Proceedings of the Annual Meeting of the Cognitive Science Society

Title

Front-end Serial Processing of Complex and Compound Words: The APPLE Model

Permalink

https://escholarship.org/uc/item/6cf6m8h5

Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 14(0)

Author

Libben, Gary

Publication Date

1992

Front-end Serial Processing of Complex and Compound Words: The APPLE Model[1]

Gary Libben
Department of Linguistics
University of Calgary
2500 University Drive N.W.
Calgary, Alberta, Canada
T2N 1N4
(403) 220-7315
libben@uncamult

Abstract

Native speaker competence in English includes the ability to produce and recognize morphologically complex words such as *blackboard* and *indestructibility* as well as novel constructions such as *quoteworthiness*. This paper addresses the question: How do subjects 'see into' these complex strings? It presents, as an answer, the Automatic Progressive Parsing and Lexical Excitation (APPLE) model of complex word recognition and demonstrates how the model can provide a natural account of the complex and compound word recognition data in the literature. The APPLE model has as its core a recursive procedure which isolates progressively larger substrings of a complex word and allows for the lexical excitation of constituent morphemes. The model differs from previous accounts of morphological decomposition in that it supports a view of the mental lexicon in which the excitation of lexical entries and the construction of morphological representations is automatic and obligatory.

A fundamental claim of all linguistic approaches to the study of morphology is that words such as UNHAPPINESS, INDESTRUCTIBILITY and BLACKBOARD are composed of smaller units and that these basic units are organized in specific ways to form complex words. This claim is supported by the observation that native speaker competence in a language is characterized by two significant abilities: (1) the ability to understand and produce complex words of the language and (2) the ability to understand and produce novel complex words. (e.g., QUOTEWORTHINESS, COMPUTERIZABILITY, WHITEBOARD).

The question of the relationship between morphological structure and native speaker competence has also been the subject of much investigation in the psycholinguistic literature. It has been assumed that a native speaker's vocabulary is stored in a mental lexicon which is organized to meet the processing demands of access and retrieval speed as well as storage efficiency. One way in which the organization of the mental lexicon could exploit the morphological structure of a language such as English would be to store multimorphemic words in their morphologically decomposed form, thereby greatly reducing the number of entries in the lexicon[2]. This possibility was first suggested by Taft & Forster (1975) who proposed that the morpheme rather than the word is the basic unit of the mental lexicon. In the Taft and Forster model, there is no separate lexical entry for the word UNLUCKY. Rather, the word is decomposed into its morphological constituents during the process of word recognition and is ultimately recognized through the representation of its root morpheme LUCK.

---

[1] This research was supported by Social Sciences and Humanities Council of Canada Research Grant 410-90-1502 to the author.

[2] Clearly the question of morphological decomposition is language specific. It is extremely unlikely that for agglutinating languages such as Turkish, words could be represented in their full forms. (See Hankamer 1989 for a discussion of this).

In the fifteen years since its first publication, the morphological decomposition hypothesis has been investigated using a variety of experimental paradigms in studies which have addressed both the general issue of decomposition and specific differences that might exist in the representation and processing of particular affix types. However, these research efforts have neither yielded clear support for the morphological decomposition hypothesis nor a clear refutation of it (see Henderson (1985) for a review of this literature).

Despite the lack of empirical consensus, the Taft and Forster model has retained a certain degree of attractiveness because it provides a bold and explicit account of both the organization of the mental lexicon and the process by which multimorphemic words are recognized. The hypothesis has thus far received greatest support from studies which investigate prefixed words such as REVIVE. Although Taft & Forster (1975) claim that decomposition should apply to all affix types, they present evidence solely for prefixed words (as does Taft (1981)). Overall, the data from studies which employ suffixed words have been less supportive of the view that morphological decomposition is achieved through automatic and indiscriminate affix stripping (e.g., Henderson Wallis & Knight 1984; Mandelis & Tharp 1977; Stanners et. al. 1979). Taft (1985) provides an account of this discrepancy by claiming that only prefixes are stripped prelexically, whereas suffixes are stripped by a left-to- right scanning procedure which isolates increasingly larger substrings until a match is found in the mental lexicon. The notion that left-to-right parsing plays an important role in morphological decomposition is also found in Taft & Forster (1975) and Hankamer (1989).

In this paper I argue that left-to-right parsing is a fundamental component of the recognition of all multimorphemic word types. Prefixes hold no special status with respect to morphological decomposition. Rather, left-to-right scanning simply creates the appearance of prefix stripping. I also argue that the prefix stripping hypothesis is only tenable under the questionable assumption that the mental lexicon is restricted to monomorphemic entries. I suggest that a more natural account of the data in the literature is provided under the view that all units of meaning (rather than only the simplest units of meaning) are represented in the mental lexicon.

The APPLE model

As a formalization of this argument, I propose the Automatic Progressive Parsing and Lexical Excitation (APPLE) model of visual word recognition. Below, I provide a description of the details of the model and attempt to show how it provides a natural account of the complex and compound word recognition data in the literature.

The APPLE model contains features of the original Taft & Forster (1975) account of morphological decomposition but begins with a very different view of the purpose and status of prelexical parsing. Early morphological decomposition proposals assumed that the purpose of prelexical parsing is to preprocess multimorphemic strings and thereby simplify access to the lexicon. Taft & Forster's (1975) affix stripper falls into this class of preprocessing procedures because its goal is to identify and remove affixes from a string. The initial assumptions of the APPLE model differ from those of models which see the problem of visual word recognition as a problem of isolating a particular entry in a store of perhaps 100,000 lexical items. The APPLE model assumes that all entries that can be excited are excited- the problem of visual word recognition is not to excite the entries in the first place, but rather to choose between the entries which have been automatically excited. In short, the lexicon is hungry!

Parsing in the APPLE model is essentially goalless. I claim that left-to-right parsing falls out from general properties of the language processing system and is not motivated by a 'desire' to identify any particular type of morpheme (see Cutler, Hawkins & Gilligan (1985) for a

```
Procedure MorphParse

Repeat until all letters of StimulusString are used
Begin
  Add next letter of StimulusString to TargetString;
  Allow lexical excitation of TargetString;
  If TargetString lexical and remainder legal[3] then
    Begin
      Make the remainder the new StimulusString;
    Do MorphParse;
    End;
End.
```

Figure 1: *The MorphParse Procedure*

---

[3] In the face of findings which indicate that illegal nonwords (e.g., FTANG) are rejected more quickly than legal nonwords (e.g., FRANG) it seems reasonable to postulate a well-formedness 'gating' mechanism as the initial component of lexical access. When the inital component of a string excites a lexical entry but the remainder of that string is not legal (e.g., hen-chman), the remainder is not examined further.

1.	F	
2.	FO	
3.	FOO	
4.	FOOT	
5.		B
6.		BA
7.		BAL
8.		BALL
9.	FOOTB	
10.	FOOTBA	
11.	FOOTBAL	
12.	FOOTBALL	

Table 1: *The operation of MorphParse on the compound FOOTBALL*

discussion of left-right parsing and language universals). The core of the APPLE model is the MorphParse procedure represented in Figure 1. This procedure simply moves automatically across the input string isolating increasingly larger substrings on the left until there are no remaining graphemes on the right. On the way, it generates the exhaustive lexical excitation of all legal substrings in a stimulus.

The key features of the MorphParse procedure are obligatoriness, recursion, the isolation of *initial* substrings, and the independence of parsing and lexical excitation. These features produce morphological parses of compound and complex stimuli which have a particular set of properties. It will be argued below that precisely these properties are required to provide a principled account of the compound and complex word data reported in the literature.

Compound Words

The operation of the MorphParse procedure is represented as a series of derivations such as those provided in Table 1. Note how the excitation of a lexical entry (indicated by an underscored representation) causes MorphParse to proceed in an identical fashion across the remainder of the string. MorphParse 'pops' back to and continues a higher analysis when the graphemes of the current StimulusString have been exhausted. In so doing, it leaves behind a 'path' of lexical excitation (indicated in Table 1 by successive indentations). A property of the APPLE model is that for any multimorphemic string, a left to right morphologically decomposed analysis is available before a whole word analysis.

We may now consider the operation of the APPLE model for novel compound stimuli such as those used in Taft & Forster's (1976) lexical decision study. They found that lexical decision latencies to strings which had real-word initial substrings were longer than latencies to strings which had either no real-word substrings or only final real-word substrings.

Table 2 represents the novel compounds used in the Taft and Forster study and the mean reaction time for each stimulus type. Applying the MorphParse procedure to these stimuli highlights the relationship

	WW (RT=758)		WN (RT=765)		NW (RT=682)	NN (RT=677)
	DUSTWORTH		FOOTMILGE		TROWBREAK	MOWDFLISK
1.	D		F		T	M
2.	DU		FO		TR	MO
3.	DUS		FOO		TRO	MOW[a]
4.	DUST		FOOT		TROW	MOWD
5.		W		M	TROWB	MOWDF
6.		WO		MI	TROWBR	MOWDFL
7.		WOR		MIL	TROWBRE	MOWDFLI
8.		WORT		MILG	TROWBREA	MOWDFLIS
9.		WORTH		MILGE	TROWBREAK	MOWDFLISK
10.	DUSTW		FOOTM			
11.	DUSTWO		FOOTMI			
12.	DUSTWOR		FOOTMIL			
13.	DUSTWORT		FOOTMILG			
14.	DUSTWORTH		FOOTMILGE			

Note. Taft and Forsters RT data are given above each stimulus type.

[a] The string MOW does not trigger a call to Morphparse because the remainder DFLISK is illegal.

Table 2: *The APPLE Model Analysis of Taft and Forsters (1976) Data.*

between the operation of the model and characteristics of the stimuli. The observed reaction times fall out naturally from the architecture of the APPLE model. If we assume that each iteration of the parsing procedure consumes time which is measurable in a lexical decision task then the model creates a processing cost that increases the greater the number of real-word initial substrings and the closer those substrings are to the beginning of the stimulus.

Affixation

The APPLE model makes no distinction between types of morphemes. Prefixed and suffixed words are treated exactly in the same manner as compounds. Some interesting differences fall out, however, from the fact that prefixes occur at the beginning of strings and suffixes at the end. The APPLE model predicts that although there is no special mechanism to identify prefixes, they will appear to be stripped from their stems, whereas suffixes will not. This can be seen by considering the strings REVIVE and SENDER in Table 3. Each of these strings has a two-character affix and a four-character stem. However, because of the positional differences of the affixes, REVIVE is parsed in 10 steps and SENDER is parsed in 8 steps. Moreover, according to the APPLE model, the difference between the number of steps required to parse prefixed vs. suffixed words increases with the length of the string. This is due to the fact that in any derivation, the number of parsing steps is equal to the sum of the lengths of the TargetStrings (as defined in the MorphParse algorithm). Thus a ten-character stem prefixed by RE would be parsed in 22 steps, whereas a ten-character stem suffixed by ER would be parsed in 14 steps. It seems probable that this characteristic of the model could provide an account of the fact noted at the outset of this paper-- namely that in general morphological decomposition effects have been much more evident in studies which investigate prefixation than in studies which investigate suffixation.

In contrast to the prefixation literature, the suffixation literature presents an unclear, often contradictory, view of whether suffixed words are decomposed in the process of visual word recognition. It has been found that in repetition priming experiments, a suffixed word such as CARING will prime its root constituent CARE (Fowler, Napps & Feldman, 1985; Napps, 1989). The opposite relationship (i.e., one in which CARE primes CARING) has also been found by Murrell & Morton (1974). In a study which employed a frequency mapping paradigm, Burani, Salmaso & Caramazza (1984) found that lexical decision response times to suffixed Italian words is influenced by both the frequency of the root as well as the frequency of the entire string.

The above findings all suggest that at least part of the recognition of suffixed words involves the dissociation of roots and suffixes and may be taken as support for the extension of Taft and Forster's prefix stripping hypothesis to suffixes. On the other hand, the findings in studies which investigate pseudosuffixation seem to argue against such an extension.

As predicted by the Taft and Forster hypothesis, Bergman, Hudson & Eiling (1988), Smith & Sperling (1982), and Lima (1987) found that pseudoprefixed words such as RELISH are more difficult to process than truly prefixed words such as REVIVE . This evidence, which is counter-intuitive and constitutes strong support for the morphological decomposition hypothesis has not been found in studies which investigated the role of pseudosuffixation. Such studies (e.g, Henderson, Wallis & Knight (1984); Mandelis & Tharp (1977); Rossman-Benjamin (1986)) have failed to find differences in processing time between suffixed stimuli such as SENDER and pseudosuffixed stimuli such as SISTER. The absence of suffixation-pseudosuffixation differences constitutes evidence against the view that suffixes are obligatorily stripped from word stems.

I suggest that the contradictory findings referred to above are not contradictory at all, but fall out naturally from the architecture of the APPLE model. Note in Table 3 that although the prefixed words RELISH and REVIVE are both parsed in 10 steps, a lexical decision 'yes' response to REVIVE can be given at Step 6 (the point at which lexical excitation has occurred for both constituents). In the case of RELISH, the 'yes' response can only be given after all 10 steps have been completed.

Turning to the effect of pseudosuffixation, the model again correctly predicts that no difference will be found between the 'yes' latencies to SISTER and SENDER. In both cases the correct response is available at Step 6 of the derivation. Note that in the APPLE model this does not mean that prefixes are stripped but suffixes are not. As has been stated above, the appearance of prefix stripping is simply a consequence of parsing direction.

Finally, the model also provides a natural account of the stem priming effects and the stem frequency effects for suffixed words. Note that in the derivation of SENDER, the units SEND, ER and SENDER are all activated, predicting just the results obtained by Napps (1989) and Burani, Salmaso & Caramazza (1984).

I claim therefore that there never was a contradiction between the pseudosuffixation effects and the stem priming frequency effects. Rather, its appear-

	Stimulus Type			
	Pseudoprefixed	Prefixed	Pseudosuffixed	Suffixed
	RELISH	REVIVE	SISTER	SENDER
1.	R	R	S	S
2.	RE	RE	SI	SE
3.	L	V	SIS	SEN
4.	LI	VI	SIST	SEND
5.	LIS	VIV	SISTE	E
6.	LISH	VIVE	SISTER	ER
7.	REL	REV		SENDE
8.	RELI	REVI		SENDER
9.	RELIS	REVIV		
10.	RELISH	REVIVE		

Table 3: *The APPLE Model Analysis of Affixed Words*

ance resulted from the investigation of different phenomena which turn out not to be two sides of the same coin after all. Under this view, the question of whether suffixes are stripped is quite distinct from the question of whether stems are activated. The investigation of these phenomena requires explicit reference to both the details of the experimental task and the details of the processing model.

Implications of the model

Serial processing in a parallel world

The details of the APPLE model show promise in their ability to provide a unified explanation for a number of seemingly unrelated findings in the visual word recognition literature. An important characteristic of this model is that it is event-driven rather than teleological. It is, however, clearly serial. In my view, the serial nature of this 'front-end' to the word recognition process makes no claims about the nature of the rest of the recognition process or about the preferred nature of human cognition. Rather it seems simply to be a response to the serial nature of morphemic organization. There are currently no parallel models of morphological parsing in the literature and it seems unlikely that the positional effects discussed in this paper could plausibly be accounted for in a parallel model. Nevertheless, there is good reason to suppose that the lexical system which the MorphParse algorithm feeds is characterized by parallel processing. Indeed, an important area of future research in the elaboration of this model concerns the spread of activation resulting from the activation of individual lexical items during the parse. For example, the APPLE model predicts that a 'yes' lexical decision response to a word such as REVIVE is possible as soon as both constituent morphemes have been recognized but that a 'no' response to a novel construction such as RE-DISK requires an exhaustive parse. This effect assumes an automatic spread of activation within the lexicon which is independent from the parsing procedure and is currently being modeled in our laboratory.

The mental lexicon

The reinterpretation of key findings in the word recognition literature in terms of the APPLE model supports a view of the mental lexicon in which the excitation of entries is automatic and obligatory. It points to a view of the lexicon (and of language processing in general) which is radically different from that which guided the work of Taft & Forster (1975; 1976). The role of morphological parsing is not to simplify word recognition by reducing the number of lexical entries which must be activated. Rather, I propose that lexical excitation is essentially cost-free as is the construction of morphological representations. This position is consistent with a view of language processing which has emerged from a number of disparate investigations. It has been shown by Onifer & Swinney (1981), Swinney (1979) and Tannenhaus, Leiman & Seidenberg (1979), that both meanings of a semantically ambiguous word are automatically activated. Tannenhaus, Carlson & Seidenberg (1985) have found similar effects for the processing of sentence ambiguity. These findings support the general view that language processing is characterized by modular multilevel processing in which all possible representations at all linguistic levels (i.e, phonology, morphology, syntax and semantics) are created. These representations may later be acted upon by a set of evaluation processes which unlike the representation- creating processes are not insulated from the effects of context.

References

Bergman, M. W., Hudson, P. T. W., and Eiling, P. A. 1988. How simple complex words can be: Morphological processing and word representations. *Quarterly Journal of Experimental Psychology, 40A*, 41-72.

Burani, C., Salmaso, D., and Caramazza, A. 1984. Morphological structure and lexical access. *Visible Language, 8*(4), 342-352.

Cutler, A., Hawkins, J. A., and Gilligan, G. 1985. The suffixing preference: A processing explanation. *Linguistics 23*, 723-728.

Fowler, C. A., Napps, S. E., and Feldman, L. 1985. Relations among regular and irregular morphologically related words in the lexicon as revealed by repetition priming. *Memory and Cognition, 13*, 241-255.

Hankamer, J. 1989. Morphological parsing and the lexicon. In W. Marslen-Wilson (Ed.), *Lexical representation and process*. Cambridge, Mass: MIT Press.

Henderson, L. 1985. Toward a psychology of morphemes. In A.W. Ellis (ed.), *Progress in the psychology of language, volume 1*. London: Lawrence Erlbaum.

Henderson, L., Wallis, J., and Knight, D. 1984. Morphemic structure and lexical access. In H. Bouma & D. Bouwhuis (Eds.), *Attention and Performance X*. Hillsdale, New Jersey: Lawrence Erlbaum.

Lima, S. 1987. Morphological analysis in sentence reading. *Journal of Memory and Language, 26*, 84-99.

Mandelis, L. and Tharp, D. A. 1977. The processing of affixed words. *Memory and Cognition 5(6)*, 690-695.

Murrell, G. and Morton, J. 1974. Word recognition and morphemic structure. *Journal of Experimental Psychology, 102*, 963-968.

Napps, S. E. 1989. Morphemic relationships in the lexicon: Are they distinct from semantic and formal relationships; *Memory and Cognition, 17(6)*, 729-739.

Onifer, W. and Swinney, D. 1981. Accessing lexical ambiguities during sentence comprehension: effects of frequency and meaning on contexual bias. *Memory and Cognition, 9*, 225-236.

Rossman-Benjamin, T. 1986 . *The psychological reality of morphological structure: evidence from language performance*. Unpublished manuscript. Department of Psychology, University of Pennsylvania.

Smith, P. T., and Sterling, C. M. 1982. Factors affecting the perceived morphological structure of written words. *Journal of Verbal Learning and Verbal Behavior*, 21, 704-721.

Stanners, R.F., Neiser, J. J., Hernon, W. P., and Hall, R. 1979. Memory representation for morphologically related words. *Journal of Verbal Learning and Verbal Behavior, 18*, 399-412.

Swinney, D. 1979. Lexical access during sentence comprehension. (Re)consideration of context effects. *Journal of Verbal Learning and Verbal Behavior, 18*, 645-660.

Taft, M. 1981. Prefix stripping revisited. *Journal of Verbal Learning and Verbal Behavior, 20*, 289-297.

Taft, M. and Forster, K. I. 1975. Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior, 14*, 638-647.

Taft, M. and Forster, K.I. 1976. Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behavior, 15*, 607-620.

Taft, M. 1981. Prefix stripping revisited. *Journal of Verbal Learning and Verbal Behavior, 20*, 289-297.

Taft, M. 1985. The decoding of words in lexical access: a review of the morphological approach. In D. Besner, T. G. Waller, and G. E. Mackinnon (Eds.), *Reading research: advances in theory and practice, Vol. 5*. Academic Press.

Tannenhaus, M., Carlson, G, and Seidenberg, M. 1985. Do listeners compute linguistic representations: In D. Dowty, L. Karttunen and A.. Zwicky (eds.) *Natural language parsing*, Cambridge, England: Cambridge University Press.

Tannenhaus, M., Leiman, J. and Seidenberg, M. 1979. Evidence for multiple stages in the processing of ambiguous words in syntactic contexts. *Journal of Verbal Learning and Verbal Behavior, 18*, 427-441.