tional brain, although inarticulate and unreasoning, can be expressive and intuitive. Like the art it is responsible for inspiring, the limbic brain can move us in ways beyond logic that have only the most inexact translations in a language the neocortex can comprehend.

The verbal rendition of emotional material thus demands a difficult transmutation. And so people must strain to force a strong feeling into the straitjacket of verbal expression. Often, as emotionality rises, so do sputtering, gesticulation, and mute frustration. Poetry, a bridge between the neocortical and limbic brains, is simultaneously improbable and powerful. Frost wrote that a poem "begins as a lump in the throat, a sense of wrong, a homesickness, a love sickness. It is never a thought to begin with."

Neither does love begin with a thought. Anatomical mismatch prevents intellectual talons from grasping love as surely as it foils a person who tries to eat soup with a fork. To understand love we must start with the feelings—and that is where the next chapter begins.

T. Lewis, M.D., F. Amini, M.D., R. Lannon, M.D.

Three

ARCHIMEDES' PRINCIPLE

How we sense the inner world of other hearts

A body in water is subjected to an upward force equal to the weight of the water displaced. This is the skeleton of Archimedes' principle, true to mathematical relationships, cold to the touch. What breathes life into this dry dictum is the legend behind it. As the story goes, twenty-two centuries ago Hiero II, the king of Syracuse, commissioned Archimedes to determine if a certain crown was sterling gold or a tainted alloy. As Archimedes was stepping into his bath, he conceived of submersing the crown and comparing the amount of water it displaced to that displaced by an equal weight of solid gold. Any discrepancy between the two would indicate the crown and the test weight were different densities, and the crown, therefore, at least a partial fraud. This aquatic solution provided Archimedes with both his principle and its famous expression. After his inspiration, he is said to have run from his bath naked into the streets of the city, shouting, "Ευρηκα!"*

The centerpiece of this tale is not the crown or the gold or the cleverness, but Archimedes' passion, hot and pure. As Plutarch describes it:

> *Ofttimes Archimedes' servants got him against his will to the baths, to wash and anoint him, and yet being there, he would ever be drawing out of the geometrical figures, even in the very embers of the chimney. And while they were anointing of him with oils and sweet savours, with his fingers he drew lines upon his naked body, so far was he*

* In its English spelling, "Eureka!"

taken from himself, and brought into ecstasy or trance, with the delight he had in the study of geometry.

As elegant as his insight may be, it is the force of Archimedes' emotion that calls to us down the centuries. His thrill, not his intellectual dexterity, is what has given his theorem its notoriety. The real principle behind his principle is that most people will never fathom its mathematics—but his exuberance they do understand. That rush of joy comes to some from seeing an out-of-the-park home run, to others in the colors of the sun setting into the Pacific, or in the eyes of a newborn baby. Archimedes' delight transmits itself across two millennia in a heartbeat.

Why should we feel a kinship with Archimedes' enthusiasm, even if his physics leave us tepid? To answer that question, we would first have to know the answers to these: what *are* emotions? How do they work? Where do they come from, and what are they for?

The superficial purposes of emotionality are plain. Exhilaration, longing, grief, loyalty, fury, love—they are the opalescent pigments that gild our lives with vibrancy and meaning. And emotions do more than color our sensory world; they are at the root of everything we do, the unquenchable origin of every act more complicated than a reflex. Fascination, passion, and devotion draw us toward compelling people and situations, while fear, shame, guilt, and disgust repel us from others. Even the most desiccated neocortical abstractions pulse with an emotional core. Greed and ambition run beneath the surface of economics; vengefulness and reverence under the veneer of justice. In all cases, emotions are humanity's motivator and its omnipresent guide.

Our society underplays the importance of emotions. Having allied itself with the neocortical brain, our culture promotes analysis over intuition, logic above feeling. Cognition can yield riches, and human intellect has made our lives easier in ways that range from indoor plumbing to the Internet. But even as it reaps the benefits of reason, modern America plows emotions under—a costly practice that obstructs happiness and misleads people about the nature and significance of their lives.

That deliberate imbalance is more damaging than one might suppose. Beyond the variegated sensations and the helpful motivations, science has discovered emotionality's deeper purpose: the timeworn mechanisms of emotion allow two human beings to receive the contents of each other's minds. Emotion is the messenger of love; it is the vehicle that carries every signal from one brimming heart to another. For human beings, feeling deeply is synonymous with being alive. In this chapter we will explore why.

THE SECRET SOCIETY OF MAMMALS

The first scientist to devote himself to the study of emotion was Charles Darwin. After delivering *The Origin of Species,* Darwin wrote three treatises that extended his ideas about evolution and natural selection: *The Variations in Animals and Plants Under Domestication; The Descent of Man, and Selection in Relation to Sex;* and *The Expression of the Emotions in Man and Animals,* the last published in 1872. As his title suggests, Darwin considered emotions an evolutionary adaptation of organisms, no different from a host of other bodily modifications—claws, legs, stingers, gills, scales, wings. Natural selection should favor emotionality for the same reason that it does any feature—enhanced survival. Organisms with an advantageous somatic structure gain a competitive edge and live to pass their genes on to the next generation, while those less equipped fade into the paleontology texts. In Darwin's mind, emotions had to be bodily functions that persisted because of their inherent usefulness. He set about dissecting emotional expressions to discern the underlying biological utility he was certain they possessed.

After years of cataloguing emotional expressions as carefully as he did the bills of Galapagos finches, Darwin set out his conclusions. He proposed that the eyebrows lift in surprise to improve ocular mobility and the extent of the visual field, that the indrawn breath of a startle prepares one for a sudden flight that might follow, that the upturned lip of a socialite's sneer is the remnant of a dog's snarl, in which the animal exposes a cuspid to warn an opponent of its ferocity. Some of Darwin's hypotheses regarding the origins of expressions have scarcely been improved upon; others may strike us as fanciful. But however accurate his assertions about the profitability of individual expressions may have been, the essence of Darwin's approach was right on the mark. Emotions have a biological function—they *do* something for an animal that helps it to live, and if we study emotions carefully enough we might find out what.

Unfortunately, Darwin's evolutionary take on emotionality died an early death. As the study of the mind was launched at the beginning of the twentieth century, behaviorism soon dominated psychology, as psychoanalysis reigned over psychiatry. Both disciplines espoused views of emotion that were as distant from the evolution of terrestrial creatures as the moon. Darwin's ideas were relegated to obscurity for decades. For over fifty years, the preeminent theories of emotion in psychology and psychiatry were more philosophy than science: they were discussed and debated endlessly, tested rarely, and had only the faintest connection to human biology. In the mid-1960s, however, a handful of researchers revived Darwin's original concept of emotion as a heritable neural advantage. And the discoveries of the new emotion science have reshaped the modern vision of the mind, human nature, and love.

It's Not Just an Expression

Thirty years ago, emotion scientists Paul Ekman and Carroll Izard, working separately, confirmed a central proposition in Darwin's

evolutionary theory of emotions: facial expressions are identical—all over the globe, in every culture and every human being ever studied. No society exists wherein people express anger with the corners of the mouth going up, and no person has ever lived who slits his eyes when surprised. An angry person appears angry to everyone worldwide, and likewise a happy person, and a disgusted one.

Convincing proof of universal emotional expressions came when Ekman reviewed 100,000 feet of movie film shot of isolated, preliterate tribes in New Guinea. The footage revealed that New Guineans make the same facial expressions as Americans. Despite differences in dress and appearance, in social milieu and custom, in climate and environment, and although none of them had ever seen a human being outside his own culture, the emotional expressions of the New Guinea natives were "totally familiar."

Ekman also tested their ability to recognize foreign facial expressions and found the same uniformity. He showed them three photographs of Americans—an angry, a happy, and a fearful face—and asked the natives to choose one that agreed with a story: "Her friends have come," or "She is about to fight." The New Guineans picked the glad photo for the former situation, the irate one for the latter. The natives were similarly adept at selecting American facial expressions that would match up with "Your child has died," and "You see a dead pig that has been lying there for a long time." Culture, Ekman found, doesn't determine the configuration of facial expressions: they are the universal language of humanity.

Proof that expressions are intrinsic is closer at hand than the South Pacific. As Darwin knew, a congenitally blind baby will smile while interacting pleasurably with his mother. Such a smile comes from a developing creature unable to speak, walk, or even sit up, but he already knows how to express happiness through a configuration of muscular contractions he has never seen on anyone's face. His knowledge has to be innate. A blind baby's smile must reflect the brain's inherited emotional architecture.

Ekman's work revealed that emotional expressiveness equips human beings with a sophisticated communications system. The receptive component allows people to acquire complex knowledge about the internal state of another person, irrespective of tribe or dialect. And all of us continually broadcast information about our inner states that any attentive human being can collect. Since emotions emanate from phylogenetic history, their antecedents must be found in other animals; our closest relatives should have emotional expressions that resemble ours. And they do.

Emotional expressions on the face of a rhesus monkey. (From Chevalier-Skolnikoff, 1973, in *Darwin and Facial Expression: A Century of Research in Review*, edited by P. Ekman. Reprinted with permission of the Academic Press.)

Because other mammals have expressions, does that mean they have *feelings*—a subjective experience of the emotional states they display? That idea was scientifically risible not so long ago. Now some emotion scientists endorse the proposition that other mammals possess emotional consciousness—that they *feel*. This reversal delights animal advocates eager to make an argument for panprotoplasmic parity. But when the zoophile Mark Derr writes, "The question of whether animals possess consciousness, intelligence, volition, and feelings has long been settled in the affirmative," he must be reporting the consensus from a species other than our

own. Animals may have decided the matter to their own satisfaction, but human beings, as far as we know, are still debating it.

The case for animalistic subjectivity must rely on tangential evidence. We know, for instance, that some animals possess much of the same neural equipment that, in humans, gives rise to the experience of fear. If such an animal *looks* frightened (shows the facial expression of fear) and *acts* frightened (demonstrates the behaviors of fear, such as freezing, trembling, fleeing), then many reasonable people, including sober scientists, will conclude that it *feels* frightened.

Whether one is moved to endorse or reject the notion of zoological feelings, no proof can be adduced to narrow the gap. Subjectivity, by its nature, is nontransferable. (Even the supposition that other *people* feel rests beyond the perimeter of verifiability and, as we shall see, that commonplace assumption is occasionally incorrect.) Science holds marvels in store for future generations, but allowing human beings direct access to the inner sensations of a hedgehog or a dormouse will not be among them.

If we grant that the emotional club has a membership roster of more than one species, what other creatures should we nominate for inclusion? As a limbic product, emotionality belongs to the mammals. Snakes, lizards, turtles, and fish, lovable though they are to a select few humans, are not capable of perceiving or expressing emotional messages. They don't possess the requisite late-breaking brain.

An evolutionary hierarchy of emotion stretches from the first reptilian precursor to our own richly nuanced apparatus. Fear is probably the limbic brain's oldest emotion, an elaboration of the primordial reptilian startle. A touch of the heebie-jeebies helped early mammals safely navigate a world replete with dangers animate and inanimate—sharp teeth, dark caves, long claws, vertiginous heights. Disgust likewise serves to warn mammals of multifarious dangers—a tacit embodiment of Pasteur's germ theory of disease, disgust affirms the invisible likelihood of contamination from rotting foods and gelatinous excretions. Such lifesaving nauseous revulsion is at least as ancient as the animal that takes most advantage of its existence: *Mephitis mephitis,* the striped skunk.

The next emotions to sprout along the evolutionary tree assisted mammals in negotiating simple interactions. Anger readies a mammal for combat and warns others to expect a ferocious opponent. Jealousy alerts a mammal to the potential usurpation of reproductive chances. Later emotions inform social mammals with increasing precision about their status in a group—contempt, pride, guilt, shame, humiliation. The most recent emotions, and the ones least likely to be shared by other mammals, are those requiring a component of neocortical abstraction. Religious fervor is liable to be beyond the reach of nonhuman animals. So is the thrill that accompanies the realization of compact elegance in Pythagoras' theorem or Newton's gravitational law.

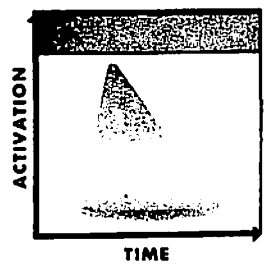
But most emotions require no thinking at all. For years, patients have told us stories about pets coming to their side and comforting them when they were distraught. Our medical training (often more hindrance than help in matters of the heart) led us to greet this allegation with a skeptical eye. How could a dog or a cat, with its diminutive brain, apprehend a phenomenon as complex as human emotion? One might as well expect an armadillo to master algebra. But cats and dogs are mammals—neocortically primitive and limbically mature. The limbic ancestry they share with humans should allow them to read and respond to certain emotional states of their owners. So when a person says he has a cat that can tell when he's had a bad day and hides under the bed, or a dog that detects sorrow and comes to console him, we no longer think he is being extravagantly anthropomorphic. The reciprocal process is dead easy: a perceptive human can tell if a dog is fatigued, contented, fearful, guilty, playful, hostile, or excited.

Not so with an animal that predates the limbic brain—try reading the inner state of a turtle, a goldfish, or an iguana. Animals with a common phylogenetic history share trait similarities: just as there are wide resemblances in the bony structure of the wrist or ankle among mammals, so too are there underlying commonalities in emotional perception and expression. Variants of the same emotional language exist throughout the mammalian family, some incomprehensible to us and others relatively close and accessible to our interpretative instrument, the limbic brain.

MUSIC AND MAYFLIES

Emotionality's code arises from a uniform neural architecture. The task of emotion science is to excavate this archaic structure, and as it has done so, it has unearthed the very roots of love.

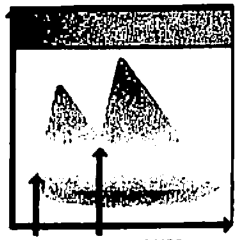
Human beings, as tool-making animals, are prone to associate importance with durability. The columns of the Parthenon or the massive stone blocks of looming pyramids easily elicit our wonder and awe. The momentousness of emotions in human lives stands in befuddling contrast to their impossible brevity. Emotions are mental mayflies, rapidly spawned and dying almost as quickly as they arise. High-speed videography shows that facial expressions begin within milliseconds of a provocative event, and they fade immediately. We might sketch the concise life of a normal emotion in this way, with time extending along the horizontal axis and activity in the emotion circuits along the vertical:



Emotions possess the evanescence of a musical note. When a pianist strikes a key, a hammer collides with the matching string inside his instrument and sets it to vibrating at its characteristic frequency. As amplitude of vibration declines, the sound falls off and dies away. Emotions operate in an analogous way: an event touches a responsive key, an internal feeling-tone is sounded, and it soon dwindles into silence. (The figures of speech "pluck at one's heartstrings" and "strikes a chord in me" have found a home in our language for just this reason.) Rising activity in the emotion circuits produces not sound, but (among other things) a facial expression. When the neural excitation exceeds a shadowy threshold of awareness, what emerges is a *feeling*—the conscious experience of emotional activation. As neural activity diminishes, feeling intensity decreases, but some residual activity persists in those circuits after a feeling is no longer perceptible. Like the ghost of Hamlet's father, an emotion appears suddenly in the drama of our lives to nudge the players in the proper direction, and then dissolves into nothingness, leaving behind a vague impression of its former presence.

Moods exist because of the musical aspect of an emotion's neural activity, the lower portion imperceptible to our conscious ears. In our usage (adapted from Ekman), a mood is a state of enhanced readiness to experience a certain emotion. Where an emotion is a single note, clearly struck, hanging for a moment in the still air, a mood is the extended, nearly inaudible echo that follows. Consciousness registers a fading level of activation in the emotion circuits faintly or not at all. And so the provocative events of the day may leave us with emotional responsiveness waiting beneath our notice.

If a man spills coffee on himself, his annoyance is relatively short-lived—on the order of minutes. After the conscious feeling is gone, residual activity in the anger circuits lingers. He will pass into an *irritable mood*—a quickness to anger, the only reflection of the waning activity in those circuits. If he trips over his son's skateboard on the living room floor a bit later, his wrath will be faster and greater than the accident deserves on its own merits. Since the neural activation that creates a given emotion decreases gradually, provoking it again is easier within the window of the mood.



If emotions are ephemeral, how can we account for the person who feels sad all morning or frustrated all day? We must call upon the same generous pointillism that allows geometry to blend a collection of dimensionless dots into a uniform line or a graceful curve. The smooth impression of a lengthy emotion is often created by serial evocation, a repetitive string of one brief feeling that rings out its plangent tones again and again.

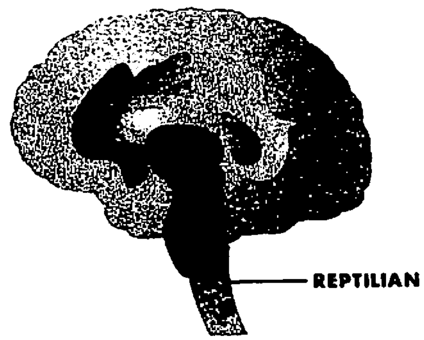
The most common precipitant of this reiterant emotionality is cognition: people tend to think about emotionally arousing occasions afterward, recirculating the experience and stimulating the consequent emotion just as if the inciting event had actually reoccurred. The human penchant for this post hoc cogitation can magnify the physiologic impact of an emotion many times. Anger sharply increases blood pressure on a short-term basis, for instance, but it may well be the recurrent stewing over provocative events that causes sustained hypertension in touchy people like type A executives. The neocortical brain's tendency to wax hypothetical then becomes a deadly liability. The limbic brain, unable to distinguish between incoming sensory experience and neocortical imaginings, revisits emotions upon a body that was not designed to withstand such a procession.

Certain brain configurations permit a single emotion to blare on unceasingly, without the rapid decay that typifies normality. Major depression is one such disease state, in which an acidic despair perpetually dominates the mind for weeks or months, sometimes blotting out all competing feelings, thoughts, and motivations. The manic extremity of bipolar disorder is another instance of uncommon durability in emotion, although in this case the irrepressible feelings tend toward euphoria and bonhomie. No one yet knows what causes the brain to get stuck on a single emotion, and in many cases, getting it unstuck is no simple matter.

AN EMOTIONAL EPIC

Scales and Wires

Imagine a scene from 200 million years ago. A hatchling crocodilian rests motionless beneath the overhanging leaves of a damp fern, its mottled skin blending into the dirt and shadowed leaves. Jaws parted, tiny teeth bared, eyes unblinking, it might be carved from stone. On its left, a low-hanging branch yields a sibilant shudder as something large moves through the jungle. And with a push and paddle of its short legs, the young reptile splashes into the facing pond and disappears. For the moment, it has survived.



The reptilian brain.

Now let time spin through the intervening ages to the present. Continents fracture and slide across the globe, the ice caps extend and recede, countless species flash into existence and wink out again. But the crocodilian and the brain it possessed through all those millions of years remain essentially unchanged. The reptilian brain in our own skulls has not endured in that pristine state—it has adapted, changed, and learned to communicate with the two later brains that followed. Nevertheless, a rendition of the reptilian brain, the primal precursors of emotion within, is still contained within our own. The reptilian brain sits perched on the top of the human spinal cord, in appearance not unlike a bulbous frog crouching on a lily pad. Here one can find ancient control centers for vital bodily functions, including the primordial seeds of emotional responsiveness.

"Dream delivers us to dream, and there is no end to illusion. Life is a train of moods like a string of beads, and, as we pass through them, they prove to be many-colored lenses which paint the world their own hue.... Temperament is the iron wire on which the beads are strung." Writing these lines in 1844, Ralph Waldo Emerson may deserve credit as the first to propose that emotionality is hardwired. He was right: inborn emotionality is undeniable. From the first day out of the womb, some babies are criers, while others lie placid; some are easy to soothe and some inconsolable; some reach for a new rattle, while others shrink away. C. Robert Cloninger, M.D., has proposed that emotional control centers in the reptilian brain determine innate temperaments. Through the programmed responses of these groups of cells, the reptilian brain contributes the background tone to emotional life. That ancient brain becomes the filament upon which the later brains string the resplendent, multicolored crystals that merge into the mosaic of our emotional lives.

FRETFUL FRAMEWORK

Some people are risk-averse by nature: they save rather than spend, avoid rather than plunge, and hold back rather than let go. They have a temperament that tends toward *worry*, an aspect of emotional tone Cloninger thinks is controlled by the *raphe nucleus* in the reptilian brain. Worry is an inborn proneness to fear—an inclination to imagine future harm, and to activate the body's flight response system in case escape proves expedient.

The reptilian brain usually comes outfitted with a worry setting near the middle of the scale, a compromise that maximizes survival: too much fear is globally inhibiting, while too little promotes recklessness. The prehistoric crocodilian needed enough daring to venture out in the open from time to time, but it also required the wariness that allowed it to slip into the pond on a moment's notice. Most people have a moderate amount of inbred worry, although our popular culture is fond of idealizing individuals whose worry is nonexistent. Arnold Schwarzenegger and Bruce Willis are the latest in a string of actors whose screen personas wisecrack coolly in the face of heart-stopping danger. When we identify with their bravado, we treat ourselves to the vicarious thrill of a temperament most can never experience.

For this privation we should feel only gratitude. In the historical jungle of evolution, a minute level of worry invited disaster too often. Many of our ultralow-anxiety ancestors were bitten by snakes, gored by tusks, and fell out of trees. Those premature deaths shifted the gene pool toward higher trepidation. Children born today with a diminutive level of worry—those whose emotional physiology underreacts to stress, novelty, and threat—grow up to become criminals much more often than average. Criminality has long been known to be partially heritable, and a worry volume set to "low" in the reptilian brain is part of the mechanism. Anxiety deters people from high-risk acts. Those who do not experience the emotional weight of adverse consequences will not be sufficiently warned off. They will not know when they are about to do something they should by all rights fear and avoid.

As DNA shuffles and recombines in humanity's gene pool, the unlucky inherit extremes of temperament. For the most part, their eccentric dispositions will not serve them well. Before they dared to creep from beneath the protection of a fern, the reptilian precursor to worry gave our predecessors the hesitance to act and the predilection to flee that saved their lives. While the locus of danger in our lives has changed, the underlying neural mechanisms remain. Those worry circuits still perform the same function: under their direction, people imagine future harm, withdraw from potential threats, and their hearts, lungs, and sweat glands warm up for sudden use. An unfortunate few suffer from a hair-trigger sensitivity in this primordial system. When the neural alarm apparatus goes off with a bang, the result is a panic attack—a paroxysm of terror, an explosion of somatic sensations and reactions (chest tightness, racing heart, sweaty palms, churning stomach), and an outpouring of fear-soaked expectations and plans.

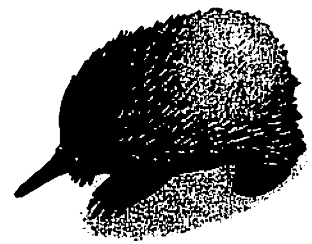
When anxiety becomes problematic, most people try vainly to think their way out of trouble. But worry has its roots in the reptilian brain, minimally responsive to will. As a wise psychoanalyst once remarked of the autonomic nervous system (which carries the outgoing fear messages from the reptilian brain), "It's so far from the head it doesn't even know there is a head." A high-worry temperament, however, does not doom its every possessor to a lifetime of anxiety. The brute force of will cannot undo temperament. But, as we shall see in later chapters, subtler means of emotional influence exist that can tame even the wild beast of panic.

The emotion circuits in the reptilian brain, like those responsible for worry, create a broad behavioral disposition. We can glimpse in them the earliest form of a neural system that scans the environment and quickly prepares an animal's physiology for the lifesaving response—as when a young reptile slides into the safety of a lagoon at the hint of a nearby predator. But the perceptive range of a reptile is limited, and the reptilian brain alone can orchestrate only coarse physiologic changes. With the arrival of the limbic brain, the neural resources aimed at coordinating physiology and environment expanded lavishly. When evolution brought mammals into being, it created an organism with a novel kind of neural responsiveness—one that permitted the intimate mental embrace of love.

The Bridge Between Worlds

In 1792, George Shaw of the Royal Zoological Society in London received a specimen from Australia. He found before him a squat, spiny creature, something like an undersized porcupine bearing a protuberant hollow snout. Shaw did not realize that he was holding a remnant of one of evolution's most important crossroads—the one that led to the birth of mammals.

The echidna, the creature Shaw received, is technically classified as a mammal, but it is either the most reptilian mammal or the most mammalian reptile imaginable. Echidnas locomote with the

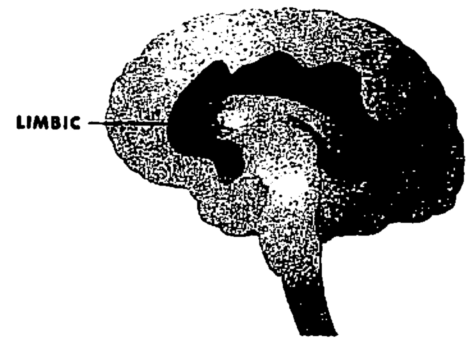


The Australian echidna.

same low-slung, waddling gait as a lizard. They lead solitary lives, coming into each other's company only long enough to mate. And the product of that copulation is a leathery, reptilian egg, which the female carries next to her body between two elongated folds of skin—an open-air uterus. An egg-laying mammal was a bewildering conflation of reptile and mammal to the classifications of nineteenth-century science. Most experts of the day refused to believe that monotremes—the taxonomic category to which echidnas belong—were truly egg layers. The naturalist William Caldwell provided definitive proof in 1884, when he saw with his own eyes an egg in an echidna's primitive pouch. His telegram back to civilization—*"Monotremes oviparous"*—rocked the scientific world.

Arising somewhere between 100 million and 150 million years ago, monotremes demonstrate the beginnings of the departure from a reptilian way of life. Although it was far from obvious to early taxonomists, the feature that distinguishes mammals from reptiles is the appearance of a new brain within their skulls—the limbic brain. The echidna possesses not only nature's most primitive uterus, but also her most primitive limbic apparatus. Of all mammals, echidnas alone lack one limbic process: they do not dream during sleep.

In its present form, the limbic brain is not only the seat of dreams, but also the center of advanced emotionality. The primor-



The limbic brain.

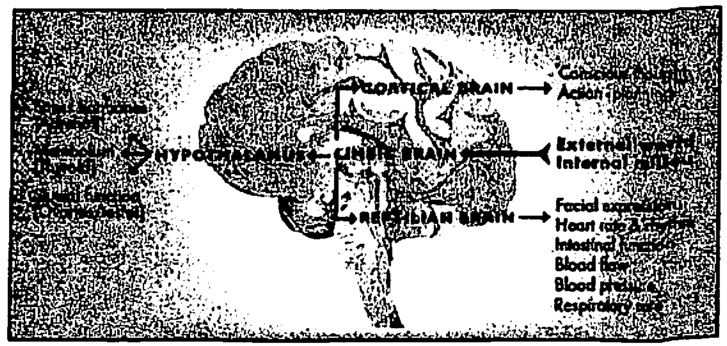
dial purpose of the limbic brain was to monitor the external world and the internal bodily environment, and to orchestrate their congruence. What one sees, hears, feels, and smells is fed into the limbic brain, and so is data about body temperature, blood pressure, heart rate, digestive processes, and scores of other somatic parameters. The limbic brain stands at the convergence of these two information streams; it coordinates them and fine-tunes physiology to prime the body for the outside world.

Some of these modulations are immediate, such as changes in sweating, breathing, or heart rate. The limbic brain effects these alterations through its connections to the control centers of the reptilian brain. Other bodily changes of limbic origin are longer-lasting: its outputs to the endocrine system allow emotional states to affect global bodily functions like immune regulation and metabolism. The neocortical brain, although a latecomer to the emotional scene, also receives limbic directives. These influence the tone of symbolic activities, like language, and strategic operations, like action planning. And the limbic brain orchestrates brain changes that serve a purely communicative role—in response to limbic stimulation, small muscles on the mammalian face contract in precise configurations. The face is the only place in the body where muscles connect directly to

skin. The sole purpose of this arrangement is to enable the transmission of a flurry of expressive signals.

Consider, for instance, this situation: a man is riding to work on a bus, heading for the financial district in downtown San Francisco. A tattooed teenager with a shaven head (not a rarity in these parts) boards the vehicle, glares at the commuter, and bumps by him. That sensory experience flashes to the limbic brain, which will sift the event for its significance and prepare physiology to meet *that* singular moment. Our man's limbic brain will receive input about the intruder's facial expression, his pupil size, his body posture and gait, and perhaps even his scent. The limbic brain evaluates the nature of the other's intention—is it careless, aggressive, friendly, sexual, submissive, indifferent? A given limbic brain arrives at conclusions based on the collaboration of its genetically specified wiring scheme and past experience of similar situations. In this case, let us suppose our man's limbic apparatus detects hostility and, to meet the situation, equips him with the emotion of anger.

Once the limbic brain has settled on an emotional state, it sends outputs to the neocortical brain, spawning a conscious thought (*Who the hell does this guy think he is?*). At the same time, limbic outputs to the premotor areas of the neocortex are directing action-



The centrality of the limbic brain.

planning. Meanwhile, outputs to the endocrine system will alter stress hormone release, which may impact the entire body for hours or days afterward. Limbic instructions to the lower brain centers will cause facial muscles to contract in the configuration of anger: eyes narrowed, brows drawn together, lips pressed, with the edges of the mouth turned down. The limbic brain will direct the reptilian brain to change cardiovascular function. Heart rate will increase, as will blood flow to the arms and hands—because the outcome of anger may be a fight, the limbic brain readies the physiologic systems most suited to fisticuffs. The entire maneuver is executed with the speed and grace of a ballerina's pirouette. One moment a man is minding his own business—two seconds later, anger swells, his brow furrows, and his hands start to clench.

Suppose that a woman follows just behind the belligerent youth. Witnessing the encounter, she shoots our traveler a look of sympathetic recognition and mock exasperation. *Can you believe what it's like on the buses these days?* she might say, if she were speaking. She isn't. But our commuter's limbic brain will nevertheless discern the message in her eyes and her face. To an emotionally insensate organism, the two interactions look exactly the same: for an instant, a moving person glanced at another. But the emotional implications of the infinitesimal differences are enormous. Because of the limbic brain's split-second precision, one can successfully distinguish an impending fight from the empathetic communication of kindred spirit.

SOLITARY CONFINEMENT

The limbic brain collects sensory information, filters it for emotional relevance, and sends outputs to other brain areas thousands of times a day. Most of the time its processing is flawless, but occasionally the limbic brain malfunctions. One way to appreciate healthy emotionality is to examine what happens when it goes haywire. Human beings are immersed in a sea of social interchange, surrounded by a subtle communications network that most do not

notice. The limbic brain is our internal cryptographic device, allowing us to decipher a flood of complex messages in an instant. But when decoding breaks down, the resulting deficits can show us what emotionality enables the rest of us to do.

Several years ago we encountered a sixteen-year-old high school sophomore whom we'll call Evan. His mother wanted him to see a psychiatrist because she was concerned about his lack of friends. Other children had teased and rejected him since he was a young boy.

Upon meeting Evan, it was not hard to understand the derivation of the taunts. Evan was pleasant and friendly, but his social behavior was discordant and jarring. He stood too close when shaking hands, for instance, and he spoke too loudly. His voice was strangely flat, his eye contact sporadic, and his style of dress atypical for California teenagers: a plaid shirt with a solid blue tie.

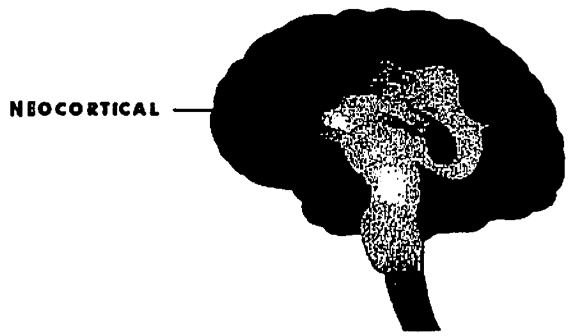
Evan's professed purpose was not to attain eccentric prominence among his peers. He was genuinely confused by their rejection, and he wanted to know what he could do to get along with them better. His intellect was keen and his grades excellent, but as we got to know him better, we discovered that Evan was completely unable to intuit the rules of social interchange—hence his dress, manner, and style of greeting. He once tried to ask a girl out by presenting her with a lollipop. She thought he was making fun of her and became angry. He, in turn, was baffled by her reaction. As he explained, he had observed that people proffer gifts as a token of friendship, including the occasional lollipop.

Most of us understand that lovers exchange flowers, candy, and poems, while lollipops are given to children and birthday celebrants. Who can say why lollipops do not express romance? The code that governs this conduct is surely capricious, but most people have no trouble interpreting it. This boy didn't acquire social conventions naturally; even with monumental effort they persistently eluded him. He could accept concrete guidelines about human interchange, like "Most people expect you to stand about *this* far away when you speak to them." But he could not grasp the *essence* of interaction—he was never able to pick up on another's discomfort and adjust his distance accordingly, as a limbically fluent person would. Emotional signals remained obscure hieroglyphics to him. The limbic brain that should have given him the Rosetta stone to his emotional life had failed him. He remained lost, a socially blind person in a relentlessly social world.

The Viennese pediatrician Hans Asperger first described this affliction in the 1940s; it is now known as *Asperger's syndrome.* Children with Asperger's can be intellectually bright or brilliant, but they are emotionally clumsy, tone-deaf to social subtleties in others, and sometimes to their own emotions. When we asked a young woman with Asperger's what made her unhappy, she was quick to correct us: "I know that the words *happy* and *unhappy* signify something to other people, and I have heard others use them, but I do not know what they mean," she told us. "As far as I know, I have had no experience of either. I have no basis on which to answer your question." Startled, we tried to find a broader area of emotionality she could relate to. "Do you have a sense of what it's like to play?" one of us asked her. She stared for a moment, puzzled, and then asked, "As opposed to what?"

Finishing Touches

Because the last brain in the evolutionary sequence directs the abstract mind, we must credit the neocortex for the towering human achievements in cognition—language, problem-solving, physics, mathematics. Emotional function doesn't require many hypotheticals—it takes neocortical genius to formulate the theory of relativity, but not to be sad after a loss, or to be thrilled at seeing the person you love across a crowded room. But while the neocortical brain does not produce emotionality, it does have a role in modulating feelings and integrating them with some of its own symbolic functions.

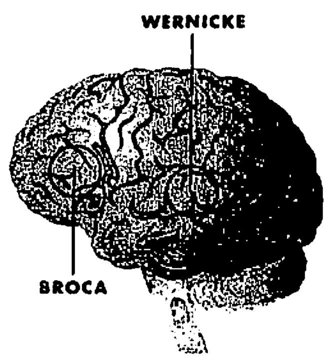


The neocortical brain.

In a Different Voice

With its power to weave and unravel abstractions, the neocortex produces language—a string of arbitrary symbols that convey a message. While having emotions is under limbic control, *speaking* of them falls under the jurisdiction of the neocortex. That division of labor creates translation troubles. One of the neural mechanisms that bridges the gap is *prosody*—a process the neocortex borrows to inflect its dry concepts with emotional relevance.

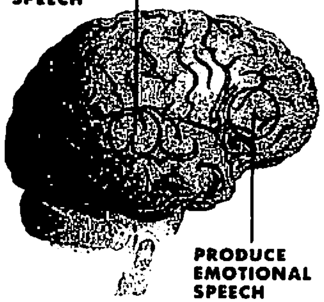
The two language centers of the brain reside in the *left* temporal neocortex.



Language centers on the left side of the neocortical brain.

[redacted]

Wernicke's area translates the whistles and clicks of inbound speech into meaning, while *Broca's area* spins thoughts into a steady string of words. People with damage to Wernicke's area cannot understand what is said to them, though they can express themselves verbally, while those with damage to Broca's area can no longer talk, but they can still comprehend others who do.



Emotional language centers on the right side of the neocortical brain.

The mirror-image areas of the *right* temporal neocortex perform the same functions on the emotional content of speech. People with damage to these areas evidence *aprosodia:* a significant fraction of them can no longer discern the emotional meaning of speech, while others cannot deliver emotional nuances in spoken language. These are crippling deficits, because sentences with identical semantic structure can easily have opposite meanings when they differ in prosody. Sarcasm owes the whole of its existence to tone. A sentence as apparently straightforward as "That's a nice haircut" is thoroughly ambiguous without prosody—the words can convey anything from "I'd like to go to bed with you" to "You look like a fool." Anyone who has cohabited with a teenager knows that single monosyllables—yeah, right, sure—can express assent, contempt, enthusiasm, indifference, or a thousand other delicately shaded meanings. A person with damage to the right-side mirror of Wernicke's area can't distinguish among the limitless possibilities mere words suggest. Those with damage to the dextro–Broca's area can't imbue their speech with emotional inflections—where they should be able to draw upon the chromatic palette of emotions to tinge their words with felt meaning, their speech remains dull and opaque. Their words cannot sound threatening, playful, or affectionate, which makes it nearly impossible to communicate successfully with emotionally fluent human beings, who rely on those clues to derive a speaker's intention.

While damage to the right temporal neocortex is fairly rare, millions of people experience daily aprosodia in their e-mail. At night all cats are gray, and in e-mail everyone is aprosodic, because the medium consists of curt sentences lacking emotional inflections. This is why people misunderstand one another so readily by e-mail, and why it is so much easier to lie on the Internet than in other social interactions. Minus the perceptible cues of voice tone, eye contact, and expression, e-mail so lends itself to emotional deception that people assume outrageously fabricated identities, simply because they can.

The human need for prosody is too great to go unanswered, and so it has spawned text-based emotional inflectors, *emoticons.* An emoticon sketches a facial expression with a couple of punctuation marks—to derive the meaning, the viewer mentally rotates the image ninety degrees clockwise. Pleasure and displeasure were the broad emotional states first so caricatured and communicated—

:) :(

—and as the popularity of e-mail has exploded, so has the inventiveness of emotional iconographers. More than two hundred emoticons now exist for conveying a raft of mental states ranging from mischievous:

>:–)

to astonished:

#:–0

The quick rise of emoticons confirms the intolerable ambiguity of the neocortical brain's advanced symbolic tools, and the problem this poses for successful communication between limbic creatures. But no matter how creatively designed, emoticons cannot compete with emotions—a delicately decorated parenthesis cannot depict nostalgia, jealousy, wistfulness, or envy. In our increasingly digitized world, e-mail is a convenient substitute for dialogue, but it does not convey the richness that humans unthinkingly transmit when they use emotionally tempered speech and facial expressions.

That missing limbic data is extraordinarily valuable. Telecommunications giants are currently sinking hundreds of millions of dollars into the race to develop affordable two-way video sent over a phone line or a cable television connection. Even with advanced information compression algorithms, a data stream with resolution fine enough to catch the subtleties of facial expression requires about four hundred kilobits per second. That should give us an idea of the massive sensory fire hose the limbic brain is tapping into as it discriminates remorse from disdain, delight from terror, indignation from admiration.

A RESOUNDING SUCCESS

Animals with little neocortical brain—dogs, cats, opossums—have emotions. So does the world's most interesting noncognitive mammal, the human infant. Infants are early masters of detecting and expressing emotions, which may help to explain their inborn fascination for faces. If you want to capture the attention of an infant, you will have more luck using an expressive human face than any other object in the world. Babies have an intrinsic appetite for faces: they look at them, peer at them, gaze at them, stare at them. But what exactly are they looking *for*?

Researchers now know that babies are looking at the expressions on the faces they fix on. In studying what attracts infant attention, researchers rely on measurements of gaze, because babies will look longer at novel objects than familiar ones. One can demonstrate in this manner that infants just a few days old can distinguish between emotional expressions.

What is so important to a baby about knowing his mother's emotional state? A scenario called the *visual cliff* suggests an answer. A baby is placed on a countertop, half solid and half clear Plexiglas. From the baby's point of view, he reaches an abyss when the Plexiglas begins, and he seems in danger of falling. The translucent plastic provides real, albeit invisible support, and thus, the visual cliff presents babies with an ambiguous threat. To an infant unschooled in the nature of Plexiglas, it appears he will fall, but since the surface is solid to the touch, he can't be sure. How does he make sense of it?

A typical baby crawls to the edge of the cliff, sees the possible precipice, and then looks at his mother—and makes his assessment of the cliff's lethality by reading her expression. If she radiates calm, he continues crawling, but if he finds alarm on her face, the baby stops in his tracks and cries. Whether they realize it or not, mothers use the universal signals of emotion to teach their babies about the world. Because their display is inborn, emotions not only reach across the gaps between cultures and species, but they also span the developmental chasm between mother and infant. Emotionality gives the two of them a common language years before the infant will acquire speech, the arbitrary symbolic system of the neocortical brain.

But an infant doesn't check up on his mother's face only when ambiguity threatens—babies continuously monitor their mothers' expressions. If a mother freezes her face, her baby becomes upset and begins to cry in short order. How much expressiveness do babies demand? Imagine a double video camera setup, in which mother and baby can see each other, but not face-to-face; each sees the other in their respective monitors. In real time, mother and infant look at each other, smile and laugh, and both are perfectly happy. If the baby sees a videotape of his mother's face instead of the real-time display, he quickly becomes distraught. It isn't just his mother's beaming countenance but her *synchrony* that he requires—their mutually responsive interaction. Restore his mother's face in real time to his TV monitor, and his contentment returns. Introduce a delay into the video circuit, and the baby will again become distressed.

An infant can detect minute temporal changes in emotional responsiveness. This level of sophistication is coming from an organism that won't be able to stand up on his own for another six months. Why should a creature with relatively few skills be so monomaniacally focused on tiny muscular contractions visible beneath the skin of another creature's body?

The answer lies in the evolutionary history of the limbic brain. Animals have highly developed neural systems for processing specific informational needs. The sonar system of bats serves them admirably in chasing small bugs in a pitch-black night; within the cacophony of their high-pitched echoes, they can see a world we are blind to. The intricate cellular structure of certain eels allows the precise mapping of perturbations in nearby electric fields; the eel recognizes other fish, including its prey, by the pattern of electricity their muscles cast off.

The limbic brain is another delicate physical apparatus that specializes in detecting and analyzing just one part of the physical world—the internal state of other mammals. Emotionality is the social sense organ of limbic creatures. While vision lets us experience the reflected wavelengths of electromagnetic radiation, and hearing gives information about the pressure waves in the surrounding air, emotionality enables a mammal to sense the inner states and the motives of the mammals around him.

The reptile brain, capable of reading the world and altering internal physiology to meet changing conditions, contains the germ of emotion. In mammals, emotionality vaulted to a vastly more sophisticated level. A young crocodilian can sense a possible predator behind a wavering frond, and it can mobilize its physiology to evade the threat. But a mammal can turn its advanced neural sensor not only on the inanimate world but also on other animals that are emotionally responsive. A mammal can detect the internal state of another mammal and adjust its own physiology to match the situation—a change in turn sensed by the other, who likewise adjusts. While the neural responsivity of a reptile is an early, tinny note of emotion, mammals have a full-throated duet, a reciprocal interchange between two fluid, sensing, shifting brains.

Within the effulgence of their new brain, mammals developed a capacity we call *limbic resonance*—a symphony of mutual exchange and internal adaptation whereby two mammals become attuned to each other's inner states. It is limbic resonance that makes looking into the face of another emotionally responsive creature a multilayered experience. Instead of seeing a pair of eyes as two bespeckled buttons, when we look into the ocular portals to a limbic brain our vision goes deep: the sensations multiply, just as two mirrors placed in opposition create a shimmering ricochet of reflections whose depths recede into infinity. Eye contact, although it occurs over a gap of yards, is not a metaphor. When we meet the gaze of another, two nervous systems achieve a palpable and intimate apposition.

So familiar and expected is the neural attunement of limbic resonance that people find its absence disturbing. Scrutinize the eyes of a shark or a sunbathing salamander and you get back no answering echo, no flicker of recognition, nothing. The vacuity behind those glances sends a chill down the mammalian spine. The prelimbic status of mythological creatures that kill with their gaze—the serpent-crowned Medusa, the lizardlike basilisk, hatched from a cock's egg by toads or snakes—is no accident. These stories create monsters from ordinary reptiles by crediting them with the power to project out of their eyes what any mammal can see already dwells within: cold, inert matter, immune to the stirrings of limbic life.

To the animals capable of bridging the gap between minds, limbic resonance is the door to communal connection. Limbic resonance supplies the wordless harmony we see everywhere but take for granted—between mother and infant, between a boy and his dog, between lovers holding hands across a restaurant table. This silent reverberation between minds is so much a part of us that, like the noiseless machinations of the kidney or the liver, it functions smoothly and continuously without our notice.

Because limbic states can leap between minds, feelings are contagious, while notions are not. If one person germinates an ingenious idea, it's no surprise that those in the vicinity fail to develop the same concept spontaneously. But the limbic activity of those around us draws our emotions into almost immediate congruence. That's why a movie viewed in a theater of thrilled fans is electrifying, when its living room version disappoints—it's not the size of the screen or the speakers (as the literal-minded home electronics industry would have it)—it's the *crowd* that releases storytelling magic, the essential, communal, multiplied wonder. The same limbic evocation sends waves of emotion rolling through a throng, making scattered individuals into a unitary, panic-stricken herd or hate-filled lynch mob.

It seems a strange irony that we need science to rekindle faith in the ancient ability to read minds. That old skill, so much a part of us, is not much believed in now. Those who spend their days without an opportunity for quiet listening can pass a lifetime and overlook it altogether. The vocation of psychotherapy confers a few unexpected fringe benefits on its practitioners, and the following is one of them. It impels participation in a process that our modern world has all but forgotten: sitting in a room with another person for hours at a time with no purpose in mind but attending. As you do so, another world expands and comes alive to your senses—a world governed by forces that were old before humanity began.