Proceedings of The Institute of Acoustics

THE IMPLEMENTATION OF LEXICAL STRESS RULES IN THE CSTR TEXT-TO-SPEECH SYSTEM

J.M. McAllister

Department of Linguistics, and
Centre for Speech Technology Research, University of Edinburgh

1. Introduction

Correct lexical stress assignment contributes to the intelligibility and naturalness of speech produced both by humans and by machines. Quite apart from the variations in duration, amplitude and fundamental frequency which are associated with the production of stressed syllables [1], the underlying vowels in a word will be realised as full or reduced, depending on whether the syllable in which they appear is stressed or unstressed (compare the different pronunciations of the initial syllables in the noun and verb corresponding to the orthographic string contest).

In a morpheme-based text-to-speech system, such as that currently under development at CSTR, the stress patterns of words cannot, in the majority of cases, be marked in the dictionary: instead, they must be assigned by rule. This paper will describe work which led to the implementation of a set of lexical stress assignment rules in the CSTR Text-to-Speech system.

2. Conceptual basis

In English, the stress pattern of a word is determined by its morphological and phonological structure [2]. In a morphologically simple word, that is, in a word containing no prefixes or suffixes, stress placement is governed by the number and structure of the syllables it contains. Disyllabic words are generally stressed on their first syllable; words of three or more syllables will be stressed on the penultimate or antepenultimate syllable, depending on the number and type of vowels and consonants in the last two syllables.

In a morphologically complex word, the position of primary stress may be influenced by the presence of affixes. Each affix has associated with it a so-called 'accentual property' (1), which denotes its behaviour with respect to stress assignment. A large number of affixes (such as the suffixes ly , ing , est , and the prefixes un and em) have no effect on the placement of stress; the domain of the stress rules discussed in this section is limited to that portion of the word which remains after the exclusion of such affixes. Therefore, in a word such as uncertainly , the stress rules will operate on the morphologically simple element certain , which will receive stress on its first syllable. Because of their lack of effect on the process of stress assignment, such suffixes are termed 'stress neutral'.

(1) Much of the terminology used in this section derives from Fudge [2].

Other affixes cause stress to fall on syllables in particular positions relative to themselves. For example, one group of suffixes, which will be referred to as 'autostressed', attract stress on to the syllable which contains them: ique in unique , esce in coalesce. Another class of suffixes, which includes ic and ity , has the effect of placing stress on the immediately preceding syllable: the final suffixes of the words therapeutic and rapidity are therefore termed 'prestressed-1'. Analogously, a third class of suffixes, exemplified by cide and tude , carries the label 'prestressed-2', since such suffixes cause stress to fall two syllables back: suicide , pulchritude. Finally, the presence of a suffix such as ive will result in stress being assigned either one or two syllables back, depending on the structure of the syllable preceding the suffix: compare expensive , stressed on the syllable immediately preceding the suffix because this syllable ends with a consonant (2), with competitive , in which stress falls two syllables back. Such suffixes are termed 'prestressed-1/2'. In cases where words contain a sequence of stress-determining suffixes (e.g. authenticity , whose constituent morphs are auth , ent , ic and ity), it is the rightmost which determines the position of the stressed syllable.

The presence of prefixes is only significant in the absence of stress-determining suffixes. Stress-determining prefixes have the effect of shifting the location of stress to the right of the position predicted by the rules for morphologically simple words. Thus, the prefix dif causes stress to fall on the second syllable in two-syllable words: diffract , diffuse. The stress assignment process is complicated in the case of prefixes by the fact that certain prefixes affect stress placement only in particular grammatical categories (3): thus, while the string con causes stress to fall on the second syllable in disyllabic verbs (e.g. consume), disyllabic nouns such as concord are stressed as though they are morphologically simple, that is, with stress falling on the first syllable. It is this characteristic of prefixes which gives rise to many so-called 'stress-shifting' pairs, in which the pronunciation cannot be determined from the orthographic representation alone: convert and abstract for example, may both be stressed on either the first or the second syllable, depending on word class.

Unfortunately, the situation is further complicated by another factor. Approximately one third (forty-eight) of the affixes discussed by Erik Fudge in his book English Word Stress [2] exhibit two or more different behaviours depending on the context in which they appear. For example, although ism is stress neutral when it is attached to stems which can stand alone as

(2) The syllabification algorithm used by the system divides words into a sequence of open syllables unless this results in an unacceptable consonant cluster at the start of the next syllable.

(3) More precisely, such tests apply to that portion of the word which remains after the removal of any stress-neutral affixes. The distinction becomes significant when a stress-neutral affix which changes grammatical category terminates a word. For example, the prefix per causes stress shift to occur in verbs and adverbs (perform , perhaps) but not in nouns and adjectives. If the grammatical category of the whole word were at issue, primary stress would fall on the final syllable of the word perfectly ; however, the stressing of the initial syllable indicates that it is the grammatical category of the disyllabic adjectival stem perfect which is relevant.

words (e.g. imperialism), in other cases stress is placed two syllables before the suffix, as in metabolism. Other tests which are used to disambiguate affixes are the number of syllables in the word and its grammatical category. A similar type of ambiguity is exhibited by prefixes, (in addition to the syntactically-resolved kind discussed above).

Fudge [2] details, for each ambiguous affix, the test to be applied. Unfortunately, an implementation in which rules are indexed via individual affixes (such as Fudge's linear treatment would imply) is not computationally efficient: in effect, it would be necessary to list an individual rule for each ambiguous affix, which would increase the size of the module by some 48 rules. However, an inspection of the data reveals that it is possible to make certain generalisations regarding the behaviour of ambiguous affixes, and to exploit these generalisations in the computational modelling of the stress assignment process.

In order to approach the problem of handling ambiguity in suffixes, a matrix was constructed such that the rows and columns were marked with the labels discussed above (stress-neutral, autostressed, prestressed-1, prestressed-2 and prestressed-1/2) and suffixes were assigned to the cell denoting their particular effect on stress assignment. For example, the suffix ism (see above) was assigned to the cell denoted by the column label 'stress-neutral' and the row label 'prestressed-2'. Unambiguous affixes were therefore entered on the diagonal. This matrix, presented in Table 1, shows that ambiguous suffixes are not evenly distributed across the matrix, but tend to cluster in three cells (4). Furthermore, when the disambiguation tests were examined, a further useful generalisation emerged: the majority of the ambiguities could be resolved by a rule of the form 'if the stem is free, the suffix is stress-neutral'. Prefixes can be similarly analysed.

The results of these two analyses have led to the institution of three further suffix classes and three further prefix classes (in addition to those suggested by Fudge) which are used in the implementation of the stress assignment rules. The membership of each of the six new classes is defined by a common test-outcome sequence: for example, nine of the eleven suffixes in the 'stress neutral/prestressed-1/2' cell of Table 1 share the disambiguation test 'is the stem free' with the outcome 'stress neutral' in the affirmative case and 'prestressed-1/2' otherwise; these nine affixes now constitute one of the six additional classes used in the module.

3. Implementation

The rules described above have now been implemented in Prolog. For each word, the input to the stress module is in the form of a list of sublists. The first sublist contains entries corresponding to each prefix in the word, the second the root and the third the suffix(es). For each affix in the input, the orthographic and phonemic representation, as well as its accentual property, are marked. The first major sub-routine which is encountered deals with ambiguous affixes. This sub-routine is organised according to the category of the accentual property label which each affix carries. Labels may be of three types:

(4) Two affixes have been excluded from the matrix because they are not amenable to this two-way analysis.

LEXICAL STRESS RULES

Table 1: Distribution of suffixes across cells denoting their effect on stress placement.

(Note: Two suffixes which exhibit more than two stress assignment patterns are excluded from the matrix.)

	stress neutral	auto stressed	pre-stressed 1	pre-stressed 2	pre-stressed 1/2
stress neutral	33				
auto stressed		21			
prestressed 1		1	9		
prestressed 2	8	4		13	
prestressed 1/2	11			1	16

(1) 'simple', corresponding to one of Fudge's accentual properties, and used by the lower-level stress placement rules. The presence of such a label indicates that no disambiguation is required and the affix is passed unaltered to the stress assignment rules.

(2) 'complex', resulting from the research described in the previous section. When the program encounters one of these labels the appropriate test is executed and the resulting 'simple' label substituted.

(3) 'unique', signifying that the affix requires special (combinations of) tests which are necessary for no other affix. The presence of this label causes the program to search a set of tests, indexed by the orthographic form of the affix in question, to execute the test and to substitute the appropriate simple label.

Subsequent routines in the module make no appeal to orthography, and this input is therefore discarded.

When the ambiguity of affixes has been resolved, the placement of stress is a relatively simple matter. The prefix list is examined from left to right and the first stress-determining prefix identified: any prefixes to the left of this are temporarily excluded from the computation. A similar operation, working from right to left, is performed on the suffix list. If the new prefix and suffix lists are empty, stress is assigned according to the rules for morphologically simple words described above. (This section of the program embodies a syllabification subroutine which is used elsewhere in the module.) Otherwise, stress is assigned by affix: suffixes take precedence over prefixes in the stress assignment process. At the final stage, stress-neutral affixes, which had earlier been removed, are re-appended to the stressed string.

4. Conclusion

This paper has described research leading to the implementation of the lexical stress module of the CSTR Text-to-Speech system. The performance of the module has now been evaluated on a small, randomly-selected corpus of polysyllabic words which the system is known to decompose correctly into constituent morphemes: a 96% level of accuracy was achieved. Sub-routines which assign secondary stress and perform vowel reduction, where appropriate, have also been implemented and integrated into the system.

References

[1] Lehiste, I. 1970. Suprasegmentals. Cambridge: MIT Press.

[2] Fudge, E. 1984. English Word Stress. London: George Allen and Unwin.