CHAPTER

5

Interpreting Words

Through words we perceive the intentions of others as well as compose and express our own thoughts. The use of words in language is a remarkable human skill that, once developed, functions in an effortless manner for most of us. Because we use our native language with such ease, we easily overlook its importance in our everyday lives. This nonchalance quickly changes when we journey to a country where the language is unfamiliar, and we are forced to rely on a variety of crude, laborious measures to communicate even our simplest needs. Occasionally, we are also faced with the tragic and revealing consequences of brain injury, when a stroke deprives a friend of full language comprehension and meaningful communication.

The manner in which language skills are acquired and organized in the human brain has been the subject of intense investigation for more than a century. Neurosurgeons, neurologists, and neuropsychologists have contributed to our understanding through their studies of patients whose use of language has been impaired by disease, usually a stroke that injures particular areas of the brain. Cognitive scientists, somewhat independently, have examined in detail the component mental operations necessary for language by studying the behavior of normal subjects. Collectively, a great deal has been learned.

Missing from the study of language development and organization until recently has been the ability to study the normal human brain. A combination of modern functional brain imaging techniques and experimental strategies from cognitive science has now remedied this deficiency. Scientists today are able to explore the intriguing question of how language is actually organized in the normal human brain.

This book actually began the process of exploring language organization in the human brain in Chapter 3, where we presented the way in which our brains respond passively to visually presented, familiar words. In this chapter and the next, we will move forward to the semantic dimension: we examine what transpires in our brains that enables us to interpret the meaning of words and, in turn, to express meaning through the use of words. One promise of work in this area is that it will ultimately give us a better understanding of dyslexia and other neurological and psychiatric disorders that involve language and higher thought.

NEUROLOGICAL MODELS

Language has had the longest history of study within neurology of any cognitive system. The idea that distinct areas of the human cortex perform different functions began in earnest with the work on language of Pierre Paul Broca. Born in the Bordeaux region of France, he graduated in medicine from the University of Paris and worked initially in surgery. Gradually his interest shifted from that field to anthropology and ethnography. In 1859 he founded the *Société d'anthropologie* and the *Revue d'anthropologie*.

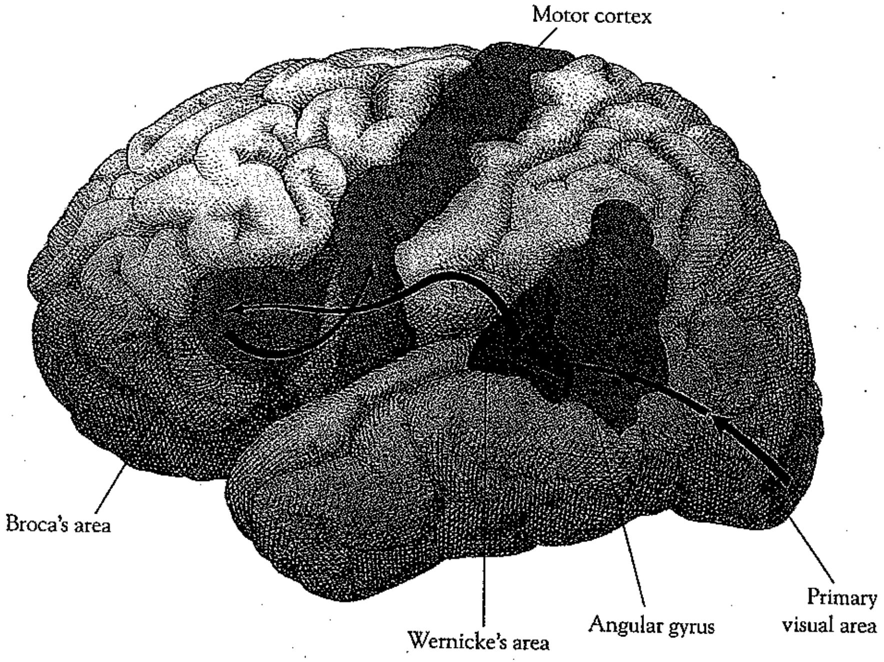
In a presentation before the *Société d'anthropologie* in Paris on April 18, 1861, Broca read a report on a patient named Le Borgne who had lost the ability to speak. The hospital staff called the patient "Tan" because "tan" was the only word he could utter. After Le Borgne's death on April 17, 1861, his left frontal lobe was found to have a lesion, the almost certain cause of Le Borgne's symptoms. Broca made his historic report to the *société* the next day! He called the damaged area the *circonvolution du language*, a designation that later gave way to the term "Broca's area," which is still in use today. Patients who exhibit difficulty speaking due to a lesion in this area are often said to have Broca's aphasia.

Broca's proposal that language was localized in the cerebral cortex initially received a mixed reception. The great English neurologist John Hughlings Jackson was particularly opposed to the idea. At a now historic session of the British Association for the Advancement of Science held in Norwich in 1868, the audience's enthusiastic support of Broca's view, coupled with their indifference to Jackson's part in the discussion, was a personal triumph for Broca. From that time on his basic idea of localization of function dominated research on the cerebral cortex.

Broca's views also received support in 1874 when the German neurologist Carl Wernicke published a small but highly influential book on aphasia, *Der aphasische Symptomenkomplex*. Wernicke had observed various language disturbances in patients with small lesions of the cerebral cortex. In his book, he interpreted these disturbances as the consequences of impairments of various elementary mental operations, which were carried out in different parts of the cortex. In the course of his studies, he described, for the first time, a condition that he termed sensory aphasia. Individuals afflicted with this condition, usually as the result of a stroke, had profound difficulty comprehending spoken language. The area of the brain usually damaged was on the left side where the temporal and parietal lobes meet. This area has come to be known as Wernicke's area.

Following the lead of Broca and Wernicke, neurologists active at the turn of the century such as Ludwig Lichtheim developed diagrams of information flow within the brain. These diagrams showed the path of information processing leading from visual and auditory reception areas near the back of the brain to motor areas near the front; the diagrams indicated the relationships between these brain areas and such linguistic activities as writing, reading, and speaking. The neurological diagram makers described the

Geschwind proposed this anatomical model showing the successive participation of several brain areas as a person speaks a written word.



Neurological model:- Serial
- reflexive (bottomup)
- fixed.
- Assumes phono code → semantic code.

Cog models:- //
- top down influence
- flexible
- Allows semantic access w/o phono access

processing of individual words as being largely serial and reflexive, or what we have called "bottom up." That is, when a stimulus word was presented to a subject, the processing of the word proceeded in a somewhat rigidly predetermined set of steps through a fixed set of processing stations.

The work of the late Norman Geschwind nicely summarizes the ideas of this neurological school. His work provides a precise account of the pathways through the cerebral cortex involved in reading words aloud and repeating words aloud. These ideas have been embodied in anatomical models of language that are still taught in many medical schools.

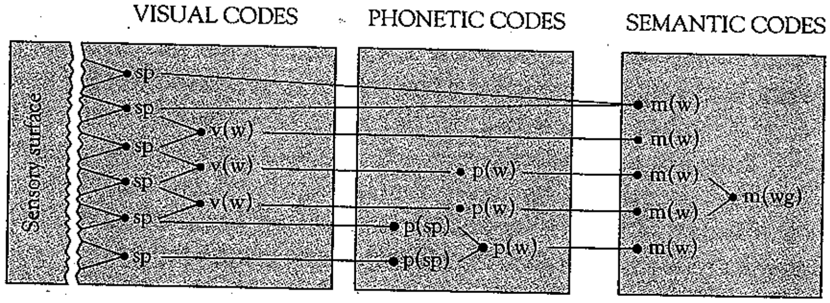
These neurological models have been important in guiding thinking about language mechanisms in the brain, and they are consistent with the observed deficits in patients with brain injury. The models are lacking, however, because they provide for little flexibility in the brain's processing of language. The performance of normal subjects in experiments indicates considerable flexibility in language-processing strategies, which may be parallel as well as serial. In addition, the neurological models tell us little about how top-down processes such as attention and our understanding of words might influence language processing. The work of recent decades in cognitive science provides some important insights into how to think about such issues.

COGNITIVE MODELS

When we hear a word spoken or see a word on the page, what happens to allow us to interpret its meaning? It seems clear that some matching process takes place, in which the stimulus (the word seen or heard) triggers our memories of that word, a process called lexical access. The study of lexical access is one of the most active areas of cognition.

What exactly is it about a word, whether seen or heard, that triggers a memory or, in other words, that leads to lexical access? Many of the early cognitive studies of lexical access can be summarized by a cognitive flow diagram developed by psychologists David LaBerge and Jay Samuels, then at the University of Minnesota, in 1974 and shown on this page. According to their summary, a visually presented word is analyzed by the brain in terms of several different and independent types of mental representations, what psychologists refer to as codes. Three general categories of mental representations or codes can be easily identified—the visual, the phonological, and the semantic.

Subjects mentally use these codes to answer a variety of questions concerning particular words, as we described with our example of the word "pint" in Chapter 1. Subjects can consider visual aspects of the word (e.g., whether some of the letters of "pint" ascend above the others), phonological aspects (whether "pint" rhymes with "lint"), or semantic aspects (whether a pint



LaBerge and Samuels constructed this diagram, showing the logic of information flow in reading, in 1973 from a variety of cognitive studies. The model begins with the visual orthographic code (sp) on the left. From there the representation can be converted to the visual word form (v(w)), or it can take the pathway outlined in red, which contacts the phonological orthographic code (p(sp)) and then the phonological word form (p(w)). Or, it might even proceed directly from the orthographic code to the semantic code for a single word (m(w)), as in the blue pathway.

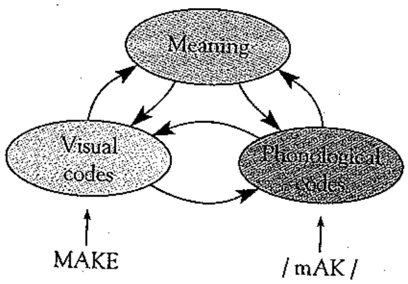
is less than a quart). In each instance, a different mental representation or code of the word "pint" is used in arriving at the appropriate answer.

Visual code: %in – feature code
– letter code
– ortographic code
(regularity).

Each of these three codes can be subdivided into "subcodes" that represent more detailed aspects of the word. For example, the visual representation of a word can be subdivided into feature codes representing the orientation of lines of varying lengths that serve to form letters; letter codes (both upper- and lowercase) representing the highly specific arrangements of lines that we have learned to recognize as the building blocks of words; and more generalized orthographic codes that capture the regularity of letter order within the word. For example, the nonword TWEAL would be recognized as an arrangement of letters that behaves according to the pronunciation rules of the English language (i.e., the letters are "orthographically regular"), whereas the consonant letter string LTZMG would not. This orthographic code is insensitive to the case or font of the letter (e.g., TWEAL is handled just like tweal) as though the code were an abstract visual representation that includes different fonts and letter cases within the same visual word form. The final visual code is the visual word form, the entire word perceived as a single unit. Similar subdivisions are made in the phonological representations of words.

Although the model diagrammed on the previous page looks serial, it is actually highly parallel. Many pathways within the visual code can be activated in parallel as well as serially; that is, the brain can process multiple visual features at once. For example, it can recognize several letters simultaneously. Moreover, once activated, pathways from visual codes can contact representations in phonological and semantic codes simultaneously as well as serially. For example, using this model one may think of two ways in which the meaning of a word can be analyzed. One is for the visual representation to be converted into a phonological representation before the codes for meaning are accessed. In this case, words would be internally sounded out, or phonologically recoded so to speak, before their meaning could be understood. It is of interest that, since the time of Carl Wernicke, the neurological models have largely assumed that visual word forms only have access to semantic codes via phonological recoding.

Alternatively, the cognitive models have held that there is also a direct route from visual to semantic codes. Whether semantic codes are directly accessed by visual word forms or accessed only through the mediation of phonological coding has been one of the most investigated questions in the study of reading.



A highly simplified model of the type implemented on computers, showing reciprocal connections involved in processing single visual and auditory words.

More recently, models of word processing have been implemented on computers. These models extend the LaBerge and Samuels cognitive model by emphasizing reciprocal rather than one-way connections between levels of information processing. Thus, the models allow for both bottom-up and top-down processing. An example of a very general model produced by the newer theoretical approach comes from the work of Jay McClelland of Carnegie Mellon University and Mark Seidenberg of the University of Southern California. Like the earlier cognitive models, it proposes levels of visual and phonological coding; the codes include features, letters, and words, in both their visual and auditory forms. And, like the earlier cognitive models, it suggests pathways from code to code that would be followed to achieve lexical access, so that a word could be connected to its meaning. Unlike the earlier models, however, it states that the codes at each level of analysis are joined together by reciprocal connections: information from higher levels acts in a downward direction on the coding process at lower levels, as well as the reverse. Thus, the visual and auditory word form at the word level can be activated either by external stimulation, as when we read or hear a word, or in a top-down manner by internal signals from the semantic code. It can even be activated by both external and internal stimulation. Given as input an external stimulus such as a word or an internal stimulus such as a meaning, a computer can be programmed to compute the representation at each level of the model, following the reciprocal, parallel connections among the codes.

This theoretical network can be used to simulate and thereby better understand behavior observed in subjects that could not be explained by earlier cognitive models featuring one-way, bottom-up connections, like the model of LaBerge and Samuels. For example, studies of visual word processing show that a letter is recognized more quickly if it falls within a real word rather than within a group of letters not forming a word. This is known as the word superiority effect. One way to demonstrate the word superiority effect is to flash briefly a string of letters on a screen and ask the viewer if the final letter is a "D" or a "K." The responses are faster and more accurate when the letters spell a word ("WORD") than when they do not ("OWRK"). From the usual bottom-up view of word processing, in which letters feed information to higher systems, this finding seems inexplicable. However, when the system allows top-down information from stored words to affect the activation of the letters, the word superiority effect results quite naturally.

Similarly, if one removes a phoneme from an auditory word and replaces it with white noise, what is often heard is the correct word with a burst of noise superimposed. Once again, the activation of higher-level codes appears to restore the missing phoneme in a top-down manner. Top-down processing also explains an unexpected ability of patients with damage to the right parietal lobe: although they have lost the ability to report the left side of nonwords, they are nevertheless able to read words that occupy the same space (a subject we discussed in Chapter 2). Presumably information in higher-level codes is conveyed to the visual code, allowing these patients to treat the letters of a word as a unit even when some of the components are missing.

Although both the cognitive and the neurological models of language processing have reached an advanced state, many questions remain about the actual state of affairs in the human brain. Despite years of research, the cognitive and neurological models have not converged on a single explanation of language processing. The neurological models are largely serial and reflexive, whereas the cognitive models employ a strongly parallel architecture that allows for top-down as well as bottom-up processing of words. As a result, cognitive and neurological models do not agree on whether it is really necessary to convert the visual representation of a word or group of words into its corresponding phonological representation before meaning can be extracted. The neurological models generally say this step is necessary; many cognitive models say it is not. Regardless of when semantic codes are accessed, it is not clear where they are represented in the brain. Do they reside somewhere in the posterior reaches of the left temporal lobe as Carl Wernicke suggested over one hundred years ago? Or are they represented in more complex networks of several areas as typically proposed by cognitive models? These and other questions require access to the functional architecture of the normal human brain. Functional brain imaging with PET is now providing that access.

STUDIES OF LEXICAL ACCESS

In 1988, with colleagues Steve Petersen, Peter Fox, and Mark Mintun, the authors of this book began a series of studies that used PET scans in an attempt to learn more about language organization in the human brain. The initial study examined the seemingly simple task of giving an appropriate