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Visual Word Recognition

The goal of research on visual word recognition is to understand the kinds of capacities that underlie the rapid and almost effortless comprehension of words in READING, how these capacities are acquired, and the impairments that occur developmentally and following brain injury (DYSLEXIA). Visual word recognition has also provided a domain in which to explore broader theoretical issues concerning knowledge representation, learning, perception, and memory; for example, it played a significant role in the development of both modular (MODULARITY OF MIND) and connectionist (COGNITIVE MODELING, CONNECTIONIST) approaches to cognition.

Studies of EYE MOVEMENTS in reading indicate that most words are fixated once for durations ranging from 50 to 250 ms. Short function words are sometimes skipped and longer words may be fixated more than once. Word recognition speeds vary depending on reading skill, the type of text, and how carefully it is being read; large increases in reading speed can only be achieved with significant loss of comprehension, as in skimming. The main bottleneck is perceptual: the perceptual span is approximately four letters to the left of fixation and fifteen to the right when reading from left-to-right (it is asymmetrical to the left in reading languages such as Hebrew). Letter identities can be determined only over a smaller range, approximately five to six letters; further from fixation only letter shape and length are perceived (Pollatsek and Rayner 1990).

A long-standing issue for reading researchers and educators is whether words are recognized on a visual basis or by first computing a phonological representation (see PHONOLOGY). Using visual information might seem to be more efficient because it involves a direct mapping from spelling to meaning; using phonology (translating from orthography to phonology to meaning) involves an extra step. However, a compelling body of research suggests that skilled readers compute phonological information as part of the recognition process (e.g., Van Orden 1987). Studies of learning to read have also highlighted the important role of phonological information (Wagner and Torgesen 1987). The quality of prereading children's knowledge of the structure of spoken language is a good predictor of later reading skill; children who are good readers are better able to translate from spelling to sound; and many dyslexic persons exhibit minor deviations in their representation of spoken language that disrupt reading acquisition (e.g., Bradley and Bryant 1983). Despite this evidence, reading education in most English-speaking countries attempts to discourage children from using phonological information on the mistaken view that it discourages reading efficiency. There is also strong evidence that learning to read an orthography has a reciprocal impact on phonological representation (Morais et al. 1986).

One barrier to using phonology in reading English and many other writing systems would seem to be the quasi-regular (Seidenberg and McClelland 1989) character of orthographic-phonological correspondences: most words can be pronounced "by rule" (e.g., *gave, mint*) but there are many exceptions that deviate from the rules in differing degrees (e.g., *have, pint*). This observation led to the development of "dual-route" models in which there are separate mechanisms for reading rule-governed words and exceptions (Coltheart 1978). Connectionist models provide an alternative approach in which a single network consisting of distributed representations of spelling, sound, and meaning is used for all words. Such networks can encode both "rule-governed" forms and "exceptions," while capturing the overlap between them. Whereas the older models involved parallel, independent visual and phonological recognition pathways, connectionist models permit continuous pooling of information from both sources until a word's meaning has been computed.

Research on WRITING SYSTEMS organized along different principles (see papers in Frost and Katz 1992) suggests that there may be more commonalities in how they are read than the differences among them might otherwise suggest. One major difference among writing systems is in how transparently they represent phonological information. For example, whereas the pronunciations of orthographic patterns in Finnish and Serbo-Croatian are highly predictable, many English words are irregularly pronounced, and the nonalphabetic Chinese writing system provides only partial cues to pronunciation. These differences have often led to suggestions that one or another writing system is optimal for learning to read. Writing systems exhibit trade-offs among other design features, however, that tend to level the playing field (Seidenberg 1992). For example, English has many irregularly pronounced words but they tend to be very short and to cluster among the highest-frequency words in the language; hence they are likely to be easy to learn and process. Serbo-Croatian is more transparent at the level of letters and phonemes but there are few monosyllabic words and there is also a complex system governing syllabic stress. The pronunciations of words in Hebrew can be reliably predicted from their spellings except that the vowels are normally omitted. Studies of reading acquisition in different writing systems do not suggest large differences in the average rate at which children learn to read.

A major unresolved issue concerns the role of subword units such as syllables and morphemes (see MORPHOLOGY) in word recognition. Does reading a word such as *farmer* involve parsing it into the morphemes [farm] + [er] or merely using orthographic and phonological information? Although several studies have provided evidence for lexical decomposition, the extent to which it occurs in reading is not known. Any decomposition scheme runs up against what to do with cases like *corner* or *display,* which appear to be morphologically complex but are not. Connectionist models have also begun to provide an alternative account in which morphological structure reflects an emergent, interlevel representation mediating correlations among orthography, phonology, SEMANTICS, and aspects of grammar.

Other research has addressed how readers determine the meanings of words and integrate them with the contexts in which they occur. Words in texts tend not to be very predictable, which makes using context to guess them an inefficient strategy. The computation of a word's meaning is nonetheless constrained by context, as is clearly the case for ambiguous words such as *rose* and *plane* but also relatively unambiguous words such as *cat.* For example, in a sentence about petting, the word *cat* may activate the feature <fur>; in a context about getting scratched, *cat* will activate <claws> (Merrill, Sperber, and MacCauley 1981).

Impairments in word recognition are characteristic of developmental dyslexia. Dyslexia is often associated with phonological impairments that interfere with learning the relationship between the written and spoken forms of language (Liberman and Shankweiler 1985). In other cases, dyslexic persons have normal phonology but are developmentally delayed: they read like much younger children. This delay may reflect impoverished experience or other deficits in perception or learning (Manis et al. 1996).

Dyslexia also occurs as a consequence of neuropathologic discorders such as Alzheimer's disease or herpes encephalitis. Three major subtypes have been identified: phonological dyslexia, in which the main impairment is in pronouncing novel letter strings such as *nust;* surface dyslexia, in which the main impairment is in reading irregularly pronounced words such as *pint;* and deep dyslexia, in which the patient makes semantic paraphasias such as pronouncing *sympathy* "orchestra" (Shallice 1988). Current research focuses on using computational models of normal word recognition to explain how these patterns of impairment could arise (see MODELING NEUROPSYCHOLOGICAL DEFICITS). For example, connectionist models of normal performance can be "lesioned" to create the reading impairments seen in several types of patients (Plaut et al. 1996). A growing body of neuroimaging evidence is beginning to clarify how the representations and processes specified in these models are realized in the brain.

See also CONNECTIONIST APPROACHES TO LANGUAGE; MAGNETIC RESONANCE IMAGING; POSITRON EMISSION TOMOGRAPHY; SPOKEN WORD RECOGNITION

—Mark Seidenberg

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Further Readings

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von Neumann, John

John von Neumann was born in Hungary in 1903 and died in the United States in 1957. He was without doubt one of the great intellects of the century, and one of its most distinguished mathematicians. At the time of his death he was a member of the Institute for Advanced Study, at Princeton, New Jersey.

Von Neumann's scientific interests were very broad, ranging through mathematical logic, automata theory and computer science, pure mathematics—analysis, algebra and geometry, applied mathematics—hydrodynamics, meteorology, astrophysics, numerical computation, game theory, quantum and statistical mechanics, and finally to brain mechanisms and information processing. In addition von Neumann was heavily involved in the Manhattan Project both at the University of Chicago and at Los Alamos. After World War II he became a member of the Atomic Energy Comission, and of course he was a key figure in the early U.S. development of general purpose digital computers.

So far as the cognitive sciences are concerned, von Neumann's main contributions were somewhat indirect. Together with Oscar Morgenstern he developed a mathematical model for GAME THEORY that has many implications for human cognitive behavior. He also published two papers and one short monograph on AUTOMATA theory and related topics.

The first paper, published in the 1951 proceedings of the Hixon Symposium, was entitled "The General and Logical Theory of Automata." In it von Neumann introduced what are now known as cellular automata, and discussed in some detail the problem of designing a self-reproducing automaton. In some ways this is a remarkable paper in that it seems to anticipate the mechanism by which information is transmitted from DNA via messenger RNA to the ribosomal machinery underlying protein synthesis in all pro- and eukaryotes. Of more relevance for cognitive science was von Neumann's analysis of the logic of self-reproduction, which he showed to be closely related to Gödel's work on metamathematics and logic (see GÖDEL'S THEOREMS and SELF-ORGANIZING SYSTEMS). His starting point was MCCULLOCH and PITTS's ground-breaking work on the mathematical representation of neurons and neural nets.

The McCulloch-Pitts neuron is an extremely simplified representation of the properties of real neurons. It was introduced in 1943, and was based simply on the existence of a threshold for the activation of a neuron. Let $u_i(t)$ denote the state of the ith neuron at time t. Suppose $u_i = 1$ if the neuron is active, 0 otherwise. Let $\varnothing\,[v]$ be the Heaviside step function, $= 1$ if $v \geq 0$, 0 if $v < 0$. Let time be measured in quantal units Δt, so that $u(t + \Delta t) = u(n\Delta t + \Delta t) = u(n + 1)$. Then the activation of a McCulloch-Pitts neuron can be expressed by the equation:

$$u_i(n+1) = \varnothing[\Sigma_j w_{ij} u_j(n) - v_{TH}]$$

where w_{ij} is the strength or "weight" of the $(j \to i)$th connection, and where v_{TH} is the voltage threshold. Evidently activation occurs iff the total excitation $v = S_j w_{ij} u_j(n) - v_{TH}$ reaches or exceeds 0.

What McCulloch and Pitts discovered was that nets comprising their simplified neural units could represent the logical functions AND, OR, NOT and the quantifiers $\forall$ and $\exists$. These elements are sufficient to express most logical and mathematical concepts and formulas. Thus, in von Neumann's words, "anything that you can describe in words can also be done with the neuron method." However von Neumann also cautioned that "it does not follow that there is not a considerable problem left just in saying what you think is to be described." He conjectured that there exists a certain level of *complexity* associated with an automaton, below which its description and embodiment in terms of McCulloch-Pitts nets is simpler than the original automaton, and above which it is more complicated. He suggested, for example, that "it is absolutely not clear a priori that there is any simpler description of what constitutes a visual analogy than a description of the visual brain." The implications of this work for an understanding of the nature of human perception, language, and cognition have never been analyzed in any detail.

In his second paper, "Probabilistic Logics and the Synthesis of Reliable Organisms from Unreliable Components," published in 1956 (but based on notes taken at a lecture von Neumann gave at CalTech in 1952), von Neumann took up another problem raised by McCulloch, of how to build *fault tolerant* automata.

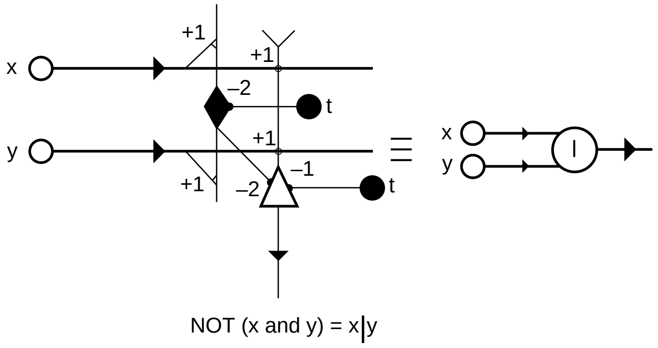

Figure 1. McCulloch-Pitts neurons. Each unit is activated iff its total excitation reaches or exceeds 0. For example, the first unit is activated iff both the units x and y are activated, for only then does the total excitation, $(+1)x + (+1)y$ balance the threshold bias of –2 set by the threshold unit, *t*, whenever both *x* and *y* equal +1 (activated). The *t*-unit is always active. The numbers (±1), etc. shown above are called "weights." Positive weights denote "excitatory" synapses, negative weights "inhibitory" ones. Similarly, open circles denote excitatory neurons; filled circles, inhibitory ones.