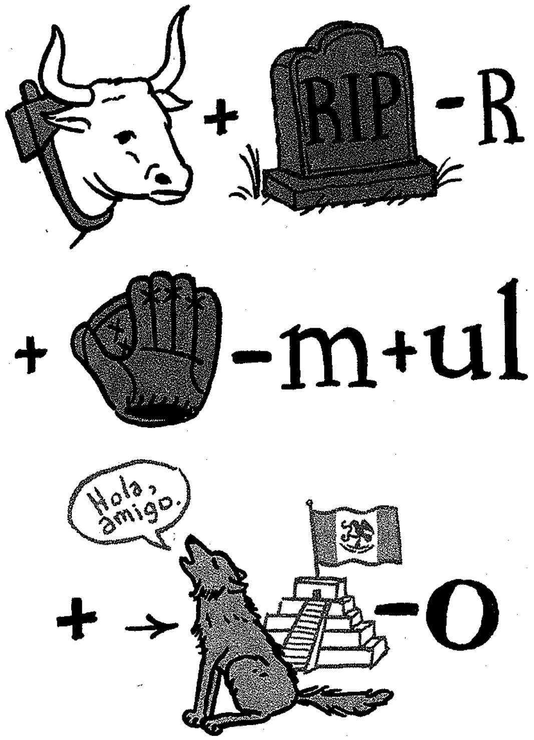
CHAPTER FOUR

Facing Brain Damage

Circuits of neurons in turn combine to form larger structures, like our sensory systems, which analyze information in advanced ways.



A man lies along a table, a mask of plaster covering his face. The mask looks normal—nose, ears, eyes, teeth, lips. But when it's lifted, part of the soldier's face beneath seems to lift off with it, leaving a crater in his flesh. Sitting up, the soldier gets his first deep breath since the plaster was painted on a half hour before. Assuming he has a nose, he might catch the scent of the flowers kept nearby to brighten the Paris studio. Assuming he has ears, he might hear the clatter of dominoes across the room, from other mutilated soldiers waiting for their turn on the table. Assuming he has a tongue, he might sip some *vin blanc* to revive himself. And assuming he has eyes, he might see dozens of other masks hanging on the wall—the befores and afters of fellow-*mutilés* who'd lost their faces in the Great War and hoped the masks would help them resume a normal life.

The woman making the masks had no medical qualifications, only artistic ones. Although American, Anna Coleman Ladd had lived most of her early life in Paris and studied sculpture there in the late 1800s; Auguste Rodin himself had advised her. Still, she lacked the élan to be famous. She ended up carving staid satyrs and nymphs for fountains and private gardens, and she all but gave up sculpture when she returned to Boston to marry a Harvard medical professor. They had an unconventionally independent marriage, but Ladd followed him to Europe in 1917 and later snuck into Paris. Inspired by a similar outfit in London, called the Tin Noses Shop, Ladd opened her prosthetic mask studio in 1918 in a fifth-floor walk-up in an ivied building. She populated the courtyard below with her old busts and sculptures—sculptures with classically beautiful faces that, however passé to the art world, must have stirred the hopes of the *mutilés* sneaking in for appointments beneath the cover of dawn or dusk.

In one sense Ladd's studio was conducting an artistic experiment in the tradition of Pygmalion—how realistic could realism get? At the same time she was conducting a psychological experiment—could she fool the brain into mistaking a mask for flesh? We humans often conflate our faces with our very selves. So by restoring a face torn in two by a bullet, she was attempting to restore a soldier's identity. But she had no way of knowing whether other people—or the soldiers themselves—would accept the new faces as authentic.

Rebuilding a face wasn't something doctors often worried about before 1914. A few soldiers and brawlers in history—most notably the emperor Justinian II and astronomer Tycho Brahe—had lost their noses in sword duels. Most received silver or copper replacements, and some surgeons did develop "natural" methods for replacing lost tissue. (One involved sewing the face to the crook of the elbow for a few weeks, until the arm skin adhered to the bridge of the nose and provided a cover flap.*) But the trench warfare of World War I produced orders of magnitude more facial casualties than ever before, the result of grenades, mortars, machine guns, and other methods of flinging metal at high velocities. Just before going down, many soldiers heard a crackle or whistle from a shell, then felt their facial bones explode. One man compared the feeling to "a glass bottle [dropped] into a porcelain bathtub." Even dense jawbones might pulverize on contact, reduced to sand beneath the skin. And while metal helmets protected the brain, the helmet itself sometimes exploded into shrapnel when struck, gouging into eyes and ears. In all, tens of thousands of men (and a few women) woke up in a mudhole to find their noses torn off or tongues dangling. Some who lost eyelids slowly went blind as their corneas dried out. Other soldiers' faces looked punched-in, like a Francis Bacon portrait.* Officers instructed men on watch duty that, when peeking at the enemy, they should put their heads *and* shoulders over the parapet, since snipers would aim for the body, a more agreeable place to be shot.

The apocalyptic Battle of the Somme in 1916—when newspapers had to print not just columns but whole pages of casualties—spurred the British military to open a hospital for facial injuries on a dairy farm in Kent. The head surgeon there, a part-time painter, had seen how slapdash plastic surgery could be: he'd once encountered a young man in a POW camp who had hair growing on his nose because someone had grafted skin from his scalp onto his face. Determined to end such practices, the surgeon emphasized the aesthetics of facial reconstruction, even demanding multiple surgeries to get things right. In all, the Kent hospital performed eleven thousand surgeries on five thousand British soldiers, and often tended them for months between operations. Some victims could swallow only liquids, so the farm also raised chickens and cows and fed the men an eggnog slurry for protein. As part of their rehabilitation, some soldiers tended the animals, while others learned trades such as making toys, repairing clocks, or hairdressing. Many of the men formed deep friendships with their fellow "gargoyles," while others, being soldiers, also flirted with whatever women happened by. The boldest patients won their nurses as wives, and one exhilarated female visitor declared that "men without noses are very beautiful—like antique marbles."

Not everyone was so broad-minded. The soldiers felt safe enough while in the wards to tease each other, even call each other ugly; but they always wore red ties and cornflower-blue jackets when visiting the nearest village, to warn people off from a distance. Shopkeepers wouldn't sell the men liquor because some became unhinged when drunk, and outsiders dreaded eating with them because their food sometimes reappeared through extra holes when they chewed and swallowed. Some hospitals forbade the men mirrors, and when released from the safe cocoon of the facial ward, many patients killed themselves. Others found work in a new industry, enjoying long hours of dark solitude as cinema projectionists. And some of the direst cases, those that surgeons couldn't salvage, sought out Ladd or her London counterpart.

To sculpt a face, Ladd used a man's siblings or a preinjury photograph as models. A few hopeful soldiers brought in pictures of Rupert Brooke, a disarmingly handsome celebrity poet. Most, though, didn't care about being gorgeous. They wanted only to become anonymous again. As a first step, Ladd plugged any holes in their faces with cotton and painted plaster onto whatever portion needed masking. She sculpted the new features with clay, then created the actual mask a few days later by electroplating thin layers of copper and silver onto the clay surface. She might affix some absorbent pads behind the façade if the man's tear ducts or salivary glands leaked, but otherwise the six-ounce metal mask rested directly on the face, anchored by spectacles. She colored the masks with cream bath enamels to match skin tones, then made mustaches of metal foil, since real hair didn't adhere. Each mask took a month to produce, cost around $18 ($250 today), and could be cleaned with potato juice. Ladd's studio produced especially brilliant work. She painted gorgeous eyes, and left the slightest hint of blue in the cheeks to make them look freshly shaved. She also made foil mustaches so realistic that Frenchmen could twirl them (they much appreciated this), and even left their metal lips agape for cigarettes (ditto).

Plaster casts of soldiers' faces. Notice the finished, wearable masks on the bottom. (Library of Congress)

Ladd and her assistants made hundreds of soldiers achingly happy. "The woman I love no longer finds me repulsive," one lad wrote, "as she had a right to do." One veteran wore his mask during his wedding, and many more were buried in theirs over the next few decades. But however grateful, many found the masks too uncomfortable for daily use. The face has inordinate numbers of nerve endings, and the masks sometimes rubbed scars raw. Worse, the masks didn't function like real faces—didn't chew, didn't smile, didn't kiss. Even visually, the masks sometimes didn't cut it. The features didn't age the way skin did. The enamel chipped or corroded. And electric lighting, increasingly popular, often exposed the *Phantom of the Opera*–like seam between façade and flesh.

In the end, then, Ladd fell short: however artistic, her masks couldn't quite simulate the experience of seeing a real human face. As a result, the deeper, more psychological questions that her work raised—can the brain adjust to seeing a new face in the mirror? would that change someone's sense of self?—remained unanswered. It would take another century of work to get at those questions. And answering them would require understanding not only how the brain analyzes faces but, even more fundamentally, understanding how the brain sees the world around us at all.

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The twentieth century's first major discovery about vision came about, once again, because of war. Russia had long coveted a warm-water port on the Pacific Ocean, so in 1904 the czar sent hundreds of thousands of troops to Manchuria and Korea to bully one away from the Japanese. These soldiers were armed with high-speed rifles whose tiny, quarter-inch bullets rocketed from the muzzle at fourteen hundred miles per hour. Fast enough to penetrate the skull but small enough to avoid messy shattering, these bullets made clean, precise wounds like worm tracks through an apple. Japanese soldiers who were shot through the back of the brain—through the vision centers, in the occipital lobe—often woke up to find themselves with tiny blind spots, as if they were wearing glasses spattered with black paint.

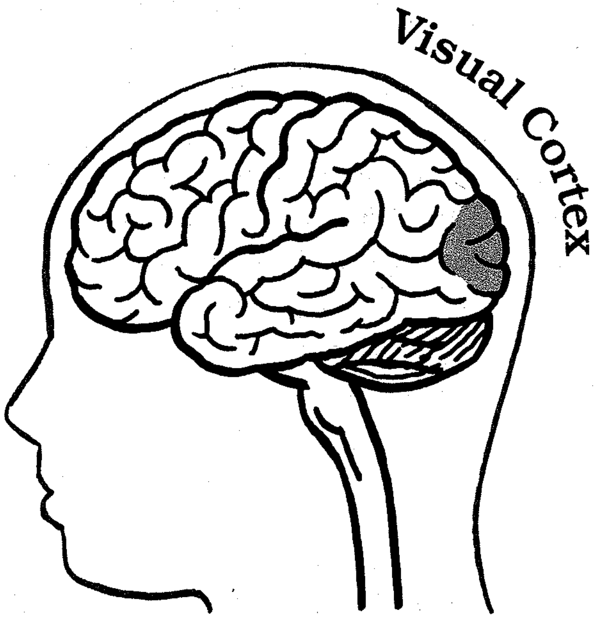
Tatsuji Inouye, a Japanese ophthalmologist, had the uncomfortable job of calculating how much of a pension these speckled-blind soldiers should receive, based on the percentage of vision lost. Inouye could have gotten away with merely showing them a few pictures and jotting down what details they could and couldn't see. But he was that rare thing, an idealistic bureaucrat, and he saw that his work revealed something deeper.

By 1904 neuroscientists knew a little about how vision worked in the brain. They knew that everything to the left of your nose (called the left visual field) gets transmitted into the brain's right hemisphere, and that everything to the right of the nose (the right visual field) gets transmitted into the left hemisphere.* Moreover, scientists knew that the occipital lobe was somehow involved with vision, since strokes back there often blinded people. But strokes caused such messy, widespread damage that the inner workings of the lobe remained mysterious. Scorching Russian bullets, in contrast, produced focal lesions as they entered and exited the brain. Inouye realized that if he could chart each man's specific brain damage, and match that damage to the part of the eye where a blind spot now appeared, he could basically produce a map of the occipital lobe—and thereby determine what sections of the brain analyzed each part of the visual field.

Before he got too far along with this work, Inouye stopped to examine a big assumption—that bullets followed a straight line through the brain. Perhaps they ricocheted around inside the skull, or got gummed up and followed a twisted path instead. So Inouye hunted down soldiers who'd been shot through the top of the head while lying on their stomachs. In this position the bullets ran parallel to their spinal cords. So in addition to a skull entry wound and a skull exit wound, most men also had, crucially, a third wound where the bullet left the skull and plugged them in the chest or shoulder. Inouye had the men re-create their postures the moment they'd been shot,

and he found that all three wounds always described a straight line. Confident now that he hadn't overlooked anything, Inouye began mapping the occipital lobe, especially what's now called the primary visual cortex (PVC).

His most important finding was that our brains effectively magnify whatever we're looking at, by dedicating more neurons to the center of the visual field. Part of the primary visual cortex lies on the surface of the brain, just below the bump on the back of the noggin, and part of it lies buried beneath the brain's surface. It turns out that soldiers with black speckles in the center of their vision always had damage to surface patches, while men with peripheral speckles had damage to the subterranean stuff. The consistency of this correlation proved, as Inouye had hoped, that certain regions of the brain always controlled certain parts of the eye.



But the patches that processed the center, he discovered, were vastly larger in area than the patches that covered the periphery. In fact, it wasn't even close. Scientists now know that the focal center of the eye, the fovea, takes up just one ten-thousandth of the retina's surface area. Yet gobbles up a full one-tenth of the PVC's processing power. Similarly, around half of the PVC's 250 million neurons help us process the central 1 percent of our visual field. Inouye's half-blind patients helped him see this special magnification for the first time in history.

Unfortunately for Inouye, other scientists got credit for his discoveries. During World War I, two English doctors, ignorant of his work, duplicated his experiments on the visual cortex with their own brain-damaged troops. They obtained the same results, but these doctors had the cultural advantage of being European. What's more, in his major paper on vision, Inouye used a convoluted Cartesian graph to plot the relationship between the eyes and the primary visual cortex. It was precise, but it left readers cross-eyed themselves. The Englishmen meanwhile used a simple map, something scientists could grasp at a glance. When this intuitive diagram was published in textbooks worldwide, Inouye slipped into obscurity. Blindness can be a generational affliction, too.

The next major discovery in vision neuroscience took place far from the battlefield. In 1958 a pair of young neuroscientists at the Johns Hopkins University, one Canadian and one Swedish, began investigating neurons in the visual cortex. In particular, David Hubel and Torsten Wiesel wanted to know what sights or shapes got these neurons excited—what made them fire? They had a good hunch, based on other scientists' work. Signals from the eyes actually make a quick layover in the thalamus, in the center of the brain, before reaching the visual cortex. And other scientists had shown that thalamic neurons respond strongly to black-and-white spots. So Hubel and Wiesel decided to take the obvious next step and investigate how neurons in the visual cortex responded to spots.

When shown their new lab, a grimy basement with no windows, Hubel and Wiesel rejoiced. No windows meant no stray light—

perfect for vision work. They were less enthusiastic about the equipment they inherited. Their experiments involved, à la *A Clockwork Orange,* strapping down an anesthetized cat into a harness, immobilizing its eyes, and forcing it to stare at spots projected onto a bedsheet. But because the harness they inherited was horizontal, the kitty had to lie on its back, staring straight up toward the ceiling. Therefore the duo had to flip their slide projector toward the ceiling, too, then drape a sheet over the pipes up there "like a circus tent," Hubel remembered. Insects and dust rained down, and to see the screen, the duo had to stare upward themselves, straining their necks.

And this was just the setup—actually studying the neurons proved no easier. By 1958 scientists had built microelectrodes sensitive enough to monitor a single neuron inside the brain; some researchers had already examined hundreds of individual cells this way. (This head start intimidated Hubel and Wiesel, who felt like amateurs. So they "catapulted [themselves] to respectability," as they said, by starting the count in their experiments at number 3,000. Whenever people visited the lab, they made sure to announce what number they were on.)

Each electrode had fine platinum wires that slid into the cat's primary visual cortex. Hubel and Wiesel wired the electrode's other end to a speaker, which clicked whenever a neuron fired in response to a spot. Or at least it should have clicked. The first experiments proved dreadful, taking nine hours each—their necks were killing them—and running into the wee hours. Wiesel would start blathering in Swedish around 3 a.m., and Hubel almost nodded off and crashed one night while driving home. Worse, the neurons they monitored would not fire. They tried white spots. They tried black spots. They tried polka dots. "We tried everything short of standing on our heads," Hubel recalled—including cheesecake shots from glamour magazines. But the stubborn stupid neurons refused to click.

Week after maddening week passed, until September 1958. During the fifth hour of work one night, starting with cell 3009, they dropped yet another slide with yet another dot into the projector. According to different accounts, the slide either jammed or went in crooked, at an angle. Regardless, something finally happened: one neuron "went off like a machine gun," Hubel said—*rat-a-tat-tat-tat-tat-tat.* It soon fell silent again, but after an hour of desperate fiddling, they realized what was going on. The neuron didn't give a fig about the dot; it was firing in response to the slide itself—specifically, to the sharp shadow that formed on the screen as the edge of the slide dropped into place. This neuron dug lines.

More hours of fiddling followed, and the duo quickly realized how lucky they'd been. Only lines within about ten degrees of one orientation set this neuron off. Had they dropped the slide in any less crookedly, the cell would have continued to give them the silent treatment. What's more, other neurons, in follow-up experiments, proved equally picky, firing only for lines like \ or /. It took many more years of work, and many more cats, to firm everything up, but Hubel and Wiesel had already gotten a peek at the first law of vision: neurons in the primary visual cortex like lines, but different neurons like different lines, raked at different angles.

The next step involved looking a little wider and determining the geographical patterns of these line-loving neurons. Did all of the neurons that liked a given angle cluster together, or was their distribution random? The former, it turned out. Again, neuroscientists knew by about 1900 that neurons are arranged in columns, like bits of stubble on the brain's surface. And Hubel and Wiesel found that all the neurons within one column had similar taste: they all preferred one specific line orientation, like \. What's more, if Hubel and Wiesel shifted their platinum wire a smidge, about two-thousandths of an inch, to another column, all of that column's cells might respond to |, a line ten or so degrees different. Successive, tiny steps into new "orientation columns" revealed neurons that fired only for /, then ⁄ and so on. In sum, the optimal orientation shifted smoothly from column to column, like a minute hand creeping around a clock.

The geographical patterns didn't stop there, though. Further digging revealed that, just as cells worked together in columns, columns worked together in larger clusters, like a bundle of drinking straws. Each bundle had enough orientation columns to cover all 180 degrees of possible lines, from — to | and back to —. Each bundle also responded best to one eye, right or left. Hubel and Wiesel soon realized that one left-eye bundle plus one right-eye bundle—a "hypercolumn"—could detect any line with any orientation within one pixel of the visual field. Once again, this took years of work to firm up, but it turns out that no matter what lovely shape our eyes lock onto—the swirl of a nautilus shell, the curve of a hip—the brain determinedly breaks that form down into tiny line segments.

Eventually Hubel and Wiesel relieved their neckaches and got their apparatus turned the right way around, so that the clockwork kitties stared straight forward, toward a proper screen. And the discoveries just kept coming. Beyond simple line-detecting neurons, Hubel and Wiesel also discovered neurons that loved to track motion. Some of these neurons got all excited for up/down motion, others buzzed for left/right movement, and still others for diagonal action. And it turned out that these motion-detecting neurons outnumbered the simple line-detecting neurons. They outnumbered them by a lot, actually. This hinted at something that no one had ever suspected—that the brain tracks moving things more easily than still things. We have a built-in bias toward detecting action.

Why? Because it's probably more critical for animals to spot moving things (predators, prey, falling trees) than static things, which can wait. In fact, our vision is so biased toward movement that we don't technically see stationary objects at all. To see something stationary, our brains have to scribble our eyes very subtly over its surface. Experiments have even proved that if you artificially stabilize an image on the retina with a combination of special contact lenses and microelectronics, the image will vanish.

With these elements in place—Inouye's map of the visual cortex, plus knowledge of line detectors and motion detectors—scientists could finally describe the basics of animal vision. The most important point is that each hypercolumn can detect all possible movements for all possible lines within one visual pixel. (Hypercolumns also contain structures, called blobs, that detect color.) Overall, then, each one-millimeter-wide hypercolumn effectively functions as a tiny, autonomous eye, a setup reminiscent of the compound eyes of insects. The advantage of this pixilated system, besides acuity, is that we can store the instructions to create a hypercolumn just once in our DNA, then hit the repeat button over and over to cover the whole visual field.*

Some observers claimed that science learned more about vision during Hubel and Wiesel's two decades of collaboration than in the previous two centuries, and the duo shared a much-deserved Nobel Prize in 1981. But despite their importance, they took vision science only so far. Their hypercolumns broke the world down quite effectively into constituent lines and motion, but the world contains more than wriggling stick figures. Actually *recognizing* things, and summoning memories and emotions about them, requires more processing, in areas of the brain beyond the primary visual cortex.

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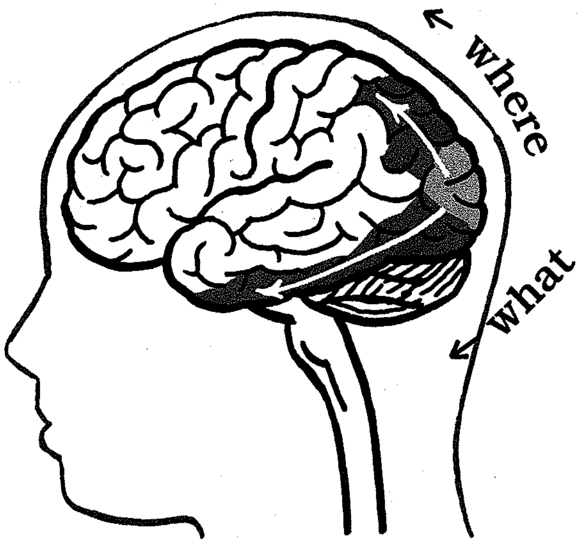
Fittingly, the next advance in vision neuroscience—the "two streams" theory—appeared in 1982, just after Hubel and Wiesel won the Nobel. All five senses have primary processing areas in the brain, to break sensations down into constituent parts. All five senses also have so-called association areas, which analyze the parts and extract more sophisticated information. It just so happens with sight that, after the primary visual cortex gets a rough handle on something's shape and motion, the data get split into two streams for further processing. The *how/where* stream determines where something is located and how fast it's moving. This stream flows from the occipital lobes into the parietal lobes; it eventually pings the brain's movement centers, thereby allowing us to grab onto (or dodge) whatever we're tracking.

The *what* stream determines what something is. It flows off into the temporal lobes, and taps into the memories and emotions that make a jumble of sensations snap into recognition.



No one knows for sure how that snap takes place, but one good guess involves circuits of neurons firing in sync. At the beginning of the what stream, neurons are rather indiscriminate: they might fire for any horizontal line or any splash of red. But those early neurons feed their data into circuits farther upstream, and those upstream circuits are more picky. They might fire only for lines that are red *and* horizontal, for example. Still farther upstream, circuits might fire only for red horizontal lines with a metallic glint, and so on. Meanwhile, other neurons (working in parallel) will fire for clear glass lines at a certain angle or black rubber circles. Finally, when all these neurons throb at once, your brain remembers the pattern—red metal, glass, rubber—and says, *aha, a Corvette.** The brain also integrates, over a few tenths of a second, the Corvette's sound and texture and smell, to further aid in recognition. Overall, then, the process of recognition is smeared out among different parts of the brain, not localized in one spot. (Important note.*)

In everyday life, of course, we don't bother distinguishing between seeing a car (primary visual cortex), recognizing a car (what stream), and locating a car in space (how/where stream). We just look. And even inside the brain, the streams aren't independent: there's plenty of feedback and crosstalk, to make sure you reach for the right thing at the right time. Nevertheless, those steps are independent enough that the brain can stumble over any one of them, with disastrous results.

If the primary visual cortex suffers damage, people lose basic perceptual skills, a problem that becomes obvious when they draw things. If they sketch a smiley face, the eyes might end up outside the head. Tires might appear on top of cars. Some people can't even close a triangle or cross an X. This is the most devastating type of visual damage.

Damage to the how/where stream hinders the ability to locate objects in space: people whiff when they grab at things and constantly run into furniture. Even more dramatic, consider a fortysomething woman in Switzerland who suffered a parietal lobe stroke in 1978. All sense of movement disappeared for her, and life became a series of Polaroid snapshots, one every five seconds or so. While pouring tea, she saw the liquid freeze in midair like a winter waterfall. Next thing she knew, her cup overflowed. When crossing the street, she could see the cars fine, even read their license plates. But one moment they'd be far away, and the next they'd almost clip her. During conversations, people talked without moving their lips—everyone was a ventriloquist—and crowded rooms left her nauseous, because people appeared and reappeared around her like specters. She could still track movement through touch or sound, but all sense of visual motion vanished.

Finally, if the what stream malfunctions, people can pinpoint where objects are but can no longer tell one object from another. They cannot find a pen again if they put it down on a cluttered desk, and

they're hopeless in parking lots at the mall. Bizarrely, though, they can still perceive surface details just fine. Ask them to copy a picture of a horse, a diamond ring, or a Gothic cathedral, and they'll render it immaculately—all without recognizing it. Some people can even draw objects from memory, but if shown their own drawings later, nothing registers. In general, these people retain their perceptual skills, since the primary visual cortex works, but the details never snap into recognition and identity eludes them.

Sometimes damage to the what stream is more selective, and rather than all objects, people fail to recognize only a narrow class of things. Many of these so-called category deficits arise after attacks of the herpes virus, the same bug that causes cold sores. Herpes means "creeping," and although it's normally harmless, the virus does sometimes go rogue and migrate up the olfactory nerves to the brain, where it ravages the temporal lobes. When this happens, neurons begin to fire in panic, and victims complain of funny smells and sounds; as more tissue dies, they suffer headaches, stiff necks, and seizures. Many fall into comas and die. Those patients who wake up again often have sharply focused brain damage, as sharply focused as if a Russian bullet had pierced them. And if just the right spot gets nicked, they might display a correspondingly sharp mental deficit. Most commonly, people lose the ability to recognize animals. Inanimate objects they recognize fine—strollers, tents, briefcases, umbrellas. But when shown any animal, even cats or dogs, they stare, mystified, as if looking at beasts dragged back from an alien zoo.

Loads of similar cases exist, some of which beggar belief. Contra the cases above, some herpes victims can recognize living things just fine, but not tools or man-made objects: cash registers become "harmonicas," mirrors become "chandeliers," darts fairy-tale transform into "feather dusters." (Scarily, one man with so-called object blindness continued to drive. He couldn't tell cars from buses from bicycles, but because his how/where stream still worked, he could detect motion, and simply steered clear of anything coming at him.) To get even more specific, some brain-damaged people can recognize objects and animals but not food. Others blank out only on certain categories of food, such as fruits and vegetables, while still others can name cuts of meat but not the animals they came from. "Color amnesiacs" cannot remember where lemons fit into the rainbow, nor whether blood and roses are of similar hues. One woman struggled with questions about, no kidding, the color of green beans and oranges.

Usually these "mind-blind" folks can identify things through another sense: let them touch a toothbrush or sniff an avocado, and it all comes back. Not always, however. One woman who couldn't recognize animals by sight also couldn't recognize animal sounds, even though she could identify inanimate objects via sound. She had difficulties with spatial dimensions, too, but again only with animals. She knew that tomatoes are bigger than peas, but couldn't remember whether goats are taller than raccoons. Along those lines, when scientists sketched out objects that looked like patent-office rejects (e.g., water pitchers with frying-pan handles), she spotted them as fakes. But when they drew polar bears with horse heads and other chimeras, she had no idea whether such things existed. For some reason, as soon as an animal was involved, her mind gummed up.

These pure category deficits, while rare, imply something important about the evolution of the human mind. Our ancestors spent a lot of time thinking about animals, whether furry, feathered, or scaly. The reason is obvious. We're animals ourselves, and the ability to recognize and pigeonhole our fellow creatures (as food, predators, companions, beasts of burden) gave our ancestors a big boost in the wild. Eventually, we probably developed specialized neural circuitry that took responsibility for analyzing animals, and when those circuits crap out, the entire category can slip clean out of people's minds. Our ancestors exploited fruits and vegetables, too, as well as small, tool-like objects. Probably not coincidentally, these are the two other categories of things that commonly disappear from people's mental repertoire. Our brains are natural taxonomists: we cannot help but recognize certain things as special. But the danger of specialized circuitry is that if the circuits go kaput, an entire class of things can go extinct mentally.

The way we catalogue the world teaches us something else about mind-brain evolution. I hesitate to even evoke the m-word, since it's such a contentious term. But after reading about fruit deficits and animal deficits and color deficits, it seems pretty clear that our brains do have *modules* on some level—semi-independent "organs" that do a specific mental task, and that can be wiped out without damaging the rest of the brain. Some neuroscientists go so far as to declare the entire brain a Rube Goldberg machine of modules that evolved independently, for different mental tasks, and that nature stuck together with gum and rubber bands. That "massive modularity" pushes things too far for some scientists: they see the mind-brain as a general problem solver, not a collection of specialized components. But most neuroscientists agree that, whether you call them modules or not, our minds do use specialized circuits for certain tasks, such as recognizing animals, recognizing edible plants, and recognizing faces.

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In some sense we analyze faces the same way as other objects, by scribbling our eyes over the lines and shadows and contours we see, which causes certain ensembles of neurons to harmonize and hum. That said, analyzing faces requires more sophisticated brainware than analyzing other objects, both because social creatures like us need to read people's thoughts and feelings on their visages, and also because—let's face it—most people's features look pretty darn similar overall.

As with any mental faculty, many different patches of gray matter contribute to analyzing faces. But certain patches near the brain's south pole, like the fusiform face area, have special responsibilities. On brain scans the FFA lights up whenever people study faces, and disrupting it electrically causes faces to morph and stretch in funhouse ways. The most notable feature of the FFA is holistic processing. Instead of piecing together a face feature by feature—the way we seem to process regular objects—we read faces instantly, at a glance. In other words, a whole face is greater than the sum of the eyes and nose and lips in isolation.

To be sure, the FFA can light up in other circumstances. Ornithologists and auto aficionados and Westminster judges get lots of pings there when they study birds and cars and dogs, respectively. In other words, whenever we need to parse a narrow class of nearly identical things, our plastic brains might recruit the FFA to help out.

Still, the balance of evidence suggests we do have a specialized, if nonexclusive, face circuit. Even with object and animal aficionados, the FFA lights up strongest for faces. And beyond the FFA—which is just one component of a larger system—our brains also process faces in more complicated ways than other objects: we have circuits that light up only for certain emotional expressions or only when someone looks in a certain direction. Also unlike with cars or whatever, we constantly detect faces where they don't exist, in bathroom fixtures and tortillas and random piles of rocks on other planets (a tendency called pareidolia). Anytime we see two dark spots hovering above a quasi-horizontal line, we can't help but want to introduce ourselves. Seeing faces is mandatory.

At least for most people. The best evidence for a specialized face circuit comes from people who struggle to recognize faces because of damage to the FFA or faulty wiring there. Some face-blind people brush right past their dearest friends on the street without blinking. For birthday bashes, even their own, they might ask people to wear name tags; same for family reunions. To recognize people at all, they either listen to their voices; memorize how they walk; or scan for distinctive moles, scars, or haircuts. (The great portrait painter Chuck Close has severe face-blindness; this seems ironic at first, but his need to scrutinize faces probably enhances his talent.) Some face-blind people cannot even determine gender or age. A Welsh mining engineer who fell asleep after a few drinks and had a stroke woke up unable to tell his wife from his daughter. In another case, a lesion left an Englishman so bereft of face-recognition skills that he quit society and became a shepherd. After a few years he could tell most of his sheep apart by looks, but he never did get the hang of humans again.*

The selective *sparing* of face circuits can also reveal a lot. In 1988, in Toronto, a man named C.K. was struck by a car while jogging and suffered a closed head injury. Aside from some emotional outbursts and memory problems, he more or less recovered and eventually completed a master's degree in history with the help of a voice-activated computer. Still, one faculty never recovered: C.K. couldn't tell any inanimate objects apart, even food. His neurologists recalled taking him to a buffet and watching him shuffle around, bewildered. Everything looked like "differently colored blobs," and at the table he seemed to stab his fork at random and eat whatever he speared. At home he could no longer stage mock battles with his beloved toy soldier collections, since Greek and Roman and Assyrian armies all looked the same. He couldn't recognize body parts, either: more than once he tried giving the heave-ho to a strange pink thing poking out from his sheets—his foot. Yet for all this blundering about, C.K. proved a savant with faces and learned them readily. He even startled his neurologist in the shower at the gym once by helloing the doctor well before the doctor could place him.

Intrigued by the purity of his deficit, neuroscientists ran C.K. through a battery of facial-recognition tests. He proved he could recognize celebrities easily, even with parts of their faces blacked out; he could also recognize celebrities when scientists superimposed disguises (e.g., Groucho glasses) on them. He could instantly pick out all the faces in those find-the-hidden-picture puzzles that conceal faces in, say, a forest scene. He could recognize Bugs Bunny, Bart Simpson, and other cartoon characters, and recognized caricatures of Elvis, Bob Hope, and Michael Jackson. (Caricatures often send people's FFAs into a frenzy, because they exaggerate facial features. It's like face porn.) Most impressively, C.K. could scan a stranger's face in a photograph just once, then pick him out of a photographic lineup of near twins, even when the target was facing a different direction. On many of these tests C.K. scored higher than normal, control people did.

On the flip side, C.K. floundered on other tests. When shown upside-down faces, for instance, even faces he'd identified before, recognition always eluded him. Neuroscientists have long known that inverting any object hinders recognition, and that inverting faces hinders recognition even more than inverting animals, buildings, and other things. But while other people can usually puzzle through an upside-down face, C.K. was clueless. He couldn't even identify upside-down cartoon faces, something most people found laughably easy. Splintering or scrambling a face, by exploding it into parts, also flummoxed him. And when shown an Arcimboldo—those odd, sixteenth-century "portraits" pieced together from fruits and vegetables—C.K. rarely saw anything but the overall mien; he was oblivious to the pear noses and apple cheeks and green-bean eyelids that make the rest of us gasp.

C.K.'s troubles imply that the brain can normally recognize faces through two channels. There's the FFA circuit, which recognizes faces quickly and holistically. This system escaped damage in C.K. But the FFA circuit is picky: it needs to see the eyes hovering above the mouth and needs to detect rough symmetry, or it fails to engage. In that case a backup system should take over. This backup system is slower, and probably pieces upside-down or fractured faces together feature by feature. In other words, it treats the face more like an object. In fact, it probably employs our general object-recognition brainware—which explains why C.K. suddenly floundered, since his object-recognition skills hovered in the bottom percentile. Dehumanize a face—turn it into a mere object—and the face savant became face-blind.

* * *

Naturally, the same circuits you use to recognize people around you also light up when you recognize your own features in the mirror. But seeing your own face also stirs up deeper associations—it taps into

your id, your ego, your sense of self. And it was this aspect of the self that the facial wounds of World War I so threatened.

The study of facial disfigurement really took off in the twentieth century, and not only because of modern war. The rise of handguns and especially cars produced plenty of accidents among civilians. Surprisingly, though, in all groups studied, many disfigured people rebounded quite well: even some of the most severely injured showed few psychological hang-ups. Like the *mutilés* who married their nurses, these people tended to brush the disfigurement aside and keep living life. Some also joked about their scars when they caught people staring, mentioning a botched bear-wrestling career or saying, "God hit me with a frying pan."

Still, many victims reacted more predictably. They showed symptoms of mourning at first, grieving for their faces as for the dead. And they remained isolated long after their physical injuries had healed, suffering the gapes and double takes in silence. Years after the injury, a few were still startled by their reflections in plate-glass windows. A self-image is hard to let go of.

In the past decade psychologists have expanded their understanding of facial trauma by studying a new group of patients—the recipients of face transplants. A face transplant involves just what it sounds like, the surgical transfer of a nose, lips, cheeks, and other tissues from a dead person to a living one. In this way it combines the heroic reconstructive surgery of World War I with the lifelike masks of Anna Coleman Ladd and others. What's more, because a face transplant involves a living mask, a mask that can speak and express emotions, psychologists could finally probe the question that Ladd's work evoked so long ago: would the brain accept a new face as its own?

The first recipient of a face transplant, a thirty-eight-year-old Frenchwoman named Isabelle Dinoire, swallowed a mouthful of sleeping pills in May 2005 after an argument with her daughter. She didn't expect to wake up again but did. Groggy, she put a cigarette in her mouth and found it wouldn't stay. That's when she noticed the pools of blood: her Labrador retriever had mauled her while she slept. Dinoire staggered to a mirror. Tousled, dirty-blond hair still ringed her face, but the dog had gnawed her nose down to two skeletal holes, and no lips covered her teeth or gums. Although emergency care stabilized her, in later months Dinoire became a recluse, hiding behind a surgical mask at all times.

In the years leading up to Dinoire's injury, the medical world had worked itself into a froth over the ethics of face transplants. A few fear-mongering doctors actually suggested that donors' families might start stalking transplant recipients, or that a black market in beautiful faces would spring up. Some activists proposed banning even the *discussion* of face transplants, to spare the feelings of the already disfigured. Less hysterical types opposed the surgery on medical grounds. Transplanting skin provokes an especially strong immune response, so transplant recipients would have to take heavy-duty immunosuppressants, increasing their risk for catching many diseases and probably shortening their lives.

Nevertheless, other doctors pursued the idea. They cited surveys suggesting that people would indeed trade many years of life to restore a damaged face. Surgeons favoring facial transplants also pointed out that naysayers had sown similar fears of identity crises before the first heart transplants, and none of those had come to pass. Doctors emphasized the limits of alternative treatments as well. Plastic surgeons could do clever things like fashion a new nose from a toe (really), but it often looked terrible and obviously didn't function the same way. There's just no substitute for facial tissue.

In examining the risks of face transplants, doctors turned to whatever approximations they could find. To determine whether the new face would look more like the donor (who would supply the skin and cartilage) or the recipient (who would supply the underlying bone structure), surgeons swapped faces on cadavers, then asked volunteers to judge before-and-after photographs. They concluded that (aside from certain features, like eyebrows) the face would look different than both the donor and recipient. It would be a new, unique face. Doctors examined the outcomes of other radical transplants as well, like tongue, larynx, and especially hand transplants. As with face transplants, hand transplants involved multiple kinds of tissue, so the demands on the patient's immune system would be similar. Hand transplants also proved that the brain could integrate neurologically demanding tissues pretty easily. (It probably helps that, as with faces, we have specialized neurons that fire only in response to viewing hands—a legacy of hand gestures in prelanguage communication.*)

Doctors also evaluated the psychology of transplants. First and foremost, people needed to accept the foreign tissue as part of them. With hands, doctors made sure to correct any Freudian slips, forcing patients to refer to "my hand," not "*the* hand" in conversation. Doctors also emphasized the need to use the hands in daily activities, the more intimate the better: while the surgeons on one transplant team scowled to see a patient nervously chewing the nails on his new hand, his psychologists rejoiced—you don't bite someone else's fingernails. Unfortunately, those psychological safeguards didn't always work. The first hand transplant, in 1998, for one Clint Hallam, had gone quite well surgically, and Hallam had felt sensation creeping back into his new hand at a rate of a few millimeters per day. But after twenty-nine months Hallam stopped taking immunosuppressants, saying that the hand now creeped him out. His immune system attacked it, and doctors had to amputate.

If something went wrong with a face transplant, amputation wasn't an option. Nevertheless, French surgeons—who tempted fate by comparing themselves to Copernicus, Galileo, and Edmund Hillary—pushed ahead in 2005 with Isabelle Dinoire, the woman whose Labrador had mauled her. They picked Dinoire partly because she'd lost "only" her nose, lips, and chin (the facial triangle), which made for an easier surgery. A suitable donor turned up in November 2005, when a forty-six-year-old woman in a nearby town tried to hang herself and ended up brain-dead. She matched Dinoire in age, blood type, and skin tone, and Dinoire's surgeons rushed into action. They spent hours "recovering" the hanged woman's face—peeling away her skin and connective tissue along with blood vessels and nerves, leaving only a red mask of muscle behind. The transfer onto Dinoire then took the better part of a day.

During recovery, Dinoire's new face swelled frightfully, and on day eighteen her body nearly rejected it. Meanwhile the media got pretty frenzied; British tabloids even outed the identity of the brain-dead donor. But Dinoire recovered better than anyone could have hoped. She was eating with her new lips within a week and talking shortly thereafter. Hot and cold sensation returned within a few months, as did most movement. Most important, she started leaving the house again, resuming her social life and meeting new people. The one facial movement that lagged was smiling—at ten months she could only half smile, like a stroke victim. But by fourteen months she could smile fully again. She had reason to.

Chinese surgeons performed the second face transplant in April 2006, and more soon followed, with remarkable results. Many patients could speak, eat, and drink by day four. Sensation usually returned within a few months. And brain scans revealed that their faces came back "online" quickly, much more quickly than hands did. (Patients in fact got a kick out of watching their once-dormant face territories "wake up" on the scans.) The psychological adjustment usually went smoothly as well. It seemed to help that, unlike with a hand, you don't have to look at your face constantly. And when people did look in a mirror, they found it easy to accept the reflection. It wasn't the old "them," certainly. But the underlying bone structure was enough to evoke a feeling of "me, that's *me*" in the mirror.

Bolstered by these early successes, a few teams have now performed the more demanding full-face transplant. One early recipient, the third full-facial, was Dallas Wiens. In November 2008 the twenty-three-year-old Wiens was painting some structures on the roof of a Fort Worth, Texas, church when he accidentally steered his

hydraulic lift into some power lines. The air around his head reportedly glowed blue for fifteen seconds, and the current running through his face melted it into a blank mask, one writer noted, not unlike "Mr. Potato-Head without the features."* In March 2011 Wiens got a replacement. The new face arrived in a blue cooler in a slurry of ice water; it was the size and thickness of medium pizza dough when unfurled.

Surgeons first hooked the donor face up to Wiens's blood supply through his carotid arteries. This took some creative suturing, since the donor had cigar-sized carotids, while Wiens's vessels (which had atrophied) looked like drinking straws. The transplant team felt enormous relief when the face started to flush pink, a sign that it was taking blood. In all, the surgery ran seventeen hours, during which time Wiens's new face smirked, winked, and grimaced as surgeons manipulated it to reattach various nerves and muscles. Afterward, doctors rolled him into the ICU to see if Wiens would be able to smirk, wink, and grimace on his own.

When Wiens awoke, he felt his new, swollen face pressing down hard, like a lead mask. He could breathe only through a tube in his trachea. But all the discomfort seemed worth it a few days later. In a moment so mundane it's poignant, he found he could finally smell food again. Lasagna. Touch sensation returned not long after, and he felt, really felt, his daughter's kiss for the first time in years. Wiens even began dreaming of himself with his new face. These were moments the World War I masks, even the most artistic, could never replicate.

As with hand transplants, doctors found that the more patients used their transplanted faces—shaving, smiling, applying makeup, smooching, getting smooched—the more they accepted the new faces as theirs, regardless of what they looked like. Humans do rely on vision to an extraordinary degree, and our visual circuits occupy far more brain territory than other sensory circuits. It's no surprise that looks are so tied up with our sense of self. Ultimately, though, one important truth of neuroscience is that the brain constructs our sense of self from more than mere looks. As we'll see later, our sense of self also draws on our emotional core and our memories and our personal narratives of our lives. The earliest face transplants took place in 2005, so their long-term medical viability remains unknown. But psychologically, at least, they've succeeded: the brain will indeed accept a new mien in the mirror—in part because it's only a mien, a covering. As one observer noted, "If a face transplant demonstrates anything about what it means to be human, it may be that we are less superficial than we imagine."

PART III

BODY AND BRAIN