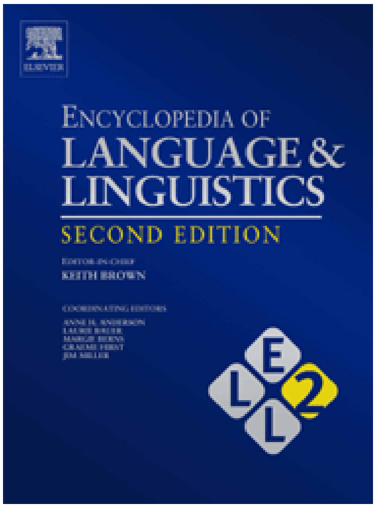

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a comprehensive statement of order. Currently, ways of doing this are being elaborated, which assign a relative weighting to each of the possible orderings and specify how conflicting tendencies defining mutually exclusive linearizations are likely to be resolved within individual languages and across languages. This line of research represents the first serious attempt to integrate syntactic, semantic, and pragmatic aspects of order within specific models of grammar and therefore, in view of the far from satisfactory treatment of word order in modern grammatical theory, undoubtedly, is a step in the right direction.

See also: Categorial Grammars: Deductive Approaches; Greenberg, Joseph H. (1915–2001); Lexical Functional Grammar; Word Grammar.

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Word Recognition, Written

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What are the processes that the brain engages in when making the journey from a visual input of intersecting lines and curves to making contact with meaning? This question has stimulated considerable research since the days of Cattell (1886), generating findings that inform not only psycholinguistics but also domains as diverse as computational modeling (Plaut *et al.*, 1996; Coltheart *et al.*, 2001), automatic and attentional processes (Neely, 1977), pattern recognition (Selfridge and Neisser, 1960), and the neural substrates of language processing (Petersen *et al.*, 1988). Research at the word level is particularly tractable and revealing as words are well-defined units that can be analyzed and processed at various levels (i.e., spelling, sound, grammar, meaning; Balota, 1994).

How Is Word Recognition Studied?

There are many procedures that researchers have developed to study the processes involved in word recognition. For example, in perceptual identification, words are visually degraded by masking or brief presentations, and subjects are asked to identify them, with identification accuracy being the dependent measure. In eye-tracking studies, subjects' eye movements (e.g., fixation, location, and duration) are tracked as they read text. In semantic categorization tasks, subjects are asked to classify words (e.g., is *dog* an animal?), with response latency and accuracy being the dependent measures. In neuroimaging studies, inferences about the processes involved in word recognition are made from on-line measures of the time course and location of neural activity via event-related potentials, positron emission tomography, or functional magnetic resonance imaging. Researchers also study individuals with isolated disruptions in reading (specific subclasses of dyslexia) to better understand normal reading.

Although each of these approaches has benefits, there are also some costs (see Balota *et al.*, 2004). Hence researchers continue to rely most heavily on two relatively simple tasks (lexical decision and naming) to study isolated word recognition. In speeded lexical decision, subjects are presented with either a real word or a nonword (e.g., *flirp*), and they are required to make the word/nonword discrimination as quickly and as accurately as possible. In speeded naming, words (and occasionally nonwords) are visually presented to subjects and their task is to pronounce the words aloud as quickly and accurately as they can. For both tasks, researchers are primarily interested in how quickly people name words or make lexical decisions across different experimental conditions, with the assumption that naming and lexical decision latencies reflect processes involved in accessing lexical representations (Seidenberg, 1990).

Clearly, no single task or method can fully capture the dynamics of lexical processing. A word recognition task measures both lexical processes and operations specific to that task. For example, the lexical decision task is sensitive to discrimination processes that are independent of lexical identification (Balota and Chumbley, 1984). Similarly, naming latencies are heavily influenced by a word's initial sound (Kawamoto and Kello, 1999). Consequently, there is a growing consensus that reading processes are best understood by considering converging evidence across multiple experimental paradigms (Jacobs *et al.*, 1998).

Models of Word Recognition

Many models have been proposed to explain how word recognition takes place (see Jacobs and Grainger, 1994 for a review). One of the earliest models proposed was the logogen model (Morton, 1970), which posits a word detector (logogen) for every word in the reader's lexicon. Each logogen possesses some resting level of activation, and when a word is presented, the logogen for that word accumulates evidence until some threshold is reached. At this juncture, word recognition takes place.

Using the logogen framework as a foundation, McClelland and Rumelhart (1981) developed a very influential computational model of letter and word recognition. The interactive activation model (IAM) contains three processing levels (visual, letter, word), with respective units within each level represented by a node (Figure 1). A visual input first stimulates feature-level nodes, which send activation to letter-level nodes, and on to word-level nodes (which correspond to logogens). Over time, each node reflects the activation spreading across the units, and one can test the effect of a variable by inspecting the value of a node after a given amount of time has passed. The IAM accounts for many findings in the literature. For example, the finding that people recognize frequently encountered words (*world*) more rapidly than rarely encountered ones (*glitch*), the word frequency effect, is reflected by the fact that high-frequency word nodes have lower recognition thresholds than low-frequency ones, and so require less evidence to be recognized.

One important aspect of the IAM is its parallel and cascadic nature. In particular, during word recognition, a word is not simply recognized independently of other words stored in the lexicon. Rather, many words receive activation, and the model eventually settles into the appropriate representation across time, via a set of facilitatory and inhibitory pathways. One finding that is consistent with the activation of multiple words en route to recognition is the orthographic neighborhood effect. An orthographic neighbor is a word that can be produced by another word by simply changing a single letter (see Coltheart *et al.*, 1977). So, for example, *can* has the neighbors *cap*, *cat*, *pan*, *con*, *man*, among many others. The orthographic neighborhood effect refers to the finding that words with many orthographic neighbors produce faster response latencies than words with few orthographic neighbors, with this effect being larger for low-frequency words. Hence, multiple lexical units appear to be activated when a single word is presented. Of course, one might have expected just the opposite pattern, because of inhibition of competitors, a prediction from the original IAM. Although more recent embellishments of components of the interactive activation model can accommodate orthographic neighborhood effects (see Grainger and Jacobs, 1996), this is an important area that is still being actively researched (see Andrews, 1997 for a review).

While the IAM describes how lexical access may occur, it does not consider how we read or pronounce words. The dual-route model of pronunciation

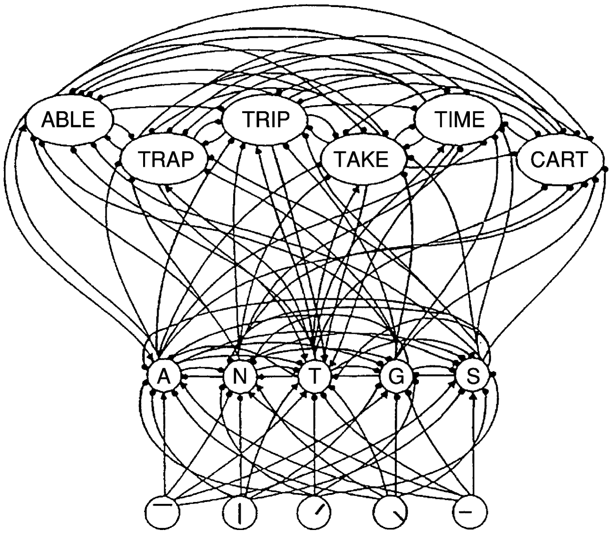

Figure 1 McClelland and Rumelhart's (1981) interactive activation model of word recognition. Copyright (1981) by the American Psychological Association. Reproduced with permission.

(Coltheart *et al*., 2001) argues that at least two routes mediate spelling and sound (Figure 2).

The lexical route is very similar to the IAM, and simply maps the word's spelling onto its lexical representation to retrieve its pronunciation. In contrast, the sublexical route assembles the word's pronunciation using English spelling-to-sound rules (Venezky, 1970). For example, if a single-syllable word ends in 'e' then the preceding vowel is long, as in *save*. In principle, we need two routes because readers can pronounce irregular words such as *have* (which violate spelling-to-sound rules and hence cannot be correctly generated by them) and nonwords such as *flirp* (which have no lexical representation).

The dual-route model is supported by two other major pieces of evidence. First, although regular words are, on average, pronounced faster than frequency-matched irregular words (Baron and Strawson, 1976), this regularity effect is much larger for low-frequency words than for high-frequency words (Seidenberg *et al*., 1984) (Figure 3). According to the dual-route model, high-frequency words (regular or irregular) can be pronounced quickly via the lexical route, before the sublexical route assembles a conflicting pronunciation. For low-frequency words, the lexical route is slower, and hence more susceptible to sublexical processes. In this situation, the two routes generate mismatching pronunciations for irregular words (e.g., for *pint*, the lexical route would generate the correct pronunciation, while the sublexical route would generate a pronunciation that rhymes with *hint*), and this conflict takes time to resolve. Early studies of acquired dyslexia also revealed a striking dissociation between the two routes. Individuals with phonological dyslexia (Patterson, 1982) can pronounce real words (that have lexical representations) but perform poorly for nonwords, suggesting a breakdown in the sublexical route. In contrast, individuals with surface dyslexia (Shallice and Warrington, 1980) tend to regularize irregular words (e.g., pronounce *broad* so that it rhymes with *road*), suggesting a breakdown in the lexical route.

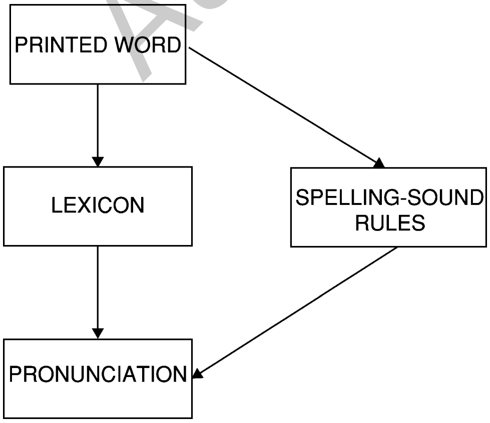

Figure 2 Dual route model of pronunciation.

One or Two Routes? An Ongoing Controversy

An influential alternative to the dual-route model is Seidenberg and McClelland's (1989) connectionist model of naming and word recognition (see Plaut *et al*., 1996 for an updated version). The model (Figure 4) contains an orthographic layer, which codes the spelling of the stimulus input, and a phonological layer, which represents the pronunciation of the stimulus output.

The network 'learns' to read (i.e., associate a word's spelling with its pronunciation) through repeated exposures to spelling–pronunciation pairs

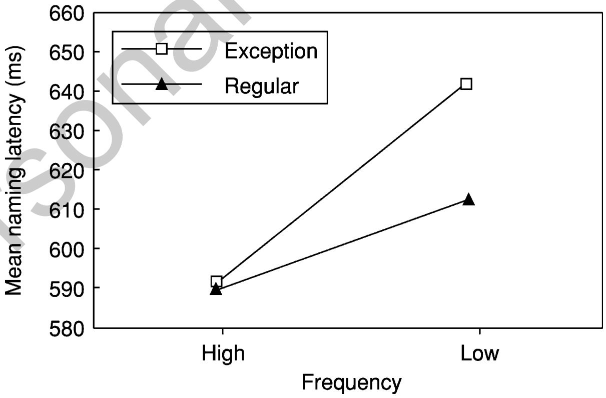

Figure 3 Experimental results from the Seidenberg, Waters, Barnes, and Tanenhaus (1984: Experiment 3) study. Copyright (1989) by the American Psychological Association. Reproduced with permission.

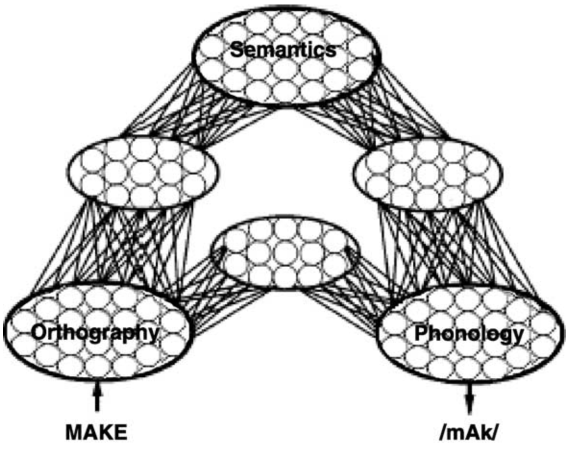

Figure 4 Seidenberg and McClelland's (1989) triangle connectionist framework for lexical processing. Copyright (1997) by Psychology Press Ltd.

(based on their frequency in English), via a feedback procedure (called back propagation). When the output of the model is incorrect, the weights of the connections are gradually changed to more closely approximate the correct response. Importantly, the model can pronounce novel nonwords and simulate critical empirical findings like the frequency by regularity interaction, without explicit spelling-to-sound rules. Plaut *et al.* have thus argued that a single mechanism is sufficient for naming regular, exception, and novel items. Importantly, this model has distributed (rather than localist) word representations. There is no one-to-one mapping between words and nodes; instead, a single word is represented by multiple nodes.

While the connectionist model is not immune to criticisms (see Coltheart *et al.*, 1993; Forster, 1994), it challenges the dual-route framework and provides a cogent alternative to it. Furthermore, the debate between one and two routes has ramifications beyond psycholinguistics. It also recapitulates the controversy between classical and connectionist models: is cognition supported by symbolic manipulation (dual route) or connectionist networks (single route)? In this instance, the contrasting models of reading function as paradigm cases for cognitive science (Perfetti, 1999).

Although considerable progress has been made in developing computational models of word recognition, these models have primarily focused on single-syllable word processing, in large part because large databases for multisyllabic words were not available. However, a web-based database of over 40 000 multisyllabic, polymorphemic words has recently been developed, containing both behavioral measures and a powerful search engine. Hopefully, this will help guide future work and extend these models into larger word units.

Context Effects on Word Recognition

Of course, words are most often not presented in isolation, but occur in the context of other words. Researchers have studied context effects in word recognition via both single-word context and studies that have manipulated sentence contexts. With respect to single-word contexts, there have been many studies of a phenomenon referred to as the semantic priming effect (see Neely, 1991 for a review). In this situation a prime is presented before a target word and one manipulates the relationship between the prime and the target (e.g., *doctor-nurse* vs. *carpet-nurse*). The intriguing finding here is that response latencies to the second word are faster when it follows a related prime than when it follows an unrelated prime, even though no overt response is required of the prime stimulus.

There appear to be least two important mechanisms that underlie priming effects (Neely, 1977). One is relatively slow and involves subjects attending to the relation between the prime and the target. For example, when presented with *doctor*, they may generate words that might follow and when one of the generated words is presented (e.g., *nurse*), they are relatively fast to make a response. The second, more intriguing, mechanism is a fast-acting process that has been likened to a spread of activation within an interrelated network (see Figure 5). This second mechanism presumably acts independently of the subjects' conscious processing and appears in situations where the prime is presented so briefly that subjects are unaware of its presence. Interestingly, Balota and Lorch (1986) found priming between words that on the surface do not appear to be directly related (e.g., *lion-stripes*). This is predicted by the spreading activation network perspective, because hidden within the presumed semantic network are mediating nodes (e.g., in this case *tiger*). In this way, researchers use the priming technique to make inferences about the representation of knowledge in the lexicon, and the processes used to access that information (see Hutchison, 2003 for a recent review).

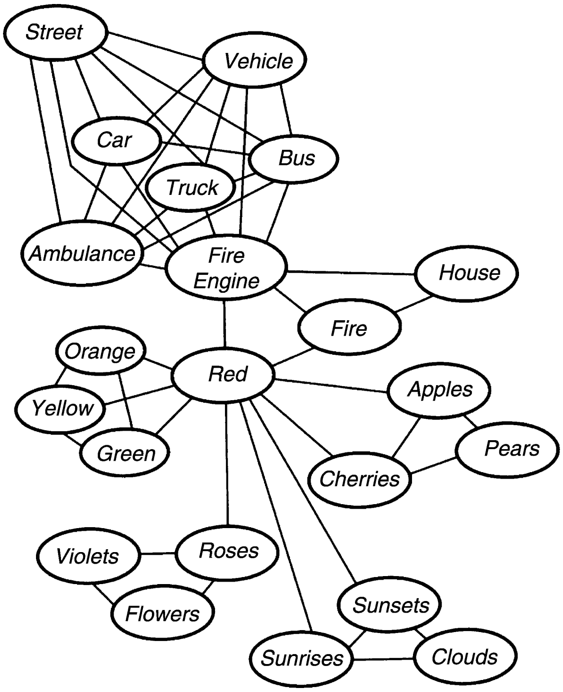

Figure 5 Collins and Loftus's (1975) spreading activation model network. Copyright (1975) by the American Psychological Association. Reproduced with permission.

In addition to single-word contexts, there have been many studies investigating the influence of sentence context on word recognition latencies (see, for example, Stanovich & West, 1983). One of the intriguing initial findings in this area is that sentence context does not influence lexical processing immediately but has an influence later on in integrating the word with the context. For example, Swinney (1979) found similar levels of activation, as reflected by priming techniques, for the interpretation of *bug* referring to *spy device* and *insect*, even though the word *bug* was immediately preceded by "spiders, roaches, and other" as part of a sentence context. It is only later on in processing that the sentence context disambiguates the word. Thus, it was argued that early lexical processes proceed relatively uninfluenced by sentence context, akin to the mechanism of automatic spreading activation mentioned above. This work was particularly important in advocating a dedicated self-encapsulated lexical module (e.g., Fodor, 1984). More recent work on this topic suggests that context can have an early influence if it is sufficiently strong (see Tabossi and Sbisa, 2001 for a review).

Word Recognition: the Future

The study of visual word recognition will continue to be a vital area of research in experimental psychology and psycholinguistics, with a number of important challenges. For example, we believe that future models will take into consideration the manner in which attention and task constraints influence the lexical processing system. As one can see from the models described above, most models assume a relatively passive lexical system that responds to stimulus input. However, a more comprehensive model will most likely include an attentional system that modulates the weights on specific pathways depending upon the goals of a given task. In addition, there will be some constraints provided from the *in vivo* studies of the human brain while it is engaged in lexical processing, via neuroimaging techniques. As noted above, multiple models may be able to accommodate the same set of findings. It is likely that understanding patterns of neural activity in circumscribed brain areas will provide an important next step in this literature (e.g., Binder *et al.*, 2003).

See also: Developmental Dyslexia and Dysgraphia; Human Language Processing: Connectionist Models; Human Language Processing: Symbolic Models; Lexical Semantics: Overview; Phonological Awareness and Literacy; Phonological Impairments, Sublexical; Phonological, Lexical, Syntactic, and Semantic Disorders in Children; Psycholinguistics: Overview; Radio: Language; Second Language Reading; Speech Recognition: Psychology Approaches.

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