

A Hero of the Brain

Israel Rosenfield

Selected Papers on Language and the Brain

by Norman Geschwind.
D. Reidel, 549 pp., \$63.00;
\$18.95 (paper)

Cerebral Dominance:

The Biological Foundations
edited by Norman Geschwind and
Albert M. Galaburda.
Harvard University Press,
232 pp., \$27.50

Dyslexia: Current Status and Future Directions

edited by Frank Hopkins Duffy
and Norman Geschwind.
Little, Brown, 223 pp., \$32.50

Nineteenth-century neurology was dominated by two opposing schools of thought. Early in the century the Austrian neuroanatomist Franz Gall and his disciples claimed that, to those practiced in the art, an examination of bumps on a person's head revealed talents and psychological characteristics; traits of character, he held, were controlled by specific regions of the brain. Gall had a fashionable success in France, but was ridiculed by the leading neurologist of the day, M.J.P. Flourens, who had performed experiments on birds' brains. At the height of his fame in the 1840s, when he defeated Victor Hugo for membership in the French Academy, Flourens believed that he had conclusively demonstrated that activities such as walking and flying were not dependent on any particular region of the brain. The brain functions as a whole, he argued, and it was impossible to predict the specific effects of any form of damage.

In 1861 the French neuroanatomist Paul Broca demonstrated that damage to a specific region on the left side of the cerebral cortex caused severe language problems, such as an inability to speak fluently. This was the first serious challenge to Flourens and the "holistic" school. Subsequently, the German neurologist Carl Wernicke found another region on the left side of the brain that apparently controlled different aspects of language, including the ability to understand speech. Wernicke argued that the region on the left side of the brain that had been discovered by Broca was somehow responsible for translating language formulated in the brain into the mechanical movements of the vocal cords, the tongue, and the mouth. A band of fibers called the arcuate fasciculus connected Broca's region to the same region that Wernicke himself had discovered; and Wernicke believed that the region he had discovered was responsible for the recognition, or sorting, of speech as distinct from other sounds. Clinicians soon found that such "localization" of brain functions explained many other patterns of neurological disorders in addition to language. In 1884, for example, a patient with epilepsy and partial paralysis had a brain tumor removed in the first such operation in medical history. The neurological symptoms enabled the surgeon to locate the exact position of the tumor.

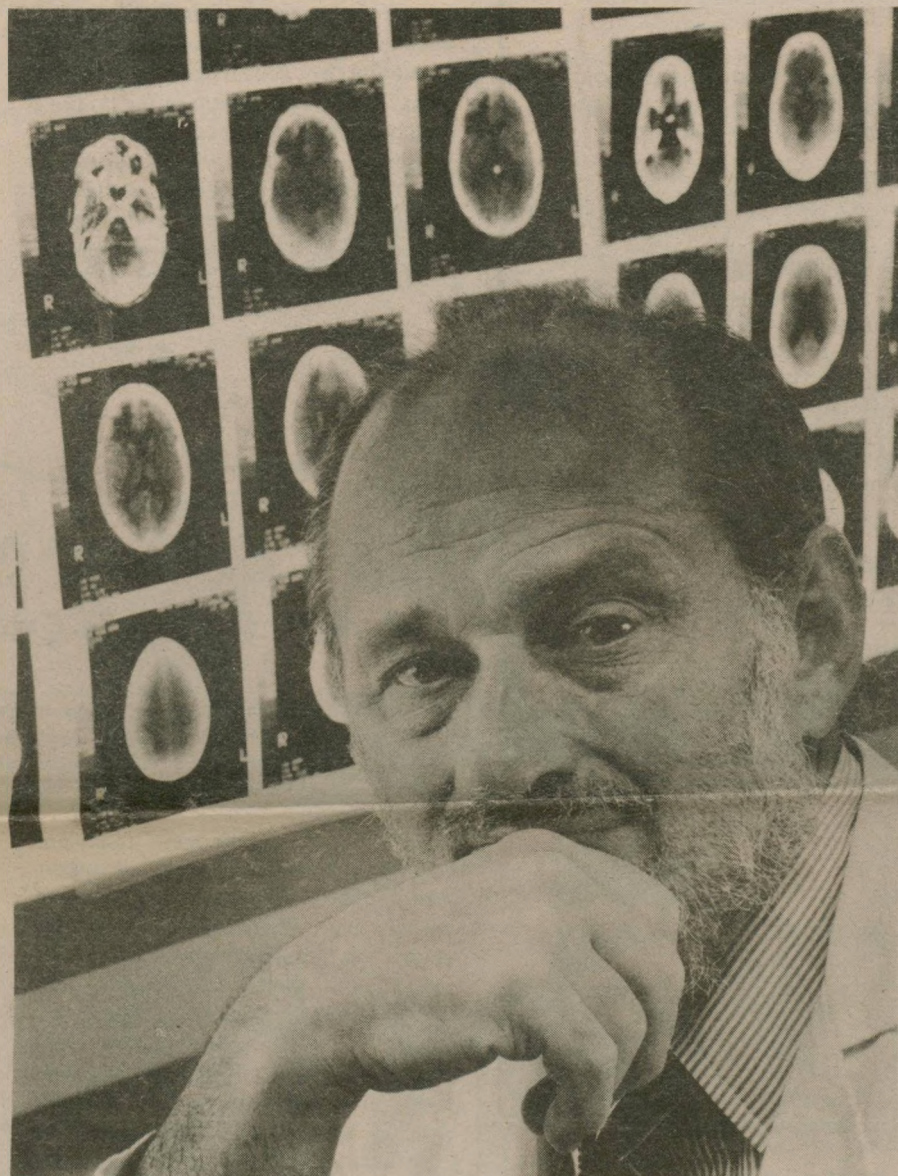
During the early years of the twentieth century, however, the belief that psychological behavior derived from separate mental faculties, each controlled by different centers in the brain, became increasingly unpopular; most neurologists

and psychologists considered this an implausible view of human psychology. In 1927 a neurology textbook noted:

Neurologists have been prone, even up to the present time, to fall into the error of attempting to find specific centers for particular mental functions or faculties. But the evidence at present available gives small promise of success in the search for such centers. It is, in fact, theoretically improbable that such discov-

ers was true of human beings as well. By the 1950s the localization argument appeared dead. The standard American medical textbook commented in the 1958 edition:

Knowledge of the location of speech functions has come almost exclusively from study of human beings who have succumbed to local brain diseases. From the available information it seems almost certain that the whole language mechanism is not



Norman Geschwind, 1926-1984

eries will ever be made, for psychology today recognizes no such mosaic of discrete mental faculties as would be implied by such a doctrine.¹

For many neurologists, the anatomical evidence also failed to support the nineteenth-century localization doctrine. Specific functions, they argued, were attributed to regions in the brain that were not well defined anatomically; and the patterns of brain damage found on post-mortem examination proved to be more variable than the localization arguments had predicted. Perhaps most dramatic were the claims of the Harvard psychologist Karl Lashley, who poked holes in rat brains. As Flourens had argued a century earlier, Lashley claimed that the rats' neurological problems were a function of the amount of brain damage, not the specific sites of damage. While Lashley did not claim that his rat experiments were relevant to an understanding of human brain function, other people thought that what was true of

divisible into a number of parts, each depending on a certain fixed group of neurones. Instead, speech must be regarded as a sensorimotor process roughly localized...in the left cerebral hemisphere, and the more complex elaborations of speech probably depend on the entire cerebrum.²

Today, however, most psychologists and neurologists would argue that speech and other brain functions can indeed be divided "into a number of parts." Studies in information processing and artificial intelligence have plausibly suggested how the brain processes information as a series of discrete subtasks; and the same studies do much to explain the symptoms that puzzled and confused neurologists in the first half of this century. Yet well before these arguments had begun to take shape in the 1970s, Norman Geschwind, who until his death in November 1984 was a professor of neurology at Harvard Medical School, had started a thorough reexamination of the classical neuro-

logical writings that had first suggested the arguments for localization. Geschwind vindicated the localization approach that had been dismissed by neurologists and psychologists between the 1920s and 1950s. His work is the culmination of the classical tradition of Broca and Wernicke and helped to set the stage for new approaches to the brain.

In 1961 Geschwind came upon a rarely mentioned study by the French neurologist Jules Joseph Dejerine, published in 1892. It was this work that led to his re-examination of other forgotten, dismissed, and even misquoted writings, and to the publication in 1965 of his own monograph, largely a defense of the classical approach, "Disconnexion Syndromes in Animals and Man." (The essay appears in *Selected Papers on Language and the Brain*.) Dejerine had described the case of a very intelligent businessman who on awakening one morning found that he could no longer read. When looking straight ahead he could not see the color of objects on his right (known as the right visual field), though he had no trouble seeing the color of objects on his left. His speech and comprehension were perfectly normal. He could write but he was unable to read what he had written. Yet he had no difficulty reading and writing numbers. And he could copy written material without understanding what he was copying.

Though he could not read visually, he could read when he traced the outlines of letters with his fingers. He had no trouble naming objects, including pictures of complicated scientific instruments. "There was no evidence," Geschwind wrote, "of any general intellectual disturbance since the patient continued during his illness to operate a highly successful business, to gamble at cards successfully, and to learn vocal and instrumental parts of operas by ear since he could no longer read music."

These symptoms can be explained as follows: normally, the two sides, or hemispheres, of the brain communicate directly through the band of fibers called the corpus callosum. The nerves that carry information from the eyes to the brain cross; information from the right visual field goes to the left hemisphere of the brain and information from the left visual field goes to the right hemisphere. The man's color blindness in the right visual field meant that the visual areas of his left hemisphere were partly damaged. This damage, however, was extensive enough to destroy the fibers carrying visual information from both hemispheres to the language centers discovered by Broca and Wernicke. The patient's ability to see words without understanding them meant that the words and sentences he saw never reached the language centers in the left hemisphere. His color blindness in the right visual field provided the clue to the site of the damage in the left hemisphere. Information presented in tactile form, however, went directly to the language centers to be "read."³

³Geschwind appears to have misread Dejerine's paper and therefore gave a different analysis of the case in his disconnection syndrome paper. But the basic idea that attracted him, that visual information fails to reach the language centers, remains the same as in the above descrip-

¹Charles Judson Herrick, *Introduction to Neurology* (W.B. Sanders, 1927; first edition 1915), p. 338.

²T.R. Harrison, *Principles of Internal Medicine* (McGraw-Hill, 1958), p. 368.

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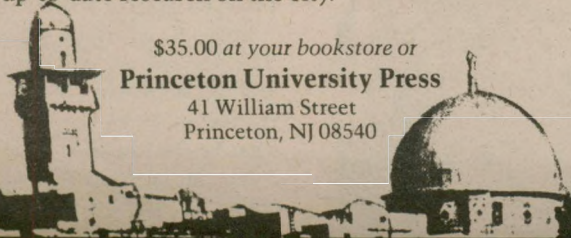
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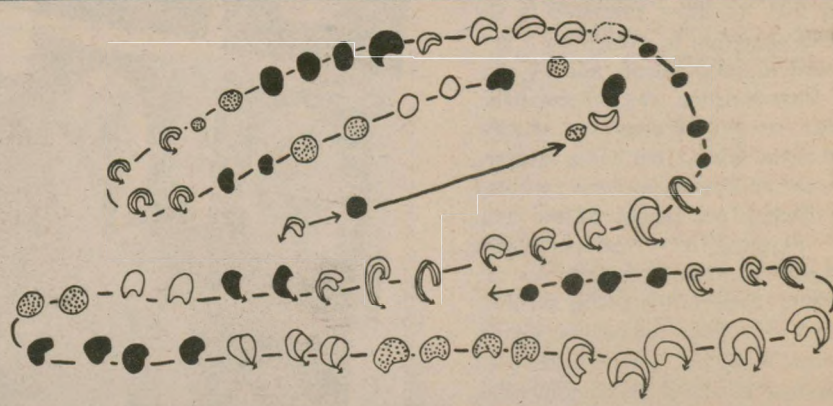
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Geschwind's study of classical neurological cases such as Dejerine's as well as his own clinical work provided the basis for his 1965 monograph on the disconnection syndrome—the clinical consequences of the destruction of fibers that link functional units of the brain. Important, too, was Roger Sperry's report in the 1950s that the severing of the corpus callosum in animal brains caused behavioral changes. In his paper Geschwind concluded that, in both higher animals and human beings, sensory information—from sight, sound, smell, and touch—is initially processed in the primary sensory areas of the brain. The information is then relayed to neighboring brain regions known as association areas. In higher animals, but not in human beings, the information then goes from the association areas to the limbic system of the brain—a structure that activates emotional responses such as "fight, flight, and sexual approach." The sight of a snake will therefore cause a monkey to flee. If for some reason the connections between the

little mixing of sensory information in animal brains.

In human brains this is not true: information received through the senses passes from the primary sensory regions to the association areas, as in the higher animals, but the limbic system is circumvented. Instead, nerve fibers pass sensory information to a secondary association area (which includes the language centers)—"the association area of association areas." This frees human beings from domination by limbic system responses. Instead of the direct connections between auditory or visual information and limbic responses that are characteristic of animals, human beings have powerful associations between visual and auditory sensations as well as between the tactile and the auditory, the tactile and the visual, etc. All these associations take place in the secondary association areas. Geschwind called them "cross-modal" associations. As he wrote: "In sub-human forms the only readily established sensory-sensory associations are those between a non-limbic (i.e. visual, tactile or



A schematic representation by Alexander Marshack of the sequential notation of lunar phases that was engraved on a 28,000-year-old bone found at the Abri Blanchard near Les Eyzies in southern France. The turns in the serpentine pattern fall at the points where the moon changes phases. The indications of particular lunar phases in each marking have been added by Marshack.

visual areas of the monkey's brain and the limbic system are broken, or disconnected, the monkey will fail to respond when seeing a snake. However, this disconnection will not prevent it from fleeing should it touch the snake, assuming, of course, that the touch connections are intact. For subhuman mammals, each form of sensory information has relatively direct connections to the limbic system, permitting "recognition" and consequent limbic reaction using visual, tactile, or auditory information. There is

tion. For a discussion of these discrepancies and further clinical evidence see A.R. Damasio and H. Damasio, "The Anatomic Basis of Pure Alexia," *Neurology* (December 1983), pp. 1573-1582.

The first known record of a case like Dejerine's was in 1673. A similar but considerably more complicated case is found in *The Man with the Shattered World* by A.R. Luria, the great Russian neuropsychologist. Here is his patient's description of his discovery that he could no longer read following a war injury:

I went into the hall to look for a bathroom I'd been told was next door. I went up to the room and looked at the sign on the door. But no matter how long I stared at it and examined the letters, I couldn't read a thing. Some peculiar foreign letters were printed there—what bothered me most was that they weren't Russian. When a patient passed by, I pointed to the sign and asked him what it was. "It's the men's room," he replied. "What's the matter with you can't you read?"

He eventually learned to decipher written material "letter by letter, syllable by syllable, word by word." He had virtually no difficulty learning to write normally.

auditory) stimulus and a limbic stimulus [fight, flight, or sexual response]. It is only in man that associations between two non-limbic stimuli are readily formed."

These associations, Geschwind argued, give human beings the capacity for speech. "The ability to acquire speech," he wrote, "has as a prerequisite the ability to form cross-modal associations." In his 1965 paper, he claimed that language was a consequence of the association of two or more kinds of sensory information, for example, the association of the spoken word "dog" with the visual image of a dog. A disconnection between the visual cortex and the limbic system in the monkey explains why it fails to respond to the sight of a snake (though it certainly sees the snake); the disconnection between the visual cortex and the language centers of Broca and Wernicke in Dejerine's patient destroyed his ability to read—though he could see the written words, he could not read them with his eyes. But he could still "read" by using his sense of touch, which was not disconnected from the language centers.

Geschwind's study of disconnection syndromes suggested that psychological capacities such as "recognition" of objects—capacities that many of his contemporaries thought depended on the "entire cerebrum" and could not be divided into subfunctions—were composites of independent brain operations. A

*At a memorial symposium on Geschwind's work at Harvard on May 30, 1985, M. Mishkin noted that recent work indicates that Geschwind may have slightly underestimated the amount of cross-modal association in higher animals.

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man could see an object without recognizing it; and yet he could touch the same object and have no difficulty naming it. A careful study of anatomy and clinical syndromes was beginning to make sense of the work of the classical neurologists that had been ignored for half a century.⁵

The brain's anatomy is therefore related to its functions after all. Since, Geschwind argued, the language centers are generally found in the left hemisphere, and other specialized capacities such as the understanding of spatial relations are found in the right hemisphere, these functional capacities must be reflected in anatomically distinctive features in each of the two hemispheres. The left hemisphere was traditionally called the dominant hemisphere, and Geschwind tried to clarify the ways in which it was functionally primary.

In 1968 Geschwind and Walter Levitsky reported that, on post-mortem examination, sixty-five out of one hundred human brains revealed a left hemisphere larger than the right. For the next fifteen years, Geschwind and a small group of researchers studied the anatomical and physiological differences between the left and the right sides of the brain and their relationship to the functional specializations of the two halves. Much of this work is discussed in *Cerebral Dominance*, a symposium edited by Geschwind and Albert M. Galaburda of Harvard Medical School. In infants, fetuses, and fossil remains dating as far back as Peking man (between 500,000 and 600,000 years ago), the speech centers in the left hemisphere tend to be larger than the same areas in the right hemisphere. There appear to be chemical differences between the two halves of the brain—variations in the amounts and types of neurotransmitters found in the two hemispheres—as well as different patterns of branching in nerve cells.

In *Cerebral Dominance* Geschwind describes his recent studies (with Peter O. Behan) of the striking correlations between left-handedness and certain disorders of the immune system. He suggests that these correlations have clinical implications. Left-handedness, Geschwind argues, may be the consequence of elevated levels of the male hormone testosterone in the fetus during its development in the uterus. We do not know just why testosterone should affect the development of the brain; but Geschwind thought that unusually high levels of this hormone may slow the development of the left hemisphere, allowing the right side of the brain to dominate the language functions, which for most people, as I have noted, are controlled by the left hemisphere. Left-handedness is usually associated with such domination by the right hemisphere.

High levels of testosterone will also slow the growth of the thymus gland, an important part of the immune system, increasing the possibility of immune disorders in later life. This would explain, Geschwind argues, why left-handedness and immune disease are often found in the same person. This bold and contro-

⁵In another study, Geschwind observed that patients subjected to epileptic seizures originating in the temporal lobe, when they were between attacks, often exhibited tendencies to have religious obsessions and to cling to people around them. He suggested that these tendencies may be connected with hyperactivity of the part of the limbic system called the amygdala.

versal attempt to relate immunology, endocrinology, and brain function may yet prove to be Geschwind's greatest contribution to the neurosciences.⁶

Geschwind, then, not only revived but strengthened the empirical and theoretical justification of classical neurological thought. These achievements had to be fully understood and appreciated before further advances in the understanding of the neurological basis of language were possible. But there are important suggestions in his latest published writings in *Dyslexia*, as well as in those of other contributors to the book, that hint at a larger synthesis, going well beyond the classical

⁶For more details see Geschwind's fascinating papers with Albert M. Galaburda, "Cerebral Lateralization," in the *Archives of Neurology*, vol. 42 (May 1985, pp. 428-456; June 1985, pp. 521-552; and July 1985, pp. 634-654).

tradition. Two related lines of thought were beginning to emerge in these writings, which derive from a broader view of the neurological basis of language and which add a new perspective to our understanding of linguistic skills. First, they try to define the skills of reading and writing from a neurological point of view. Second, seeking to understand how these skills developed, they reexamine prehistoric evidence of record keeping and notation going back some 28,000 years.

Geschwind's interest in prehistory was stimulated by the work of Alexander Marshack, who for the past twenty years has studied prehistoric artifacts, including the markings on bones left in caves in France some 28,000 years ago.⁷

⁷See Alexander Marshack's *James Arthur Lecture on the evolution of the human brain* published by the American Museum

Geschwind in his essay in *Dyslexia* called attention to this work. One of the bones found in a cave in the Gorge d'Enfer in southwestern France by the archaeologist Edouard Lartet in the 1860s has a sequential set of markings that, Marshack argued, was probably an early system for noting the phases of the moon. A similar bone of the same size, shape, and date was found nearby at the Abri Blanchard in the 1930s. It has, Marshack wrote, "a non-arithmetic, observational lunar notation covering a period of 2¼ months, with the turns representing the periods of 'turning' in the lunar phases." (See illustration across the page.) Although we know little about human culture during this period,

of *Natural History*, 1985. Marshack's work also attracted the attention of A. R. Luria. I would like to thank Mr. Marshack for his kind assistance in the preparation of this article.

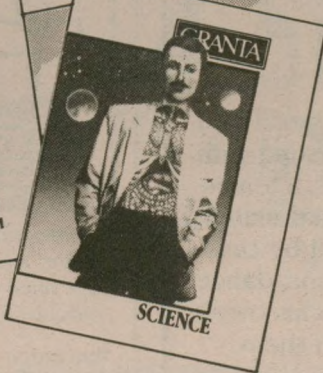


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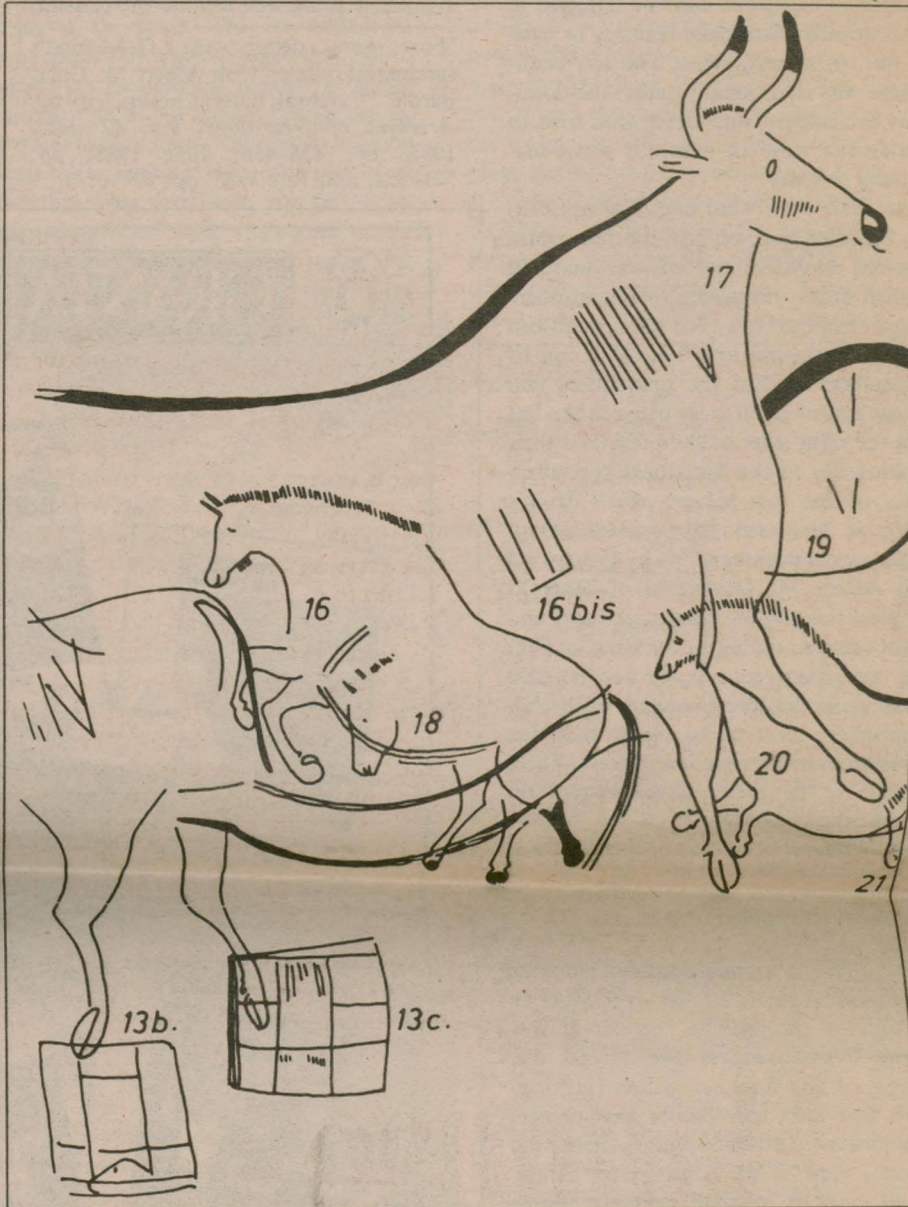
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it seems likely that there was a practice of lunar notation, an early form of writing distinct from the drawing and carving of figures which also existed at that time. On the ceiling of another cave in the Gorge d’Enfer is the carving of a male salmon, probably dating from the same period as the bone.

According to Marshack’s argument, the primitive man who made the markings on the bone was not simply making a serpentine image of phases of the moon. He was using a notational system that required several kinds of skills and information. First, there was visual information—the observation of the phases of

of time. Such notations, then, could be an example of a rudimentary use of syntax, that is, a way of sequentially structuring, or ordering, independent items or notations. Since it is most unlikely that the human brain has undergone any evolutionary changes in 28,000 years, the ability to understand the significance of the turns is probably based on some of the same brain processes and structures as those required for the ability to read. A possible test of this claim would be to see if patients who cannot read because of brain damage would be able to understand the significance of the turns. I suspect that even if the turns were ex-



In the above rendering, the “checkerboard” patterns found beneath the animal paintings in the Lascaux cave are shown at 13b and 13c. The boxes in these patterns are colored red, black, and yellow. According to Alexander Marshack, they were apparently altered over a period of time and could have been meaningful structures whose use by the local inhabitants contained a rudimentary syntax.

the moon. Second, he must have had linguistic information—a description of lunar phases probably circulated in the culture. Third, he used tactile information—the notations vary in depth and shape and required the use of different tools. Finally, he could convey spatial information since the Blanchard notation is sequentially arranged in a serpentine pattern.

The sequential serpentine pattern may have other implications. The “turns” in the serpentine pattern, Marshack writes, “fall at phase points in the presumed observational lunar notation.”⁸ The use of the “turns” to note the points of lunar phase changes suggests that they function as markers separating different periods

⁸See Alexander Marshack’s “The Ecology and Brain of Two-handed Bipedalism: An Analytic, Cognitive, and Evolutionary Assessment,” in *Animal Cognition*, edited by H.L. Roitblat, H.S. Terrace, and T.G. Bever (Lawrence Erlbaum Associates, 1984).

plained to them they would not be able to read them, any more than they could read a written language.

The person who made these lunar notations had the capacity to record the waxing and waning of the moon in a sequential serpentine pattern that has, according to Marshack, a meaning independent of the individual marks that represent the days of the month. The neurological evidence cited by Marshack and Geschwind suggests that the two abilities are separate functions, which depend on quite different areas of the brain. The sequential symbols, or notations, may be a form of protowriting.

Equally remarkable are the strange symbolic structures found alongside the famous paintings in the Lascaux and other caves. In Lascaux, for example, there are red and black “checkerboard” patterns created by members of the Lascaux community. (See illustration above.) Similar patterns are found at several places in the cave and Marshack’s examination of them indicated they

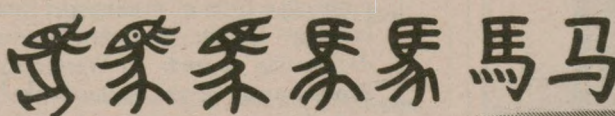
were altered over a period of time. Along the lines of the pattern are a series of scratch marks. While the meaning of these patterns and scratch marks is unknown, the fact that they all appear to represent variant forms of a general pattern suggests, to Marshack, that they are probably symbols that were altered according to certain general rules—an early example of syntactical rules. These symbolic structures could have been produced by those very brain centers that some ten thousand years later, in a different cultural setting, created the earliest known examples of writing.

These discoveries put in doubt the claims of some researchers that writing evolved out of pictorial representation—a claim sometimes justified by the use of pictographs in ancient Egyptian hieroglyphics and a number of Chinese ideograms. The best evidence we have indicates that notational systems and drawing developed at the same time. There may, of course, have been a time when only drawing existed (or only notations), but if this was ever so, evidence for it has yet to be discovered. It is therefore not surprising that when pictures were used in writing they were serving a purpose that had little or nothing to do with their pictorial nature. Egyptian hieroglyphics were finally deciphered in the nineteenth century when Thomas Young and Jean-François Champollion recognized that the “pictures” were phonetic symbols, not a visual form of storytelling. A picture understood as a picture is deciphered by the visual system; a picture used in writing is ultimately deciphered by the language centers. Pictures used in writing represent very different kinds of information from pictures used in drawing. The

马 (馬) Mǎ
horse

馬 is a picturesque representation of a brawny horse rearing. It has since undergone drastic changes, losing eyes and mane. The simplified form reduces it to three masterly strokes: 马—a skeleton horse, advanced in age but rich in experience, inspiring the proverb: “The old horse knows the way.”





马鞍	mǎ ān	saddle	马戏团	mǎ xì tuán	circus troupe
马鞭	mǎ biān	horsewhip	马拉松	mǎ lā sōng	marathon
马车	mǎ chē	horse-drawn carriage	马铃薯	mǎ líng shǔ	potato
马虎	mǎ hū	careless; casual	马不停蹄	mǎ bù tíng tí	nonstop
马上	mǎ shàng	at once; immediately	马到成功	mǎ dào chéng gōng	gain an immediate victory
马戏	mǎ xì	circus	马马虎虎	mǎ mǎ hū hū	careless; just passable

brain makes the distinction depending on what kind of information it is trying to derive from the visual information. When reading the Chinese character for a horse, no one sees that the character vaguely resembles a horse unless the process of reading is halted and the character is studied for its visual qualities. In Chinese, of course, the character is used phonetically in association with other characters to refer to things that have nothing to do with horses (see illustration above).

Clinical evidence also suggests that such pictographs or ideograms are, from a neurological point of view, unrelated to drawings. Geschwind discussed this possibility, and more recent evidence supports his claims. The Japanese use two

writing systems, Chinese ideographs (kanji) and phonetic characters (kana). The kana or phonetic system can be used to represent all the words in the language. However, because of the large number of homonyms, most Japanese writing uses a combination of kana and kanji to avoid ambiguity. Some Japanese patients with brain damage can read the ideographic form but not the phonetic form. In other cases of brain damage, the opposite is true.⁹ Moreover, recent studies have

⁹The ability of Dejerine's patient to read numbers may be related to those Japanese patients who can read kanji but not kana. In 1891 Dejerine wrote the following about a patient who could neither read nor write (“*Sur un Cas de cécité verbale avec agrophie, suivi d'autopsie.*”

shown that the classical language centers of Broca and Wernicke must be intact in order for a patient to be able to read both forms.¹⁰

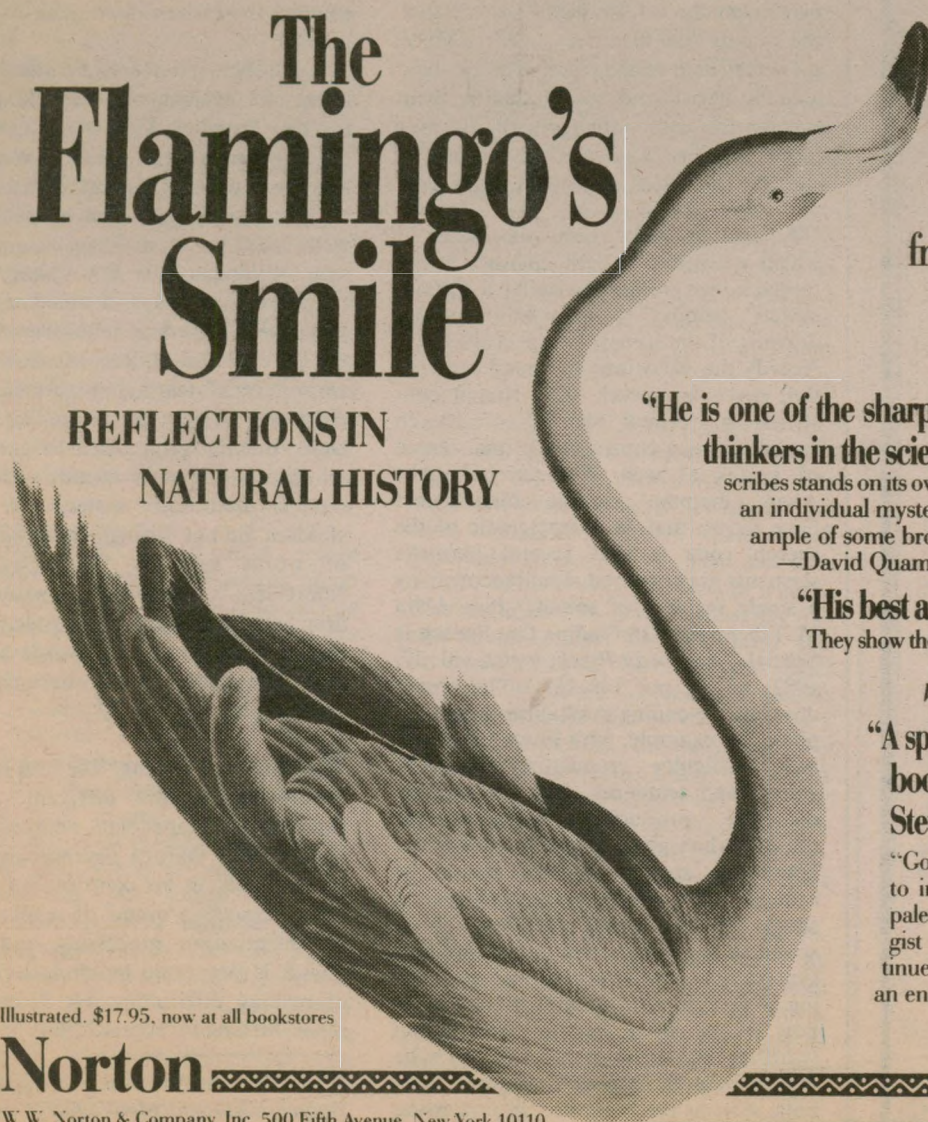
What this evidence seems to show is that even for identical expressions there can be different kinds of linguistic representations, which, because of their intrinsic differences (abstract versus pictorial, for example), are initially processed by the brain in different ways. But ultimately they depend upon the same language centers for translation into their linguistic forms. “Picture languages” are processed as language, not pictures. And

Séances et Mémoires, March 21): “He recognized numbers, on the other hand, as is frequently observed in cases of verbal blindness. We know that Arabic or roman numerals, algebraic equations, etc., as well as one's signature, are equivalent to drawings of objects, and not to letters; we learn to recognize them as conventional signs, and not as collections of letters. A patient stricken with verbal blindness will recognize, for example, the figure 8, but will be incapable of reading the word ‘eight.’” See also Max Coltheart's “Deep Dyslexia: A right Hemisphere Hypothesis,” in *Deep Dyslexia*, edited by Max Coltheart, Karalyn Patterson, and John C. Marshall (Routledge and Kegan Paul, 1980): “Mathematical signs, abbreviations, and punctuation marks are all examples of ideographic writing: but the most common examples are the Arabic numerals. If kanji characters receive privileged treatment in the right hemispheres of Japanese readers, perhaps English ideographs such as Arabic numerals are similarly privileged in the right hemispheres of English readers?”

¹⁰See *Trends in NeuroSciences* (August 1984), pp. 292-294.

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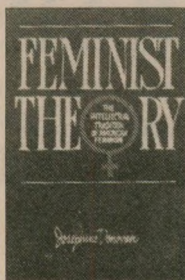
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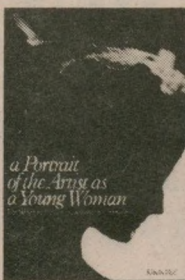
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this was probably true of prehistoric symbolic and notational systems as well. Implicit in Geschwind's last published work is the view that the skills involved in both reading and writing existed in elementary form in prehistoric times.¹¹

Geschwind also believed that neurological capacities for reading and writing were broader than had been thought. He argues, for example, that the comprehension of sign language by deaf people is probably a form of reading and that sign language has its own structure whose deciphering depends on Wernicke's and Broca's areas of the brain in the same way that any written language depends on these areas. In arguing this, Geschwind wanted to emphasize that the symbolic and syntactic structures that make up any language can be expressed and deciphered in a variety of ways—just as Dejerine's patient could trace and understand letters with his fingers, though he could not read them with his eyes.

In his 1965 paper on disconnection syndromes, previously mentioned, Geschwind thought that language resulted from the association of different kinds of information (visual-auditory) within the brain. His discussion of sign language implies that he had moved beyond this view and was beginning to embrace a computational theory of language, though he did not use this term. Today it is widely believed that language is a consequence of neurological computations based on information from a variety of sources. But it is different in kind from the visual, tactile, or auditory information on which it is based and it cannot be explained only by the association of visual and auditory information as Geschwind claimed in 1965.

Isabelle Liberman emphasizes this in her discussion in the symposium on dyslexia. She describes an experiment in which subjects were watching a person talking on a silent television screen. The person on the screen silently articulated the sounds /dee/dee/dee/, while a voice off-screen said /ba/ba/ba/. The subjects actually heard /da/da/da/, taking their cue for the consonant from the lip and facial gestures they saw on the screen and, for the vowel, from the taped voice.

"By analogy with visual processing in which variations in light intensity in the retinal image are used to derive a 'primal sketch' (similar to a two-dimensional drawing of the scene), I suspect the brain records the variations in sound patterns that make up speech—i.e., that it constructs a 'primal sketch' of speech sounds. It may construct a primal sketch of syntax as well. The psycholinguist Alvin Liberman and his collaborators have shown that 'a characteristic of the speech code is that several phonetic segments are conveyed simultaneously by a single segment of sound.' (See Alvin M. Liberman, 'On Finding that Speech Is Special,' *American Psychologist*, vol. 37, 1982, no. 2, pp. 148-167.) The breakdown of the coding mechanism might explain, for example, why Broca's aphasics have difficulty articulating syllables, words, and sentences, and yet have no difficulty producing well-articulated phrases when given external clues about how these speech elements should be ordered (such as the musical line in a song). Writing could therefore correspond to the brain's way of symbolizing syntax and sound structure. Just as drawing is recognizable because of the symbols in the visual system, writing too (whether alphabetic or pictorial) may be understandable because it employs symbolic systems the brain uses in processing language.

If they turned away from the screen they heard /ba/ba/ba/. Though the subjects knew what was happening, they could not avoid the auditory 'illusion.' 'Thus,' Liberman writes, what the 'subjects are perceiving is neither auditory nor visual—it is a linguistic event.' That is, the brain processes auditory and visual information even remotely associated with language in ways significantly different from its capacity to process pure auditory and visual information.

The brain's use of various sources of information in order to compute language is evident in early patterns of learning. Some infants at first imitate the sound patterns, variations in intonation and emphasis, of adult speech. They may become so good at imitating the different intonations that adults may be deceived into thinking that they are hearing actual sentences, though not a word can be deciphered. Since the infant finds that tonal mimicry leads to a response, it tries to produce the kinds of variations it hears in adult speech. The infant's babbling may contain a syntactic structure that the brains of both infants and adults can recognize—a syntax based on sound structures. The traditional division of linguistics into syntax and phonetics may be artificial. The ability to produce sounds that appear to contain words and sentences remains with adults who, for comic and other effects, may produce the equivalent of the infants' babbling sounds. Intonational patterns are an essential element of 'meaning' in adult speech.

Intonational mimicry is followed by the acquisition of syllables and the units of which the syllables are composed. Just as intonational variations are important in the infant babbling stage, Roman Jakobson suggested long ago that contrasts between small units of sound (for example, the sound /b/ that uses the vibrations of the vocal cords as opposed to /p/ or /t/ that do not) and not the sounds themselves are what is being learned.

We see here a sequence by which acquisition of language goes from the general to the specific: infants first acquire general abilities to imitate intonations; and the pattern of general to specific can be seen in the acquisition of meaning as well. As Geschwind wrote, 'comprehension of language is not unitary'—i.e., there are many ways of understanding a language. According to observations by the psychologist Arlene Moskowitz, the word 'clock' learned in reference to a particular object was, in the case of one child, quickly generalized to encompass all objects that were round, such as gas meters, bathroom scales, etc. Other children did not distinguish between pairs of words such as 'before/after' or 'more/less.' As Moskowitz wrote, 'children acquire first the part of the meaning that is common to both words and only later the part of the meaning that distinguishes the two.'¹²

Reading and writing, like oral language acquisition, require different, and to some extent independent, neuronal mechanisms. The Oxford psychologist, John C. Marshall, in his contribution to *Dyslexia*, presents a model of reading based on information processing and shows how it is supported by clinical examples of reading difficulties. He distinguishes three different 'routes' that could be

¹²See 'The Acquisition of Language' by Breyne Arlene Moskowitz, *Scientific American* (November 1978).

used to assign a linguistic structure to visualized written words: a route based on the sound of words (the phonetic route), a route based on seeing the word as a unit (the direct route), and a route based on the meaning of words (the lexical route). Marshall's work with brain-damaged patients shows why confusions about meaning arise when the various routes are not in perfect order.

Words may, for example, be read only phonetically (the phonic route) by such patients. One brain-damaged war veteran interpreted "listen" as a reference to the boxing champion Sonny Liston. "Billed," which he read correctly, he thought meant "build." Spelling failed to give this patient the essential clues about the different meanings of homonyms: he read the word "pair" correctly and remarked, "It's either two of a kind or it's the one for eating. I don't know which." And pronouncing the *s* in "island" he concluded, "It doesn't mean anything... there's no such word."

By contrast, brain-damaged patients who used the lexical route for analyzing words showed an ability to comprehend words without being able to read them aloud. Marshall gives the following examples: "sick" was read as "ill"; "bush" read as "tree"; "act" read as "play"; "ancient" read as "historic"; and "tall" read as "long." Some of these difficulties recall the infant's tendency to overgeneralize, as in the case of the patient who read "chair" as "table" and "down" as "up."¹³

These examples show how, with the breakdown of specific functional units—Marshall's routes, which the clinical evidence suggests have a neurological basis—the understanding of words and sentences may become abnormal. Yet normal people will probably find some "sense" in these linguistic failings as, for example, when "chair" is read as "table."

Much of what we observe in language disorders caused by brain damage is probably part of the normal process for deriving meaning from symbols, words, and visual information. Because some mechanisms are destroyed or disconnected, the brain has less of a choice in establishing suitable meanings in a given situation. By highlighting such mechanisms, brain damage gives important clues about how we derive meaning and understanding. Reading "up" as "down" is inappropriate when looking for the elevator that will go up to the eleventh floor. But it may matter less when reading the instructions on a pump: "move handle up and down." Understanding how these words are related is probably based on a neurological mechanism that classifies them together (as in the case of "before/after", etc., in children) for their common elements. The brain seems to derive meanings in many different ways,

¹³Children with a condition called hyperlexia can easily read words aloud without real comprehension. This may be analogous to the infant's mimicry of the intonational contours of adult speech. Note the following description in Herman K. Goldberg and Gilbert B. Schiffman's *Dyslexia: Problems of Reading Disabilities* (Grune, 1972): "It was recorded that these children read as early as three years of age. They were quite compulsive in their reading and were able to read fifth grade to seventh grade materials. Not only could they read English but they were adept in reading other languages. Their IQs were within normal range. From their histories, it was noted that they would make a habit, early in life, of reading posters and television commercial advertisements. They had taught themselves by phonetic ability to read far beyond their intellectual capacity."

deciding which possibilities are most appropriate in a given set of circumstances. Through some unknown procedure it then picks the most appropriate sense, always ready to switch to another choice should this prove inappropriate. Often in casual conversation we offer explanations with great confidence. Our listener responds with a damaging fact and we quickly drop our explanation, giving in its place a new one with the same confidence with which we proposed our original explanation. Similar processes probably go on unconsciously.¹⁴

Our understanding of the biological basis of language has come from a long series of clinical studies that go back to the nineteenth century. It is part of the legacy of Norman Geschwind that he helped put order into a field that until the 1960s was enormously confused and lacking in direction. He justified the relevance of the older work for contemporary neurology. In his attempt to relate brain function to anatomy and physiology he recognized that no simple relation exists: similar instances of behavior may have very different causes (as with the varieties of reading disabilities), and apparently unrelated kinds of behavior (sign language and reading) may have very similar neurological mechanisms. Geschwind's work on "disconnection syndromes" has become central to modern neurology. His more recent suggestions relating endocrinology, immunity, and left- and right-handedness, while still speculative, may have deep implications for explaining the connection between mental and physical development. The new approaches he pioneered may one day clarify the neurology of language and meaning. By forcing us to reexamine the lessons of fifty and one hundred years ago, Geschwind changed our understanding of the nervous system and the mind. □

¹⁴The late David Marr, in his pioneering book on the visual system, explained the process of selection as follows:

Given the description, "The fly buzzed irritatingly on the windowpane. John picked up the newspaper," the immediate inference is that John's intentions toward the fly are fundamentally malicious. If he had picked up the telephone, the inference would be less secure. It is generally agreed that an 'insect-damaging' scenario is somehow deployed during the reading of these sentences, being suggested in its coarsest form by the fly buzzing irritatingly. Such a scenario will contain a reference to something that can squash an insect on a brittle surface—a description that a newspaper fits, but not a telephone.

"We might therefore conclude that when the newspaper is mentioned (or, in the case of vision, seen) not only is it described internally as a newspaper and some rough 3-D [three dimensional] model description of its shape and axes set up, but it is also described as a light, flexible object with area. Because the second sentence might have continued 'and sat down to read,' the newspaper must also be described as reading matter; similarly, it must also be described as a combustible article, as something that rustles, and so forth. Since we do not usually know in advance what aspect of an object or action is important, it follows that most of the time a given object will give rise to several different coarse internal descriptions.

"Similarly for actions. It may be important to note that the description of fly swatting or reading or fire lighting does not have to be attached to the newspaper—a description of the newspaper is merely available that will match its role in each scenario." (*Vision*, W.H. Freeman, 1982, p. 358).



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