MIND *IN MOTION*

How Action Shapes Thought

BARBARA TVERSKY

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Contents

To Amos, whose mind was always in motion.

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PROLOGUE

Moving in Space: The Foundation of Thought

A creature didn't think in order to move; it just moved, and by moving it discovered the world that then formed the content of its thoughts.

—Larissa MacFarquhar, "The mind-expanding ideas of Andy Clark," *The New Yorker*

Everything is always in motion. Physicists tell us that if the quivering molecules in your desk moved in sync, the desk would leap from the floor. Even sedentary plants grow and sway and turn toward the sun and open and close. They have to; they would die if they didn't move. Space places two fundamental constraints on movement, constraints that are reflected in thought: proximity—near places are easier to get to than far ones; and gravity—going up is more effortful than going down.

Thought, too, is constantly moving, and sometimes hard to catch. Ideas leapfrog over ideas. But there it is: idea. I've frozen it, reified it into something static, the only way to catch it. From the never-ceasing flux around us, we carve entities out of space and out of time: people, places, things, events. We freeze them, turn them into words and concepts. We change those moving things into static things so that we can act on them with our minds.

Constant motion in space is a given, the background for everything that has happened and that will happen. No wonder it is the foundation of thought. Action in space came long before language, as did thought based on action in space.

Our actions in space change space, change ourselves, and change others. Our actions create things we put in space that change us and others. They change our thought and the thought of others. The things we create (like these words) stay there, in space, changing the thought of people we will never know and can't even imagine.

We don't just freeze the stuff in space and time. We study its form and look for its structure: in our bodies, in our actions and reactions, in the world, in the events that happen in the world, in the language we speak. We find the parts and how they connect to form a whole. The parts and how they fit together tell us what the things can do and what can be done with them. We look for patterns, lines, circles, shapes, branching. We create structure, too, in actions, in talk, in communities, in science, in art—painting, sculpture, film, dance, poetry, drama, opera, journalism, fiction, music. Structure is what holds the pieces together; without structure, things fall apart. And sometimes we do just that, deconstruct and even destroy, to see what happens, to shake things up, to find new structures. Pick Up Sticks. Rearrange the furniture. Reorganize the company. Select musical notes from a random number table. Read *Hopscotch* in any order. Revolt. Spew chaos on the world.

Prose is linear, one word after another. Narratives have a linear structure driven by time, theories have a linear structure directed by logic. In theory, that is. The structure of Perec's *Life: A User's Manual* is place, an apartment building and a puzzle, not time. The linearity of prose doesn't harness readers, they can jump back and forth. Speaking is linear, one word after another, but that doesn't stop speakers from interrupting themselves with tangential thoughts nor does it stop listeners from doing the same. Then there are our own thoughts, frequently articulated in inner speech; they hardly walk a straight line and sometimes fly out in too many directions at once. Music is linear in time but spatial over the instruments, which can come in at different times and play different notes at different paces and places. Painting has composition, not linear, but center and periphery. Until Pollack and Rothko. Structure is complicated. It gets done, undone, and redone.

Pleas, plays, sermons, campaign speeches. Like music, they zig and zag between the earthly and the lofty, the logical and the emotional, stories that become parables with messages; they zig and zag emotionally, pensive, spirited, ominous, wistful, joyful. They change pace, slow and ponderous, fast and light. Narrative does that, too.

Formal gardens are arranged in perfectly symmetric patterns, with distinct straight paths among the beds of flowers and pruned trees; everything is clear and certain; don't dare go off the paths. Chinese gardens are different. The paths curve and twist this way and that, up and down, always new vistas around the bend pulling you onward; little is clear, nothing certain; you get lost, and then found.

Writing a book makes you, or me, think of structure. There is structure to this book, but you don't have to stay on the paths, you are free to explore it like a Chinese garden rather than a formal one. The book means to show how we think about space and how we use space to think. These are the two parts of the book. The premise is audacious: spatial thinking, rooted in perception of space and action in it, is the foundation for all thought. The foundation, not the entire edifice. Try describing the faces of friends, places you love, events that were meaningful. The memories and images may be vivid, but words flail and fail to capture them. Think about rearranging the furniture in your living room or how to fold a sweater or how many windows were in your childhood home or where the X key is on the keyboard. You might feel your eyes moving or your body squirming. Words alone won't do it.

This focus, on space, action, and thought, means that there are large swaths of excellent work I couldn't include, to my regret. This book is meant to interest many different communities, the diverse communities that I've had the good fortune to work with: psychologists, computer scientists, linguists, neuroscientists, biologists, chemists, designers, engineers, artists, art educators, museum educators, science educators, and others who, for one reason or another, are interested in spatial thinking. As for a stroll in a Chinese garden, some of you may want to walk from end to end, others may go hither and thither, visiting some sights and skipping others. You don't have to look at every tree and flower.

Below, a guide for special interests.

For the fundamentals, how perception and action mold thinking about the spaces we inhabit: Chapters One (space of the body), Two (space around the body), Three (space of navigation).

For varieties and transformations of spatial thinking and spatial ability, Chapter Four.

For ways gesture reflects and affects thought, Chapter Five.

For talk and thought about space and just about everything else: Chapters Five, Six, and Seven.

For designing and using cognitive tools, maps, diagrams, notation, charts, graphs, visualizations, explanations, comics, sketches, design, and art, Chapters Eight, Nine, and Ten.

An artist I know and admire, Gideon Rubin, says he always leaves his paintings unfinished. That way, the viewers finish them. His art is based in old nostalgic photographs, the kind you might find in your grandparents' albums, sweet photos of children and youths in happy settings, looking at the camera. He paints over the faces so you find yourself looking at, indeed feeling, the postures of the body and you realize how much you learn from the bodies and the clothing and the background. You look at the background and the clothing and you realize that you usually miss that because you're looking at the faces. You can fill in the empty faces, with your grandmother's or your cousin's, and you realize that you forgot what people looked like when they were young. And many viewers fill in so intently that they are sure they saw a face.

In science, history, politics, perhaps even more than in art, nothing is ever finished.

That said, this book is finished. Or rather, I have to let it go.

Research is nearly impossible to do without funding, and I have been fortunate for support from NSF, ONR, NIMH, AFOSR, and the John Templeton Foundation. I have been blessed by the many students, friends, and colleagues whose thinking I have drawn on, directly or indirectly, over many years. Most of you are unaware of this book and haven't seen it. I apologize to those I've forgotten, to those I've misrepresented or failed to represent. There was so much more I wanted to include. I've reduced you to an alphabetic list, which pains me; each of you gave me something unique and each of you is insightful, inimitable, and irreplaceable. Maneesh Agrawala, Gemma Anderson, Mireille Betrancourt, Gordon Bower, Jonathan Bresman, Jerry Bruner, David Bryant, Stu Card, Daniel Casasanto, Roberto Casati, Juliet Chou, Eve Clark, Herb Clark, Tony Cohn, Michel Denis, Susan Epstein, Yvonne Eriksson, Steve Feiner, Felice Frankel, Nancy Franklin, Christian Freksa, Randy Gallistel, Rochel Gelman, Dedre Gentner, John Gero, Valeria Giardino, Susan Goldin-Meadow, Pat Hanrahan, Eric Henney, Bridgette Martin Hard, Julie Heiser, Kathy Hemenway, Azadeh Jamalian, Danny Kahneman, Andrea Kantrowitz, T. J. Kelleher, David Kirsh, Stephen Kosslyn, Pim Levelt, Steve Levinson, Elizabeth Marsh, Katinka Matson, Rebecca McGinnis, Julie Morrison, Morris Moscovitch, Lynn Nadel, Jane Nisselson, Steven Pinker, Dan Schacter, Roger Shepard, Ben Shneiderman, Ed Smith, Masaki Suwa, Holly Taylor, Herb Terrace, Anthony Wagner, Mark Wing-Davey, Jeff Zacks.

For not enough years, there was Amos, and his voice stays with me. The kids, too, my second biggest fans, I can hear all of them echoing him, shouting, "Go, Mom," the way I shouted at them watching their soccer games.

PART I

THE WORLD IN THE MIND

CHAPTER ONE

The Space of the Body: Space Is for Action

In which we show that we have an insider's view of the body, one shaped by our actions and sensations, unlike our outsider view of other things in our world that is shaped by appearance. Mirror neurons map others' bodies onto our own, allowing us to understand other bodies through our own and to coordinate our actions with theirs.

We begin in our skin, that thin, flexible membrane that encloses our bodies and separates us from everything else. A highly significant boundary. All our actions take place in the space outside our skin, and our lives depend on those actions. As any mother will happily tell you, that activity begins before birth. Who knows why those curious creatures growing inside us keep "kicking"—perhaps to find a more comfortable position? Or why they seem so active at importune times—one of them kept popping my dress up and down during my PhD orals.

Mercifully, bodies do far more than kick. They eventually perform an astounding assortment of activities. The harmonious coordination underlying those diverse behaviors depends on the continuous integration of a variable stream of information from many senses with the articulated actions of dozens of muscles (apologies for beginning with such a mouthful!). Although our skin encloses and separates our bodies from the surrounding world, accomplishing those activities entails countless interactions with the world. We cannot truly be separated from the world around us. It is those interactions that underlie our conceptions of our bodies.

Viewed from the outside, bodies are like other familiar objects: tables, chairs, apples, trees, dogs, or cars. We become adept at rapidly recognizing those common objects, primarily from their outlines, their contours, in their prototypical orientations. The contours of objects are, in turn, shaped by the configuration of their parts, legs and bodies for dogs and tables, trunks and canopies for trees. That skill, recognizing objects, takes up residency in a slew of places in the brain. Faces in one array, bodies in another, scenes in yet another. Those regions are active—light up—when we view those kinds of things and not when we view things from other categories.

For objects (and faces), some views are better than others. An upside-down table or tree is harder to recognize than a right-side-up version; the backside of a dog or the top view of a bicycle is harder to recognize than side views of either. A good view is one that shows the distinctive features of the object. A prototypical dog has four legs (like a prototypical table), an elongated horizontal tube for a body, and a symmetric head with eyes, snout, and a mouth as well as ears protruding from either side. The best view of a dog would show those features. Exactly those views, the ones that present more of the characteristic features in the proper configuration, are the ones we are fastest to recognize and the ones we judge as better representations of the object. For many objects, like dogs or tables, the best views are of course upright, and three-quarters view or profile. In many cases, the contours or silhouettes of good views are sufficient for rapid recognition.

BODIES AND THEIR PARTS

Just as for objects, contours of canonical orientations are especially effective for recognizing bodies—when we view them from the outside. But, singularly, for bodies we also have an insider perspective. That intimate insider perspective comes with many extras. We know what bodies can do and what bodies feel like from the inside. We can't have that knowledge for chairs or even bugs (Kafka aside) or dogs or chimpanzees. We know what it feels like to stand tall or sit slumped, to climb stairs and trees, to jump and hop, to fasten buttons and tie shoes, to signal thumbs up or OK, to cry and laugh. We know not only what it feels like to act in those ways but, even more significantly, also what it *means* to act in those ways, stretching or slumping, crying or laughing.

Importantly, we can map other bodies and their actions onto our own, suggesting that we understand other bodies not only by recognizing them but also by internalizing them.

Before that, we map our bodies onto our brains, onto the homunculus, the "little man," sprawled ear-to-ear across the top shell, the cortex, of our brains. (See Figure 1.1.) The cortex is a thick, crenellated layer splayed over the parts of the brain that are evolutionarily older. From the outside, the brain looks like a giant walnut. And like a walnut, the brain is divided front to back into two not quite symmetric halves, or hemispheres, right and left. For the most part, the right hemisphere controls and has inputs from the left side of the body. The reverse holds for the left hemisphere. Each hemisphere is divided into plateaus called lobes that are separated by valleys, or sulci (singular, *sulcus*). It's hard not to talk about the cortex geographically, and undoubtedly there are analogies in the formation of plateaus and layers and valleys on the earth and in the brain. Those wrinkles create more surface, important for the land and important for the brain. The inputs from the various sensory systems are partly channeled to separate lobes of the cortex, for example, vision to the occipital lobe at back of the head and sound to the temporal lobes above the ears. Yet each lobe is wondrously complex, with many regions, many layers, many connections, many kinds of cells, and many functions. Remarkably, even single neurons can be specialized, for a specific view of a face or for tracking an object that moves behind a screen. And there are billions of them in the human brain. A recent estimate is eighty-six billion.

There are actually two pairs of homunculi splayed along the central sulcus; one pair maps the sensations from the body, the other pair maps motor output to the body. The pair on the left side of the brain maps the right side of the body and the pair on the right side of the brain maps the left side of the body. The sensory and motor homunculi face each other. The motor homunculus is, perhaps significantly, positioned more forward (technical terms: *anterior* or *frontal*), toward the eyes and nose. It controls the output, telling the muscles how to move. The sensory homunculus is positioned toward the back of the head (technical terms: *posterior* or *dorsal,* from Latin for "tail"). It brings the input from the many kinds of sensations our bodies respond to, position, pain, pressure, temperature, and more. The homunculi are strange little people, with oversized heads, huge tongues, enormous hands, and skinny torsos and limbs.

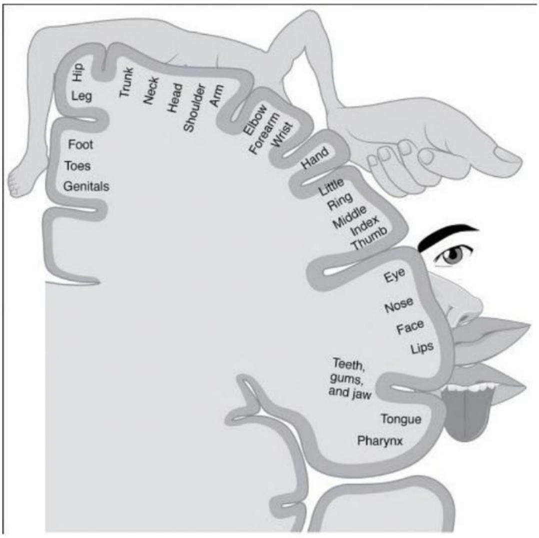

FIGURE 1.1. Sensory homunculus.

You can't help but see that these cortical proportions are far from the proportions of the body. Rather than representing the sizes of the body parts, the sizes of the cortical representations of the various body parts are proportional to the quantities of neurons ascending to them or descending from them. That is, the head and hands have more cortical neurons relative to their body size, and the torso and limbs have fewer cortical neurons relative to their body size. More neural connections mean more sensory sensitivity on the sensory side and more action articulation on the action side. The disproportionate sizes of cortical real estate make perfect sense once we think about the multitude of articulated actions that the face, tongue, and hands must perform and the sensory feedback needed to modulate their actions. Our tongues are involved in the intricate coordinated actions necessary for eating, sucking, and swallowing, for speaking, groaning, and singing, and for many other activities that I will leave to your imagination. Our mouths smile and frown and scowl, they blow bubbles and whistle and kiss. Hands type and play the piano, throw balls and catch them, weave and knit, tickle babies and pat puppies. Our toes, on the other hand, are sadly underused, incompetent, and unnoticed—until we stub them. That functional significance trounces size is deep inside us, or rather, right there at the top of the head.

Significance trounces size not only in the brain but also in talk and thought. We saw this in research in our laboratory. We first collected the body parts most frequently named across languages. Zipf's Law tells us that the more a term gets used, the shorter it gets; *co-op, TV,* and *NBA* are examples. The presumption is that if a body part is named across languages, it's probably important irrespective of culture. The top seven were head, hands, feet, arms, legs, front, back. All the names are short, and, in fact, all are important even compared to other useful parts, like elbow or forearm. We asked a large group of students to rank those parts by significance and another group by size. As expected, similar to the homunculus in the brain, significance and size didn't always line up. Significance reflected size of cortical territory, not body size: head and hands were rated as highly significant but aren't particularly large, and backs and legs are large but were rated lower in significance.

Next, we asked which body parts were faster for people to recognize, the large ones or the significant ones? We tried it two ways. In one study, people saw pairs of pictures of bodies, each in a different pose, each with a part highlighted. You might be thinking that people would naturally find large parts faster. To make all parts equal irrespective of size, we highlighted with a dot in the middle of the part. In the other study, people first saw a name of a body part and then a picture of a body with a part highlighted. In both studies, half the pairs had the same part highlighted and half had different parts highlighted. Participants were asked to indicate "same" or "different" as fast as possible. An easy task; there were very few errors. Our interest was in the time to respond: Would people respond faster for significant parts or for large ones? You've probably already guessed what happened. Significant parts were faster.

The triumph of significance over size was even stronger for name-body comparisons than for body-body comparisons. Names are a string of letters; they lack the concrete features of pictures like size and shape. Names, then, are more abstract than depictions. Similarly, associations to names of objects are more abstract than associations to depictions of objects. Names of things evoke abstract features like function and significance, whereas pictures of things evoke concrete perceptible features.

First General Fact Worth Remembering: Associations to names are more abstract than associations to pictures.

Remember that all the parts used in our studies were significant compared to familiar but less significant parts like shoulder or ankle. Notably, the word for each part—*head, hands, feet, arms, legs, front,* and *back*—has numerous extended uses, uses so common that we're unaware of their bodily origins. Here are just a few: head of the nation, lost his head; right-hand person, on the one hand, hands down; foot of the mountains, all feet; arm of a chair, arm of the government; the idea doesn't have legs, shake a leg, break a leg; up front, front organization; not enough backing, behind the back. Notice that some of these figurative meanings play on the appearance of the parts, elongated as in *the arms and legs of a chair;* others play on the functions of the parts, such as *the head of the nation* and *the idea has no legs*. Of course, many other body parts have figurative extensions: someone might be the butt of a joke or have their fingers into everything. Then there are all the places claiming to be the navel of the world—visiting all of them could keep you traveling for months—the navel, that odd dot on our bellies, a remnant of the lifeline that once connected us to our mothers. Once you start noticing figurative uses, you see and hear them everywhere.

Like our knowledge of space, we know about our bodies from a multitude of senses. We can see our own bodies as well as those of others. We can hear our footsteps and our hands clapping and our joints clicking and our mouths speaking. We sense temperature and texture and pressure and pleasure and pain and the positions of our limbs both from the surface of our skin and from proprioception, those sensations of our bodies from the inside. We know where our arms and legs are without looking, we can feel when we are off balance or about to be. It's mind-boggling to think of how much delicate and precise coordination of so many sensory systems is needed just to stand and walk, not to mention shoot a basket or do a cartwheel. We weren't born doing those things.

Babies have so much to learn. And they learn so fast: their brains create millions of synapses, connections between neurons, per second. But their brains also prune synapses. Otherwise, our brains would become tangled messes, everything connected to everything else, a multitude of possibilities but no focused action, no way to strengthen important connections and weaken irrelevant ones, no way to choose among all those possibilities and organize resources to act. Among other things, pruning allows us to quickly recognize objects in the world and to quickly catch falling teacups but not burning matches. But that process has costs: we can mistake a coyote for a dog and a heavy rock for a rubber ball.

This brings us to our **First Law of Cognition: There are no benefits without costs.** Searching through many possibilities to find the best can be time consuming and exhausting. Typically, we simply don't have enough time or energy to search and consider all the possibilities. Is it a friend or a stranger? Is it a dog or a coyote? We need to quickly extend our hands when a ball is tossed to us but quickly duck when a rock is hurled at us. Life, if nothing else, is a series of trade-offs. The trade-off here is between considering possibilities and acting effectively and efficiently. Like all laws in psychology, this one is an oversimplification, and the small print has the usual caveats. Nevertheless, this law is so fundamental that we will return to it again and again.

INTEGRATING BODIES: ACTION AND SENSATION

With this in mind, watching five-month-old babies is all the more mystifying. On their backs, as they are now supposed to be placed, they can suddenly catch sight of their hand and are captivated. They stare intently at their hand as though it were the most interesting thing in the world. They don't seem to understand that what they are regarding so attentively is their own hand. They might move their hand quite unintentionally and then watch the movement without realizing that they've caused it. If you put your finger or a rattle in their hand, they'll grasp it; grasping is reflexive. But if the hand and the rattle disappear from sight, they won't track them. Gradually, sight and sensation and action get integrated, starting at the top of the body, hands first. Weeks later, after they've accomplished reaching and grasping with their hands, they might accidentally catch their foot. Flexible little things with stubby legs, they might then bring their foot to their mouth. Putting whatever's in the hand into the mouth is also quite automatic, but at first they don't seem to realize that it's their own foot.

Babies start disconnected. They don't link what they see with what they do and what they feel. And they don't link the parts of their body with each other. We take the connections between what we see and what we feel for granted, but human babies don't enter the world with those connections; the connections are learned, slowly over many months. Ultimately, what unites the senses foremost is action. That is, the output—action—informs and integrates the input—sensation—through a feedback loop. Unifying the senses depends on acting: doing and seeing and feeling, sensing the feedback from the doing at the same time.

It's not just babies who calibrate perception through action. We adults do it too. Experiments in which people don prismatic glasses that distort the world by turning it upside down or sliding it sideways show this dramatically. The first known experiments showing adaptation to distorting lenses were performed in the late nineteenth century by George Stratton, then a graduate student and later the founder of the Berkeley Psychology Department. Stratton fashioned lenses that distorted vision in several ways and tried them himself, wearing them for weeks. At first, Stratton was dizzy, nauseated, and clumsy, but gradually he adapted. After a week, the upside-down world seemed normal and so was his behavior. In fact, when he removed the lenses, he got dizzy and stumbled again. Since then, experiments with prismatic lenses that turn the world every which way have been repeated many times. You can try the lenses in many science museums or buy them on the Web. A charismatic introductory psychology teacher at Stanford used to bring a star football player to class and hand him distorting lenses. Then the instructor would toss the player a football, and of course the star player fumbled, much to everyone's delight. A rather convincing demonstration! That disrupted behavior, the errors in reaching or walking, is the measure of adaptation to the prismatic world.

The surprising finding is this: seeing in the absence of acting doesn't change perception. If people are wheeled about in a chair and handed what they need—if they don't walk or reach for objects—they do not adapt to the prismatic lenses. Then, when the lenses are removed, the behavior of passive sitters is normal. No fumbling. No dizziness.

Because acting changes perception, it should not be surprising that acting changes the brain. This has been shown many times in many ways, in monkeys as well as in humans. Here's the basic paradigm: give an animal or a person extensive experience using a tool. Then check areas of the brain that underlie perception of the body to see if they now extend outside the body to include the tool. Monkeys, for example, can quickly learn to use a hand rake to pull out-of-reach objects, especially treats, to themselves. After they become adept at using a rake, the brain regions that keep track of the area around the hand as it moves expand to include the rake as well as the hand. These findings were so exciting that they have been replicated many times in many variations in many species. The general finding is that extensive practice using tools enlarges both our conscious body image and our largely unconscious body schema.

That extensive tool use enlarges our body images to include the tools provides evidence for the claim that many of us jokingly make, that our cell phones or computers are parts of our bodies. But it also makes you wish that the people who turn and whack you with their backpacks had had enough experience with backpacks that their backpacks had become part of their body schemas. Too bad we don't use our backpacks the ways we use the tools in our hands.

The evidence on action is sufficient to declare the **Second Law of Cognition: Action molds perception.** There are those who go farther and declare that perception is for action. Yes, perception serves action, but perception serves so much more. There are the pure pleasures of seeing and hugging people we love, listening to music we enjoy, viewing art that elevates us. There are the meanings we attach to what we feel and see and hear, the sight of a forgotten toy or the sound of a grandparent's voice or the taste, for Proust, of a madeleine. Suffice it to say that action molds perception.

Earlier I observed that our skin surrounds and encloses our bodies, separating our bodies from the rest of the world. It turns out that it's not quite that simple (never forget my caveats and my caveats about caveats). It turns out that we can rather easily be tricked into thinking that a rubber hand—yuck—is our own.

In a paradigmatic experiment, participants were seated at a table, with their left arm under the table, out of view. On the table was a very humanlike rubber hand positioned like the participant's real arm. Participants watched as the experimenter gently stroked the rubber arm with a fine paintbrush. In synchrony, the experimenter stroked the participant's real but not visible arm with an equivalent brush, matching the rhythm. Amazingly, most participants began to think that the arm they could see, the rubber arm, was their own. They reported that what they saw was what they felt. Action, per se, is not involved in creating this illusion, but proprioceptive feedback seems to be crucial. Both hands, the participant's real hand and the rubber hand, are immobile. What seems to underlie the illusion is sensory integration, the integration of simultaneously seeing and feeling.

If people perceive the rubber arm as their own arm, then if they watch a threat to the rubber arm, they should get alarmed. This happened in subsequent experiments. First, as before, participants experienced enough synchronous stroking of their hidden real arm and the visible rubber arm to claim ownership of the rubber arm. Then the experimenters threatened the rubber arm by initiating an attack on the arm with a sharp needle. At the same time, they measured activation in areas of the brain known to respond to anticipated pain, empathetic pain, and anxiety. The more participants reported ownership of the rubber hand, the greater the activation in the brain regions underlying anticipated pain (left insula, left anterior cingulate cortex) during the threatened, but aborted, attack with a sharp needle.

The rubber hand phenomenon provides yet another explanation of why people's body schemas enlarge to include tools but don't seem to enlarge to include their backpacks. Ownership of a rubber hand depends on simultaneous seeing and sensing, seeing the rubber hand stroked and sensing simultaneous stroking on the real hand. We can't see our backpacks and whatever sensations we have are pressure or weight on our backs and shoulders, which give no clue to the width of the backpack generating the pressure.

UNDERSTANDING OTHERS' BODIES

Now to the bodies of others. It turns out that our perception and understanding of the bodies of others are deeply connected to the actions and sensations of our own bodies. What's more, the connection of our bodies to those of others is mediated by the very structure of the brain and the nervous system. Let's begin again with babies, let's say, one-year-olds. Babies that young have begun to understand the goals and intentions of the actions of others, at least for simple actions like reaching. You might wonder how we know what babies are thinking. After all, they can't tell us (not that what we say we are thinking is necessarily reliable). We know what babies are thinking the same way we often know what adults are thinking: from what they are looking at. Sometimes actions can be more revealing than words.

The most common way researchers infer the thoughts of babies is through a paradigm known as habituation of looking. Two ideas underlie this paradigm: people, even, or especially, babies, look at what they're thinking about; and second, stuff that's new grabs attention and thought. In a typical task, researchers show infants a stimulus or an event, in this case, a video of someone reaching for an object. At the same time, they monitor how much the infants are looking at the event. They show the event again, and monitor again. The researchers show the stimulus or the event over and over until the baby loses interest and looks away, that is, until the infant *habituates* to the event. After the infant habituates, the researchers show a new event that alters the previous one in one of two ways. They change the goal of the action by switching the object of reaching or they switch the means of attaining the goal by changing the manner of reaching. The question of interest is whether infants will look more at the event where the goal of reaching was changed or the event where the means of attaining the goal was changed.

If the infant understands that it's the goal that matters, not the means to the goal, the infant should look more when the goal changes than when the means changes. At ten months, infants were indifferent to the changes; they looked equally at both. Both events were new, and the infants didn't regard a change of goal as more interesting than a change of manner of attaining the goal. That changed in only two months. Twelve-month-old infants looked more when the goal changed than when the means to the goal changed. A leap of understanding of goal-directed behavior in two months.

More support for the notion that one-year-olds understand action-goal couplings comes from tracking their eye movements as they watch someone reaching. Remarkably, the eye movements of one-year-old infants jump to the goal of the action before the hand even reaches the goal, suggesting that they anticipate the goal.

Perhaps even more impressive is what happens even earlier, at three months. At that tender age, if infants have performed similar actions, they are more likely to understand the goals of others' actions. At three months, infants don't have good motor control, they cannot yet reach and grasp reliably, and their hands flail about. The clever experimenters put mittens with Velcro on the baby's hands and a toy in front of the infant. Eventually, with enough flailing, the Velcroed hand would catch the toy. The infants who had had practice "grasping" objects in this way anticipated the viewed reaching and grasping actions of others more reliably than infants without practice grasping.

This is remarkable evidence that infants can understand the intentions behind the actions of others. Not all intentions and actions, of course, but reaching for an object is an important and common one, and there are undoubtedly others. Understanding others' intentions comes about in part because of experience enacting similar actions with similar intentions. Moreover, as we shall see next, it has become clear that the very structure of the brain is primed for understanding observed action, through the mirror neuron system.

MIRROR NEURONS

In the late 1980s, a group of neuroscientists in Parma, Italy, led by Giacomo Rizzolatti made a surprising discovery. They implanted tiny electrodes in individual neurons in premotor cortex (inferior frontal gyrus and inferior parietal lobe) of macaque monkeys that allowed them to record activity in single neurons in animals who were moving about as they normally do. They found single neurons that fired when the monkey performed a specific action, like grasping or throwing. What was remarkable was that the exact same neuron fired when the animal saw someone else, in this case, a human, perform the same action. They called these remarkable neurons *mirror neurons*. Mirror neurons unite doing and seeing for specific actions. This extraordinary discovery means that action and perception are joined automatically by specific individual neurons without any mediation whatsoever. Different actions are encoded by different neurons: for monkeys, grasping, throwing, tearing. You can watch the action and listen to the simultaneous firing of these neurons online. More generally, the finding suggests that action mirroring, sometimes called motor resonance, underlies action understanding. Seeing is mapped to doing and doing is mapped to seeing. I understand what I see you doing because an echo of the doing resonates in my own action system. Of course, it's just an echo; I'm not actually doing what I'm seeing, which is a good thing. Otherwise, we'd be caught in an unending cycle of imitation. Mirror neurons underlie the understanding part of imitation, but not the doing part.

Naturally, these findings, now replicated many times, have generated enormous excitement. Overinterpretation of tantalizing findings like these is inevitable. Might mirror neurons underlie imitation, learning, and memory? The research group in Parma has gone to great effort to explain that seeing is not imitating and that understanding is not doing. If it were that simple, we'd all be expert pianists or basketball players or acrobats. Motor resonance, however, is real: that is, seeing action causes associated motor regions of the brain and even associated muscles to activate.

It's problematic to perform these experiments in humans. We don't simply implant electrodes in individual neurons in other humans. There are cases, however, when recording from single cells in the alert human brain is crucial for people's health and well-being, for example, for people with intractable epilepsy. Epilepsy can often be controlled by destroying the brain tissue that seems to initiate seizures, but neurosurgeons first make sure the brain locations are not involved with core functions like speech. The way to find out is by implanting electrodes in the suspect areas, and sometimes in other areas, where the electrodes would cause no damage. Studies recording from single cells in those patients have found evidence for mirror neurons in multiple parts of the human brain, for example, individual neurons that responded when people observed or performed actions and also when people viewed or expressed facial emotions.

The actions of bodies are qualitatively different from the actions of other objects. A crucial difference: bodies are self-propelled, which means bodies can perform gravity-defying actions, like jumping up in the air all by themselves, feats that baseballs and leaves cannot perform. Even small children do a decent job telling whether a path of motion is from an animate being or an inanimate object. Of course, animacy is far more than paths of motion, and even small children understand that. Yet, it is significant we and small children can make a good guess as to whether something moving is animate or not simply from an easily perceivable path of motion. It is sometimes surprising how much deep essential qualities like animacy are apparent from superficial perceptual features. Earlier we saw that objects can be recognized by their contours. Other examples to come.

MOTOR RESONANCE

Just as infants understand viewed actions better if they have performed the same actions, not surprisingly, so for adults. Our experience performing specific actions modulates our perception of the same actions performed by others. In an experiment that has generated smiles, excitement, and even some controversy, experts in capoeira, experts in ballet, and nonexperts viewed videos of standard movements in capoeira and ballet while in a scanner that measured their brain activity. Brain activity in a network involved in the mirror system (premotor cortex, intraparietal sulcus, right superior parietal lobe, and left posterior superior temporal sulcus) showed more activation when observers watched the movements for which they were experts.

The broader implication is by now a familiar one: we understand actions that we view by simulating the actions in our bodies, by embodying the perception. Many names for more or less the same phenomenon: motor simulation, motor resonance, embodiment. There are even more.

Motor simulation has implications beyond understanding action. It affects our predictions and expectations about action, for example, whether a basketball will make the basket. In one study, professional basketball players, sports reporters, and professional basketball coaches were asked to predict whether free throws would make the basket. Coaches and sports reporters have extensive outsider, that is, visual, experience watching basketball, and from many different points of view. Basketball players have that visual experience, but they also have the insider view. They know what it feels like to shoot a basket, and most likely they have developed good intuitions about which shots they take themselves will make the basket. Professional basketball players are so practiced at shooting baskets that they have often been called shooting machines.

You've guessed the results. All three groups, coaches, reporters, and players, were impressively good at predicting which balls would land in the basket. That said, the players were far better. Their extensive insider knowledge enabled professional basketball players to predict shots better than coaches or sports reporters. The experimenters stopped the videos at varying intervals from the beginning of the shot until the ball was very close to the basket. What was especially impressive is that the players' predictions were superior even before the ball left the player's hands! This suggests that the players had insider motor understanding of the body kinematics underlying basketball shots, and that this understanding allowed them to better predict the outcomes of the actions. Players have more motor experience than coaches and sports reporters and that motor experience enables better predictions. Along with other evidence and more to come, it suggests that we map body action that we see onto our own body's action system. Perception of action acquires meaning through motor understanding. Experts with more articulated motion systems perceive more meaning in what they see.

Back in the 1970s, a Swedish psychologist, Gunnar Johansson, dressed people in black and attached small lights to their major parts and joints, head, shoulder, elbow, wrist, hips, and so forth. He then filmed them as they performed a common set of human actions, walking, running, and dancing. This paradigm, using point-light videos, has been adopted, adapted, and simulated many times since. You can find many captivating examples online. A static image of any of the point-light bodies is unidentifiable; it looks like a random collection of dots. But once the set of dots is set in motion, you can immediately see that it's a human body, you know if it's walking or running or dancing, you know if it's a man or a woman (by the ratio of the shoulders to the hips), you can tell if it's happy or sad, energetic or tired, heavy or light.

More recently, a group of researchers used that paradigm to ask how well we can recognize individuals from point-light videos. They brought pairs of friends into their laboratory, dressed them in black, attached lights to their heads and joints, and filmed them dancing, running, boxing, walking, playing Ping-Pong, and more, altogether ten different activities. Some months later, all participants were invited back to the lab to view all the videos. For each video, they were asked to identify the specific person moving. Perhaps not surprisingly, people were pretty good at recognizing their friends from their friends' movements but poor at recognizing strangers. It was far easier to recognize individuals from the videos depicting more vigorous activities like dancing, jumping, playing Ping-Pong, and jumping than from the videos showing walking and running. The next finding is truly surprising. Participants were best at recognizing themselves! Most of us, and certainly the participants in this experiment, don't spend a lot of time looking at our movements in the mirror unless we are dancers or models or yoga practitioners. How is it that we are best at recognizing ourselves, people we never or rarely see playing Ping-Pong or jumping, better than we are at recognizing our friends, whom we've presumably had extensive experience watching in motion? As before, the mirror system, motor resonance, seems to underlie that impressive ability. The theory goes like this. As participants watched the videos of people in action, their mirror systems resonated to the actions they were seeing as if they were trying the movements on for size. When they watched videos of themselves in action, the movements fit perfectly, they felt right, felt natural, felt like themselves.

COORDINATING BODIES

Birds flock, fish school, troops march. Bees gather nectar, ants build nests; basketball players coordinate on the court; boxers, on the mat; improvisors, on the stage. Commuters race every which way through Grand Central. For the most part, there are no collisions and there's no one directing the traffic. There are so many ways that organisms rapidly coordinate their behavior with each other and so many reasons for the coordination. The mere presence of others affects our behavior, without any need to coordinate. You're sitting alone in a waiting room or on a seat in a train or in line to buy a ticket. A total stranger arrives and does the same, sits down across the aisle or stands behind you in line. Unless you are completely distracted, say, by the smartphone at your fingertips or near your ear, you can't help but be aware of the presence of the other, and that presence affects your behavior.

In situations like those, standing in line, sitting in a waiting room or on a train, you and the stranger are performing the same action at the same time in the same space. Providing that there is plenty of room for each of you, your actions do not have to be coordinated. If the train or waiting room is crowded, you might have to coordinate, making room for each other and each other's belongings. Walking down nearly empty streets doesn't require much coordination with others; nor does clapping at the end of a performance. Yet, remarkably, pedestrians tend to synchronize their walking and audiences their clapping.

Presumably, like birds flying in flocks, the synchronization of the group organizes and eases the actions of the individuals. Since my walking or clapping is in sync with others', I can attend less to mine. In the human case, perfect strangers fall into rhythm. Rhythm is deeply embedded in our bodies, in our hearts, our breathing, our brains, our actions—walking, talking, thinking, dancing, sleeping, waking—our days and nights. Our rhythms organize and synchronize our bodies and come to organize and synchronize our bodies with the bodies of others.

The games we play with babies practice those skills, although that's probably not why we play them. The baby says "ahh." We say "ahh." The baby says "ahh." We take turns doing the same thing. Later we change our responses slightly, they say "ahh," we say, "ahh ahh." We roll a ball to baby, baby rolls it back to us. We clap together or in alternation. Our play is unintentionally training the elements of joint action: synchronization, turn-taking, imitation, entrainment, joint attention, joint understanding. And we—and they—just thought we were having fun. We were. There is something so satisfying about doing something together, in sync.

In humans, coordination quickly turns into cooperation. As early as fourteen months, when a child sees an adult trying to get an object out of reach but close to the child, the child will hand the object to the adult. Both the social understanding and the social behavior are remarkable, all the more so because they don't require language or any explicit coordination. Other primates, monkeys and great apes, can be induced to work together to achieve a joint goal. The standard laboratory task is jointly pulling on separate ropes to bring some nuts or bananas in reach. Elephants cooperate, as do dolphins, both often with humans, just like dogs. Indeed, research in Tomasello's lab has shown that cooperation is the origin of moral behavior; we need to work together, but then we must, or rather should, split the rewards. When small children are given more than their share, they share their share with the others.

At the other end of the continuum of joint action are tasks that require continuous and continuously changing coordination. To study this kind of coordination, we brought pairs of students who had never met each other into a lab room. On a table was a stack of parts of a TV cart and a photo of the completed cart. The pairs were asked to assemble the TV cart using the photo as a guide. We'd done many experiments on TV cart assembly by then, so we knew that students could do this individually, even without instructions. We even began to think this simple experiment was an important part of their undergraduate education.

Sure enough, the pairs were successful at assembling the TV cart. They did it correctly and efficiently, if each pair differently. Unlike walking or clapping, assembling the TV cart required partners to work together while performing different actions that were the components of each assembly step. The pairs spontaneously assumed different roles, usually implicitly, without even speaking. One would take the role of the *heavy lifter* and the other, the role of the *attacher*. The heavy lifter would hold a large part steady so that the attacher could connect another part to it. Each step in the assembly was more efficient with both partners, and to accomplish each step, the partners had to perform complementary actions. What was fascinating is that so much of the coordination happened without explicit negotiation, without words, even though the assembly actions were asymmetric and had to be done together. What's more, each partner knew what the other needed to do, often anticipating the partner's next action. The heavy lifter might see that the attacher would soon need a specific part and hand it to the attacher. When the attacher had the next part in hand, the heavy lifter would position the base so the attacher could easily attach the part. And so on. A kind of dance.

It seems amazing that this intricate set of interactive actions can happen almost wordlessly, without explicit organization. But on deeper reflection, perhaps it should not be so surprising. An orchestra needs a conductor, but a string quartet does not. Jazz improv can be beautifully coordinated as can comedy improv, without scores or scripts or a leader. At the core of joint action is joint understanding, shared knowledge of the goals and subgoals of the task and the procedures needed to accomplish it. For the TV cart, the procedures are a sequence of actions on parts, placing each part in turn in the correct configuration and attaching it with the appropriate means of attachment. The joint understanding of the goals of the task resides in each partner's mind. In fact, people have numerous event schemas in their minds, representations of the sequences of actions on objects needed to accomplish a range of ordinary tasks, like making a bed or doing the dishes or assembling a piece of furniture. These representations allow people to interpret ongoing action, to predict what happens next in ongoing action, and to generate step-by-step instructions to accomplish the tasks.

Peering inside the brain can reveal some of the processes that track joint action. Both electroencephalogram (EEG) and functional MRI (fMRI) research shows that participants keep their joint task active in the brain as well as in the mind. Surprisingly, partners keep each other's task in mind even when doing so interferes with their own performance, slows them down, and makes them more prone to error.

Although the representation of the task resides in each partner's mind, the set of procedures to carry out the task relies on objects and partners in the world. Participants have to keep in mind the overall goal and procedures and use that to guide their own actions. To prepare their own actions, people need to monitor each other's actions as they proceed step-by-step. This means that colonize in other parts of the body, that many of us had a fraternal twin who disappeared in utero and that we may be carrying the twin's DNA. Others aren't just in our minds. We really are parts of others and they of us, even within our own skin.

CHAPTER TWO

The Bubble Around the Body: People, Places, and Things

In which we learn how people recognize, categorize, and understand the people, places, and things around us. We note that many everyday categories such as chairs and dogs are bins of common features that differentiate them from the feature bins of even nearby categories, such as carpets and snakes. But not always, and then we need to think harder, about dimensions and the features shared across categories.

> *We live not only in a world of thoughts, but also in a world of things.*
>
> —Vladimir Nabokov

Surrounding our bodies are the people, places, and things in reach of eye or hand. These are the immediate influences on our perception, on our behavior, and on our thought. In a fraction of a second, before we can find the words to say it, we know where we are, at home, in the supermarket, at the park. We know what's around us, chairs and tables or shopping carts and packages of food or trees and swing sets. We know who's around us, what they are doing, making dinner, shopping, swinging. We know what kind of people they are, we can sense their feelings and their health from their faces and bodies, we can judge their social and economic status from their clothing and behavior, we can make good guesses as to their ages, gender, even political leanings. We people wear so much of our insides on our outsides. We take in our surroundings automatically and instantly. Unless we are blindfolded and our ears are covered, we can't *not* pick it up. This isn't to say that we are always correct, but it is remarkable how often we are.

We didn't enter the world with this impressive ability. Newborns need to learn to see the very elements of objects, edges and corners, and to connect them to form the shapes that are used to recognize people and things. They need to learn to discern and recognize faces and objects and scenes. Babies learn that wordlessly in the first few months of life, simply by looking. It happens so fast that parents miss it unless they know what to look for. Much of that learning happens while the brain is maturing. People who were born blind and gain sight as adults can't make heads or tails out of what they see, a surprising and often wrenchingly disappointing outcome. Fortunately, blindness from birth has become far less frequent, and with training and experience, some visual competence can be acquired if sight is restored later in life.

Who, what, and *where* are so fundamental that the brain has specialized regions for recognizing them, in fact, usually multiple regions for each: faces, bodies, objects, scenes. The retina captures information as it is arrayed in the world, if upside down. The upside-down part is the easy part for the brain. Making sense of what's on the retina is far harder. That information is essentially an array of raw pixels, devoid of meaning. It has to be segmented into figures and background. That entails finding edges and connecting them. Both figures and ground need to be interpreted, given meaning. That happens by routing information from the retina, and for that matter, from all the senses, to different parts of the brain. The different locations perform different computations on the information from the senses, computations specialized for creating the different meanings relevant to our lives, computations specialized for faces, places, and things of all sorts.

When and *why* are far harder. They can't be easily computed from sensory input the ways that color and shape and even faces and objects and scenes can be. Except for a handful of hyperorganized individuals who remember the exact dates and details of many events of their lives, the brain doesn't put a date stamp on events. And even in those perhaps enviable individuals, memory is constructed, the time stamp is added symbolically, in words and numbers from the conventional Gregorian calendar. No brain area codes that. *Why* is even more complicated, so many events have so many possible explanations, providing endless work for scientists, political analysts, and advice columnists. And disagreements between couples and countries. Because the mechanisms we use to construct *when* and especially *why* are imperfect and biased, so are our judgments and explanations.

THINGS

Of all those crucial entities in the world, and components of knowledge, things are the simplest. Yet, there are so many things, how to make sense of them? One way to make sense of things is to group them into categories, but which categories? First, consider this set of categories from the literary philosopher Jorge Borges:

> The following is a taxonomy of the animal kingdom. It has been attributed to an ancient Chinese encyclopedia entitled the *Celestial Emporium of Benevolent Knowledge:* On those remote pages it is written that animals are divided into (a) those that belong to the Emperor, (b) embalmed ones, (c) those that are trained, (d) suckling pigs, (e) mermaids, (f) fabulous ones, (g) stray dogs, (h) those that are included in this classification, (i) those that tremble as if they were mad, (j) innumerable ones, (k) those drawn with a very fine camel's hair brush, (l) others, (m) those that have just broken a flower vase, (n) those that resemble flies from a distance.

Poetic categories they are, but useful they are not. Good categories sort most things into separate bins, not partially overlapping ones. Good categories should be easy to identify. Good categories should be informative, they should tell us what they're good for. Good categories should reduce the enormous numbers of different things to a manageable number. The key to recognizing and categorizing things, objects, is *shape:* objects have shapes and the visual system is biased toward finding them. It homes in on edges and connects the dots when objects occlude other objects.

Around the first year of life, parents and babies begin to play a naming game, pointing, showing, labeling everything that catches the baby's attention. Babies and children acquire words at an amazing speed. One estimate is that seventeen-year-olds know eighty thousand words. For convenience, let's say babies begin learning words around their first birthday (of course they begin much earlier, before they can talk). That would mean five thousand words a year, or fourteen a day, and undoubtedly many more of them earlier in life than later. This pace is much faster than the naming game; kids are picking up words for things without being taught. This astounding pace of acquisition is just for the labels of things. To add to the wonder, we have labels for only a fraction of what we, babies, children, learn and know, people, places, things, emotions, and more.

HIERARCHICAL ORGANIZATION

Basic level

Toddlers learn to call the things around them apples and bananas, cars and buses, shirts and shoes. They don't begin with labels like *Gala apple* or *fruit, Prius* or *vehicle, knit shirt* or *clothing.* Even adults prefer those simple labels. Calling ordinary things with more abstract or more specific labels sounds odd in ordinary situations. If I offer you a ride because I've brought my Tesla X, I'm showing off. If I tell you I've brought my vehicle, I'm being silly. If I ask you to put the animal out instead of the dog, I'm implying the dog is wild and beastly rather than docile and friendly. Languages have those more abstract and more specific labels for good reasons, but for everyday use, the middle level, the level of *apple, car,* and *shirt,* is preferred. Interestingly, these labels are typically shorter and more frequent than more general or more specific labels (Zipf's law again: more frequent words are shorter). The default and neutral way of referring to things, the level first used by children, the level of *apple* and *car,* has been called the *basic* level. The more general level, the level of *vehicle, fruit,* and *animal,* has been called the *superordinate* level, and the more specific level, *Tesla, Gala apple,* and *cocker spaniel,* has been called the *subordinate* level.

The basic level is special for many reasons. Objects at the basic level like apples and tables and hammers and belts generally have the same shapes, so it is easy to identify them. So do their including faces and bodies. It is hard to overestimate the importance of faces and bodies in our lives. Who is that? Friend or foe? Old or young? Sick or healthy? Native or foreign? Drunk or sober? Rich or poor? What are they feeling? What are they thinking? What are they doing? What are they going to do? So much of that vital information and more is right there on the surface, on the face or in the body. Insides make their way to outsides. We turn to some of that information now. We need to absorb it quickly because it guides our own behavior. And we do absorb it quickly. Quick appraisal doesn't guarantee accuracy. Remember the **First Law of Cognition: No benefits without costs.**

Here the benefit is speed, necessary in the savannah or on a dark street or even on a well-lit one—you must flee danger and greet a friend, but not a stranger, who might interpret your smile as an invitation. Identical twins create this problem; I was once miffed when a friend didn't greet me only to realize that it was his twin, who quite understandably had no idea who I was. Speed and accuracy trade off in just about everything we do; the trick, as with all trade-offs, is to find the sweet spot. That depends on the costs of both errors, falsely greeting a twin stranger warmly or failing to greet a friend. Mistaking a coyote for a dog can be costly, but mistaking a dog for a coyote less so.

Who: Faces

Try this. Describe a person you know to someone who was at a party with that person but who isn't sure whom he or she is. Not easy. Easy only in those rare cases when someone has a distinctive feature, neon hair or unusual glasses. In general, everyone has eyes, noses, mouths, and ears. We have good words for those, but they don't distinguish one person's face from another's. We don't have good words for the features that do distinguish one face from another, the subtle differences among eyes, noses, mouths, and ears, or the subtle differences in their configurations and expressions. Like their parents, each of my three children has "blue" eyes. Five pairs of eyes, five shades of blue, and I'd never confuse them. Despite the near impossibility of describing individual faces, most of us can recognize thousands of them. That disparity says loudly that face recognition can't be based in language. We don't normally bother describing faces to distinguish one from another. Rather, we give each face an arbitrary name, a name that has something to do with the person's family but nothing to do with the person's appearance. And that disconnect between the vivid appearance and the disconnected name is part of why so many complain that they never forget a face but can't remember names.

Recognizing faces is fundamentally different from recognizing objects. For one thing, whose face is important, but which chair or which hammer is usually not. Chairs and hammers are typically interchangeable, but individuals, for better or worse, are not. Silhouettes work for recognizing chairs and giraffes and shirts and bananas, but shape won't do for faces. All faces have more or less the same shape. Recognizing faces depends on what's inside the shape, but not just the features themselves, again because we all have those, and so do dogs and monkeys. Key for faces is the qualities of those internal features, eyes, nose, mouth, and how they are arrayed. That's a hard problem, one that the fusiform gyrus, tucked underneath the cortex, is good at solving. Other areas of the brain, the occipital face area (OA) and the superior temporal sulcus (fSTS), respond to face parts in any configuration, the kinds kids have fun making, but the fusiform face area is sensitive to properly configured faces.

Now a few interesting facts about memory for faces. Memory for faces is specific to faces, independent of other abilities. It is stable over time, and doesn't seem to be trainable. Perhaps not surprisingly, it turns out to have a strong genetic base. Recognizing faces improves with age, especially through adolescence (ten to twenty years), and peaks at thirty-two.

Despite the importance of individual faces in our lives, not everyone's brain can distinguish and recognize individuals. What do Brad Pitt, Oliver Sacks, and Chuck Close have in common? Sure, they're famous. And supremely talented. But the exotic feature they share is *prosopagnosia*. Practice a bit and the syllables will roll off your tongue. Yes, it's Greek; *prosopon* is Greek for "face"; *agnosia,* for "not knowing." Face blindness. A problem in the fusiform gyrus. People with prosopagnosia can sense they are looking at a face but do not know whose. Painfully, some can't even recognize their spouses. If you suspect prosopagnosia, don't take it personally. It's the brain's fault; apparently, the neural circuitry that responds to faces in prosopagnosics differs wildly from the neural circuitry in those who recognize faces effortlessly.

Not recognizing faces is not just embarrassing but a serious problem. Prosopagnosics develop compensatory mechanisms, analyzing and memorizing critical features, attending to other aspects of individuality like voice, body, and clothing. Fortunately, more wonders of the brain, the inability to identify individual faces doesn't interfere with the ability to detect emotional states. Fascinating, isn't it, that recognizing identity and recognizing emotion are computed independently, in different areas of the brain?

Faces and emotion

If cooperation is key to the success of our species, emotion is key to cooperation. To work with you, I need to trust you, to like you, to think positively of you. There are widely diverse views of emotion, but there is one thing on which they agree: emotions can be readily divided into positive or negative. Like/dislike. And quickly expressed in behavior. Positive means approach; negative, avoid. Emotions come on quickly, expressed by the face, the body, the voice. Emotions are rapidly recognized and hard to suppress. e e cummings famously opened a poem, "since feeling comes first," an insight later supported by research (and contributing the Third Law of Cognition). People viewing random meaningless forms have gut feelings about them before they know whether the forms are familiar. And they feel more positively toward the forms they've seen even when they fail to recognize them. Recognition and emotion are separate systems that are slow to talk to each other. The essence of emotion, positive or negative, is a rapid distillation of the essence of social glue, approach or avoid. This fundamental dimension has been anointed with a term from chemistry, *valence*. In chemistry, valence underlies the bonding of molecules; in psychology, the bonding of people. Emotional valence is the great reducer, the bottom line. **Third Law of Cognition: Feeling comes first.**

Emotions not only come on quickly in ourselves and are sensed

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