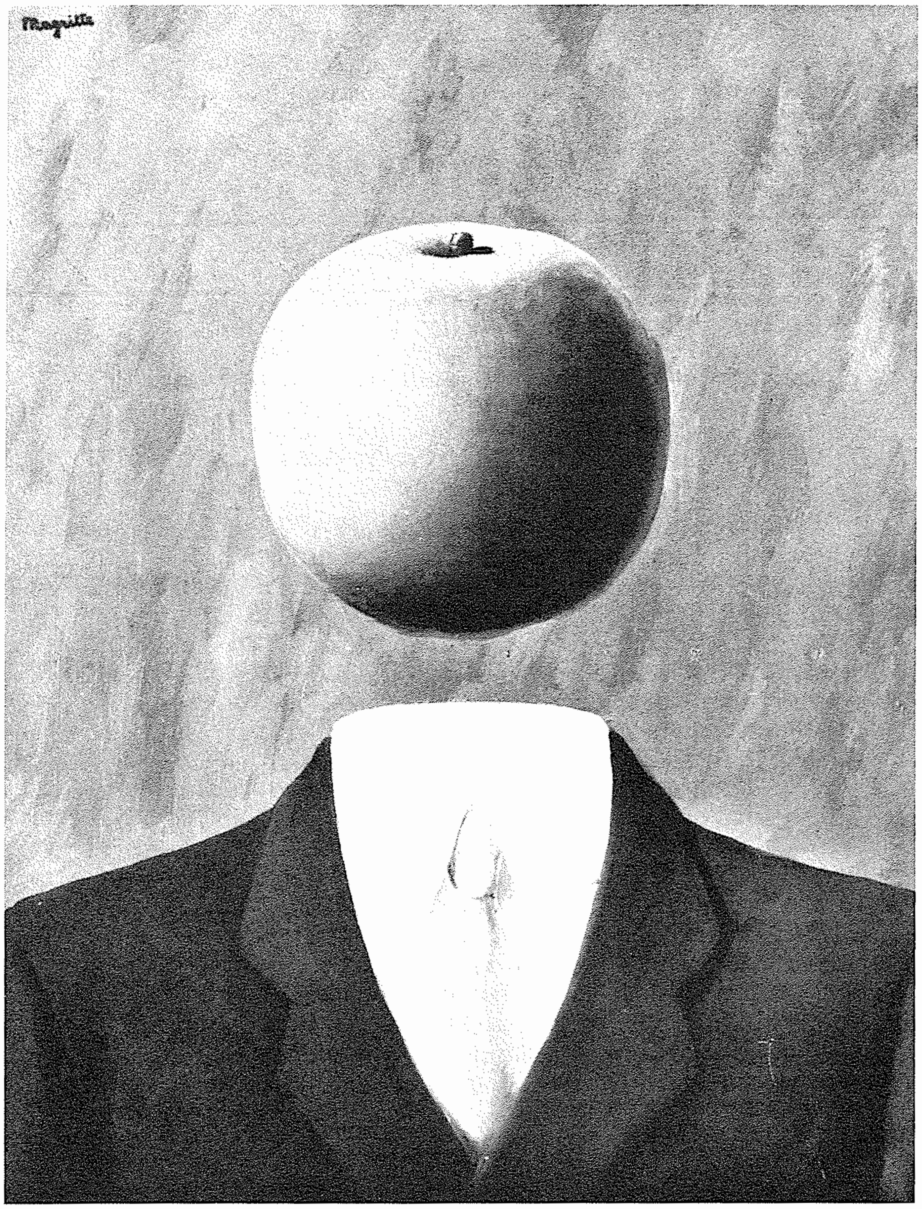


René Magritte, L'Idée, *1966.*

At the micromolecular level, there is no difference between a piece of fruit and a brain. What enables the latter and not the former to generate ideas? Why was it Newton who discovered gravity and not the apple?

The Brain

"To look into the heart is not enough," T. S. Eliot once wrote. "One must also look into the cerebral cortex." Last year, three American researchers—Roger Sperry of Cal Tech and Torsten Wiesel and David Hubel of Harvard—shared a Nobel Prize in medicine for doing just that. Brain research is both very new and very old. Contemporary specialists wrestle with problems that confounded the ancient Greeks, even as their findings alter the way we think (as individuals and as a society) about sexuality, childhood, education, senility, personality, and much else. While the advances of the past century in our understanding of the brain are real, so are the baffling vistas that every new advance brings into view. Here, in a three-part essay, neurologist Richard Restak reflects on what we know, don't know, and by all odds can *not* know about the brain.

by Richard M. Restak

To Aristotle, the brain was merely a cooling system for the blood as it left the heart. Assyrians favored the liver as the seat of the "soul." The Egyptians who embalmed the pharaohs carefully preserved most major organs in special jars—but not the brain, thinking it inconsequential.

Natural philosophers and physicians in ancient Greece eventually ascertained the true state of affairs—some centuries before the birth of Christ—but enlightenment gave rise to mysteries of a subtler sort. Granted that the brain is, after all, the center of conscious experience. Granted that it governs the way we perceive, think about, and react to the world; holds our memories in trust; sows, germinates, tends, reaps, harvests, and husbands our emotions; sustains our very sense of self. Given all that, how does the organ *work*?

The functioning of the brain has been variously likened to the workings of a telephone switchboard, a railway system, a computer. None of these models has proved entirely adequate. So far as we know, the brain is unlike any other structure in the universe, and perhaps only the vast universe itself presents conceptual problems of equal complexity.

In terms of "hardware" alone, we are dealing with an organ composed of 10 to 15 billion highly differentiated yet profoundly interlocked brain cells. Beyond issues of structure lurk questions that transcend biology. "Know thyself," Socrates advised. But can one, really?

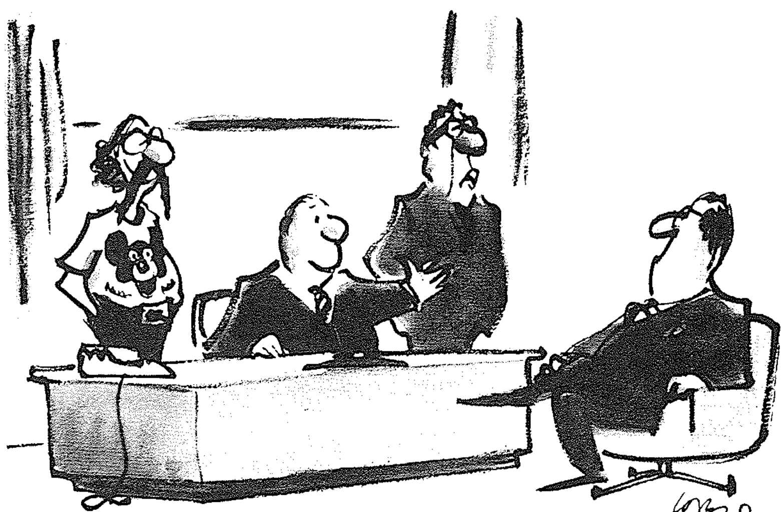
The issues posed by "the brain" are as broad as life itself. What happens inside our heads when we write poetry, solve a puzzle, conduct business, fall in love? What made Rembrandt Rembrandt? Why are we sad or happy? How do we learn? Why do we forget? How do we remember? What is mental illness? What causes it? How "real" is "perception"? Driven by curiosity, altruism, or professional ambition (and what, incidentally, is the source of *these* drives?), hundreds of researchers in America and Europe are engrossed in such questions. Here and there, they are closing in on something that may approximate the truth. Here and there, they have run into a fog bank.

I MAPPING THE HEMISPHERES

The research conducted by Roger Sperry, Torsten Wiesel, and David Hubel that led to a Nobel Prize in 1981 involved the study of the two cerebral hemispheres. While their research was carried out during the past 25 years, the first investigations into the functioning of the hemispheres occurred nearly 25 centuries ago. The investigator was the Greek, Hippocrates (ca. 460–377 B.C.).

Hippocrates was the first to suggest that the brain was the organ of the mind. In his treatise *On the Sacred Disease* (epilepsy), he wrote: "Not only our pleasure, our joy, and our laughter, but also our sorrow, pain, grief, and tears arise from the brain, and the brain alone." A meticulous observer, Hippocrates also noticed

Richard M. Restak, 40, is a neurologist and a member of the faculties at Georgetown University Medical School and the Washington School of Psychiatry. Born in Wilmington, Del., he received an A.B. from Gettysburg College (1962) and an M.D. from Georgetown (1966). He took his residency training in psychiatry at Mount Sinai Hospital in New York City and in neurology at George Washington University. He is the author of Premeditated Man: Bioethics and the Control of Future Human Life *(1975) and* The Brain: The Last Frontier *(1979). A new book,* The Self-Seekers, *will appear later this year.*



"Foster here is the left side of my brain, and Mr. Hoagland is the right side of my brain" was the caption of this 1977 New Yorker *cartoon. The nature, degree, and implications of the differences between the two cerebral hemispheres remain a matter of debate.*

that a sword wound to the right side of a soldier's head would affect only the left side of the body—and vice versa. From this, he concluded that "the brain of man is double." There matters rested for more than two millenniums.

While the Romans, Arabs, and medieval Christians often mused on the locus and nature of "mind" and "soul," it was not until the 19th century that brain research came into its own.

In 1861, a young French physician named Paul Broca published an account of a patient in the Salpetrière who had suffered a stroke years earlier. Rather than rendering him completely mute, however, the stroke had allowed the patient to speak in short, laborious, telegraphic sentences (e.g., "I went restaurant food"), a condition Broca called *aphasia*. Examination of the patient's brain after death revealed a precise area of destruction in the left cerebral hemisphere that, Broca postulated, was responsible for speech.

Examination of other patients later corroborated Broca's assertion and initiated a lively interest (which continues) in correlating behavior with discrete parts of the brain. Thus, we can now "map" the brain in a rough sort of way, pinpointing which portions are generally involved with vision, smell, movement, bodily sensation. One of the unintended consequences of the work of Broca and others was to lend impetus to the already popular "science" of phrenology, which, though misguided, did spur further interest in brain/behavior research.

Meanwhile, other researchers busied themselves with the larger implications of a human brain made up of two hemispheres. In 1844, an English physician, A. L. Wigen, published a little-noticed paper *(The Duality of the Mind)* describing the illness, death, and autopsy of a lifelong friend and patient. At the autopsy, Wigen discovered to his amazement that his friend, who had been neurologically normal in every respect, possessed only *one* cerebral hemisphere. "If only one cerebrum was required to have a mind," Wigen concluded, "the presence of two hemispheres [the normal state] makes possible and perhaps even inevitable the possession of two minds."

Wigen's speculations remained largely untested until the 1940s when brain researchers began cutting the *corpus callosum* (a tract of nerve fibers, also called the *cerebral commissure,* connecting the two hemispheres) to prevent seizure discharges from being relayed from one hemisphere to the other. The earliest researchers reported that the operation had no detectable effect on behavior. Clarification of the true situation awaited the Nobel Prize–winning efforts of Sperry and his colleagues. They

Culver Pictures.

Phrenology was promoted by a Viennese physician, Joseph Gall (1768–1828), who believed that a person's mental faculties—intelligence, spirituality, "amativeness"—could be deduced from the configuration of the skull. "Palpating" the skull was all the rage on both sides of the Atlantic.

demonstrated in "split-brain" subjects that each hemisphere is specialized for carrying out certain functions. Thus, in general, the right hemisphere is specialized for functions that deal with nonverbal processes (e.g., drawing, spatial awareness) while the left hemisphere is dominant for language.

While work with split-brain subjects has contributed immensely to our understanding of the hemispheres, the implications of that work have often been oversimplified. Some have claimed that Western society may be overly dependent on logical, linear, "left hemisphere" processes while Eastern thought is more "holistic" in its orientation. Some American educators have jumped on the bandwagon by suggesting that classroom techniques be modified to encourage freer expression of the "silent, non-dominant" right hemisphere.

When the Blind Can See

We should remember, however, that commissurotomy has been performed on very few people, all of whom have suffered unusual, chronic brain disease or disabling seizure disorders. Moreover, most authorities believe that hemisphere specialization can be altered profoundly by events early in life (e.g., birth trauma, infection). Thus, it is risky to leap from pathological cases to speculation about how the two hemispheres operate in presumably "normal" people.

Cooperation rather than competition between the two hemispheres seems to be the situation prevailing under most conditions. Both hemispheres, relying on different modes of information processing, operate in tandem to construct a continuous model of reality. Contradictions are resolved via interhemispheric connections—principally but not exclusively the corpus callosum. There are other important connecting links located deep beneath the cerebral hemispheres, where subcortical nerve cells serve as relay points enabling the two hemispheres to "talk" with each other. A significant degree of "processing," it appears, is carried out here long before nerve signals ever reach the cerebral cortex.

Take the phenomenon of "blind sight."

Penetrating injuries to the back of the head sustained by soldiers during World War I first revealed to researchers that the posterior parts of the brain, the occipital lobes, are involved in vision. Soldiers lost their sight in proportion to the amount of damaged "visual cortex." In the most devastating wounds, vision was lost altogether, an often cited "proof" that vision was "located" in the occipital lobes. But it turns out that things aren't nearly that simple.

For example, if a flash of light or sudden movement occurs in front of a blind person and he is asked to point in the direction of the visual stimulus, he will respond correctly 85 percent of the time. This is possible because of the connections that still exist between the eyes and portions of the brain far below the cerebral hemispheres. In monkeys, these connections are so developed that, in the event of cerebral damage to the visual cortex, the animals may recover useful sight. The phenomenon of "blind sight" also shows that the brain's performance is not dependent on consciousness, for the blind person insists that he is unable to "see" any visual stimulus at all.

Synthesizing Perception

The visual cortex, it turns out, is the seat of *conscious* awareness. But often we perceive things *unconsciously*. Waking from a sound sleep to the noise of a ringing telephone is an example. The visual area of the brain, neurobiologists now think, is more concerned with the *interpretation* of visual stimuli rather than simply with "sight." Immediately adjacent to the area for visual reception in the cortex are the visual association areas, which correlate what we see with what we hear, taste, touch, and smell. The resulting "product" of this interlocking system is our perception of reality. I do not mean to imply that the "real world" is only a construction of our brain. That form of idealism died out with Bishop Berkeley. It does suggest, however, that we impose *meaning* upon our perceptions.

The cerebral cortex is responsible for the synthesis of sight and sound and touch into a coherent whole. Usually, this synthetic process occurs effortlessly, but, on occasion, the process breaks down. For example, a patient with *visual agnosia* may be incapable of recognizing an object or person by vision alone. Though not blind, he must touch the object or hear the person speak in order for recognition to occur.

It is sobering to think that the ability to "make sense" of our world is at the mercy of the slightest alteration in the amount of blood delivered to the brain. A person who has suffered a stroke may be incapable of understanding speech or written language. He may fail to recognize that his own arms and legs belong to him. Some of these lost functions may be recovered after a time, indicating that the brain has great recuperative powers and can "reassign" certain tasks (e.g., speech) to undamaged areas. But the degree of recovery is almost always incomplete.

Interestingly, if the injury occurs early enough, total "refit" is possible. A child of eight or nine can suffer brain damage or even the complete loss of a cerebral hemisphere and yet go on to develop normally—as apparently happened with Dr. Wigen's patient. But by age 10 or 12, the prognosis will be similar to that for an adult: a largely irreversible loss of function. Why? Neurobiologists cannot say for sure. The brain's recuperative powers are thought to depend on an early "plasticity." As time goes on, specialization takes over and specific functions establish "squatter's rights" in one hemisphere and not the other.

Brain researchers are now trying to discover precisely why this occurs and whether the brain's early plasticity can ever be regained. There are some hopeful signs. For example, as Michael Gazzaniga, director of the Division of Cognitive Neurosciences at Cornell University, has shown, the right hemisphere is capable of primitive speech (on the level of a six- or eight-year-old child). It is possible, then, that drawing, speaking, writing, and other abilities exist "holistically" within the brain, at least potentially, and are not limited to specialized "centers" within one hemisphere or the other.

"No, I Can Never Say 'No'!"

The notion of "holistic" brain functioning can be traced back 120 years. During the 1860s, a dour and solitary English neurologist, John Hughlings Jackson, developed the novel theory that the central nervous system has a complex "vertical" organization with many functions somehow represented at different levels, starting with the lowest (and, biologically, most ancient) spinal cord level and proceeding up to the rarified realm of the cerebral cortex. Jackson's theory was based on his observation that a circumscribed injury never leads to a *complete* loss of function—even Broca's "aphasic" patient was able to speak, albeit clumsily.

As proof of a multilevel organization, Jackson cited a patient of his who could not voluntarily speak the word "no," but one day blurted out in frustration: "No, Doctor, I can never say 'no'!" A similar anomaly has been observed in stroke victims who, under the power of a strong emotion, can move a paralyzed limb. Such performances are possible, according to Jackson, because the brain is able to utilize alternative pathways that, under ordinary circumstances, are either totally unused or merely complementary to the main pathway. The difference is perhaps analogous to that between the Post Road and I-95.

Jackson's theory of alternative brain pathways met with disbelief in his own time, but many modern brain researchers

THE UNSOLICITED GIFT

There was once an illiterate shopkeeper in an Arab bazaar, called Ali, who, not being very good at doing sums, was always cheated by his customers—instead of cheating them, as it should be. So he prayed every night to Allah for the present of an abacus. . . . But some malicious djin forwarded his prayers to the wrong branch of the heavenly Mail Order Department, and so one morning, arriving at the bazaar, Ali found his stall transformed into a multi-storey, steel-framed building, housing the latest I.B.M. computer with instrument panels covering all the walls, with thousands of fluorescent oscillators, dials, magic eyes, et cetera; and an instruction book of several hundred pages—which, being illiterate, he could not read. However, after days of useless fiddling with this or that dial, he flew into a rage and started kicking a shiny, delicate panel. The shocks disturbed one of the machine's millions of electronic circuits, and after a while Ali discovered to his delight that if he kicked that panel, say, three times and afterwards five times, one of the dials showed the figure eight! He thanked Allah for having sent him such a pretty abacus, and continued to use the machine to add up two and three—happily unaware that it was capable of deriving Einstein's equations in a jiffy. . . .

now find it fits both research findings and common sense observations. In their view, mental processes should be regarded as complex functions that are diffused throughout the brain and nervous system, not "localized" (à la Broca).

A creative tension persists today between the view that the brain can be understood by separating it into functional areas and the opposite orientation, which holds that mental life is a single, indivisible, "holistic" phenomenon, a function of the whole brain working in a unitary fashion. Some neuroscientists straddle the fence by postulating that the most basic brain functions (movement, sight) can be localized while symbolic activities (thought, the exercise of "will") cannot. Like the Missouri Compromise, this gallant effort does not quite do.

The exercise of "will," for instance, may be electrically distributed throughout the brain even when the resulting action is extremely localized in its final form. If a person in an experimental situation is instructed to move his finger at any time he wishes, the first recorded electrical event preceding the movement is a widespread "readiness potential" that can be recorded over a large area of both cerebral hemispheres. Only several milliseconds later can a distinct readiness potential be

Ali's children, then his grandchildren, inherited the machine and the secret of kicking that same panel; but it took hundreds of generations until they learned to use it even for the purpose of simple multiplication. We ourselves are Ali's descendants, and though we have discovered many other ways of putting the machine to work, we have still only learned to utilise a very small fraction of the potentials of its estimated hundred thousand million circuits. For the unsolicited gift is of course the human brain. As for the instruction book, it is lost—if it ever existed. Plato maintains that it did once—but that is hearsay.

The comparison is less far-fetched than it may seem. Evolution, whatever the driving force behind it, caters for the species' immediate adaptive needs; and the emergence of novelties in anatomical structure and function is by and large guided by these needs. It is entirely unprecedented that evolution should provide a species with an organ *which it does not know how to use*; a luxury organ, like Ali's computer, far exceeding its owner's immediate, primitive needs; an organ which will take the species millennia to learn to put to proper use—if it ever does.

—Arthur Koestler

recorded specifically from the "hand area" of the motor cortex.

Widely separated parts of the brain are required for carrying out the simplest of actions. Voluntary movement of the hands, for instance, is virtually impossible without the cerebellum, which designs movements that must be "preprogrammed" since they occur too fast and too "unthinkingly." Electrical recordings taken just before I put pen to paper might well register "readiness" in the sensory cortex, cerebellum, and motor control centers beneath the cortex, as well as in the limbic system, the "emotional area" of my brain.

The most convincing proof that the brain is organized along functional rather than strictly anatomical lines comes from stimulation studies of the exposed cerebral cortex. Because the brain does not contain pain fibers, a person undergoing a neurosurgical procedure can remain awake while parts of his cerebral cortex are stimulated with an electronic probe. From such "fishing expeditions," scientists have learned that the various parts of the body are represented on the cortex not according to *size* but in proportion to usefulness. The thumb and the tongue, for instance, occupy a huge area, while the small of the back and the chest wall have only tiny representations.

II THE ARCHAEOLOGY OF THE SELF

During the 1950s, neurosurgeon Wilder Penfield and his colleagues at the Montreal Neurological Institute made a startling discovery. They learned that past events in a patient's life could be mentally "brought to life" by an electrode applied to the temporal lobe—the "interpretive cortex" as Penfield called it. Although bodily movements could also be induced, these movements never proceeded beyond crude clutching or grasping motions. Electrodes could not elicit responses requiring fine motor control or coordination, because the stimulation never involved part of a willed act or "program" such as we use when carrying out a complex movement. Penfield's work was, in fact, one of the earliest indications that *acts* rather than separate muscle movements are programmed within the brain.

Penfield's patients frequently reported that, upon stimulation, everything around them seemed to have occurred before. One patient heard his mother speaking on the telephone. Another patient experienced the vivid hallucination of riding in a car around Fordham Square in the Bronx with his father.

Throughout, the patients remained fully aware that their strange mental experiences did not correspond to any events actually taking place in the operating theater, but were somehow the direct result of the surgeon's electrical probe. It was obvious to Penfield that "there is, beneath the electrode, a recording mechanism for memories of events. But the mechanism seems to have recorded much more than the simple event. When activated, it may reproduce the emotions which attended the original experience. . . ."

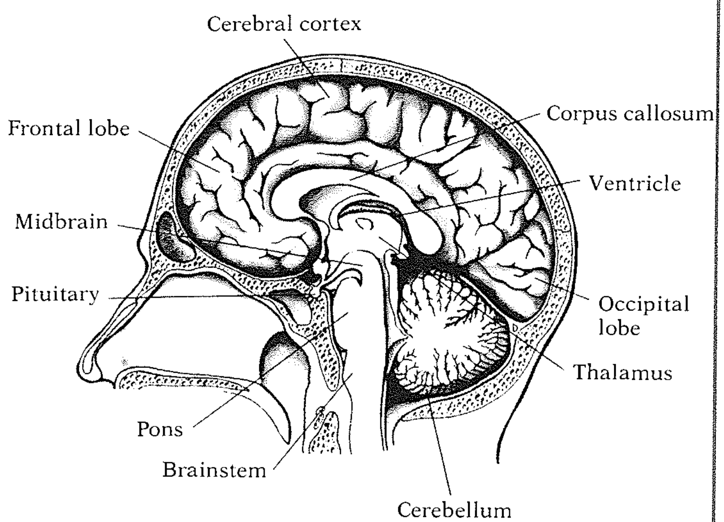
The temporal lobe is the center for the integration of experience. Here sight and sound and touch are synthesized into three-dimensional reality bounded in space and time. Disturbances within the temporal lobe, such as temporal lobe epilepsy, result in emotional distortions. Time and space may seem elongated or foreshortened. Anxiety may alternate with feelings of cosmic unity. The individual may express a sense of oneness with all of creative matter. Or he may cringe in fear, gripped by a terrible existential *angst*.

Fyodor Dostoyevsky, a temporal lobe epileptic, described in *The Idiot* the ecstasy that accompanied the onset of an epileptic attack. "[T]here was always one instant," he wrote, "just before the epileptic fit—when suddenly in the midst of sadness, spiritual darkness, and oppression, his brain seemed momentarily to catch fire and in an extraordinary rush all his vital forces were at their highest tension."

Our own sense of certainty, personal cohesion, and familiarity with our surroundings are dependent on the smooth functioning of the temporal lobe. The temporal lobe is an extension of the ancient limbic system, which in lower animals is concerned with smell. In higher mammals and man, the smell function has decreased in importance to be replaced by vision and hearing. Indeed, in humans, the *rhinencephalon*, once concerned with smell, has become associated with emotion.

Studies of ancient brain structures have been carried out at the Laboratory of Brain Evolution and Behavior of the U.S. National Institute of Mental Health in Poolesville, Maryland. The director, Dr. Paul MacLean, who originated the term limbic system, compares the human brain to an archaeological site. The outermost portion, the cerebral cortex, which is highly de-

THE HUMAN BRAIN



Enclosed within a bony skull and three enveloping membranes, the human brain is nourished by the one and one-half pints of blood pumped through it each minute. Since the time of our hominid ancestors, the human brain has grown in size by 300 percent, more than any other part of the body.

veloped in man, envelops deeper layers that contain structures shared with our reptilian and mammalian forebears.

MacLean believes that many of our mental processes are related to those that prevailed in ancient subhuman forms. For instance, human aggressiveness is a carry-over from a time when hominids often faced a simple choice: Kill or be killed. In modern society, by contrast, aggressiveness generally leads only to trouble. The tension between, say, talking peace and preparing for war can be understood, according to MacLean, as "schizo-physiology," a split between the thinking portions of our brain (the cerebral cortex) and the feeling portions (the limbic system).* In epilepsy and certain forms of mental illness, especially schizophrenia, dysfunctions in the limbic system produce emotional reactions that are "irrational"—out of touch with reality. Brain researchers are now trying to develop drugs that will harmonize the limbic and cerebral structures.

Theories Old and New

The deeper brain scientists dig, the more they discover. Like archaeologists, they tag and catalogue new findings, testing old theories against fresh evidence. As a result, during the past several years, many long cherished concepts of brain function have been discarded. The implications for our ideas about memory, language, and mind may be profound.

Consider the "one neuron, one neurotransmitter" hypothesis, formulated during the 1930s. A neuron (brain cell) was thought to contain a single neurotransmitter that, upon stimulation, was released into the synaptic cleft, the tiny gap separating one nerve cell from another. At the time, only two transmitters were known and they were conveniently appropriated to explain "excitation" and "inhibition." An inhibitory neurotransmitter prevented adjoining neurons from "firing"; an excitatory neurotransmitter activated adjoining neurons.

Despite its appeal, the "one neuron, one neurotransmitter" doctrine eventually came a cropper. For one thing, the menagerie of neurotransmitters has turned out to be very large. Only a few years ago, new neurotransmitters were being discovered every few months. Moreover, during the past few years, more than 20 peptide hormones (short-chain amino acids) have

*A similar split between "thinking" and "feeling" may also be seen in today's professed enthusiasm for avoiding firm commitment in male-female relations. This view denies the limbic underpinnings of sexual desire, possessiveness, and jealousy. Although a good argument could be made that human relationships might run more smoothly in the absence of these complicated emotions, it is unlikely that they will disappear if we simply ignore them.

been identified in the brain. The tasks performed by these peptides vary from place to place. Some of them are neurotransmitters. The much publicized *enkephalins* or *endorphins* (the body's own narcotic) control our perception of pain. Within the eye, other peptides process various kinds of visual information.

Scientists at the Karolinska Institute in Stockholm have demonstrated that some cells in the brain contain both peptides and "classical" neurotransmitters. They have also shown that pairs of neurotransmitters are located at individual synaptic junctions (where communication between cells takes place) implying that a nerve cell is capable of releasing one or both.

Brain cells, in short, do not behave quite like pinballs. Limiting our observations to whether a neuron "fires" is as satisfactory as trying to appreciate a Brahms symphony by assiduously determining from moment to moment whether a particular violin happens to be in play. Modulation, subtleties of response, and polyphonic interaction among many neurons are the key to understanding the action of single neurons.

The most exciting recent finding is that cells that have no direct connection with neurons employing peptides as neurotransmitters are nonetheless influenced when the nearby peptide synapses are activated. Presumably, the peptides diffuse from the synaptic area and activate receptors on the cell's surface. This means, essentially, that at least in some areas of the brain, information transfer can take place without the presence of synapses. This shatters notions of brain function as a linear process (a "digital" process in computer terminology).

The Question of Language

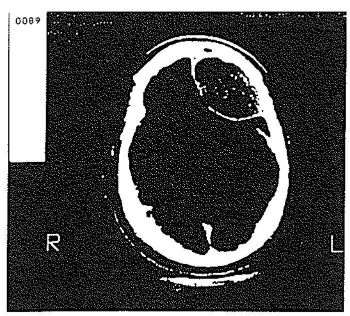
During the past few years, then, researchers have abandoned many entrenched beliefs about brain function. Freed from conceptual straitjackets, they have undertaken imaginative "I wonder what would happen if . . ." kinds of excursions into unknown territory. Thus, Dr. Floyd Bloom, director of the Arthur Vining Davis Center for Behavioral Neurobiology at the Salk Institute in San Diego, has investigated memory by injecting small amounts of vasopressin (a neuropeptide) into the brain ventricles of rats previously trained to jump onto a pole in order to avoid a painful electrical shock. Bloom found that these rats retained "memories" of their training for longer periods of time than did rats injected only with salt water. Bloom later performed experiments on people, with similar results. Neuropeptides, he believes, may signal "that the survival of the animal is challenged and that the animal had best be attentive

ELECTRONIC "WINDOWS"

The first tool that provided a "window" into brain functioning was the electroencephalogram (EEG), developed 57 years ago by a German psychiatrist, Hans Berger. A shy, reclusive man, greatly interested in psychic phenomena, he rarely spoke publicly of his belief that the human brain generated spontaneous electrical signals that could be measured and interpreted. Not until 1934 were Berger's findings confirmed.

Among the newest and most exciting instruments of exploration are CAT and PET scanners. The CAT (*computerized axial tomography*) scanner combines conventional x rays with computer techniques to provide, in essence, a cross section of the brain or any other part of the body. Since its introduction in 1972, the CAT scan has revolutionized medicine by allowing neuroscientists to envision the subtle structural changes within the brain that accompany tumors and strokes. The newer PET (*position emission tomography*) scanner reveals activity within the brain—what is going on metabolically or chemically. For instance, an injection of glucose tagged with a radioactive "tracer" can be tracked through the brain to the site where it is metabolized.

BEAM (*brain electrical activity mapping*) uses computers to produce a color contour map of the electrical activity at the brain's surface. The computers can also be used in "evoked potentials" studies to average out the background "noise" that is present even when the brain is "idling." This enables neuroscientists to trace elementary sounds and flashes of light through multiple "way stations" within the brain. A single clicking sound, for example, can be broken down into eight different components starting with the ear and extending up to the auditory cortex. Abnormalities point to the location and, often, the nature of a disease.



CAT scan shows abscess forming inside the skull of a teenager. The youth had been hit in the head with a baseball.

to its surroundings"—thereby enhancing memory. It is not too far-fetched to think that various neuropeptides will, one day, be assumed into the repertoire of pharmacology for humans.

An interest in behavior is shared by brain scientists of diverse persuasions and interests. Why do animals—and people—act the way they do? What brain events correspond with conscious experience? For instance, what is going on in my brain when, in a restaurant, I order a chocolate soufflé? How does it differ from events that would accompany my choosing apple pie à la mode instead? Implicit in such questions is the assumption that there must exist correlations between my choices and the events going on in my brain. But what are they?

The answer immediately introduces two levels of discourse masquerading as only one. To choose a chocolate soufflé is an act of will. It requires the use of words in a language that will be meaningful to the waiter and involves innumerable variables that can never be reduced to an explanation at the level of a chemical slipping across a synapse. Why am I in the restaurant in the first place? What does my ordering of a highly caloric dessert imply about my attitude toward obesity?

To ask such questions is immediately to participate in a long-standing debate regarding the place of language in human motivation. To some researchers, human language is only a more sophisticated version of the kinds of communication seen in lower primates. Attempts to teach chimps to speak have, on occasion, been declared successful; yet, invariably, the "language" has been revealed as only a clever form of imitation or, in the words of Sir Edmund Leach, a series of "circus tricks."

Nothing But, Nothing More

The debate over the uniqueness (if such it is) of human language and culture has great implications for brain research. And, if Sir Edmund is correct, then the social sciences—sociology, psychology, anthropology, and the rest—can never be based on the kinds of rules that govern the natural sciences; human attitudes, voting behavior, choices can never be predicted, or even explained with any precision. In other words, a detailed study of the brain is not ever going to shed much light on why I choose a chocolate soufflé over pie à la mode. As Leach put it, the capacity to make choices, which is linked to language, "represents a major discontinuity with the rest of nature." Our biology may *constrain* our behavior, but it does not *dictate* it.

How, then, is the mind related to the brain? "Reductionism," the simplest and currently the most popular view among nonbiologists, assumes that the mind is nothing more than the brain. As Carl Sagan wrote in *The Dragons of Eden*, "My fundamental premise about the brain is that its workings—what we sometimes call 'mind'—are a consequence of its anatomy and physiology and nothing more." Sagan's "nothing more" is a first cousin of the "nothing but . . ." argument ridiculed a few years ago by Arthur Koestler: "Love is *nothing but* sublimated sexuality. The mind is *nothing but* the brain and so on." Such "nothing but" arguments reduce complex biological phenomena to principles everyone *thinks* he is familiar with. In neurobiology, the argument takes the form: "If we only knew enough about the brain, all of the mysteries concerning 'mind' would disappear."

Yet everything that we have learned about the brain over the years points away from any simplistic relationship between neurons and the expression of mind. Performance is not confined to any specific portion of the brain but is "spread out." The brain is thus highly localized yet exhibits confounding "nonspecificity." Brain researchers still have not resolved this conundrum, and perhaps never will.

III WHAT IS "UNDERSTANDING"?

Can the brain understand itself? There is no way for us to stand back and "objectively observe" the brain or even theorize about it, without encountering constraints that are inherent in our neuronal networks. To what extent can "reality" or "truth" be ascertained when the inquiring organ—the brain—itself exhibits significant perceptual biases that can never be altered?

In 1922, Werner Heinsenberg, a student of Danish physicist Niels Bohr, asked his mentor: "If the structure of the atom is as closed to descriptive accounts as you say, if we really lack a language for dealing with it, how can we ever hope to understand atoms?" Bohr's response could be applied to our attempt to "understand" the human brain: "I think we may yet be able to do so. But in the process we may have to learn what the word 'understanding' really means."

In recent years, physicists have joined forces with brain researchers. From this marriage of "hard" and "soft" science have come some impressive advances in our capacity to observe the brain. The advent of CAT scans has laid bare the structure of the human brain in ways that formerly were impossible without wielding saw and scalpel and actually "taking a look." PET and BEAM scans let us see the brain "in action."

But the marriage has sometimes been stormy, for physics, ever since the development of quantum mechanics, has been an extraordinarily "counterintuitive" discipline. Its principles are not readily grasped. It does not "make sense" in the same way that Newtonian physics did. As Heisenberg put it, "All the words or concepts we use to describe ordinary physical objects such as position, velocity, color, size, and so on become indefinite and problematic if we try to [apply them to] elementary particles."

While many brain researchers continue to suggest models of the brain based upon the notion that its functioning must inevitably involve a process that can somehow be "pictured" (e.g., a telephone switchboard), others have lately been more daring. For instance, a physics-based theory of brain organization has been advanced relying on the principles of "holography," a technique invented by physicist Dennis Gabor in 1948.

A laser beam directed at a holographic plate at a precise angle will reconstitute (in space, and before one's eyes) a three-dimensional image of any object or scene previously encoded on the plate. If the hologram is a good one, the projected image—a game of chess, say—looks as if it is actually "there." The perspective will vary properly if one moves about the room. Someday, every museum will be able to display Michelangelo's Pietà.

The curious thing is that each portion of the holographic plate contains all the information necessary for reconstituting the image. One can snip off a corner or cut a hole through the middle but the plate still functions, although the quality of the image will progressively deteriorate the more one snips away.

Brain scientists, principally Stanford University's Karl Pribram, suggest that the brain, particularly the cerebral cortex, is the biological equivalent of a hologram. Such a theory is consistent with many of the findings of brain research cited earlier. Wilder Penfield's work with electrical stimulation in effect resulted in the release of a holographic memory complete down to the finest details. Rats have been shown to retain their ability to run mazes despite the excision of more than 50 percent of their cerebral cortex, with performance dropping off in proportion to the *amount* of brain removed rather than the specific *area* of removal—excepting, of course, those parts of the brain necessary for movement itself.*

Another example of the progress physics has made possible is the PET scan, which allows us to "see" biochemical processes within discrete areas of the brain. From a PET scan image taken earlier, a trained radiologist can tell whether you were reading and thinking, lifting a pair of barbells, or resting quietly as your brain was being scanned.

*There is a classic joke about a scientist who wanted to see what effect removal of an animal's legs would have on its performance. He removed one leg and said "Jump" and the animal jumped, albeit with some difficulty. He performed the same experiment after removing the animal's second and third legs. Again the animal jumped, with greater difficulty. But when all the legs were gone, the animal failed to respond. The scientist concluded that removal of all four legs had resulted in loss of will.

LIFTING THE CANOPY

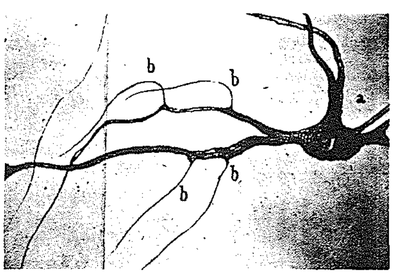
All sensation and experience are derived from signals running to the brain down tiny nerve fibers. The brain does not receive light or sound but rather patterns of electrical signals that must be decoded. How do these signals travel?

Consider a reflex. Scientists once thought that a rather simple process was involved: Striking the knee sends an impulse from a *sensory neuron* into the spinal cord, from which a *motor neuron* fires a signal that finally results in the sudden jerking of the leg—a simple two-neuron process. And so, in fact, it is in sea anemones.

But in humans, the reflex involves nerve cells as far distant as the cerebral cortex. (That is why physicians must distract patients—to "get their minds off" what is happening.) Indeed, most of the neurons involved are neither sensory (originating in the skin) nor motor (connecting directly with the muscles). Almost all (99.9 percent) are intervening *intermediate neurons*. Some 3,000 to 5,000 of them may be affecting each motor neuron, even as they communicate with each other in intricate patterns. Tracking a signal from impulse to reflex thus becomes virtually impossible.

Imagine a billiard table over which a canopy has been spread that covers the center. All that is visible in this "thought experiment" is the rectangular outer edge, around which we can periodically see stray balls careening off the cushions or dropping into the pockets. Since the initial arrangement of the balls and the angle of deflection of the shots is hidden from view, it is impossible to determine which billiard ball is affecting which of its neighbors or how. That, roughly, is the position brain researchers are in.

Some scientists believe computers will one day "lift the canopy." That view is misleading. Kenneth Boulding, a former president of the Society for General Systems Research, has noted that 10 billion neurons each capable of only a single "on-off" response would yield $20^{10,000,000,000}$ (a number so large that it would take 90 years to write it out by hand one digit per second) different possible states. And neurons are capable of more than a single on-off response.



One of the first accurate representations of a nerve cell, drawn by Otto Deiters in 1865.

In the PET technique, a biologically active chemical compound is introduced into the brain labeled with a radioactive isotope that decays immediately by emitting a positron. Almost instantaneously, the particle combines with an electron within the brain. These are then mutually annihilated with the emission of two gamma rays. The gamma rays fly off in opposite directions and penetrate the surrounding brain tissue before exiting. The fugitive gamma rays are recorded by an array of detectors hooked up to computers that then reconstruct the original path of the rays. A "picture" of the brain tissue through which they passed results.

Notice that the PET scan technique is not based on a "model" of how the brain "works." Rather, principles of physics are applied to the brain and an image of brain function emerges. It is not even necessary that the organ under study be a brain. PET scanning is often used to detect abnormalities in heart muscle before the occurrence of a clinical heart attack.

Puzzling Out the Program

But, despite the breakthroughs wrought by technology, the essential questions remain unanswered. What is the underlying structural organization of the brain? How did it develop? What is its purpose?

The situation could be compared to that of a computer engineer who one day, while driving through California's "Silicon Valley," encounters a functioning computer set down by the side of the road. His training will enable him to identify the computer's components and hazard an educated guess about its capabilities (the "hardware" considerations). But unless the engineer is also privy to the program being employed (the "software"), he may never be able to figure out what the computer will produce at any given moment.

Brain scientists have learned much about the brain's "hardware" but remain as puzzled as ever about the "programs" that activate this 10 to 15 billion cell network.

One of the most intriguing riddles is whether the brain is capable of conceptualizing *all* possible facets of reality or is limited to only some of them. Because the brain is a biological structure, it must—unless it differs from all other known biological structures—function under certain constraints. No one argues this point at least when it comes to physical constraints. For instance, a fall in the oxygen saturation of blood directed to the brain eventually results in loss of consciousness. But when it comes to concepts, ideas, and symbolizations, the presence of constraints is vehemently debated.

"When someone maintains that brains cannot be expected to understand brains, the analogy is to the aphorism that a person cannot lift himself by his own bootstraps," writes Nobel laureate David Hubel. "The analogy is not compelling. For all practical purposes, neurobiologists are working on the hunch that they can understand the brain and, for the moment, they are doing well."

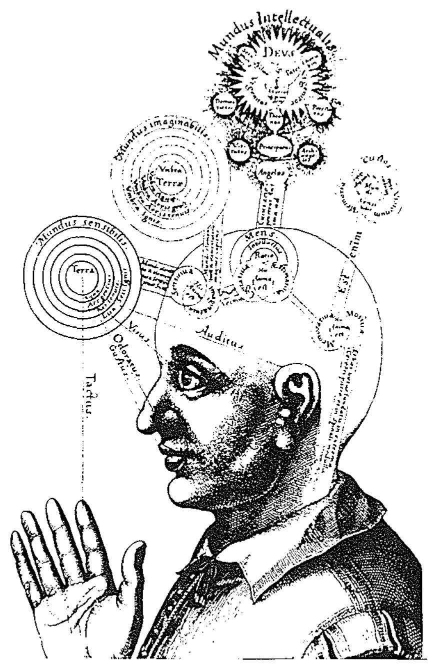
Few would deny brain researchers are "doing well." The crux of the argument, however, involves the extent to which further advances will in fact enhance our understanding of the mind-brain relationship rather than confuse us further. And what—to return to the original question—do we mean by "understanding" anyway?

Imagine a scientist who knows nothing about how a traffic signal operates. After observing the signal alternating from red to green with a few seconds of amber in between, the scientist may conclude that the signal operates according to a preselected cycle. After a few hours of studying its internal mechanism, he will probably be able to explain how it "works." At this point, most observers would agree with the scientist's confident assertion that he "understands" the traffic light.

A different observer, however, might point out that the traffic signal is only a mechanical operating device which serves as a symbol for "stop," "go," and "proceed with caution." Anyone who claims to "understand" the traffic light should be able to explain such things as, Why are people willing to behave in certain ways depending on the color of the signal? Suddenly, we are confronted with questions about human motivation and the symbolic structures of our minds. These are not so easy to answer. It is possible that some of them are unanswerable.

The Lessons of Ignorance

This is uncomfortable, disturbing, for we remain steeped in an affinity for mechanism, partly the result of our tool-making capacities and our prehensile thumb. It is natural, therefore, that many attempts to explain the brain should be based purely on neurochemistry and neurophysiology: Certain chemicals *cause* certain reactions that *result* in the brain performing in a certain way; the neuron *fires*, and the *discharge* is spread throughout parts of the neuronal network. The italicized words are the cumbersome, semantic luggage carried over rather clumsily from the 19th century, when God was considered to be a "glorified engineer." The reality may be far more complicated.



In his Ultriusque Cosmi, *17th-century mystic Robert Fludd depicted the mind as a synthesis of sensation, imagination, and intellect.*

Ann Ronan Picture Library.

Many theorists are now speculating, for example, that even the biologist's distinction between "organic" and "inorganic" matter is a false one. Why not approach the study of the brain, and, by extension, the mind, via principles that rest on the bedrock of physics rather than biology? Taken a step further, is it not possible that biology, as a discipline, has been justified primarily by our own need to believe that we—along with other "living" organisms—are somehow special? Despite the theoretical nature of these inquiries, the implications of "yea" or "nay" are enormous.

In the case of "yea," one would argue that living and nonliving matter are essentially similar. This theory—along with the quantum physics on which it is based—is remarkable for its counterintuitiveness. We feel "in our bones" that living matter differs from nonliving matter. But so far no one has succeeded in defining the difference at a molecular or submolecular level. If there turns out to be no essential difference, then many of the "dualistic" conflicts that have troubled philosophers from Descartes to Karl Popper would disappear, to be replaced by a unified theory based on physics rather than biology.

As I see it, there would be something fundamentally dis-

THE INTELLIGENCE ENIGMA

In 1969, psychologist Arthur Jensen and his colleagues at the University of California, Berkeley, attributed the low average IQ among U.S. blacks (85, versus a national average of 100) to genetic traits. In angry rebuttal, most other educators pointed to the effect of cultural and environmental factors: poverty, broken homes, lack of intellectual stimulation. Studies cited by economist Thomas Sowell and others have shown that many white groups isolated from "mainstream" American culture (e.g., Jewish immigrants during the 1920s, Tennessee "hillbillies" during the '40s) likewise evidenced a low average IQ, comparable to that of blacks today.

One useful result of this rancorous debate was to prompt a new look at the make-up of intelligence tests themselves. A second was to focus attention on a basic question: What are such tests supposed to measure? What, in other words, *is* intelligence?

In fact, intelligence is a smorgasbord of widely varying abilities. Attempts to treat it as something "unitary" (beginning with the IQ scale devised by Alfred Binet and Theodore Simon in 1904 to help the French government distinguish between students who were "stupid" and those who were merely "lazy") are mistaken. Some people are astonishingly adept at mathematics but find it difficult to write a letter. Betty Edwards, author of *Drawing on the Right Side of the Brain*, estimates that the average university graduate draws on the level of a five-year-old. Consider the "idiot savant" who can perform prodigious feats of calculation or play championship chess, but may require permanent institutionalization because "common sense" matters are beyond him.

Tests of intelligence (e.g., the Iowa Test of Basic Skills, the Scholastic Aptitude Test, the National Merit Scholarship Exam) do

turbing about such a development. Quantum theory is essentially an improvisation that is taken to be "true" only because it works. Gary Zukav, who surveyed the world of modern physics in *The Dancing Wu Li Masters*, wrote of quantum theory: "It is not necessarily how nature 'really is,' it is only a mental construction which correctly predicts what nature probably is going to do next."

A similar uncertainty exists in our study of brain organization. It simply isn't possible to know what is taking place among all of the 10 to 15 billion neurons and their interconnections. Spontaneous nerve cell discharges cannot be predicted nor does a given neuron discharge in a predictable manner even when affected by the same stimulus twice in a row. Getting a "fix" on an individual neuron is very much like trying to predict the not—cannot—assess every manifestation of intelligence. How would one gauge the intelligence of a child who, with no prior training or instruction, can unscramble a Rubik's cube in 30 seconds? Intelligence tests are concerned instead with certain "developed" abilities in reading, writing, logic, mathematics. Within strict limits, according to a recent report from the National Academy of Sciences, intelligence tests are useful "predictors" of *performance* in school and on the job. But they cannot gauge "creativity" or "motivation," and make no claim to measuring "innate" ability.

Even under the best of circumstances, a bias may persist in tests, if only because males and females tend to have a different aptitude for certain tasks. Boys, for example, are favored in tests of math and spatial abilities. During the 1960s, the National Merit Scholarship exam was so skewed toward math, science, and tests of spatial relationships that boys outperformed girls by a wide margin. The exam has since been redesigned.

Intelligence tests may also penalize individuals for their behavior. The ability to sit still and manipulate a pencil does not come easily to "hyperactive" children (almost all of whom are males). It is virtually impossible to estimate the extent to which limited attention span, poor concentration, and impulsiveness may contribute to inferior IQ test results. At the other extreme, professional "coaching" can improve students' test scores significantly.

"Intelligence" is not a useless concept, but it is difficult to define. There is no good reason why intelligence testing, properly conducted and interpreted, should not continue; indeed, new brain-wave measuring techniques have yielded much insight not only into intelligence but also into various neurological complaints. What seems certain, however, is that the day when we can measure intelligence the way we monitor blood pressure is a long way off.

location of a specific subatomic particle at a given moment. It can't really be done. As a result, no neuroscientist can ever exert experimental control over the internal state of a human brain. In a sense, then, choice, whim, and free will are rooted in the very structure of the brain itself.

This is not to say, incidentally, that brain functioning is strictly "free form." On the contrary, randomness at the micromolecular level is offset by behavioral constraints. Within the human brain, certain biases exist from birth that structure experience along certain lines. The infant, for instance, is born with the capacity to differentiate color, discriminate background noise from pure tone, even recognize and prefer the human face over all competing visual stimuli. An infant only moments out of the womb will turn its head in the direction of a voice (it prefers a female pitch), inquisitively searching for the source of the sound. Where does such a newborn infant learn such responses? Obviously, infant behavior is not learned at all. Such findings are bringing about a reconsideration of the ideas of Immanuel Kant, who held that all experience is organized according to the categories of our thought. In other words, our ways of thinking about space, time, and matter are predetermined by the structure of our mind.

Our visual system, for example, is limited to only a small segment of the electromagnetic spectrum—namely the radiation of wavelength from about 380 to 760 millimicrons. (The total range of wavelengths in the electromagnetic spectrum is from 0.00005 millimicrons to several miles.) This narrow segment contains all the colors that can be seen by the human eye. Thus, the very concept "color" depends on the neurological mechanism operating between eye and brain. Even within the visible spectrum we are not totally "free." The eyes are more sensitive to yellow-green than to violet, blue, or red.

These predispositions to perceive and behave in certain ways form the basis for recent sociobiological theories regarding individual as well as cultural development.

Brain researchers have also discovered lately that some of our most cherished ideas about how we perceive "reality" are wrong. Vision, for instance, is not based on the brain working as a kind of slide projector that receives impressions "ready made" for the eyes. Instead, the cells that gather information from the light receptors in the retina respond best to a spot of light of a particular size and in a particular point of the visual field. This information is conveyed to receptor cells in the visual cortex that are arranged according to columns that respond to variation in the angle and orientation of the lines in the visual field. Reality is a two-way street: We impose "meaning" on the world even as the world holds up cue cards.

Of even greater importance was the discovery that these recognition patterns within the brain's visual cortex required outside stimulation in order to develop normally. In a child with strabismus (crossed eyes), one of the eyes is usually suppressed in favor of the "dominant" eye. If this imbalance is not corrected, vision is lost in the eye not in use. For this reason, strabismus and cataracts are now operated on early in life. The importance of environmental stimulation of brain function persists throughout life and tells us much about ways to prevent senility. Simply put, the brain (like a muscle) must be used in order to maintain its optimal functioning. Everything else being equal, it is the actively involved, mentally stimulated elderly person who is least likely to develop senility.

We have learned much that is useful and much that is provocative about the brain during the past few decades, but it is too early to say how far we have advanced in mapping the *terra incognita* inside our skulls. Sir Charles Sherrington, a Nobel Prize-winning neurophysiologist, once referred to the brain as an "enchanted loom" that "weaves a dissolving pattern, always a meaningful pattern, though never an enduring one; a shifting harmony of subpatterns." What is most obvious today is our inability to understand these subpatterns. How are they formed? What is the guiding principle by which billions of neurons can be "orchestrated" to produce a symphony or a sonnet, a poem or play, a PET scanner or paradigm, a Trianon or a trance? We do not, of course, know.

But our ignorance on this score may be beside the point. While brain researchers remain bedeviled by frustrated curiosity, their findings have greatly improved the quality of our lives. They have enabled us to detect and, increasingly, to cure a variety of brain disorders and offered new hope to the mentally ill. Brain science has revolutionized certain forms of therapy, particularly for victims of strokes, and vastly increased our understanding, still imperfect, of the psychology of learning, of affection, of aggression.

If the workings of the brain remain elusive, even that has its uses. It reminds us that human beings are a race apart, special in a way they continually try to define and explain, never succeeding, but still the only creatures on Earth to whom it has occurred to make the attempt.

BACKGROUND BOOKS

THE BRAIN

When Lord Byron bemoaned "the petrifactions of a plodding brain," he was unaware that his own brain was about twice the average size. This discovery, made after the poet's death in 1824, delighted those who believed intelligence to be a function of brain size. The idea seemed to make sense.

Unfortunately, writes biologist Steven Rose in **The Conscious Brain** (Knopf, 1973, cloth; Vintage, 1976, paper), most of the "sensible" ideas about the human brain have turned out to be wrong. In this case, Rose notes, "when a correction is made for body size, then the brains of all humans are closely matched in weight and structure, Einstein's or Lenin's with that of . . . a 'simpleton.' "

Rose's book is one of the best overall introductions to the subject. He traces man's concepts of the brain from the "hydraulic system" envisioned by René Descartes in the 17th century to our own preoccupation with the innards of computers.

It is still impossible to explain, he writes, just how "two fistfuls of pink-gray tissue, wrinkled like a walnut, [can] store more information than all the libraries of the world."

Two fine supplements to Rose's book—each profusely illustrated—are Keith Oatley's **Brain Mechanism and Mind** (Dutton, 1972, cloth & paper) and Colin Blakemore's **The Mechanics of Mind** (Cambridge, 1977, cloth & paper).

More adventurous readers may wish to sample Gordon Rattray Taylor's **The Natural History of the Mind** (Dutton, 1979, cloth; Penguin, 1981, paper). Reading Taylor is like hearing one of the late John Coltrane's tenor saxophone solos: We are led up, down, around, and all over the place, but in the end one likes having made the effort.

One of the tragedies of brain research is that much of what we know is a consequence of injury or disease. As Howard Gardner observes in **The Shattered Mind** (Knopf, 1975, cloth; Vintage 1976, paper), what no doctor may do out of curiosity—"selectively destroy brain tissue"—is done every day by fate. The results are revealing, sometimes baffling. What is one to make of a person who can interpret "DIX" as the Roman numerals for "509" but is unable to pronounce the letters as a word—as "Dicks"?

"Holism" in the neurosciences—a conviction that the brain must be studied as an integrated whole, rather than as merely the sum of its "mechanical parts" — is eloquently defended by Russian neurophysiologist Aleksandr Romanovich Luria in **The Working Brain** (Basic, 1973, cloth & paper). He deftly covers rather esoteric subject matter in straightforward prose, without ever a trace of condescension.

Luria's brilliant and prolific disciple was Karl Pribram, whose **Languages of the Brain** (Prentice-Hall, 1971, cloth; Wadsworth, 1977, paper) is recognized as a modern classic. Pribram ponders neurological experiments that over the years have confounded brain researchers, developing along the way his notion of the brain as a hologram.

What is the relationship between mind and brain? **Consciousness and the Brain** (Plenum, 1976), edited by

Gorden Globus, Grover Maxwell, and Irvin Savodnik, offers no definitive answers, although the speculative essays in this collection are eminently readable. The most valuable philosophical investigation of mind and brain is still Gilbert Ryle's **The Concept of Mind** (Barnes & Noble, 1949, 1975).

Ryle's target was the old Cartesian notion of "duality"—a conception of mind and body as different in their very natures. Ryle so demolished this view that none dared again propose a dualistic theory of the brain until John C. Eccles came along.

Rarely does a Nobel laureate in medicine set out his ideas in a text intended for undergraduates, but Sir John did just that in **The Understanding of the Brain** (McGraw-Hill, 1973; 2nd ed., 1976, paper only). Eccles explains with precision and elegance how nerve cells communicate with one another, though his dualist convictions force him into some tricky intellectual acrobatics.

The recent enthusiasm for computer simulations of the human brain is effectively challenged in **Computer Power and Human Reason** (W. H. Freeman, 1976, cloth & paper). Author Joseph Weizenbaum concedes the apparent "plausibility" of viewing man as a "sophisticated machine" but adds that, scientifically, the notion is simplistic.

Morally, Weizenbaum contends, this notion constitutes a "slow-acting poison." "What," he asks, "could it mean to speak of risk, courage, trust, endurance, and overcoming when one speaks of machines?" And what would a "deterministic" concept of the brain do to our belief in "moral responsibility"?

The relevance of physics to the brain sciences may not be immediately apparent to the general reader. But physics has a great deal to tell us, and a good place to discover why is in Richard L. Gregory's **Mind in Science: A History of Explanations in Pyschology and Physics** (Cambridge, 1981). In this lucid, colorful, and demanding book, Gregory, a neuropsychologist, ranges widely, from Babylonian myth to relativity theory, from the nature of light to the nurture of intelligence.

We live in two worlds, Gregory explains, a world that we see and perceive, and an underworld that we do not see but can *also* (with ingenuity) perceive: the everyday world of color, hardness, "reality" versus the lately discovered world of atoms and quantum mechanics. Do these worlds know each other? How?

"Brains," writes Gregory, "construct predictive hypotheses of aspects of the world which are generally useful for survival. [Most brain hypotheses] are largely at variance with the realities of physics. Our perceptual and conceptual hypotheses float free, even from things that seem most immediately sensed and known, to create and journey into realms of fantasy, myth, poetry, and illusion. Sometimes the fantasy traveler returns to bring gifts back to our world."

Some of these gifts of knowledge are unwelcome, unfriendly, disturbing; others are joyous, benign, enlightening. What, one wonders, would our reaction be if one gift someday turned out to be a knowledge of its own origin?