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A phonetic grammar of the Polish language[1]

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Abstract

The aim of the present paper is to give an overview of the investigation of the phonic articulatory systems of Polish on the basis of the detailed articulatory descriptions existent in phonetic literature and with the use computational tools. First the theoretical foundations of the phonetic grammar are briefly introduced, then the main problem of the choice of an appropriate repertory of phones for Polish is also discussed. The last section is devoted to the presentation of the computionalamalysis of the collected data.The created application enables us to collect a given phonetic inventory, taking into consideration the division into particular languages and the database generated here makes further computer analyses possible. Owing to the introduction of numeric interpretation of the articulatory features and dimensions, the phones can be treated as vectors in n-dimensional metric space. Then the measures of distances can be employed as measures of similarity between respective phones. By means of applying the Data Mining algorithms the interdependencies in the set of phones can be automatically shown. The present paper is a first attempt to apply the axiomatic theory of language at the phonetic level to the analysis and synthesis of the phonetic system of Polish.

1 Introduction

A phonetic grammar of an language is understood as a set of relations between articulatory features and relations between dimensions of speech sounds (phones). The concept of phonetic grammar is based on the original axiomatic theory of language presented in the works of Prof. Jerzy Bańczerowski (e.g. Bańczerowski, Pogonowski, Zgółka 1982; Bańczerowski 1985; 1987; 1990; 1992).

The aim of the present paper is to give an overview of an investigation of the phonic articulatory systems of the Polish language (also planned to include other languages, e.g.

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Hindi and Chinese) on the basis of detailed articulatory descriptions existent in phonetic literature and with the use of computational tools.

2 Foundations of the phonetic grammar

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 in 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. For Polish, a set of articulatory dimensions was postulated by Bańczerowski (1982), and we suggest completing it with at least two more dimensions (bolded):

- 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.

3 Phones as objects in n-dimensional space

The original method introduced the notion of articulatory distance between phones. The distance there is interpreted as a number of differential features (features which differ given phones). It is thus equivalent to the well-known Hamming distance:

$$\mathrm{Dist_H}(\mathrm{a},\mathrm{b}) \;= \sum_{i=1}^{n} H(a_i - b_i)$$

where a,b$\in G$ and function H is defined as follows:

$$H(\mathrm{a},\mathrm{b}) = \begin{cases} 1 & \text{if } a_i \neq b_i, \\ 0 & \text{otherwise.} \end{cases}$$

Our team has proposed introducing a numerical interpretation of the articulatory dimensions. Let G be a set of all phones within which the subsets G_l of the phones belonging to a given language can be specified (where l is the index of a given language), and let $W = \{W_1, W_2, \dots W_n\}$ be a set of articulatory dimensions, where n is a number of articulatory dimensions. Each phone g from the set G is specified by a vector in n-dimensional metric space $\mathbb{R}^n$ (Fig. 1).

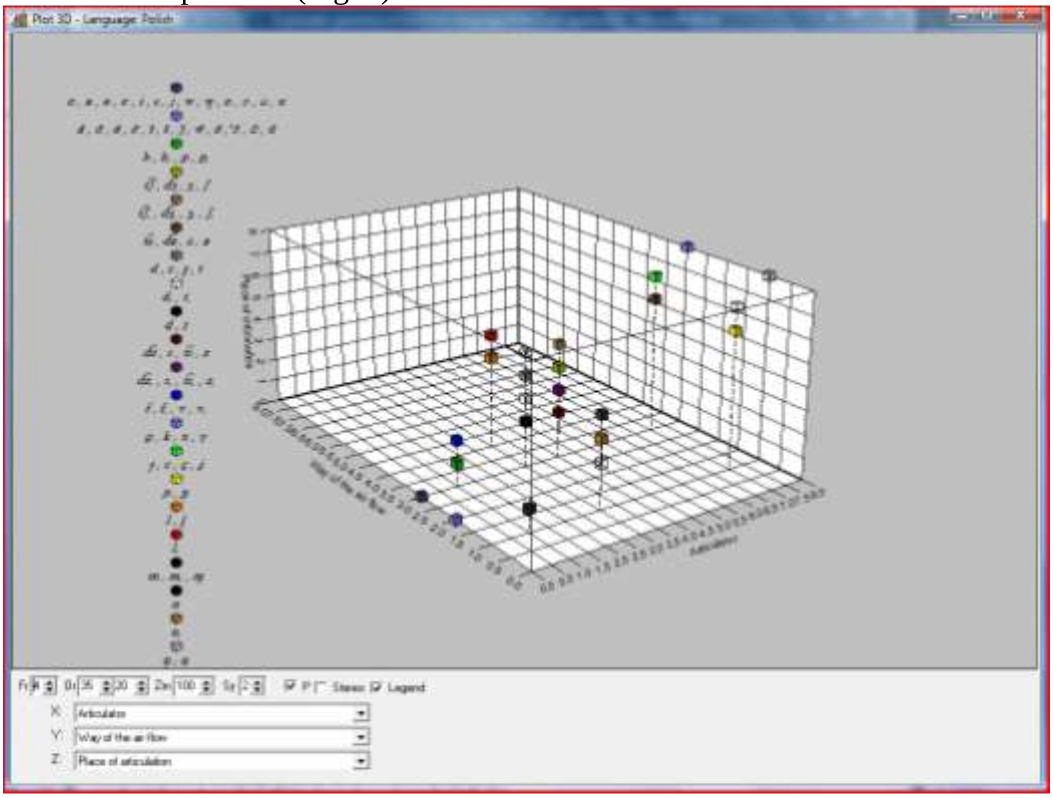

Figure 1. Phones in selected 3 dimensions

Each articulatory feature is uniformly specified by one numerical value from the interval $[0,k]$, where k is the maximal number of features in a dimension. Appropriate numerical values are assigned to the features, mirroring the natural order of the features in a given dimension. Thus each phone $g = (c_1, c_2, \dots. c_n)$ where c_i belongs to the set of features of dimension W_i.

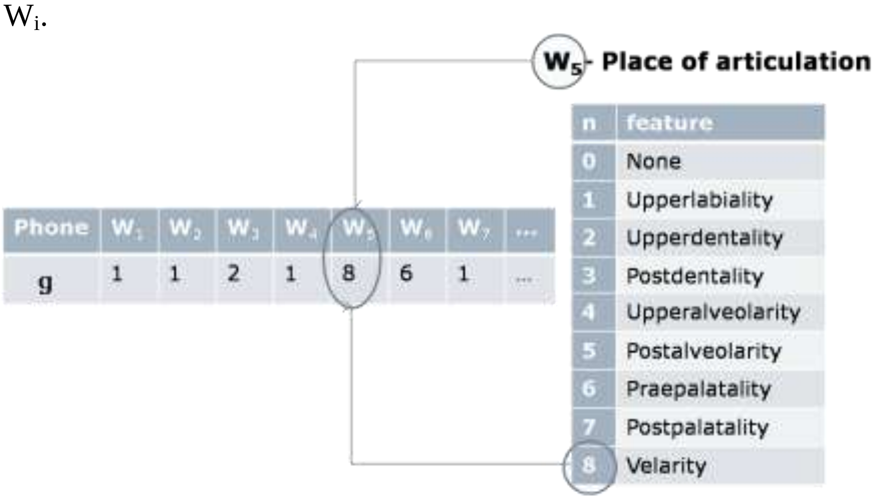

Figure 2. Vector coding example

The notion of the phone as a point in space enables the application of well-known measures of distances. For example, we can specify for the pair of phones $g_1, g_2 \in G$ the following measures of distances:

The Minkowski distance for p ≥ 1:

$$\mathrm{Dist_M}(a,b) = \left(\sum_{i=1}^{n} |a_i - b_i|^p\right)^{1/p}$$

The Manhattan distance:

$$\mathrm{Dist_N}(a,b) = \sum_{i=1}^{n} |a_i - b_i|$$

being a particular instance of of the Minkowski distance for m=1.

The Euclidean distance:

$$\mathrm{Dist_E}(a,b) = \sqrt{\sum_{i=1}^{n} |a_i - b_i|^2}$$

being a particular instance o the Minkowski distance for m=2.

The distances defined in this manner will enable us to build similarity measures between phones (and in the future between phonetic systems of given languages). We assume that sounds more distant from each other in the sense of the appropriate metrics are less similar to each other.

In the original method, articulatory distance was interpreted as the number of features which differentiate a given pair of phones, which is actually equal to the Hamming distance in n-dimensional space.

In Figure 3 we can see the distance between [b] and [p], which takes the value 1 since they differ only in the dimension W_3, i.e. the state of glottis.

	W_1	**W_2**	**W_3**	**W_4**	**W_5**	**W_6**	**W_7**	**W_8**	**…**
B	Pulmonity	Egressivity	Vibration	Medial Orality	Upperlabiality	Lowlabiality	Flatness	Plosivity	…
P	Pulmonity	Egressivity	Openness	Medial Orality	Upperlabiality	Lowlabiality	Flatness	Plosivity	…
	0	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**

Figure 3. Hamming distance between [b] and [p] equal to 1

However we can observe to what extent the use of different measures can result in different numerical interpretation of the articulatory distance between phones. Let us compare [p], [t] and [k] in the dimension W_5, place of articulation, using two metrics, namely Hamming and Euclidean distance (Fig. 4). Assignment of a numerical value to each feature makes it possible to measure (as has already been demonstrated, see Fig. 4) more precisely the nuances of the articulatory differences between phones.

Figure 4. Comparison of Hamming and Euclidean distance between [p],[t] and [k]

4 Repertory of phones for Polish

The segmentation of *hic et nunc* pronounced language utterances into sounds depends on the accepted methodological basis and available analytical tools (including experimental ones). It can also be conditioned by linguistic tradition, the degree of detail of description, and the research goals. Consequently, for a single language one can obtain different sets of sounds which form so called ‘sound basis’ of a language.

According to the above-mentioned theoretical prerequisites, every ordered pair consisting of a set of sounds and homophony relation specifies the set of phones of a given language. The set of all phones of a given language will be called its phonetic basis (cf Banczerowski et al.1982).

In the construction of phonetic grammars of languages, the most difficult linguistic problem to be solved is the choice of an appropriate repertory of phones. It is particularly important since if in the future these grammars are to be used for comparative-contrastive purposes, it is necessary to take into account the power of sets of phones and the actual, experimentally confirmed, occurrence of these units in the language in question.

For a general variant of Polish (depending on speech tempo, communicative situation and other paralinguistic factors) several dozen phone sets have been already postulated for different purposes by different scholars.

The repertory of phones adopted in the present paper comprises objects well documented in the phonetic literature and thoroughly researched from the articulatory and acoustic point of view. It is a set for a general variant of Polish in its official version, in tempo moderato, occurring in the speech of a broadly-defined set of educated Poles. We do not take into consideration either phonetic descriptions from pedagogical and popular grammars or too detailed phonetic descriptions (particularly those which deal with fast speech tempo and/or unofficial communicative situations). At the present stage, repertories of phones occurring in dialects and jargons are outside the scope of our considerations. We have also excluded phones which are present in the Polish linguistic literature, but which have not been confirmed experimentally most often due to lack of adequate research conducted on a representative corpus.

An example of the problem (although the list of unconfirmed phones is much longer) is the differentiation of two types of palatal plosives: palatalized [t,] before the phones [i] and [j] in the inlaut, and semipalatal [t`] before palatal consonants in the inlaut and auslaut and also before [i] and [j] at word boundaries. Since no substantial and detailed research has been done on this type of phones, we have decided not to include such potential differences.

5 Computer application

5.1 The tool for collecting phone inventories

The first essential element in the system has been to build a database and a suitable interface enabling data entry using the standardized International Phonetic Alphabet (IPA).

The application makes it possible:

- to input the articulatory dimensions and the features occurring in them into the system,
- to ascribe appropriate numerical values to the dimensions,
- to define a number of languages,
- to enter a repertory of phones of a given language and a description of the phones in terms of the relevant set of articulatory features.

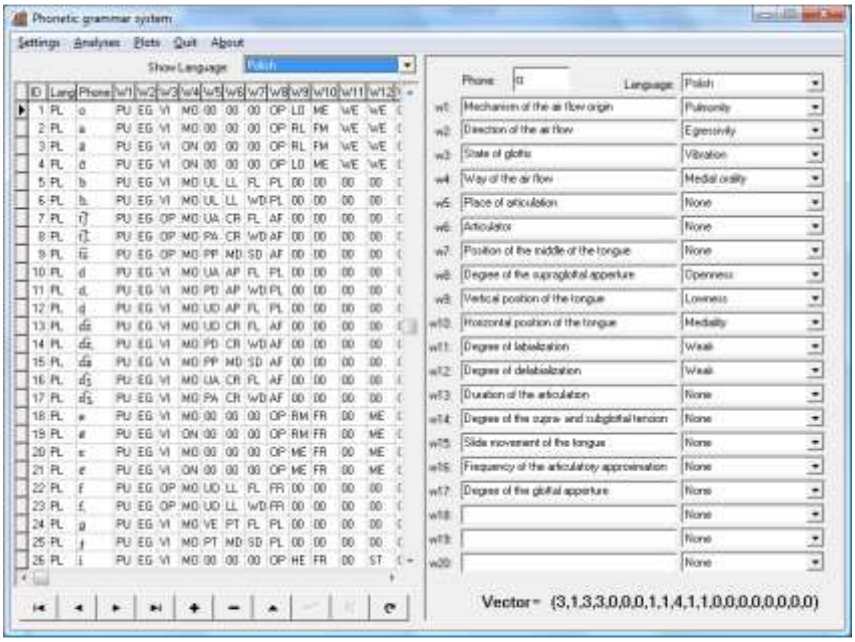

Figure 5. Inventory of phones

5.2 Basic analyses

The application enables instant access to the detailed description of all phones stored in the database (Fig. 5).

The application is used to generate data concerning detailed levels of analysis in the phonetic grammar of each of the analyzed languages:

- combining of articulatory features,
- articulatory opposition and similarity of phones,
- differential and identifying articulatory dimensions,
- articulatory distance and proximity.

The computer application will automatically generate:

- the articulatory distance of two random phones in a given language,
- the articulatory category of a given articulatory feature (or set of features),

- the dimensions in which given phones differ,
- the combining of a given set of articulatory features,
- the average articulatory distance between phones,
- the most numerous articulatory category specified by a given number of features,
- the least numerous articulatory category specified by a given number of features,
- the number of pairs of phones being discerned by particular sets of features.

5.3 Applied algorithms of the data analysis

We aim to apply data mining algorithms to find new properties and regularities in the phonetic system (systems) of a given language.

The analyses presented in the previous section are the basis of language analysis. They apply rudimentary statistical and combinatorial methods. In the present section we will explore methods in the domain of data mining, which will enable us to discover new interdependencies between phones automatically. This will in turn make it possible to show certain relations between languages which have been hitherto unnoticed. All algorithms applied here use measures of distances as measures of similarity between phones.

K-means algorithm:

The first of the algorithms requires as an input an expected number of phone clusters. It makes it possible to divide the phone inventory into a particular number of disjoint classes. For example the input k: = 2 results in the division of the set of phones into vowels and consonants.

The connected subgraphs algorithm:

This algorithm does not require the number of clusters to be input. It determines them itself on the basis of regularities in the data.

The algorithm is based on the distance matrix. This is a symmetric $n \times n$ matrix where each column-row intersection contains the distance between the corresponding pair of phones, the diagonal elements being zero. (Fig. 6).

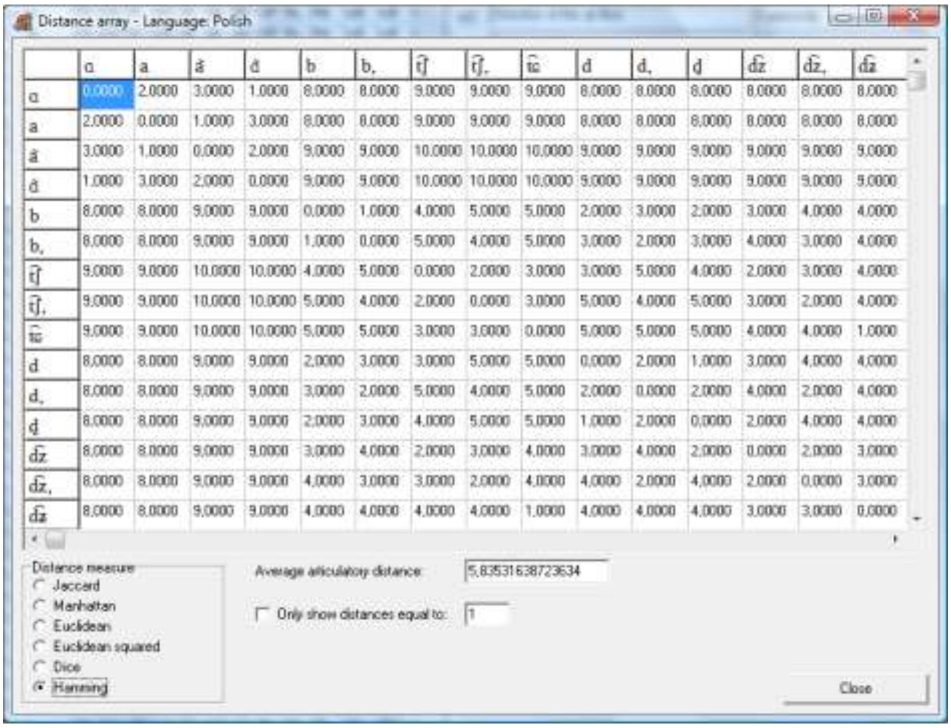

Figure 6. The distances matrix for the Hamming metrics

From this matrix the threshold graph is formed by choosing appropriate threshold level, on which Depth-First Search algorithm is applied. This results in finding the connected subgraphs which are expected clusters (cf Fig. 7).

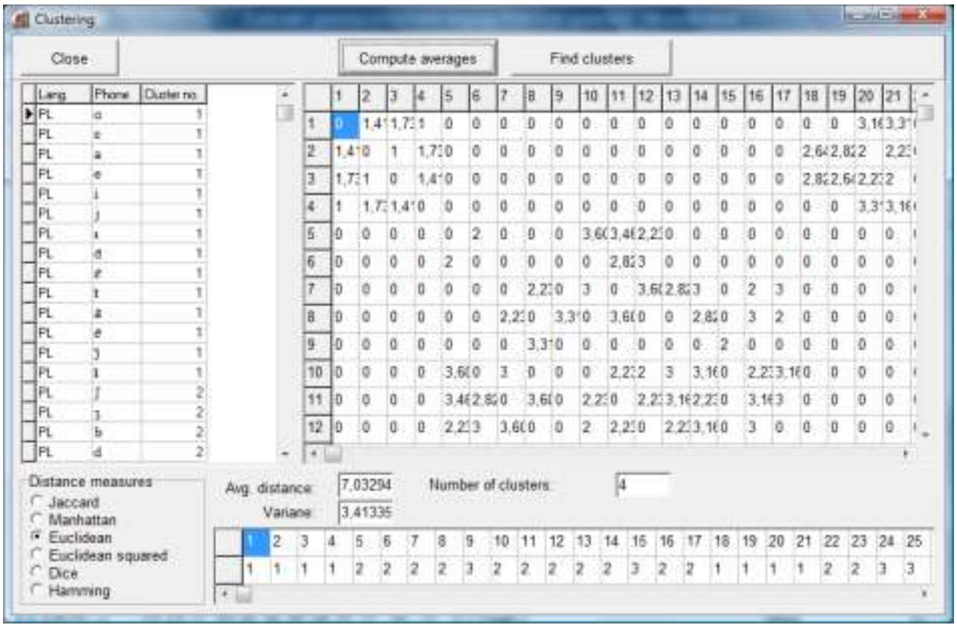

Figure 7. The effect of the execution of the connected subgraphs algorithm

Agglomerative hierarchical clustering algorithm – dendrograms:

This method does not require an input of the number of clusters either. In each step the algorithm joins together the clusters which are closeest to each other (the most similar). At the initial stage each cluster has one phone and at the final stage there is one cluster which consists of the all phones.

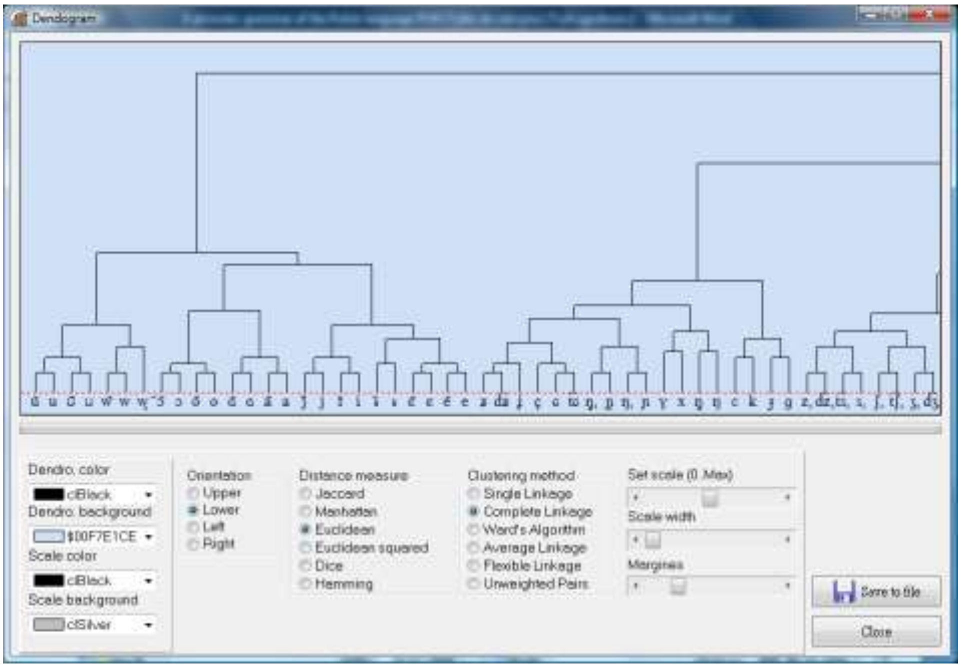

Figure 8. The example of the dendrogram

The result of the operation of the algorithm is presented in the dendrogram (Fig 8.) It is a special type of the dendric structure which makes the way of presenting the results of the hierarchical grouping more transparent. Cutting the dendrogram at the selected level we can divide the set of phones into particular number of the groups of phones.

6 Summary

The paper has presented the first stage of the realization of a more complex project which is intended to apply computer methods for the purpose of linguistic analyses.

At subsequent stages, besides interpretation of the results, we plan to apply the methods of fuzzy sets (mainly the notion of the linguistic variable) for the description of repertories of phones.

The results can be further used in different linguistic disciplines (including applied linguistics), especially in speech analysis and synthesis and in constructing the transcriptional algorithms which are employed in basic research on natural and artificial languages (in theory of linguistics and literary phonostylistics, comparative linguistics, typology, and a posteriori systems of artificial languages).

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