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Citation for published version:

Link:
Link to publication record in Edinburgh Research Explorer

Document Version:
Publisher's PDF, also known as Version of record

Published In:
Proc. Interspeech 2010

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On Generating Combilex Pronunciations via Morphological Analysis

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Abstract

Combilex is a high quality lexicon that has been developed specifically for speech technology purposes and recently released by CSTR. Combilex benefits from many advanced features. This paper explores one of these: the ability to generate fully-specified transcriptions for morphologically derived words automatically. This functionality was originally implemented to encode the pronunciations of derived words in terms of their constituent morphemes, thus accelerating lexicon development and ensuring a high level of consistency. In this paper, we propose this method of modelling pronunciations can be exploited further by combining it with a morphological parser, thus yielding a method to generate full transcriptions for unknown derived words. Not only could this accelerate adding new derived words to Combilex, but it could also serve as an alternative to conventional letter-to-sound rules. This paper presents preliminary work indicating this is a promising direction.

Index Terms: combilex lexicon, letter-to-sound rules, grapheme-to-phoneme conversion, morphological decomposition

1. Introduction

Speech technology very much relies on the availability of a mapping from words to pronunciations. As the final stage of front-end linguistic processing in text-to-speech synthesis (TTS), a specification for the pronunciation of the words in the sentence must be found. In automatic speech recognition (ASR), this mapping is typically relied upon to form the hypothesised word sequences in terms of phone-based statistical acoustic models. Two simple ways to realise this mapping are commonplace: a lexicon simply listing words and their pronunciation; and letter-to-sound (LTS) rules, either hand-written or learned automatically from data, to predict a pronunciation from a word’s orthographic form. For many languages, either one of these, or a combination of the two, gives acceptable results. For some languages, however, they are insufficient and word morphology must be taken into account. For example, agglutinating languages such as Finnish have a massive number of potential words that can be formed using a large set of affixes. It would simply not be practical to list all these in a lexicon for ASR [1]. Meanwhile for German, TTS systems benefit from morphological analysis to deal with the productive process of morphological derivation before committing it to the lexicon. The motivation for structuring Combilex in this way was twofold. First, we aimed to accelerate lexicon development itself. It proved significantly faster to enter derived words in terms of their morphology, than to enter pronunciations and POS tags for all words by hand individually. Second, this structure helps to ensure consistency, since the pronunciations for all morphologically related words are explicitly linked. If we should modify or update the pronunciation for a core word, that change would be automatically propagated to all related words.

The ability to process pronunciation strings to achieve morphological derivation has certainly proved beneficial for developing and maintaining Combilex. However, it also seems possible to exploit this functionality further. In principle, a morphological analyser, or parser, could be used in conjunction with the morphological derivation component of Combilex to generate pronunciation strings and POS tags for new words automatically. This would have two uses. In the first instance, it would make entering new derived words even more convenient and efficient, since morphological analysis could be applied automatically and the set of resulting parses presented to the user. The user could then simply select the appropriate parse, and, if desired, verify the associated automatically generated pronunciation before committing it to the lexicon. The second potential use would be generating pronunciations for OOV words “on the fly”, for TTS for example. This would be similar to using LTS rules. However, the advantage of the proposed approach would be that a full specification for OOV words would be made available. Combilex pronunciation strings provide not only the phones themselves, but also different levels of lexical stress, syllabification, morpheme boundaries, the link between the phones and the associated graphemes and POS tags. All these could be generated for a derived OOV word too, which would be as good...
as having the word in the lexicon. This is especially useful con-
sidering TTS methods such as unit selection and HMM-based
synthesis typically use extensive context features as part of their
approach to waveform generation.

As far as we are aware, no work has previously been pre-
presented on this topic, at least for English. The purpose of this
paper is therefore primarily to introduce and discuss this idea,
as well as preliminary work to indicate the extent to which this
might be a useful approach. At this preliminary stage, there
are two obvious questions. The first concerns whether we can
estimate how useful this approach might be in terms of how
many words currently outside our lexicon are likely to be de-

daved words. The second concerns the extent to which we might
expect this approach will work for that set of words.

For the remainder of this paper, Section 2 begins by giving
a brief introduction to Combilex, describing its morphologi-
cal derivations component in particular. In Section 3, we look
closer at the proposed idea of generating Combilex pronunci-
ations for unseen words via morphological analysis. Instrumental
to this, we briefly discuss the tool we have used for morphe-
ological analysis, and present some of our preliminary findings,
before finally presenting our conclusions in Section 4.

2. Main features of Combilex

Combilex is a relatively large pronunciation lexicon that has
been developed specifically for use in speech technology ap-
lications. It has been created entirely from scratch at CSTR,
and has recently been released under wide-ranging licensing op-
tions. Combilex has many advanced features compared to
other available lexicons. A fuller discussion of some of these,
and the underlying design decisions, may be found in [5, 4].
More information about obtaining and using Combilex may
also be obtained from the project web page [6].

Combilex is an accent-independent lexicon. This means we can use it to automatically generate surface lexicons specifi-
cally tailored to any accent group, or indeed to the accent of any
individual speaker. Unlike other lexicons, which may have been
created from multiple sources or authors, the pronunciations
contained in Combilex have been supervised by a single lexi-
cographer. In addition, Combilex has been created as an SQL
database, and a system of phonotactic constraints and automatic
consistency-checking rules are applied before any pronuncia-
tion is added to Combilex. This all helps guard against the
introduction of mistakes and inconsistency due to human error.
Furthermore, as mentioned in Section 1, Combilex has been
implemented so that morphologically-interdependent words are
explicitly linked. Specifically, only the minimum possible core
set of basic words and other morphemes have pronunciations
which have been entered. All other words and terms which are
predictable are then generated automatically. Not only has this
facilitated rapid development, but it also helps to ensure that the
pronunciations of morphemes in related words remain con-
sistent, which is a powerful aid in the task of maintaining the
lexicon in the long term. In short, the method of Combilex's
construction implies a high level of consistency and accuracy in
the pronunciation strings it contains.

Combilex offers rich information in addition to the phones contained in a word. This includes POS tags, lexi-
cal stress, syllabification, morpheme boundaries, free variant
and headword ordering, source domain and gender tags for
names, source language tags for loanwords, and an explicit
alignment of the phones contained in a word to their corre-
sponding graphemes. This last feature is useful for at least three
reasons. First, it can be used when generating a lexicon for a
non-native accent, for which pronunciation may often be influ-

enced by the written form of a word. Second, it can be used to
build LTS rules [4]. Almost all data-driven methods for building
LTS rules (e.g. decision trees [7] or Pronunciation by Analogy
[8, 9]) require a training set consisting of words whose letters
are aligned with the corresponding phones in their pronuncia-
tion. Finally, as we shall see in Section 2.2, this alignment is
indispensable when processing pronunciation strings to effect
many of the morphological derivations in English.

2.1. Combilex transcriptions

Combilex transcriptions are written using a set of “meta-
phones”, which are a superset of the phones found in the differ-
ent accents of English. This symbol set is based on the SAMPA
set, but has been necessarily modified and extended. These tran-
scriptions are termed “base-form” pronunciations, and can be
thought of as a generalisation of how a word is pronounced in
all accents of English. Base-form transcriptions may then be
processed automatically to yield numerous lexicons of accent-
specific “surface-form” transcriptions (termed a “surface-form
lexicon”), such as generic RP or GAM, or even transcriptions
tailored to a specific speaker.

The best way to introduce the main features of Combilex
transcriptions is with an example. Fig. 1 gives the base-form
transcription for the word “deacidify”. The braces “{...}“ indi-
cate free root morpheme boundaries, while “<“ and “>“ indi-
cate prefix and suffix morpheme boundaries respectively. Thus,
this word is encoded as a derivation of the free root morpheme
“acid”, using suffix “-ify>" and prefix “<de-“. The symbols
“<" and “>“ denote primary and secondary stress respectively,
while “." marks a syllable boundary.

Every Combilex base-form transcription contains an in-
dication of the alignment of the constituent metaphones to
their corresponding graphemes. This is denoted as pairs of
metaphones and graphemes tied together with an underscore
"_". Metaphones appear to the left of the underscore, with
graphemes to the right. For example, the symbol "<a>_s_a" rep-
resents a schwa vowel (IPA symbol /a/) that is tied to the
grapheme “a”. As a notational economy, the grapheme (and underscore) is omitted wherever it is identical to the metaphe-

Figure 1: Combilex transcription for the word “deacidify.”

2.2. Morphological derivations

Combilex currently is capable of processing base-form tran-
scriptions with more than 90 suffixes and 30 prefixes. Exam-
ple suffixes include -ed>, -ic>, -ify> and -ness>,
while example prefixes include <de-, <semi-, <re-, <cover- and so on. Affixes were added to Combilex in or-

< d % i_e ./ @a . s_c * t_i d : I49_i . f ae_y >

1975
where the phonetic form of the cated than this. Fig. 3 gives a moderately complex example, Fig. 2. Unfortunately, the majority of affixes are more compli-
append a fixed string to the root transcription, as indicated in 
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Each affix can be thought of as a function that takes a base 
transcription string and modifies it in whatever way necessary 
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ity of the processing required varies widely. Some affixes are 
very straightforward. The 

such as -s> (e.g. to make a plural noun), were added first, 
whereas a less productive suffix such as -dom> was a lower priority. Consequently, although there may be affixes which are not currently included, the major and most productive ones are very likely to have been accounted for.

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transcription string and modifies it in whatever way necessary 
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very straightforward. The 

Figure 2: An example of simple derivation: suffix -dom> is 
comparatively straightforward: the pronunciation for the suffix 
may be simply appended to the root.

Figure 3: An example of moderate complexity; the 
-s> suffix requires merely to 
append a fixed string to the root transcription, as indicated in 
Fig. 2. Unfortunately, the majority of affixes are more compli-
cated than this. Fig. 3 gives a moderately complex example, 
where the phonetic form of the 
suffix varies depending on the ending of the word to which it is attached, and English 
spelling rules such as consonant doubling must also be taken 
into account to maintain the alignment between metaphones and graphemes. However, the burden of maintaining this mapping 
is small compared to the benefit it provides for ever more complex derivations, for example those involving stress shifts and vowel changes as shown in Fig. 4. This type of derivation 
would be very difficult to implement were it not for the ortho-
graphic alignment of Combilex transcriptions. Many affixes 
cause stress pattern changes in this way, for example size>, arian>, atic>, ation> and so on, and it is exactly this 
type of phone change that proves challenging for conventional 
letter-to-sound rules. Addressing this systematically is one of 
the major attractive theoretical advantages of the proposed morphologi-
aprogression of English morphology for 
Englex 
rectly via the proposed approach. We have furthermore used 
Koskenniemi’s finite-state two-level model of morphology, in 
an experiment to investigate what proportion of derived words 
we might expect to have pronunciation strings predicted cor-
rectly via the proposed approach. We have furthermore used 
Englex (version 2.0b5), which provides a two-level description 
of English morphology for PC-KIMMO consisting of a 
set of orthographic rules and a lexicon containing approx. 20k 
roots and affixes. As a straightforward way to evaluate the pro-
posed method, we took the complete set of derived headwords 
in Combilex and analysed them using PC-KIMMO. One of 
these outcomes was possible for each word: a) the morphologi-
classical parse would match that specified in Combilex; b) the parse 
would not match; or c) no parse would be found. The results ob-
tained are shown in Table 1 (labelled “run 1”). 

Analysis of the list of words which failed to parse re-
vealed the overwhelming majority contained a root which was 
ether not present in PC-KIMMO’s lexicon, or did not include 
all possible POS types. We chose to add 10,143 new words 

3. Generating OOV transcriptions
A key question at this preliminary stage is how useful it is likely to be to generate Combilex transcriptions for derived OOV 
words via morphological analysis. The answer lies partly in 
how many OOV words are derivations, and partly in how accu-
rately we could generate morphological parses for such words.

3.1. How many OOV words are derivations? 
Unfortunately, this is by nature a difficult question. It could 
be suggested a large number of the words not included in 
Combilex are names, for which an approach based on mor-
phological analysis would be no use at all. However, it is 
true to say that names too undergo morphological transforma-
tion. For example, derived from the one name “Adam” we of 
course find “Adams”, but other less obvious derivations such as 
“Adamesque”, and even ‘Adamness’ and ‘Adamify’, may be 
easily found with a web search, and with apparent meanings as 
ones would expect!

To estimate an upper bound on the total possible produc-
tivity of morphological derivation, we could try an empirical 
approach of taking a representative set of roots and generating 
all derivations by applying all possible combinations of affixes. Unfortunately, this is impractical, not least because it is un-
clear what stopping criterion to use (neontandisestablishmentar-
ianism? postneontandisestablishmentarianism?...). Moreover, 
blindly and exhaustively generating derived words would not 
reflect human judgement about what constitutes an acceptable, 
meaningful derivation.

It seems clear intuitively that however many non-derived 
words there are, there are likely to be many multiples of that 
number which are derivations of them. The statistics from 
Combilex support this: approx. 22k headwords are “core”, 
non-derived words; 12k words are names; and 100k words have 
been entered as derivations. Thus, it seems at least likely that 
the proposed approach will be applicable to a large proportion 
of OOV words.

3.2. Morphological analysis experiment
We have used the well-known PC-KIMMO[10, 11] morphologi-
cal analysis tool (version 2.1.13), which is based on Kimmo 
Koskenniemi’s finite-state two-level model of morphology, in 
an experiment to investigate what proportion of derived words 
we might expect to have pronunciation strings predicted cor-
rectly via the proposed approach. We have furthermore used 
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ether not present in PC-KIMMO’s lexicon, or did not include 
all possible POS types. We chose to add 10,143 new words
to PC-KIMMO’s lexicon including: 5,171 proper nouns, 4,353 nouns, 870 verbs and 486 adjectives (some with multiple types). We have not so far addressed the issue of missing POS tags for existing words, which would further reduce parse failures.

Meanwhile, analysis of those words for which the parse found did not constitute a single, exact match revealed a number of reasons, which we broadly classify into three groups:

1) **Incompatible format** In some cases Englex and Combilex use a different approach to representing affix morphemes, which requires harmonisation. For example, Englex has two suffixes “-ise>” and “-ize>” whereas Combilex has only “-ise>” and treats “-ize>” as a variant spelling.

2) **Differing choices for morphological structure** For example, PC-KIMMO has a lexical entry for the word “abolition” and does not parse this word into submorphemes (although does indicate its root is “abolish”), whereas Combilex represents this word with the morphological structure “abolition>”. This means all parses for derived words based on “abolition” do not match, though they may otherwise be the same.

3) **PC-KIMMO returns multiple parses for many words.** For example, “codirector” is parsed as “<co<direct><or>” (as in Combilex) and “<co<di<rect<or>”. Multiple parses sometimes make sense (e.g. for homographs), but often some parses either do not seem likely or are certainly not correct.

Of these categories, the first is the most straightforward to remedy, and we have undertaken to harmonise the major differences in morpheme format between PC-KIMMO and Combilex. It is possible that the second category would not cause much trouble. For example, Combilex would generate the same pronunciation for “abolitionism” using the “-ism>” suffix irrespective of whether it used its ready-derived pronunciation for “abolition” or whether it processed the derivation for “abolish>” on the fly. Meanwhile, the production of multiple parses would not pose much of a problem when entering new words into Combilex, since the user would merely be required to select the desired morphological structure. However, it would be more problematic when generating pronunciations unsupervised for TTS. Overall, addressing incompatibilities of types 2) and 3) will require further investigation, and we have not addressed these in the work presented here.

Having added a number of missing roots to PC-KIMMO’s lexicon, as well as attempting to harmonise the format of morphological parses between PC-KIMMO and Combilex, we repeated the experiment. These updated results are labelled “run 2” in Table 1. This time the morphological parse for 75% of words exactly matched that specified in Combilex. This is an encouraging result.

### 4. Conclusions

This paper has proposed a method to generate the pronunciations for derived OOV words via morphological analysis and the derivation functionality of Combilex. One major use for this would be to make it very efficient to increase the coverage of words in Combilex. Another major use could be for TTS, in place of letter-to-sound rules. The attraction of the latter is that for correctly parsed words we would obtain all the same information available for words that are actually present in the lexicon. Importantly, these features are very often used to define context in HMM-based and unit selection synthesis. We have postulated that the number of OOV words that are derivations is potentially very large, and in fact there are likely to be many more derived words overall than non-derived ones. Furthermore, preliminary experimentation has shown that the large majority of these may be parsed successfully (75% correct so far, using very simple and conservative match criteria). We conclude therefore that this is a promising line of research and is very much worth pursuing.

In future work, we shall work on increasing the proportion of words which produce a parse that is compatible with Combilex. Nevertheless, it is unlikely we could achieve 100% correct parses, and we will inevitably need to address this issue, which we have not done at all at this stage. Complete failure to find a parse is arguably not a serious problem; for TTS, it would be simple to fall back to using LTS rules for example. However, the issue of incorrect parses will require more attention. Finally, once we have addressed these two issues and integrated morphological analysis more closely with the morphological derivation component of Combilex, it will be interesting to conduct a fair comparison against the performance of a state-of-the-art LTS system.

### 5. Acknowledgements

The development of Combilex was supported by a Proof-of-Concept grant from Scottish Enterprise. K. Richmond is currently supported by EPSRC grant EP/E01609x/1.

### 6. References


