Assimilation and Deletion Phenomena Involving Word-Final /n/ and Word-Initial /p, t, k/ in Modern Greek: a Codification of the Observed Variation Intended for Use in TTS Synthesis

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Abstract
The present paper is a preliminary attempt to codify assimilation and deletion phenomena in Modern Greek involving the word-final /n/ of certain high-frequency function words and the word-initial voiceless stop (/p/, /t/ or /k/) of the following word. In natural speech, every relevant phoneme combination affected by these post-lexical phonological processes will generate one phonetic realisation from a set of legitimate variants. The variants’ distribution is not random but subject to both linguistic and extralinguistic conditions. This work also explores possible ways to exploit the findings of recent sociolinguistic research on Modern Greek with a view to accommodating the observed variation and the rules codifying it within the framework of text-to-speech (TTS) synthesis. Such a development is expected to improve synthetic speech output, both in terms of naturalness and intelligibility.

1. Introduction
Variation in speech production first received special attention by the Neogrammarian scholars between the 19\(^{th}\) and 20\(^{th}\) centuries, as a possible cause or vehicle of language change [1]. Quantitative sociolinguistic research conducted since the 1960’s has revealed that variation in speech production is not random but subject to a number of competing factors, both socio-pragmatic (e.g. age, sex, social status, setting, formality level, etc.) and purely linguistic (e.g. phonological environment, word length, stress position, syntactic context, etc.) [2], [3]. Variation can be thought of as limited within a finite set of discrete identifiable variants. Their skillful manipulation in natural speech is the unmistakable sign of a linguistically mature native speaker [4].

Quantitative work on principled variation in speech production in Modern Greek has started relevantly recently and has focused mainly on the presence or absence of prenasalisation during the production of voiced stop sounds (symbolized by ŭ, ŭ, ŭ, ŭ in orthographic representations) and on the assimilation and deletion phenomena involving sequences of word-final /n/ and word-initial voiceless stop phonemes [5], [6], [7], [8], [9]. It has been found that the presence or absence of nasal elements in these contexts and the blocking or allowing of the relevant phonological processes are related to the code-switching process between careful and casual speaking styles. The evidence from field research suggests that speakers manipulate the available variation possibilities systematically, although not necessarily consciously [9].

The main aim of this work is to codify in the form of multiple output re-write rules the phonetic variation involving sequences of word-final /n/ and word-initial /p/, /t/ or /k/, as this has been attested in natural speech production in Modern Greek. Our secondary aim is to briefly explore fruitful ways in which these rules could be incorporated in text-to-speech (TTS) synthesis systems.

The structure of this paper is as follows: Section 2 discusses some positive effects on the quality and flexibility of synthetic speech which are expected to stem from the incorporation in TTS systems of models reproducing the variation under examination. Section 3 introduces a codification schema that can accommodate attested variant forms. Section 4 presents some morphosyntactic constraints limiting the distribution of the variation phenomena under examination. In Section 5, the proposed codification schema is used for the generation of candidate variant forms to be exploited in further TTS synthesis research. Section 6 discusses, in the context of TTS synthesis applications, the issue of optimal variant-selection based on sociolinguistic evidence and briefly outlines a relevant experiment currently under way. Section 7 concludes the paper.

2. The need to reproduce the attested variation in TTS synthesis
Realism and descriptive completeness in the theoretical analysis underlying and supporting a TTS synthesizer are desirable if one aims to develop a system intended to be used for different purposes and in a variety of contexts of interaction. If such a system develops into a commercial product, its output will have to sound sufficiently natural to pass the aesthetic test posed by its end users. Users will judge the system with their perfect, yet tacit and instinctive, qualitative knowledge of the communicative norms that govern spoken interaction in real life. TTS engineers attempting to improve the naturalness of their systems’ output will have to do so by simulating natural speech production through the manipulation of explicitly postulated (but necessarily imperfect) quantitative parameters. Given the findings of recent quantitative research (see Section 1), such explicit quantitative criteria could be safely extracted only through analysis of corpora of natural speech.

Not only naturalness, however, but also intelligibility is a requirement in synthetic speech, especially when synthetic
speech systems are used by people with special abilities or in (physical or virtual) communicative settings with high levels of noise. In these cases, the requirement for intelligibility will normally override that for naturalness. Although there is no quantitative evidence yet as to the distribution of such phenomena in Modern Greek (cf. [10]), phonetic variation, in principle at least, can lead to semantic ambiguity within the limits of a syntactic phrase. In speech synthesis for special purposes, overlap between the numerous phonetic variants of different linguistic units (see below) can be kept to a minimum through artificial suppression of the potential for variation. This, while at the cost of naturalness, can be in the interests of intelligibility.

Systems can be designed to produce utterances which, though not natural-sounding in all conceivable contexts of use, will be maximally comprehensible, as the phones (the concrete sounds) that will comprise them will be maximally close to the phonemes of Modern Greek, i.e. to the sounds performing semantic distinction functions in that language. Such a system, for example, would always produce the signal [tinpira] if fed with the input string <την ποτήριο> (corresponding to the linguistic unit / #tin##/pira#, “the experience”), while, at the same time, would always produce the distinct signal [timbra] if fed with the input string <την μπότιν> (corresponding to the linguistic unit / #tim##/bra#, “the beer”). In natural speech, however, the phonetic variants realising the two units overlap; for example, both the signals [tibira] and [timbira] can be legitimately used to refer to either of the two meanings.

3. An attempt towards the formal interrelation of variant forms

Three different phonological processes (Processes 1, 2 and 3; see Table 1) may be used to account for the four types of phonetic realisation commonly attested in the data (Types (ii), (iii), (iv) and (v)) and the maximally comprehensible but rather ‘artificial’ type (Type (i); see Section 2). One process or one combination of processes apply to each instance of post-lexical sequences of /-n#// and /#p-/, /#t-// or /#k-// so as to produce the variant phonetic realisation appropriate to the communicative context at hand. When two processes are required for the production of a variant (as in cases (iii) and (iv)), these apply serially, in the given order, so that the output of the first process constitutes the input of the second [11].

The four typical realisations of the phrase / #stin##/poli# /, <στην πόλη>, “to/at the city”, may be used to illustrate the five variant categories of phonetic feature combinations and the phonological processes giving rise to them, according to the schema in Table 1 (where “#” represents a word boundary and “O” the trace of a deleted phoneme). Process 0, being the ‘Null Process’, causes no changes to the underlying sounds. Process 1 is a ‘Place Assimilation’, by application of which the word-final nasal assimilates to the place of articulation of the next word’s word-initial voiceless stop consonant (progressive assimilation). Process 2 is a ‘Voicing Assimilation’, by which the word-initial voiceless stop consonant, and the /s/ which may follow it, assimilate to the voicing setting of the preceding word-final nasal (regressive assimilation). Finally, Process 3 deletes the word-final nasal.

<table>
<thead>
<tr>
<th>Example</th>
<th>Applying Processes</th>
<th>Example Output</th>
<th>Example Realisation</th>
<th>Type of Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td>/n##p/</td>
<td>0</td>
<td>/stinpologi/</td>
<td>(i)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>/stimpologi/</td>
<td>(ii)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 ‡ 1</td>
<td>/stimbologi/</td>
<td>(iii)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 ‡ 3</td>
<td>/stibologi/</td>
<td>(iv)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>/stipologi/</td>
<td>(v)</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: A proposed schema of post-lexical phonological processes, accounting for attested variant phonetic forms realising sequences of /-n#/ and /#p-/, /#t-// or /#k-//.

- “0”: Null process. “1”: regressive Place Assimilation.
- “2”: progressive Voicing Assimilation.
- “3”: Deletion of the word-final nasal.

It must be stressed here that none of the commonly attested types of phonetic realisation (Types (ii) – (v)) constitutes an ‘accent’ in its own right. A person invariably realising all relevant post-lexical sequences of phonemes according to the same type of variant would certainly sound unnatural; in fact, much of the ‘unnaturalness’ of TTS systems may be attributed to the same flaw. Variation is inherent in speech production. All variant forms are present in the linguistic repertoire of any one individual, albeit in different numbers. Furthermore, no two individuals display the same pattern of frequencies for the four variant types of realisation. Sociolinguistic research, however, commonly invokes a standardized pattern of frequencies as a sort of ‘mean’ for groups of people identified by the same set of social characteristics, such as common age, gender, class, etc. [2], [3], [9] (see Section 6).

Invariability would be justified only when maximum intelligibility were required. In that case, Type (i) realisations would probably be the safest bet: being rather ‘artificial’, they can be distributed evenly within utterances.

4. Morphosyntactic constraints on the input of the phonological processes

A TTS system implementing (some form of) the codification system presented in this paper will, at some point, have to determine which pairs of words in its input are relevant to the phonological processes presented in Section 3. This is a task distinct from and temporally preceding the task of deciding which of the pronunciation options (i) to (v) offered by the schema of Table 1 will eventually be used for the coarticulation of each legitimate pair of input words.

At this point of our research it appears that the first word (or “W1”) of each legitimate pair can only be a function word. Examining the list of the 1,000 most frequent orthographic words in the Hellenic National Corpus (HNC), the online electronic text corpus developed by the Institute for Language and Speech Processing (ILSP) ([12], [13]), we have identified only 13 words that can undoubtedly function as W1 and, therefore, trigger the rules. All of them are function words: the forms of the definite article <τον, την, τον,>, the form <δεν> of the indefinite article, the negative particles <δεν, μην>, the inflected prepositions <στον, στην, στον>
and the conjunctions <τσν, σν, ὄταν, προν> (<τσν, τνγ> can also represent the weak forms of the personal pronoun).

Despite their small number, the above word types represent in total 1,975,981 orthographic word tokens in HNC, or 5.78% of the 34,158,816 orthographic strings comprising the corpus. The high frequency of these types indicates that a successful tackling by a TTS system of the assimilation and deletion phenomena we are dealing with here can greatly contribute to the improvement of its performance.

The previous morphosyntactic constraint on W1 needs to be mirrored by one on W2: the second word of each co-articulated pair will be a content word, belonging, in the majority of cases, to one of the four prototypical inflected word categories of Greek: a noun or adjective will normally follow <τνγ, τν, στνγ, στνγ, στνγ, ενα, εναν>, while <δέν, μνγ> will normally be followed by a verb or pronoun. <τνγ, τνγ>, when representing a pronoun, can also be followed by a verb.

At present, our research does not extend to cases when both W1 and W2 are content words. Further work is required so that our proposed schema of phonological processes is adequately modified to cover such cases as well.

5. A set of Multiple-Output re-write rules

The schema of phonological processes outlined in Table 1 can also be used inversely, i.e. not only for the accommodation of attested forms, but also for the production of candidate variant phonetic forms in cases when /n/ is followed by voiceless stops other than /p/. Inspired by recent work in other fields [14], we have used our schema to generate all possible phonetic variants for post-lexical combinations involving <μνγ/> and each of the segments generally accepted as the allophones of the voiceless stop phonemes of Modern Greek [15], [16] (see Table 2). “†” marks instances of redundant application of a (set of) process(es), while “◦” is the “not” logical operator: “p(◦)” means “/p/ followed by any segment other than /s/”.

<table>
<thead>
<tr>
<th>MO Rule</th>
<th>Input string</th>
<th>Variant Output string</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>n##p(»)</td>
<td>nps np mp mb b p</td>
</tr>
<tr>
<td>2</td>
<td>n##k(»)</td>
<td>nts nt nd nd t</td>
</tr>
<tr>
<td>3</td>
<td>n##k</td>
<td>ncs nc nj n j e</td>
</tr>
<tr>
<td>4</td>
<td>n##p(»)</td>
<td>nks nk ng n g k</td>
</tr>
<tr>
<td>5</td>
<td>n##k</td>
<td>nps nps nz n mbz bz ps</td>
</tr>
<tr>
<td>6</td>
<td>n##s</td>
<td>nts nts n dz ndz dz ts</td>
</tr>
<tr>
<td>7</td>
<td>n##k</td>
<td>nks nks ngz gz ks</td>
</tr>
</tbody>
</table>

Table 2: Phonetic variants for post-lexical combinations of <μνγ/> + voiceless stop segment, as generated by the schema of Table 1. “MO”: multiple-output. “◦”: processes applying redundantly.

The complexity of the interrelated criteria that inform variant choice in natural speech could be artificially simplified for the purposes of synthetic speech production. A project, however, may seek to synthetically reproduce the different speech styles of a particular individual, or a particular style, say the relaxed vernacular style, of the inhabitants of a major urban center, irrespective of speakers’ social class, age, or even gender. An experiment currently under way is doing so for the sample of speakers providing the speech data in a recent field study [9]. The experiment utilizes the study’s findings regarding the distribution patterns for the phonetic variants of post-lexical sequences of /n/ and /p, t, k/ in the speech of the sample of speakers as a whole. The study examined the correlation of the distribution of the 4 attested variant types with 41 independent linguistic variables; by means of statistical methods it was discovered that the distribution in question correlates significantly with 8 of them:

- The grammatical category of W1.
- The grammatical category of W2.
• The place of articulation of W2’s word-initial voiceless stop.
• The existence of a word-initial consonant cluster in W2
• W2’s length measured in syllables.
• The existence of a voiced consonant in the onset of the final syllable of W1.
• The existence of a nasal in the onset of the final syllable of W1.
• The position of the stress in W2.

In the experiment, the relevant data are utilized by an optimal selection algorithm using probabilistic criteria. An existing TTS system is being modiﬁed to incorporate the algorithm. The algorithm will utilize pre-processing tools (such as a part-of-speech tagger and a syllabifyer) developed by ILSP, and will be integrated into the grapheme-to-phoneme module of the system. The system’s performance will be evaluated for naturalness by a random sample of non-specialist individuals. The experiment and its results will be reported in a forthcoming paper.

7. Summary

This paper presented a schema for the codiﬁcation of the phonetic variation involving the word-final /ν/ of certain high-frequency function words and the word-initial voiceless stop phoneme of the following word. The variation was modeled as an unordered, but potentially modifiable, system of phonological processes (two different types of assimilation and a deletion), altering the underlying forms of words and giving rise to multiple surface forms. The input to the relevant re-write rules was constrained by reference to morphosyntactic criteria. The practical gains of a possible reproduction of the attested variation within the framework of TTS synthesis were discussed. The problem of controlling the multiple output of the rules in TTS synthesis by use of linguistic and extra-linguistic criteria was posed. Finally, an experimental effort to incorporate our proposed set of multiple-output rules into an existing TTS system with a view to accomplishing perceptible levels of improvement was schematically outlined.

1 Although Type (i) realisations (i.e. nasals not assimilated to the place of articulation of the following voiceless stop) are attested extremely rarely, they certainly are not ungrammatical. They are commonly referred to as ‘orthographic pronunciations’ and are normally expected to occur in emphatic utterances. No instances of Type (i) realisations occur in the speech data we are using [9].

2 Despite linguistic intuitions as to the contrary, Type (v) realisations are well-documented in the speech data we are using [9].

8. References