Developments in Fuzzy Sets, Intuitionistic Fuzzy Sets, Generalized Nets and Related Topics. Volume I: Foundations

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Questions of information imprecision in phonetics

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Abstract

The aim of this paper is to indicate problems of imprecision in phonetic information particularly in the articulatory description of the speech sounds of a given language. The author attempts to show how fuzzy sets and interval-valued fuzzy sets can shed new light on the description of phonetic phenomena.

Keywords: articulatory phonetics, information imprecision, phonetic similarity.

1 Introduction

Phonetics involves a general study of the characteristics of speech sounds (cf. Yule [8]). There are three main branches of phonetics:

- **articulatory phonetics –** study of how speech is produced ('articulated');
- **acoustic phonetics** – deals with the physical properties of speech as sound waves 'in the air';
- **auditory (perceptual) phonetics** – deals with perception of sounds via the ear.

In this article we will concentrate exclusively on articulatory phonetics. In articulatory phonetics, it is investigated how speech is produced by humans, and which organs are used in this process.

When sound is produced by a human, it starts with air being pushed out by the lungs, then it passes through the larynx and vocal cords, which can take two basic positions:

- **voiceless** – vocal cords spread apart, such that the air from the lungs passes through them without obstacles,
- **voiced** – vocal cords drawn together, such that they vibrate when pushed by the flow of air.

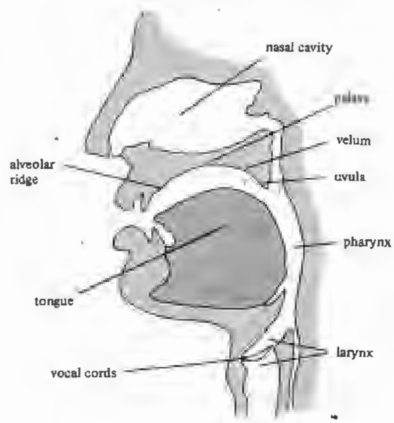

Figure 1: Parts of the oral cavity crucially involved in speech production (Yule [8])

Once the air has passed through the larynx it comes through the oral or nasal cavity. Most consonants are produced by moving the tongue towards other parts of the mouth to constrict the shape of the oral cavity.
To describe the place of articulation of most consonant sounds we start from the front of the mouth and work back (see Figure 1):

- **bilabials** – sounds produced using both upper and lower lips,
- **labiodentals** – formed with upper teeth and lower lip,
- **dentals** – tongue tip *behind* the upper front teeth,
- **alveolars** – *front part* of the tongue on the alveolar ridge,
- **alveo-palatals** – tongue at the front of the palate *near* the alveolar ridge,
- **velars** – *back* of the tongue against the velum.

Notice that the exact place of articulation can differ somewhat depending on the speaker or even on the generation of a particular sound (see Figure 2). For example, sometimes it is not easy to decide whether the tongue is in the palatal or velar position.

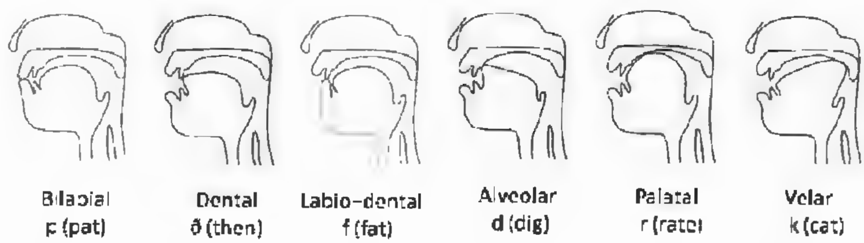

Figure 2: Examples of places of articulation (Kondrak [6])

Another aspect is the manner of articulation. Speech sounds can be produced by pushing the air stream through the oral cavity, nasal cavity or both. Thus sounds can be divided into oral, nasal, and oral-nasal.

It seems that the place of articulation which is generally accepted to be crucial in the description of consonants is not relevant for vowels. Vowels are produced with the airflow not being obstructed at any stage of articulation and moving through oral or nasal tract. To describe a vowel, we consider the way in which the tongue influences the „shape" through which the airflow must pass. It is usually presented on the vowel diagram (see Figure 3), which is a schematic arrangement of the vowels, indicating the vertical and horizontal position of the tongue.

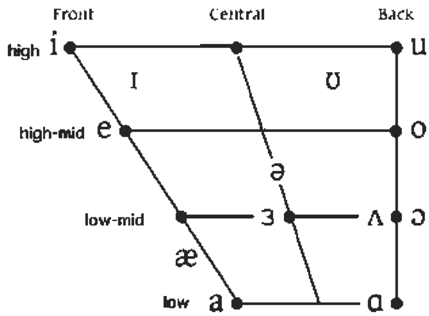

Figure 3: Vowel diagram

As can be observed, this description is given in a very imprecise manner. For example 'e' is articulated with the tongue *a little lower* than 'i' and *higher* than 'ə' and *much higher* than 'a', while 'i' is a *little more* frontal then 'e'.

2 Articulatory features

In the introduction we have presented a few very basic characteristics of speech sounds. There exist many more features describing the speech sounds generated by human beings. The theory which deals with the description of these features in a formal way is called phonetic grammar (cf. Dyczkowski et al. [4,5]). At the foundation of the theory of phonetic grammar lie several primitive terms, among which the following can be listed:

- speech sound (phone) *hic et nunc* – a physical entity produced at a certain time;
- the set of articulatory features;
- the relation of homophony;
- the relation of homogeneity.

The speech sounds are of temporal character and their number is actually infinite. To reduce the number of elements to be considered, we classify the *hic et nunc* pronounced speech sounds into sets of phones based on the relation of homophony, e.g. the set of all homophonous temporal realizations of the speech sounds p_1, p_2, p_3, p_4, …. is considered to be the phone [p]. All phones are described in terms of articulatory features. For example, the relevant features of [p] are: *voiceless, oral, hard, plosive, labial,* etc. Assigning an exhaustive feature set to a given phone is equivalent to defining the phone. The set of articulatory features is specified according to a given language. The features bound by the relation of homogeneity are classified into dimensions (cf. Bańczerowski [2,3], Ladefoged [7]). For Polish, a set of articulatory dimensions was postulated by Bańczerowski [1], and completed by Dyczkowski et al. [4,5]:

- mechanism of air flow origin,
- direction of air flow,
- state of the glottis,
- path of air flow,
- place of articulation,
- the articulator,
- position of the middle of the tongue,
- degree of supraglottal aperture,
- vertical position of the tongue,
- horizontal position of the tongue,
- degree of labialization,
- degree of delabialization,
- duration of articulation,
- degree of supra- and subglottal tension,
- slide movement,
- frequency of articulatory approximation.

The majority of the above properties are multivalued and can contain many features. Some of them, such as 'place of articulation', can take as many as ten different values, while others, such as 'state of glottis' are basically binary dimensions. All articulatory features are traditionally modelled as discrete values although it is tacitly assumed that the distances between certain features are of labile character. For example, if one takes into consideration the discretely modelled dimension of the "degree of labialization" (see Figure 4) it becomes obvious that the values are not in fact discrete.

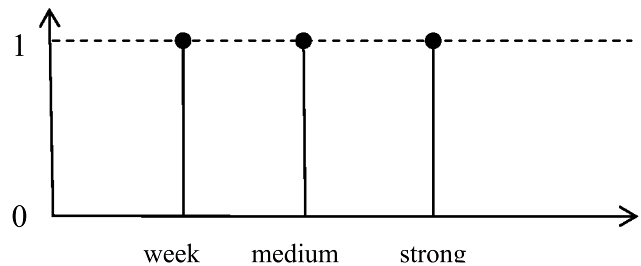

Figure 4: 'Classic' set of articulatory features in the dimension 'degree of delabialization'

They can or even should be modelled in a continuous, imprecise way, in order to express the real nature of the articulatory phenomena. For example, they can be modelled with interval-valued fuzzy numbers (see Figure 5).

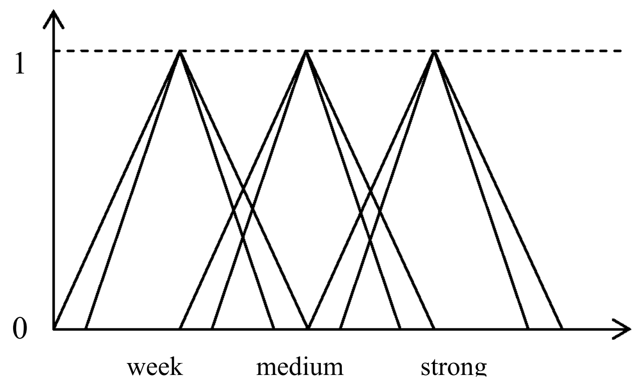

Figure 5: 'Soft' features in the dimension 'degree of delabialization'

3 Imprecise models for phonetic phenomena

In the following section we will consider several phonetic phenomena to which imprecise information modelling can be applied. They are only example problems, and further research is undoubtedly needed for better understanding of the complexities of the phonetic systems of different languages.

3.1 Phonetic similarity

How to measure more adequately the differences between phones in a given language or between languages? More precisely, the question is that of how to measure the articulatory distance between speech sounds. We can enumerate here the following problems:

- How to find similar words (i.e. words articulated in a similar manner)? Finding a solution to this problem can be helpful in:
  - audio/visual speech recognition;
  - human-computer communication;
  - database searching.
- How similar are phones in different languages? For example: Polish high centralized vowel [ɨ] (*syn* [sɨn̪] *'son')* and Hindi near high and near frontal [ɪ] in (सिर्फ़ [sɪrf] '*only'*).
- We can consider phonetic similarity between words, texts and whole language systems e.g.: which phones are more similar: [p]-[b] or [k]-[t]?. What languages are more similar to each other with respect to their phonetic systems? Is Polish more similar to Czech or to Russian?

3.2 Modelling assimilations

Speech sounds which are adjacent to each other are susceptible to assimilation. For example, the articulation of [t] in the Polish word *trzeba* [tʃɛbɑ] (*'it is necessary')* is alveolar due to the place of articulation of the following sound [ʃ], while it remains dental in other contexts e.g. *tata* [t̪ɑt̪ɑ] (*'daddy').* In less correct pronunciation, the stop [t] even becomes an affricate [ʧ], resulting in the realization: [ʧʃɛbɑ]. Both sounds, however, are voiceless. There are therefore at least a few articulatory dimensions involved in the features assimilation, namely *state of glottis*, *place of articulation*, *articulator*, *degree of supraglottal aperture*. To account for the direction of assimilation one can either apply discrete values or continuous ones. It appears that the application of continuous values makes it possible to capture the processual aspect of the articulation, which can be modelled as degree of interaction between nearest articulation features in a given dimension (see Figure 6).

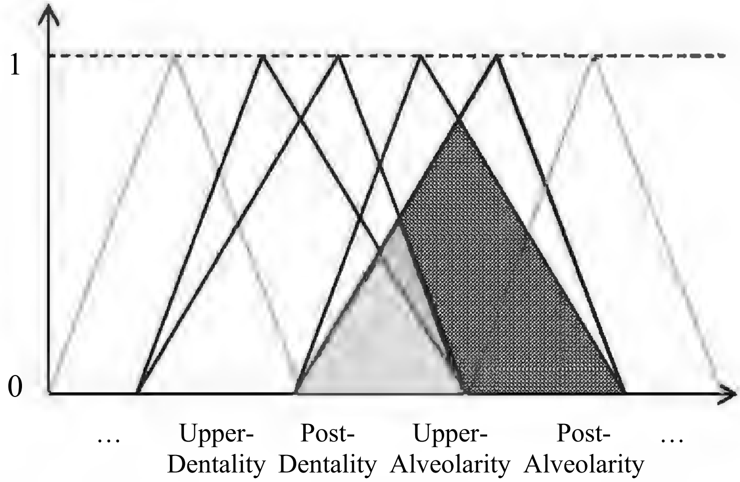

Figure 6: Degree of the interaction between the features dentality/alveolarity in the dimension 'place of articulation'

3.3 Modelling historical changes

Phonetic systems of languages undergo stadial changes in the course of history. Questions can be posed as to whether, on the basis of the current phonetic forms of languages, we can trace changes and interactions which occurred in the process of language forming and, on this basis, reconstruct the direction of those changes and presumably predict future ones. For example, we know that in Germanic PIE (Pre-Indo-European) voiceless stops became fricatives (cf. Sanskrit *bhrāṯā* (*'brother'*) and Gothic *broθ̠ar*)). This phenomenon is known as Grimm's law. In certain contexts (depending on the position of the accent) the change was however less regular and resulted in consonant voicing (Werner's law). Having at our disposal sets of different laws (rules) explaining phonetic changes and sets of cognates which are the basis of reconstruction, we can further attempt to apply continuous (imprecise) values for the purpose of better explaining language change (cf. Kondrak [6]).

4 Conclusions

Applying methods of imprecise information processing seems to be very promising in the analysis and modelling of many phonetic phenomena from both synchronic and presumably diachronic perspectives. The idea of applying an apparatus based on the theory of fuzzy sets for the purpose of better explaining language change is certainly a promising one, and deserves further research.

Acknowledgment

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The papers presented in this Volume 2 constitute a collection of contributions, both of a foundational and applied type, by both well-known experts and young researchers in various fields of broadly perceived intelligent systems.
It may be viewed as a result of fruitful discussions held during the Eighth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2009) organized in Warsaw on October 16, 2009 by the Systems Research Institute, Polish Academy of Sciences, in Warsaw, Poland, Centre for Biomedical Engineering, Bulgarian Academy of Sciences in Sofia, Bulgaria, and WIT – Warsaw School of Information Technology in Warsaw, Poland, and co-organized by: the Matej Bel University, Banska Bistrica, Slovakia, Universidad Publica de Navarra, Pamplona, Spain, Universidade de Tras-Os-Montes e Alto Douro, Vila Real, Portugal, and the University of Westminster, Harrow, UK:

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The Eighth International Workshop on Intuitionistic Fuzzy Sets and Generalized Nets (IWIFSGN-2009) has been meant to commence a new series of scientific events primarily focused on new developments in foundations and applications of intuitionistic fuzzy sets and generalized nets pioneered by Professor Krassimir T. Atanassov. Moreover, other topics related to broadly perceived representation and processing of uncertain and imprecise information and intelligent systems are discussed.

We hope that a collection of main contributions presented at the Workshop, completed with many papers by leading experts who have not been able to participate, will provide a source of much needed information on recent trends in the topics considered.

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