three hundred milliseconds before a participant communicates the answer, the EEG registers a spike of gamma rhythm, which is the highest electrical frequency generated by the brain. Gamma rhythm is thought to come from the "binding" of neurons, as cells distributed across the cortex draw themselves together into a new network, which is then able to enter consciousness. It's as if the insight had gone incandescent.

Jung-Beeman and Kounios went back and analyzed the information from the fMRI experiment to see what was happening inside the brain in the seconds before the gamma burst. "My biggest worry was that we would find nothing," Kounios said. "I thought there was a good possibility that whatever we found on the EEG wouldn't show up on the brain imaging." When the scientists looked at the data, however, they saw that a small fold of tissue on the surface of the right hemisphere, the anterior superior temporal gyrus (aSTG), became unusually active in the second before the insight. The activation was sudden and intense, a surge of electricity leading to a rush of blood. Although the function of the aSTG remains mostly a mystery-the brain is stuffed with obscurities-Jung-Beeman wasn't surprised to see it involved with the insight process. A few previous studies had linked the area to aspects of language comprehension, such as the detection of literary themes and the interpretation of metaphors. (A related area was implicated in the processing of jokes.) Jung-Beeman argues that these linguistic skills, like insight, require the brain to make a set of distant and unprecedented connections. He cites studies showing that cells in the right hemisphere are more "broadly tuned" than cells in the left hemisphere, with longer branches and more dendritic spines. "What this means is that neurons in the right hemisphere are collecting information from a larger area of cortical space," Jung-Beeman said. "They are less precise but better connected." When the brain is searching for an insight, these are the cells that are most likely to produce it.

The insight process, as sketched by Jung-Beeman and Kounios, is a delicate mental balancing act. At first, the brain lavishes the scarce resource of attention on a single problem. But, once the brain is sufficiently focussed, the cortex needs to relax in order to seek out the more remote association in the right hemisphere, which will provide the insight. "The relaxation phase is crucial," Jung-Beeman said. "That's why so many insights happen during warm showers." Another ideal moment for insights, according to the scientists, is the early morning, right after we wake up. The drowsy brain is unwound and disorganized, open to all sorts of unconventional ideas. The right hemisphere is also unusually active. Jung-Beeman said, "The problem with the morning, though, is that we're always so rushed. We've got to get the kids ready for school, so we leap out of bed and never give ourselves a chance to think." He recommends that, if we're stuck on a difficult problem, it's better to set the alarm clock a few minutes early so that we have time to lie in bed and ruminate. We do some of our best thinking when we're still half asleep.

As Jung-Beeman and Kounios see it, the insight process is an act of cognitive deliberation-the brain must be focussed on the task at hand-transformed by accidental, serendipitous connections. We must concentrate, but we must concentrate on letting the mind wander. The patterns of brain activity that define this particular style of thought have recently been studied by Joy Bhattacharya, a psychologist at Goldsmiths, University of London. Using EEG, he has found that he can tell which subjects will solve insight puzzles up to eight seconds before the insight actually arrives. One of the key predictive signals is a steady rhythm of alpha waves emanating from the right hemisphere. Alpha waves typically correlate with a state of relaxation, and Bhattacharya believes that such activity makes the brain more receptive to new and unusual ideas. He has also found that unless subjects have sufficient alpha-wave activity they won't be able to make use of hints the researchers give them.

One of the surprising lessons of this research is that trying to force an insight can actually prevent the insight. While it's commonly assumed that the best way to solve a difficult problem is to focus, minimize distractions, and pay attention only to the relevant details, this clenched state of mind may inhibit the sort of creative connections that lead to sudden breakthroughs. We suppress the very type of brain activity that we should be encouraging. Jonathan Schooler has recently demonstrated that making people focus on the details of a visual scene, as opposed to the big picture, can significantly disrupt the insight process. "It doesn't take much to shift the brain into left-hemisphere mode," he said. "That's when you stop paying attention to those more holistic associations coming in from the right hemisphere." Meanwhile, in a study published last year, German researchers found that people with schizotypy-a mental condition

that resembles schizophrenia, albeit with far less severe symptoms-were significantly better at solving insight problems than a control group. Schizotypal subjects have enhanced right-hemisphere function and tend to score above average on measures of creativity and associative thinking.

Schooler's research has also led him to reconsider the bad reputation of letting one's mind wander. Although we often complain that the brain is too easily distracted, Schooler believes that letting the mind wander is essential. "Just look at the history of science," he said. "The big ideas seem to always come when people are sidetracked, when they're doing something that has nothing to do with their research." He cites the example of Henri Poincaré, the nineteenth-century mathematician, whose seminal insight into non-Euclidean geometry arrived while he was boarding a bus. "At the moment when I put my foot on the step," Poincaré wrote, "the idea came to me, without anything in my former thoughts seeming to have paved the way for it. . . . I did not verify the idea; I should not have had the time, as, upon taking my seat in the omnibus, I went on with the conversation already commenced, but I felt a perfect certainty." Poincaré credited his sudden mathematical insight to "unconscious work," an ability to mull over the mathematics while he was preoccupied with unrelated activities, like talking to a friend on the bus. In his 1908 essay "Mathematical Creation," Poincaré insisted that the best way to think about complex problems is to immerse yourself in the problem until you hit an impasse. Then, when it seems that "nothing good is accomplished," you should find a way to distract yourself, preferably by going on a "walk or a journey." The answer will arrive when you least expect it. Richard Feynman, the Nobel Prize-winning physicist, preferred the relaxed atmosphere of a topless bar, where he would sip 7 UP, "watch the entertainment," and, if inspiration struck, scribble equations on cocktail napkins.

Kounios and Jung-Beeman aren't quite ready to offer extensive practical advice, but, when pressed, they often sound like Poincaré. "You've got to know when to step back," Kounios said. "If you're in an environment that forces you to produce and produce, and you feel very stressed, then you're not going to have any insights." Many stimulants, like caffeine, Adderall, and Ritalin, are taken to increase focus-one recent poll found that nearly twenty per cent of scientists and researchers regularly took prescription drugs to "enhance concentration"-but, according to Jung-Beeman and Kounios, drugs may actually make insights less likely, by sharpening the spotlight of attention and discouraging mental rambles. Concentration, it seems, comes with the hidden cost of diminished creativity. "There's a good reason Google puts Ping-Pong tables in their headquarters," Kounios said. "If you want to encourage insights, then you've got to also encourage people to relax." Jung-Beeman's latest paper investigates why people who are in a good mood are so much better at solving insight puzzles. (On average, they solve nearly twenty per cent more C.R.A. problems.)

Last year, Kounios and Jung-Beeman were invited to present their findings to DARPA, the central research agency of the Department of Defense. ("It was quite strange," Kounios recalls. "I never thought I'd be talking about creativity to national-security officials.") DARPA was interested in finding ways to encourage insights amid the stress of war, fostering creativity on the battlefield. The scientists are convinced that it's only a matter of time before it becomes possible to "up-regulate" insight. "This could be a drug or technology or just a new way to structure our environment," Jung-Beeman said. "I think we'll soon get to the point where we can do more than tell people to take lots of showers."

For now, though, the science of promoting insight remains rooted in anecdote, in stories of people, like Poincaré, who were able to consistently induce the necessary state of mind. Kounios tells a story about an expert Zen meditator who took part in one of the C.R.A. insight experiments. At first, the meditator couldn't solve any of the insight problems. "This Zen guy went through thirty or so of the verbal puzzles and just drew a blank," Kounios said. "He was used to being very focussed, but you can't solve these problems if you're too focussed." Then, just as he was about to give up, he started solving one puzzle after another, until, by the end of the experiment, he was getting them all right. It was an unprecedented streak. "Normally, people don't get better as the task goes along," Kounios said. "If anything, they get a little bored." Kounios believes that the dramatic improvement of the Zen meditator came from his paradoxical ability to focus on *not* being focussed, so that he could pay attention to those remote associations in the right hemisphere. "He had the cognitive control to let go," Kounios said. "He became an insight machine."

The most mysterious aspect of insight is not the revelation itself but what happens next. The brain is an infinite library of associations, a cacophony of competing ideas, and yet, as soon as the right association appears, we know. The

new thought, which is represented by that rush of gamma waves in the right hemisphere, immediately grabs our attention. There is something paradoxical and bizarre about this. On the one hand, an epiphany is a surprising event; we are startled by what we've just discovered. Some part of our brain, however, clearly isn't surprised at all, which is why we are able to instantly recognize the insight. "As soon as the insight happens, it just seems so obvious," Schooler said. "People can't believe they didn't see it before."

The brain area responsible for this act of recognition is the prefrontal cortex, which lights up whenever people are shown the right answer—even if they haven't come up with the answer themselves. Pressed tight against the bones of the forehead, the prefrontal cortex has undergone a dramatic expansion during human evolution, so that it now represents nearly a third of the brain. While this area is often associated with the most specialized aspects of human cognition, such as abstract reasoning, it also plays a critical role in the insight process. Hallucinogenic drugs are thought to work largely by modulating the prefrontal cortex, tricking the brain into believing that its sensory delusions are revelations. People have the feeling of an insight but without the content. Understanding how this happens—how a circuit of cells can identify an idea as an insight, even if the idea has yet to enter awareness—requires an extremely precise level of investigation. The rhythms of brain waves and the properties of blood can't answer the question. Instead, it's necessary to study the brain at its most basic level, as a loom of electrical cells.

Earl Miller is a neuroscientist at M.I.T. who has devoted his career to understanding the prefrontal cortex. He has a shiny shaved head and a silver goatee. His corner office in the gleaming Picower Institute is cantilevered over a railroad track, and every afternoon the quiet hum of the lab is interrupted by the rattle of a freight train. Miller's favorite word is "exactly"—it's the adverb that modifies everything, so that a hypothesis is "exactly right," or an experiment was "exactly done"—and that emphasis on precision has defined his career. His first major scientific advance was a by-product of necessity. It was 1995, and Miller had just started his lab at M.I.T. His research involved recording directly from neurons in the monkey brain, monitoring the flux of voltage within an individual cell as the animals performed various tasks. "There were machines that allowed you to record from eight or nine at the same time, but they were very expensive," Miller said. "I still had no grants, and there was no way I could afford one." So Miller began inventing his own apparatus in his spare time. After a few months of patient tinkering, he constructed a messy tangle of wires, steel screws, and electrodes that could simultaneously record from numerous cells, distributed across the brain. "It worked even better than the expensive machine," Miller said.

This methodological advance—it's known as multiple electrode recording—allowed Miller to ask a completely new kind of scientific question. For the first time, it was possible to see how cells in different brain areas interacted. Miller was most interested in the interactions of the prefrontal cortex. "You name the brain area, and the prefrontal cortex is almost certainly linked to it," he said. It took more than five years of painstaking probing, as Miller recorded from cells in the monkey brain, but he was eventually able to show that the prefrontal cortex wasn't simply an aggregator of information. Instead, it was like the conductor of an orchestra, waving its baton and directing the players. This is known as "top-down processing," since the prefrontal cortex (the "top" of the brain) is directly modulating the activity of other areas. This is why, during the focussing phase of the insight process, Jung-Beeman and Kounios saw activity in the prefrontal cortex and the neighboring anterior cingulate cortex. They were watching the conductor at work.

In 2001, Miller and Jonathan Cohen, a neuroscientist at Princeton, published an influential paper that laid out their theory of how, exactly, the prefrontal cortex controls the rest of the brain. According to Miller and Cohen, this brain area is responsible not only for focussing on the task at hand but for figuring out what other areas need to be engaged in order to solve a problem. One implication of this is that if we're trying to solve a verbal puzzle the prefrontal cortex will selectively activate the specific brain areas involved with verbal processing. If it decides to turn on parts of the right hemisphere, then we might end up with an insight; if it decides to restrict its search to the left hemisphere, we'll probably arrive at a solution incrementally or not at all.

This "integrative" theory of the prefrontal cortex suggests why we can instantly recognize the insight, even when it seems surprising: the brain has been concertedly pursuing the answer; we just didn't know it. "Your consciousness is very limited in capacity," Miller said, "and that's why your prefrontal cortex makes all these plans without telling you

about it." When that obscure circuit in the right hemisphere finally generates the necessary association, the prefrontal cortex is able to identify it instantly, and the insight erupts into awareness. We suddenly notice the music that has been playing all along.

Because Miller can eavesdrop on neurons, he's been able to see how these insights operate at the cellular level. One of his current experiments involves showing monkeys different arrangements of dots and asking them to sort the arrangements into various categories that they have been taught. The monkeys guess randomly at first, learning from trial and error. "But then, at a certain point, the monkey just gets it," Miller said. "They just start being able to categorize arrangements of dots that they've never seen before. That's the moment of categorical insight." This primate epiphany registers as a new pattern of neural activity in the prefrontal cortex. The brain cells have been altered by the breakthrough. "An insight is a restructuring of information-it's seeing the same old thing in a completely new way," Miller said. "Once that restructuring occurs, you never go back."

And yet even this detailed explanation doesn't fully demystify insight. It remains unclear how simple cells recognize what the conscious mind cannot, or how they are able to filter through the chaos of bad ideas to produce the epiphany. "This mental process will always be a little unknowable, which is why it's so interesting to study," Jung-Beeman said. "At a certain point, you just have to admit that your brain knows much more than you do." An insight is a fleeting glimpse of the brain's huge store of unknown knowledge. The cortex is sharing one of its secrets.

So it was for Wag Dodge. After the fire crossed the river, all the other smoke jumpers were fixated on reaching the ridge. Panic had narrowed their thoughts, so that beating the flames up the slope was their sole goal. But, because Dodge realized that the fire would beat them to the top, his prefrontal cortex started frantically searching for an alternative. It was able to look past his fear and expand the possibilities of his thought process, as he considered remote mental associations that he'd never contemplated before. (As Miller says, "That Dodge guy had some really high prefrontal function.") And then, just as the blaze started to suck the oxygen out of the air, some remote bit of his brain realized that he could cheat death by starting his own fire. This unprecedented idea, a flicker of electricity somewhere in the right hemisphere, was immediately recognized as the solution the prefrontal cortex had been searching for. And so Dodge stopped running. He stood still as the wall of flame raced toward him. Then he lit the match.

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