To appear in In K. Malmkjaer (Ed.) *The Linguistics Encyclopedia*. Second Edition. London, Routledge.

Psycholinguistics

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Psycholinguistics is a discipline in which the insights of linguistics and psychology are brought to bear on the study of the cognitive aspects of language understanding and production. One of the earliest psychological accounts of language was Wundt's *Die Sprache* (1900), which is essentially a psychological interpretation of the linguistic work of the Junggrammatiker (see HISTORICAL LINGUISTICS, p.194). However, the strongly empiricist and anti-mentalist attitude to science which dominated both linguistics and psychology during the first half of the twentieth century (see BEHAVIOURIST LINGUISTICS) inhibited theorizing about mental processes involved in linguistic behaviour, and it was not until the late 1950s and early 1960s that the work of Noam Chomsky (see RATIONALIST LINGUISTICS and TRANSFORMATIONAL-GENERATIVE GRAMMAR) provided a climate of thought in which the discipline could flourish.

The main impetus for psycholinguistic research in the 1960s was the wish to explore the **psychological reality** of grammars produced by linguists, that is, to try to show that these in some way mirrored what went on in speakers' and hearers' minds. The two most famous controversies within this framework were produced by the **derivational theory of complexity** (DTC), according to which a sentence would be more difficult to process the further removed its surface structure was from its deep structure, and the theory of the **autonomy of syntactic processing**, according to which the syntactic analysis of sentences constitutes an independent stage in their perception. There is now general agreement that DTC is false (Garnham, 1985, pp.71-74) and the grammars which produced it have, in any case, been superseded (see TRANSFORMATIONAL-GENERATIVE GRAMMAR).

There has also been a general shift within psycholinguistics during the 1970s and 1980s away from models which take grammar as their starting point towards more psychologically based models. The question of whether syntactic processing is carried out independently of, or is interrelated with, other processes has not been decisively answered. It is an aspect of a more general disagreement about whether language is processed in a series of autonomous stages by

autonomous components unaffected by each other, or whether there is interaction between levels of processing. The latter view became the more popular during the 1980s.

According to Clark & Clark (1977), psycholinguistics includes the study of children's acquisition of language. Many linguists would agree that both first and other language learning and also linguistic disabilities are the province of psycholinguistics (though see Garnham,1985, Preface, according to whom they are specialist areas, rather than central topics for psycho-linguistics). In this volume, language acquisition and linguistic disabilities are treated in entries of their own (see LANGUAGE ACQUISITION, APHASIA, and LANGUAGE PATHOLOGY AND NEUROLINGUISTICS). Artificial intelligence may also be regarded as an area of psycholinguistics, but this, again, has its own entry in this volume (see ARTIFICIAL INTELLIGENCE). The psycholinguistic research that will be reviewed here falls within the study of language from the perspective of cognitive psychology.

THE COGNITIVE APPROACH

Three main questions lie at the heart of psycholinguistic research within the cognitive tradition:

(i) What mental representations are retrieved and created in the course of language processing, and what is their structure? This is the point of closest contact between cognitive psychology and linguistics. However, since as mentioned above, early research failed to verify the psychological reality of transformational grammar, rather little research has directly addressed this question.

(ii) What are the processes, or algorithms, by which one representation is transformed into another. Progress on this question has been largely confined to lower levels of processing, such as word recognition and word production, and has been dominated by interactive activation (McClelland & Rumelhart, 1981) and Connectionist models (McClelland & Rumelhart, 1986).

(iii) What is the overall processing architecture? According to the modularity hypothesis (Fodor, 1983; Forster, 1979) different aspects of language processing, such as word recognition and syntax, are encapsulated in distinct modules. "First pass" processing of the input proceeds in a serial, bottom-up, fashion; each module takes as input the output of the preceding module. Modules do not have access to information outside of their domain of operations (e.g. the syntactic processing module has no access to semantic information). In contrast, according to the interactionist position (McClelland, 1987), whilst there might be distinct representational domains (e.g. of phonological and orthographic word forms, syntax, semantics) these all interact with each other during processing. Processing occurs in 'cascade', such that higher levels of processing can influence lower levels, even before processing at the lower levels is complete.

Where possible, these aspects of the cognitive research agenda will be individually addressed in each of the core areas of psycholinguistic research covered here: visual and spoken word recognition, reading and phonology, accessing meaning, syntactic processing, and general comprehension processes. Finally, research on language production is discussed.

VISUAL AND SPOKEN WORD RECOGNITION

'Word recognition' refers to a process of perceptual categorisation whereby input is matched to a known word form in memory. Different representations are assumed to be contacted by written and spoken input (referred to as written and spoken input "logogens" by Morton, 1979). Once such a representation has been contacted, it can then be used to access more information about the word, namely its pronunciation or spelling, or its semantic and syntactic properties. Before considering these aspects of what is sometimes referred to as 'lexical access', research on word recognition as such will be discussed.

Processing

A basic principle underlying models of word recognition since Morton's logogen model of word recognition (Morton, 1969), is that an input pattern simultaneously activates multiple lexical representations according to their degree of match with the input (although serial search models do not make this assumption, Becker, 1979; Forster, 1976). McClelland & Rumelhart (1981) proposed a model of word recognition which adopted this idea and made additional assumptions about how simultaneously active representations compete and interact. Their model was an early example of the class of 'Interactive Activation' models which have come to be highly influential in many areas of psycholinguistics, and which could be regarded as the forerunners of neural network, or connectionist, models.

McClelland & Rumelhart's (1981) model assumes three levels of representation: visual features, letters, and words (these representational assumptions are not critical since it is the nature of the way they interact in processing which is crucial for present purposes). Activation of units at each level is determined by the degree of activation they receive from the bottom up (i.e. their degree of match to the units active at the preceding level, and ultimately the input) and also from the top down (since units pass activation down to units at the preceding level that are compatible with them). Crucially, processing at any one level does not have to be complete before higher level representations can become active. Combined with the assumption of top down activation, the

result is what is often referred to as 'cascade' processing. Another important aspect of these kinds of models is that processing within levels is 'competitive' because units at the same level represent mutually exclusive hypotheses. McClelland & Rumelhart formalised this model mathematically, and were able to successfully simulate data from experiments on humans, such as the 'word superiority' effect on letter perception (letters are easier to perceive in words than in consonant strings). More recently, Johnson & Pugh (1994) tested one counter-intuitive prediction of Interactive Activation models: the more similar a word is to other words, the harder it will be to recognise (the less visually distinctive a word is, the greater the competition between word-level hypotheses). Johnson & Pugh (1994) confirmed this prediction, and interpreted the results within a more detailed model of visual word recognition than McClelland & Rumelhart's, but one which followed broadly similar principles. However, whether orthographic similarity to other words has inhibitory or facilitatory effects may depend upon task demands (Balota, S.T., & Spieler, 1999, pp. 24-28).

Models which assume activation of multiple hypotheses have dominated work on spoken word recognition. The TRACE model (McClelland & Elman, 1986) postulates feature, phoneme, and word level units which interact in a similar fashion to the feature, letter, and word units in the (McClelland & Rumelhart, 1981) model of visual word recognition. In contrast, Marslen-Wilson's cohort model (Marslen-Wilson, 1987; Marslen-Wilson, 1989) stresses the activation of multiple word-level hypotheses, but does not postulate an intermediate phoneme layer of representation, and rules out a top-down flow of activation from lexical to sub-lexical representations. Despite these differences, one important implication of both of these models is that a spoken word can be recognised at the point at which the acoustic information uniquely specifies a single word in the listener's lexicon, which will often be prior to the actual acoustic offset of the word (see Marslen-Wilson, 1989, for a review of supporting evidence, and Bard, Shillcock, & Altmann, 1988, for evidence that because of problems of segmentation this is not always the case in continuous speech). Both models also stress the importance of lexical constraints for dealing with variability in the acoustic signal. In Trace this is because of top-down activation from lexical to phoneme, and ultimately feature, units. There is considerable evidence for lexical effects upon phoneme perception (Ganong, 1980; Marslen-Wilson & Welsh, 1978; Samuel, 1997) although whether such effects imply top-down activation is disputed (Norris, 1993; Pitt & McQueen, 1998).

Architecture

In the case of visual and spoken word recognition, the debate between modular and interactionist positions has centred on the question of whether semantic context influences word recognition. The interactionist position predicts that it should, because semantic context provides just another

source of top-down activation which then percolates down to lower levels. According to the modular position it can not because semantic information can have no effect on the operation of the word recognition module. There is considerable evidence for semantic context effects on visual word recognition tasks, but there has been much debate over whether these effects are actually due to facilitation of the word recognition process itself, as opposed to other processes which contribute to task performance (Neely, 1991). Semantic context effects tend to be very weak or entirely absent when tasks are used which might be assumed to tap recognition most directly, e.g. speeded word reading (Forster, 1981; Hodgson, 1991; Lupker, 1984) or fixation times (Balota, Pollatsek, & Rayner, 1985). However, larger context effects can be obtained when the word is made more difficult to read (Williams, 1996), or at low levels of reading ability (see Stanovich, 1990 for a review). The latter results tend to support an interactive activation, or cascade, approach, and are consistent with the view that meaning interacts with the recognition process (see Balota, Ferraro, & Connor, 1991, for a review). However, from the modularist perspective, effects of 'semantic' context can be attributed to direct associative/collocational connections between lexical entries, and hence do not violate the assumption that semantic information influences recognition. In view of this, some research has attempted to distinguish truly semantic and associative/collocational context effects, and found that indeed associative effects are stronger than semantic effects (Lupker, 1984; Shelton & Martin, 1992; Thompson-Schill, Kurtz, & Gabrieli, 1998; Williams, 1996). This suggests that there is some representational distinction between collocational and semantic relationships. Semantic context effects have also been demonstrated in spoken word recognition although accounts of this effect differ in the Cohort and Trace models (see Marslen-Wilson, 1989, for a review).

Representation

There has been debate over whether models of spoken word recognition require a distinct level of phonemic representation (as in TRACE). Marslen-Wilson (Marslen-Wilson, 1999; Marslen-Wilson & Warren, 1994) argues that lexical representations are specified in terms of distinctive features rather than phonemes. Following the theory of “radical underspecification” (SPE) he suggests that, while the distinctive features present in the signal are indeed represented pre-lexically, the lexical entries to which they are matched are abstract in the sense that they specify only non-default values of non-redundant distinctive features. This view permits a more parsimonious account of simplification phenomena, co-articulation, and assimilation than is possible in TRACE.

Other researchers have argued that in order to ease the problem of segmenting continuous speech into words the lexical access process may utilise units of representation which are larger than the phoneme. Mehler, Dommergues, & Frauenfelder (1981) proposed that French listeners

segment the input into syllables prior to lexical access. However, Cutler and colleagues has argued that English listeners utilise full quality strong syllables (see Cutler, 1989, for a review). If segmentation strategies are language-specific then it becomes interesting to consider the case of bilinguals, an issue explored in Cutler, Mehler, Norris, & Segui (1992).

With regard to morphology, there is clearly a tension between listing complex forms as unique lexical entries (i.e. disregarding morphology in the process of lexical access), and decomposing words into their constituent morphemes prior to lexical access. While the former might seem necessary for opaque derivations and compounds (e.g. re-strain, butter-fly), the latter might be an economical means of dealing with inflections and transparent derivations and compounds (e.g. mis-judge, space-walk). Current models favour a dynamic interaction between these two kinds of representation, very much in the spirit of interactive activation models (Caramazza, Laudanna, & Romani, 1988; Taft, 1994). Working from the perspective of spoken word recognition, Marslen-Wilson, Tyler, Waksler, & Older (1994) provide evidence that morphological structure is only lexically represented for transparent forms, access being via a shared stem morpheme (see also Marslen-Wilson, 1999, for a brief review).

READING AND PHONOLOGY

Once a written or spoken form as been categorized as an instance of a known word, further information about that word can then be retrieved. In the case of a written words there has been a good deal of debate over the way in which phonology is derived, and the role that this might play in accessing meaning and general comprehension.

Representation

With regard to the issue of deriving phonology from orthography, there is good evidence to suggest that a distinction can be drawn between knowledge of the rules relating orthography and phonology (grapheme-phoneme conversion rules, Coltheart, Curtis, Atkins, & Haller, 1993) and lexically represented pronunciation. Rules seem to be needed to account for the ability to read novel words whilst rote storage is necessary to read irregular words. Some people suffering from acquired dyslexia (after brain damage) (see DYSLEXIA) are able to read novel words, but tend to produce regular pronunciations of irregular words. This so-called 'surface dyslexic' syndrome (Coltheart, Materson, Byng, Prior, & Riddoch, 1983) can be explained in terms of damage to the lexical system, and over-reliance on a rule system. In contrast, 'phonological dyslexics' (Funnell,

1983) and 'deep dyslexics' (Marshall & Newcombe, 1980) make errors reading novel words, but can read even irregular words correctly (deep dyslexics also make semantic errors, e.g. reading *dinner* as "food"). These patients appear to have problems with the rule system (and an additional problem accessing meaning in the case of deep dyslexics).

Architecture

Even if one were to draw a representational distinction between lexical and rule-based routes to phonology; that is, between rote and rule, there remains the issue of how distinct these are in processing terms. There is considerable evidence that in non-brain-damaged individuals, these two types of knowledge are in dynamic interaction. Glushko (1979) showed that pronouncing nonsense words is affected by whether there are competing lexical analogies (e.g. HEAF is relatively difficult to read aloud because of conflicting analogies with regular words like *leaf* and irregular words like *deaf*). This demonstrates an effect of lexically represented pronunciations on reading nonwords. Similar effects have been obtained for reading regular known words, for example *beard* is relatively difficult because of competition from irregular analogies such as *heard* (Jared, 1997; Jared, McRae, & Seidenberg, 1990).

Processing

Coltheart et al. (1993) explained the interaction between lexical and rule-based systems in word reading by using an interactive activation framework which preserves the representational distinction between these two types of knowledge. However, a more radical approach is to conflate lexical and rule knowledge within one representational system, and to see rule knowledge as an emergent property of lexical knowledge. Novel words are then read through an essentially analogical process, as suggested by Glushko (1979). This is one area where connectionist, or neural network models, have been relatively successful (Plaut, McClelland, Seidenberg, & Patterson, 1996; Seidenberg & McClelland, 1989). These are self-organising systems which are 'taught' the pronunciations of a sample of English words, varying in frequency and regularity. Their performance on 'reading' these words, and the pronunciations they produce for novel words, is then compared with human data. They demonstrate that it is possible for rule-like behaviour to emerge from a system which is only taught relationships between individual words and pronunciations (see Chater & Christiansen, 1999, for an introduction to connectionist approaches to language processing). Furthermore, it is claimed that when 'damaged', these systems can simulate certain dyslexic syndromes (Plaut, 1997; Plaut et al., 1996). The assumption that it is possible to conflate lexical and rule knowledge has, as one might expect, been hotly

debated, especially with reference to past tense morphology (see Chater & Christiansen, 1999, for a connectionist perspective and Clahsen, 1999, for an opposing view).

Another strand of research on phonological processing of written language has addressed the role of phonology in accessing meaning. On the one hand, it has been argued that visually presented words access meaning directly (Coltheart, 1978), whilst other researchers have made the strong claim that visual words only access meaning via phonology (Lukatela & Turvey, 1994; Van Orden & Goldinger, 1994; Van Orden, Johnston, & Halle, 1988). It must be stressed that the latter view relates to the unconscious and automatic use of phonology, and not to the subjective experience of phonology in silent reading. Jared & Seidenberg (1991) provide evidence for a middle position in which high frequency words are read directly, but phonology plays a role in reading low frequency words.

Whereas arguments for the involvement of phonology in accessing meaning are plausible in the case of alphabetic writing systems, one might expect that in non-alphabetic writing systems there would be a direct pathway between visual form and meaning. However, Perfetti & Zhang (1995) found evidence for rapid activation of phonology even from Chinese characters, and on this basis argued for a universal phonological principle. On the other hand, Zhou & Marslen-Wilson, (1999) showed that only when Chinese characters contain phonetic radicals does meaning access appear to be phonologically mediated. For characters containing no such radicals, meaning appeared to be activated directly from the visual form. Evidence for similar effects in Japanese Kanji is provided by Wydell, Patterson, & Humphreys (1993).

With regard to phenomenally experienced phonology, there is general agreement that this is used as the means of storing verbal material in short term memory (Baddeley, 1990). However, whether this form of representation plays a role in language comprehension is not clear, since even patients with severely impaired phonological short term memory can show unimpaired language comprehension. Gathercole & Baddeley (1993) suggest that only when sentences are long and syntactically complex will phonological encoding contribute to the comprehension process.

ACCESSING MEANING

Regardless of the route by which lexical representations of meaning are accessed, there remains the question of the form that those representations take (a representational issue), and how context influences what aspects of word meaning are activated (an architectural issue).

Architecture

Homonyms have provided a popular testing ground for evaluating modular versus interactive processing architectures. Early research suggested that when an ambiguous word such as *bug* is recognised, it immediately activates both of its meanings, regardless of the context, but in under a second only the contextually appropriate meaning is still active (Swinney, 1979). Seidenberg, Tanenhaus, Leiman, & Bienkowski (1982) showed that this effect is particularly strong for noun-verb ambiguities such as *box*, and that selection of the appropriate meaning occurs within 0.2 seconds of the word's offset. These findings have been interpreted as strong support for a modular view of language processing (Fodor, 1983; Pinker, 1994). However, Tabossi, (1988) found that the subordinate (i.e. less frequent) meaning of a homonym does not become active in a strongly biasing irrelevant context, although it does in a more weakly biasing context. Rayner & Pacht (1994) found that a dominant meaning becomes active even in a very strongly biasing irrelevant context. From his review of the conflicting results in this area, Simpson (1995) concludes that meaning access is affected by meaning dominance and the strength of contextual bias. This is more consistent with an interactive than a modular processing architecture (see McClelland, 1987, for the development of this point in relation to ambiguity research).

Representation

Early research on the representation of word meaning was concerned with prototype effects (see Aitchison, 1987, for a review). It was discovered that people find it quite natural to make judgements about 'goodness' of category membership (for example they will judge that an apple is a 'better' fruit than a fig). It was argued that concepts like fruit can not therefore be represented as a strict definition, but must instead be represented as a prototype which captures the central tendency, or family resemblance structure of the category (Rosch, 1975; Smith & Medin, 1981). However, Armstrong, Gleitman, & Gleitman (1983) found that people are also able to produce graded category membership judgements for concepts which are perfectly well-defined, such as odd number or female. On this basis it seems more plausible to see prototype effects as a consequence of the way in which semantic information is accessed and used in a judgement task, rather than a direct reflection of underlying representations. Armstrong et al. (1983) drew a distinction between an 'identification function' and a 'conceptual core', where the former refers to a heuristic procedure used to make categorisations, and the latter to a core definition of the concept (see also Johnson-Laird, 1987). According to Lakoff (1987) prototype effects reflect underlying 'cognitive models' of a domain, and Barsalou (Barsalou, 1985; Barsalou, 1987) argues that

prototypicality judgements can be driven by 'ideals' which can be constructed on an ad hoc basis to form context-specific categories (e.g. foods to eat on a diet).

Some work on meaning access during sentence processing has attempted to distinguish different types of semantic information in terms of time course of activation. Properties of a word have been distinguished in terms of dominance, or centrality (i.e. the ease with which they come to mind when people are asked to write down the features of a concept). It has been found that central properties (e.g. 'music' for *piano*) are active regardless of the context, whereas in an irrelevant context peripheral properties (e.g. 'heavy' for *piano*) fail to become active at all (Greenspan, 1986) or are rapidly suppressed (Whitney, McKay, Kellas, & Emerson, 1985). Where these results differ from those obtained with homonyms is that the activation of central properties appears to persist even in seemingly irrelevant contexts. Barsalou (1982) distinguished context-dependent and context-independent properties, and found that the latter persist into the final interpretation of the sentence (e.g. the property of bank "Where money is kept" is as available after reading *The bank was robbed by three bandits* as after reading *The bank had been built three years ago*). Williams (1992) extended this line of investigation to polysemous adjectives, finding that 'central' aspects of an adjective's meaning (e.g. *firm* as in 'solid' as opposed to 'strict') remain active even in an irrelevant context. Other work has drawn a distinction between functional and perceptual aspects of word meaning. Some studies found that perceptual properties are accessed before functional properties, whilst more recent work has found that, at least for words referring to artifacts, functional properties (e.g. 'shoot' for *rifle*) become active before perceptual properties (Moss & Gaskell, 1999). Moss & Gaskell (1999) also review research showing that functional properties are particularly resistant to loss in brain-damaged patients, and suggest that functional properties are at the core of concepts for artifacts.

SYNTAX

Architecture

As in the case for meaning access, the debate over the modularity of syntactic processing has focussed on the resolution of ambiguity - in this case syntactic ambiguity - and whether the initial syntactic analysis of a sentence is affected by semantic and discourse factors. A modular position has been advocated by Frazier and colleagues (see Frazier, 1987, for a review). On this view, a syntactic processing module takes as input the words of a sentence, and on the basis of their grammatical category, and only their grammatical category, constructs a single phrase marker (see Forster, 1979, for an earlier expression of this hypothesis). Although there is no commitment to a

specific parsing mechanism (see the section on processes below), it is assumed that the parser operates in a highly incremental fashion; that is, by constructing the phrase marker on a word-by-word basis. One consequence of this assumption (which has amply been supported by experimental evidence, see below) is that the processor will often find itself with a choice as to how to attach the incoming word to the current phrase marker. For example, after receiving "The spy saw the cop with the ..." the processor will know that the word *the* indicates that a noun phrase should be opened. But where should this be attached to the phrase marker of the preceding fragment? Should it be attached to the verb phrase (*saw*) or to the object noun phrase (*the cop*)? Frazier (1987) proposed that the processor deals with these kinds of local syntactic ambiguity by applying structurally-defined preferences: namely the principle of 'minimal attachment' (posit the fewest number of nodes) and 'late closure' (attach an incoming word into the structure currently being built). In this example, the principle of minimal attachment dictates that the upcoming noun phrase should be attached to the verb phrase since this involves postulating fewer nodes. Rayner, Carlson, & Frazier (1983) showed that should this sentence continue with the word *revolver*, reading times in this region are slower than if it continued with *binoculars*. This, they argue, is because *revolver* is initially attached to the verb phrase, then the thematic processor attempts to interpreted it as an instrument of seeing, and on realising that this is implausible, requests an alternative parse from the syntactic processor. When the processor's initial parsing decisions are erroneous in this way, the reader is said to have been 'garden-pathed'. In fact, the Frazier model has come to be referred to as the Garden-Path model.

The Garden-Path model has received support from a number of other experiments. Because the garden-path effects that have been examined are often extremely local, and pass unnoticed by the reader, sensitive methodologies are necessary in order to record momentary slow-downs in reading. Usually eye movement tracking (see Rayner & Pollatsek, 1989, for background to this technique) or self-paced word-by-word reading have been employed. Ferreira & Henderson (1990) compared these two techniques and obtained similar results, although Spivey-Knowlton, Trueswell, & Tanenhaus (1995) provide evidence that under single word presentation conditions the absence of information from peripheral vision has consequences for parsing. Examples of experiments which have supported the garden-path model are Mitchell (1987) who showed that the parser's initial decisions respect late closure and ignore subcategorisation information, and Britt, Perfetti, Garrod, & Rayner (1992) who showed that the difficulty of reduced relatives, which is predicted by minimal attachment (e.g. *The coffee spilled on the rug was difficult to conceal*), is not eased by what was considered to be a supportive discourse context (one which refers to both coffee on a rug and scratches on a table). For other examples see Mitchell (1994).

The interactive position makes the prediction that there should be circumstances in which parsing decisions are affected by thematic, semantic, and even discourse factors. Over recent years

evidence has accumulated for this position. Taraban & McClelland (1988) replicated the reading time differences for pairs like *The spy saw the cop with the revolver/binoculars* previously obtained by (Rayner et al., 1983), but then showed that the difference in reading times between verb-phrase and noun-phrase attachments was reversed for pairs like *The couple admired the house with a friend/garden* where the non-mimimally attached *garden* led to faster reading times. They suggest that parsing preferences are a product of general expectancies based on world knowledge. Trueswell, Tanenhaus, & Garnsey (1994) found evidence for more specific preferences based on how well a noun fulfils alternative thematic roles at the point of ambiguity. Altmann & Steedman (1988) showed effects of discourse context on the prepositional phrase attachments. For example, the phrase *with the new lock* is non-minimally attached in *The burglar blew open the safe with the new lock* but it was found to be relatively easy to read in a context in which there was a safe with a new lock and a safe with an old lock. They suggested that parsing decisions are influenced by what they called "The principle of referential support", rather than the purely structural principles proposed by the Garden-Path model. In a similar vein, Spivey-Knowlton et al. (1995) found evidence of discourse context effects on processing reduced relatives. However, Britt (1994) found evidence that there are circumstances in which the effect of referential support for a prepositional phrase is overcome by what is presumably a stronger preference derived from the thematic structure of the verb (specifically in the case of verbs like *put* which obligatorily take three arguments). For example, the prepositional phrase *on the battle* in *He put the book on the battle onto the chair* is difficult to read even in a referentially supportive context in which there are two books, but this difficulty disappears if the verb *dropped* (for which a locative phrase is optional) is used instead. These results suggest that decisions about how to attach incoming words are based on an interaction between different types of constraint, and there is no architectural barrier that prevents different information sources interacting.

Processing

In the light of the mounting evidence for an interactive view of sentence processing MacDonald, Pearlmutter, & Seidenberg (1994) suggest that syntactic decisions are the result of a process of constraint satisfaction, where the constraints come from a variety of sources, and have varying strengths (but for a critique see Frazier, 1995). Any particular input string will activate competing hypotheses in a number of domains, and the reader's task is to arrive at an interpretation that is consistent with hypotheses across domains (much as is the case in Interactive Activation models of word recognition). Take for example the input string *The workers lifted* ..... The morphology of the verb *lifted* is ambiguous between past tense and past participle. However, *lifted* is more frequent in the past tense, and thus more strongly activated. In the domain of syntax, this fragment

will activate two phrase structure representations, one a main clause and one a reduced relative. Presumably the main clause structure is the more frequently encountered, and hence the most strongly activated. There are two possible argument structures for *lifted*, one in which the subject is agent and one in which the subject is theme. The assignment of the subject *workers* to the agent role is more plausible, and hence the most strongly activated. Just as in other Interactive Activation models hypotheses in different domains mutually support each other, whilst hypotheses within the same domain are in competition. In the present example, the most highly active hypotheses at all levels support each other, leading to a very strong preference for the main clause interpretation. If the sentence were to continue *The workers lifted by ...* only the activation of the syntactic structure for the reduced relative would be increased, although this might still be temporarily overriden by the biases at other levels. However, given that the goal of the system is to achieve compatibility at all levels then the activation of options in the other domains will eventually be brought into alignment. Furthermore, there may be other factors which support the reduced relative, such as plausibility (as in *The bricks lifted*) or discourse context (two groups of workers which need to be distinguished), the frequency of the past participle form of the verb (e.g. *The workers examined . .* where *examined* is more frequent as a past participle form). Trueswell (1996) has provided evidence that indeed the frequency of the past participle versus past tense form of the verb is critical in determining the ease of processing reduced relative structures. Garnsey, Pearlmutter, Myers, & Lotocky (1997) explored the effects of putting different information sources into conflict, and McRae, Spivey-Knowlton, & Tanenhaus (1998) obtained a good fit between human reading data and a computer instantiation of the constraint-based approach. In this latter study corpora were used to establish frequencies of different morphological forms and syntactic structures, and rating studies measured thematic preferences.

Other models of parsing have aimed to be much more specific about the way that syntactic structures are computed, and in doing so have made more of an appeal to linguistic theory. Pritchett (1992) developed a model of parsing based on Principles and Parameters theory (see GENERATIVE GRAMMAR) which assumes that all of the principles of Universal Grammar are satisfied at each moment during parsing. In particular the parser seeks to satisfy the theta-criterion (i.e. assign each noun phrase a thematic role) at every point in processing. Ambiguities arise when alternative thematic roles are available for a noun phrase, and the processor selects the one which entails the lowest processing cost. This model differs from the Garden-Path model in its emphasis on thematic processing. A radically different approach is taken by Pickering & Barry (1991) who develop a theory of parsing which does not depend on a phrase-structure grammar, or on empty categories (which are central to the Principles and Parameters theory). They employ an incremental version of Categorial Grammar (see JIM'S ENTRY) in which each word contains information about how it can be combined with other words, and parsing consists of determining whether the

representations of adjacent words can be collapsed together. Since this model makes specific claims about the nature of syntactic representations, the evidence relating to it is dealt with in the following section. For a discussion of other parsing models, see Crocker (1999).

Representation

Rather little psycholinguistic work has addressed the issue of the psychological reality of specific theories of syntactic structure. Most work has been carried out in relation to empty categories, as posited by Principles and Parameters theory (see GENERATIVE GRAMMAR), and particularly wh-trace. Even though wh-traces are invisible surface markers of movement operations, it has been claimed that they have detectable effects on sentence processing. Frazier & Clifton (1989) proposed that the parser posits a wh-trace at every structural position that is consistent with the grammar (which they dubbed the "Filler-Driven" strategy). Compelling evidence for this was obtained by Stowe (1986) who found that garden-path effects occur when a potential trace position is not realised, as after *bring* in *My brother wanted to know who Ruth will bring us home to at Christmas* (i.e. the reader initially posits a trace after *bring* which is coindexed with *who* and is forced to reanalyse when *us* is encountered). Stowe, Tanenhaus, & Carlson, (1991) and Hickok, Canseco-Gonzalez, Zurif, & Grimshaw (1992) showed that a potential gap is postulated even when the resulting interpretation would be implausible. For example, in *Which bucket did the movie director from Hollywood persuade Bill to push?* Hickok et al. (1992) found evidence for reactivation of the wh- filler *bucket* at the potential, but implausible, trace position immediately after *persuade*.

The above experiments could be interpreted as providing evidence for the psychological reality of wh-traces, and of the particular approach to syntax on which they depend (see Fodor, 1989, for an elaboration of this line of argument). On the other hand, Pickering and colleagues (Pickering & Barry, 1991; Pickering, 1994; Traxler & Pickering, 1996) argue that an "immediate association" between a verb and a wh- filler can be accomplished by a parsing mechanism which does not appeal to traces at all (i.e. one based on Categorial Grammar). For example, Traxler & Pickering (1996) showed that there are circumstances under which a thematic role is assigned even before a so-called trace position has been encountered (as shown by a reaction to the implausibility of *That's the garage with which the heartless killer shot the hapless man yesterday afternoon* even at the verb *shot*). However, Clahsen & Featherston (1999) argue that since all of the above experiments examined processing immediately following the verb, effects of traces can not be distinguished from those of thematic analysis. By performing experiments in German they show that reactivation of the wh-filler can occur at other sentence positions, and argue that their data can only be explained by assuming wh-traces, as proposed by Principles and Parameters theory.

GENERAL COMPREHENSION

According to the modularity hypothesis, once a syntactic structure and thematic roles have been assigned, the construction of a full interpretation of a sentence lies in the domain of central, domain general, processes which have access to world knowledge. For this reason, processing architecture ceases to be an issue when these higher-level aspects of comprehension are considered. Early research in this area was concerned with the kind of representations which are formed as the products of the comprehension process, exploring people's memory for sentences or short texts. Theories of processing are less developed than for lower-level aspects of language, and as Gernsbacher & Foertsch (1999) remark, are so similar in spirit that they are difficult to distinguish empirically. Here we will focus on the issue of representation.

Researchers have attempted to distinguish three different types of memory representation for text or discourse: surface memory, propositional memory, and situation/mental models. Jarvella (1971) found that people's memory for the precise wording and syntactic form of what they have heard (i.e. surface memory) is remarkably short-lived, and shows sharp drop-offs at major constituent boundaries. This could be because as soon as deeper representations have been formed, surface information is purged from memory (see also Anderson & Paulson, 1977). More recent work has also emphasized that short-term recall of sentences is achieved more through a process of regeneration from a conceptual representation than through simply reading off a verbatim record of what was read or heard (Lombardi & Potter, 1992; Potter & Lombardi, 1990), although how the accuracy and apparent verbatimness of short term recall is to be accounted for on this view remains an issue (Lee & Williams, 1997). Also it should be noted that Keenan, MacWhinney, & Mayhew (1977) found that long term verbatim memory can occur for utterances that are of, what they refer to as, 'high interactional content'; that is, utterances that convey wit, humour, sarcasm, or personal criticism. By and large, though, for utterances of more neutral content, there is very rapid loss of surface information.

What form do these deeper levels of representation take? A common proposal is that they should be described in terms of propositional structures. Ratcliff & McKoon (1978) provide an elegant demonstration of how even under conditions where accurate recall of the content of utterances would be difficult, the underlying representation of their propositional structure can implicitly influence a reaction time task. Kintsch, Kozminsky, Streby, McKoon, & Keenan (1975) explored the way in which reading time and recall patterns are determined by the propositional structure of texts, showing for instance that recall accuracy is affected by the degree of interconnectedness of arguments, and that the recall of certain aspects of texts is affected by their

hierarchical position in the propositional structure. It must be noted, however, that this research employed texts that were generated from a prior propositional analysis, and so whether analyses derived from naturally occurring texts would make the same predictions is not clear (see also Brown & Yule, 1983, pp. 106-116 for criticisms of this approach).

Propositional representations do not exhaust the meaning that people are able to derive from text. They capture thematic relations, and make clear the co-reference relations between terms (e.g. the relationship between an anaphoric expression and its antecedent). But they do not encode reference or the inferences that readers make in order to arrive at a full understanding. To capture this kind of representation, researchers have referred to a 'situation model' (Kintsch, 1988) or 'mental model' (Johnson-Laird, 1983). The former term will be adopted here. This level represents the content of text or discourse as a state of affairs in the real, or a possible, world. Bransford, Barclay, & Franks (1972) were among the first to highlight the importance of this level of representation as constituting what is commonly thought of as 'understanding'. They tested people on passages which were perfectly cohesive in propositional terms, but which in the absence of an appropriate title did not produce any sense of understanding. Much of the work on this approach has focussed on spatial descriptions. For example, Bransford et al., (1972) found that after reading *The frog sat on a log. The fish swam under the log* (mixed in with a large number of other mini-texts) readers will later mistakenly judge that they actually read the sentence *The fish swam under the frog*. Since the content of this test sentence does not correspond to a proposition that was presented, it must have been inferred through the construction of a more analogical form of representation. In addition to language of this type, Johnson-Laird (1983) has applied a mental models approach to logical inference. This approach to comprehension lays great emphasis on the role of background knowledge in supporting the process of constructing a situation model. A useful discussion of the relationship between the situation model and background knowledge is provided by Sanford & Garrod (1981) (see also Garrod & Sanford, 1990) who distinguish the elements of the discourse that are represented by tokens in the situation model, which they refer to as being in "explicit focus", and background knowledge that is in an active state, or as being in "implicit focus". One function of background knowledge is to provide roles for entities mentioned in the discourse. In terms of schema theory (Schank & Abelson, 1977) these are provided by 'slots' in active schemata. For example, Sanford & Garrod (1981) describe experiments which show that, whilst there are certainly cases where definite reference to a previously unmentioned entity is infelicitous, if a role for that entity is available as part of active background information, then comprehension is unproblematic (e.g. *the clothes* in *Mary dressed the baby. The clothes were made of pink wool*). They also make the important point that when a token is introduced into explicit focus, it merely points to a slot or role in an active schema, but other information associated with that role does not necessarily become incorporated into the situation model itself

(hence the infelicity of *the material* in *Mary dressed the baby. The material was made of pink wool*). This restriction on the content that is represented in the situation model is important in relation to inferencing, as will be discussed shortly.

More recently, a mental models approach has been applied to the process of anaphor resolution (see Garnham, 1999; Garnham & Oakhill, 1992). For example, Oakhill, Garnham, Gernsbacher, & Cain, (1992) demonstrated the lack of cost in interpreting texts such as *Last night we went to hear a new jazz band. They played for nearly 6 hours*, where *jazz band* is routinely interpreted as the antecedent of *they* despite a lack of number agreement. Presumably this is because at the level of the situation model, *jazz band* is represented by a number of discrete elements (standing for the players). The ease of interpretation suggests that anaphoric expressions seek antecedents in the situation model, rather than the text itself. However, Williams (1993) provided evidence that for repeated noun anaphors, the surface form of the text may still play a mediating role in determining how the situation model is accessed. On the other hand, pronouns may access the situation model more directly (Cloitre & Bever, 1988).

The dominance of the situation model in comprehension has been highlighted by Barton & Sanford (1993) (see also Sanford, 1999; Sanford & Garrod, 1995) who explored the so-called Moses Illusion: the tendency for people to answer the question *How many animals of each sort did Moses put on the ark?* with "two". They suggest that this is because words that even vaguely fit supporting background knowledge only receive a shallow semantic analysis which is just sufficient to support construction of a situation model. Perrig & Kintsch (1985) showed that the nature of the situation model that the reader constructs may be affected by the nature of the text, and be subject to individual differences. Schmalhofer & Glavanov (1986) also demonstrated the effect of task demands, and found greater evidence for construction of a situation model when the task emphasized understanding for learning, and more evidence for construction of propositional representations when participants were merely told to summarize the text. Thus, whereas the propositional level of representation may capture the minimum that a person should have extracted from a text in order to support further comprehension processes, the content of the situation model is more variable.

In an attempt to separate out automatic and voluntary aspects of higher level comprehension processes, a good deal of research has focussed on whether there are certain classes of inference that are made spontaneously and automatically, whereas other types of inference are more optional. McKoon & Ratcliff (1992) propose a "Minimalist Hypothesis" according to which "only two classes of inference, those based on easily available information and those required for local coherence, are encoded during reading, unless a reader adopts special goals or strategies" (*ibid.*, p.441). In the first case, information that is strongly associated to words in the text triggers an elaborative inference. For example, McKoon & Ratcliff (1989) showed that when people read *The*

housewife was learning to be a seamstress and needed practice so she got out the skirt she was making and threaded her needle they spontaneously activate the concept 'sew' (a similar effect was also obtained by O'Brien, Duffy, & Myers (1986)). This appears to be an elaborative inference, but one that may be triggered through strong associations with the words in the text (in actual fact, as in much of this type of work, the methodologies only show that a concept is active, and not that a particular inference was actually made). More interesting are the second type of inference, those required for local coherence. These include anaphoric inferences and thematic role assignments (which here have been assumed necessary for construction of a propositional representation) and what Graesser, Singer, & Trabasso, (1994) refer to as "causal antecedent" inferences. The latter concern an effort to understand the immediate causes of an event mentioned in the text. For example, Potts, Keenan, & Golding (1988) found that after reading ... *the husband threw the delicate porcelain vase against the wall. It cost him well over one hundred dollars to replace the vase* there was evidence of activation of the concept 'broke' (implying that they had inferred that the vase broke), whereas this concept was not active after reading ... *the husband threw the delicate porcelain vase against the wall. He had been feeling angry for weeks, but had refused to seek help*. Only in the former case is it necessary to infer that the vase broke in order to understand the rest of the text. Similarly McKoon & Ratcliff (1989) showed that the concept 'dead' was not active after reading *The director and the cameraman were ready to shoot close-ups when suddenly the actress fell from the 14th storey*, presumably because there is nothing that requires the reader to infer that the actress died. McKoon & Ratcliff (1989) take this result as evidence against the "constructivist" approach originally advocated by Bransford et al. (1972) and taken up later in the mental/situation model approach. They argue that "A mental model of a text such as *the actress fell from the 14th story* should include the inference that she died. It would not be reasonable from the mental model point of view to leave her suspended in mid air". However, as Glenberg, Kruley, & Langston (1994) point out, mental models do not have to be complete representations of real situations; they can be highly schematic. This schematic approach to mental models is also consistent with the line taken by Garrod & Sanford, (1990). Evidence against elaborative inferences is not evidence against situation models.

The Minimalist Hypothesis has come under attack for concentrating too much upon local coherence. Graesser et al. (1994) argue that inferences that are required for global coherence are spontaneously drawn as well. These concern the "superordinate goal" of a character, the moral of the passage, and the emotional reactions of characters (see Graesser et al., 1994, for a review of the evidence). Other research has investigated whether readers spontaneously infer a specific exemplar of a superordinate category, for example that *vehicle* may refer to a car in the sentence *The reporter went to the vehicle to look for the papers* (Whitney, 1986). Both Whitney (1986) and O'Brien et al. (1986) found evidence that such inferences are only made spontaneously when the

superordinate term is foregrounded, for example in *The vehicle contained the papers that the reporter was looking for*. This points to the importance of discourse factors in determining what inferences are made spontaneously, making it difficult to maintain a strict minimalist position.

LANGUAGE PRODUCTION

Only a brief overview of work on language production will be provided here. The reader is directed to Levelt (1989) for a comprehensive review of all aspects of the production process, and to Levelt, Roelofs, & Meyer (1999) for a more up-to-date review of work on single word production.

Representation

It is generally agreed that the process of producing a word can be separated into two stages. The first, lexicalisation, stage concerns choosing the word which best matches the intended message (as represented at a conceptual level), and the second, form retrieval stage, concerns accessing and assembling the phonological information that is required to articulate the word. Note that the notion of lexicalisation, as used above, implies the existence of abstract lexical representations which mediate between concepts and word forms. These intermediate representations have been referred to as lemmas, and are also assumed to contain syntactic information associated with the word. Evidence suggesting the existence of lemmas comes from "tip-of-the-tongue" (TOT) states (Brown, 1991), where it is possible for people to have the sensation that they know the word for a particular concept that they want to express (equivalent to having accessed a lemma) but are unable to retrieve its form. Vigliocco, Antonini, & Garrett (1997) showed that when speakers of Italian are in TOT states they can report the gender of the word even when they are unable to supply any phonological information, providing support for the idea that syntactic information is associated with the lemma. Levelt et al. (1999) provide further arguments for positing a lemma level of representation. However, this assumption has been contested by Caramazza & Miozzo (1997) on the basis of data from tip-of-the-tongue experiments and aphasics (but see Levelt et al., 1999, p.66, for a response).

There has also been debate over whether the conceptual representations which are input to the production process should be specified in terms of sets of primitive features or in terms of lexical concepts which bear a one-to-one relationship to lemmas. Levelt et al. (1999) favor the non-decompositional approach on both theoretical and empirical grounds. They argue that "lexical

concepts form the terminal vocabulary of the speaker's message construction" (p. 8). This implies that a good deal of language-specific conceptual processing needs to be done to package the intended message in such a way as it can be fed to the production process; what Slobin (1996) referred to as "thinking for speaking".

At the level of form retrieval, there is convincing evidence that the phonological form of a word is not simply retrieved as a whole unit, but rather that it is constructed, or "spelled out", by inserting sub-syllabic units into syllabic frames (Levelt, 1989; Levelt et al., 1999). Speech error data have traditionally provided the strongest evidence for this assumption. When sounds exchange between two words they invariably occupy the same position in the syllable structure of the word, as in for example in *mell wade* (exchange of onsets from *well made*), *bud beggs* (exchange of syllable nuclei from *bed bugs*), *god to seen* (exchange of codas in *gone to seed*). Although it may seem inefficient to construct the form of words when those forms are already lexically represented, Levelt et al. (1999) point out that this is necessary to cope with the fact that in continuous speech, syllabification does not always respect lexical boundaries; that is, the syllable structure of words in citation form does not always correspond to their syllable structure in continuous speech. As regards the types of unit which fill the slots in syllabic frames, the fact that exchanges of phonological features can also occur (as in the voicing exchange which underlies *glear plue sky* for *clear blue sky*) suggests that abstract, and possibly underspecified, phonological representations are involved.

It is generally assumed that the formulation processes underlying sentence production can be divided into two stages (Garrett, 1990). In the first stage the intended message is used to select relevant lemmas, and these are inserted into a representation of the functional argument structure of the sentence to form what Garrett refers to as the 'functional level representation'. Speech errors such as *This spring has a seat in it* (for *This seat has a spring in it*) where the exchanged words are of the same grammatical category can be interpreted as errors in the assignment of words to slots in the functional level representation. In the second stage, syntactic encoding procedures generate a syntactic planning frame which contains slots for the content words specified in the functional representation. These slots are also carry diacritic markers for tense and number, and so on. The phonological forms of the relevant lemmas are then inserted into the relevant slots in the planning frame. This explains why when words exchange, they are appropriately inflected for the position they occupy in the syntactic structure (as in *I'd hear one if I knew it* for *I'd know one if I heard it*). Kempen & Hoenkamp (1987) present a model of sentence production which respects these general distinctions, whilst stressing the incremental nature of sentence production.

Processing and Architecture

The two main models of the production of single words are Dell's (1986) Interactive Activation model, and Levelt et al's (1999) WEAVER model. There are two main differences between these models. First, Dell allows information to flow bidirectionally between levels (as in the McClelland & Rumelhart, 1981, model of word recognition), whereas Levelt et al only allow activation to flow from higher to lower levels in a feed-forward network. Second, whereas Dell achieves the binding between phonemes and structural positions through control of timing, Levelt et al's model achieves this through a checking operation. However, both models assume that there is competition between lemmas in lexical selection, consistent with evidence obtained by Wheeldon & Monsell (1994), as well as picture-word interference studies such as those reported by Schreifers, Meyer, & Levelt (1990). The latter studied the effects of auditorily presented distracter words on picture naming times, and found that semantically related distracters (e.g. *goat* for a picture of a sheep) produced interference (slower picture naming times) if they occurred just prior to presentation of the picture. The distracter word can be thought of as increasing the activation of a lemma which competes for selection with that corresponding to the target picture. However, whereas the Dell model allows competing, but not selected, lemmas to also activate their phonological form, the Levelt et al model does not because they assume a more serial processing architecture. Peterson & Savoy (1998) and Jescheniak & Schreifers (1997) have found evidence for phonological activation of non-selected lemmas, provided they are synonyms of the picture name (e.g. *soda* interferes with production of *couch*), a result which supports the interactive activation model (although see Levelt et al., 1999, for discussion). Another feature of the interactive activation approach is that once a lemma has activated phonological representations, these can then back-activate lemmas of similar-sounding words. This assumption permits an elegant explanation of the higher-than-chance incidence of speech errors where the produced word is both semantically and phonologically related to the intended word (e.g. *rat* for *cat*). The phonological form of *cat* activates the lemmas for phonologically similar words such as *rat, bat, mat* and so on, but since the *rat* lemma is already partially active because it is similar to the intended message, it has a greater probability of being produced than the others. However, Levelt et al. (1999) argue that there may be alternative explanations for the prevalence of mixed errors. For example, a self-monitoring mechanism (the properties of which are described by Levelt, 1989) might be less likely to detect, and prevent, a speech error that is broadly related to the context.

The debate over the appropriate processing architecture for word production continues, but it is worth noting that this mirrors that between interactive activation models of spoken word recognition (McClelland & Elman, 1986) and the Cohort Model (Marslen-Wilson, 1989), in that whilst the former permits activation from the lexical level to filter down to sub-lexical levels of

representation in recognition, the latter only permits an upward flow of activation from lower to higher levels. At the same time, both of these models of spoken word recognition stress multiple activation and competition between representational elements. This is a general theme which as we have seen runs through work on visual word recognition, word reading, syntactic processing, and language production, and reflects the dominant way of thinking about psychological processes in modern psycholinguistics.

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