論文

Usage-based visual representation of phonological systems

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要　旨

本稿は，用法基盤アプローチ（usage-based approach）を基に，音韻体系の「視覚的側面」を追及する。国際音声記号（IPA）チャートは，世界の言語の音声システムの記述と研究に長年貢献してきた。そしてまた，個別言語の音の記録や音の言語的普遍性とその構成要因についての理論化をも容易にしてきた。本稿では，まず第一に IPA に関する先行研究を簡潔ではあるが纏め，用法基盤モデルに基づく分析の可能性を追及する。換言すれば，これらの可能性がこれまでの我々の IPA に対する理解にどの程度貢献できるかを探ることになる。最後に，用法基盤アプローチを用いた音の記述例を紹介すると同時にこのアプローチがどのような分析を可能にするかを提示したい。

キーワード：音韻体系の図，国際音声記号（IPA）チャート，言語類型論，音素の合併，用法基盤モデル

Keywords: diagrams of phonological systems, IPA chart, linguistic typology, phoneme merger, usage-based models

1. Introduction

The field of phonology has been built upon structural descriptions of sounds and sets of sounds that constitute the phonemic inventories of languages. The field was born in the early 20th century from the desire to understand the function of sounds in conveying meaning. At the time, linguists were focusing on phonetics, the study of the physical properties (e.g., body movements, sound waves) of sounds (Vachek & Dušová, 1983). Research efforts centered on understanding the physiology of sound production by means of "a most careful registration of all the movements of the speech organs during speech or of their results" (Mathesius, 1929, p. 128). The Prague School developed a framework and specialized terminology to study and describe the cognitive and expressive functions of sounds in language. The terms *phoneme, phonemic contrast, phonological opposition*, *markedness*, *universals*, *features*, and *functional load* were coined in order to describe phonological systems and the structure that sounds give words (Bičan, 2005; Mathesius, 1929; Trubetzkoy, 1939; Vachek & Dušová, 1983). This terminology has shaped the discourse of the field ever since.

Usage-based theories have gained attention recently in a large part due to the availability of corpora which sample and capture actual language use. As Ernestus and Baayen (2011, p. 374) point out, corpora "bridge the gap between the analyst's conception of the data and the actual data themselves" and findings from corpus-based research have revealed that some long-held generalizations based on purely structural descriptions "do not do justice to the data". Bybee (2001, p. 2) asserts that phonology is shaped by language use and that structural descriptions need to be supplemented by the descriptions of the *substance* of language (i.e., phonetics and semantics) and demonstrates by means of corpus data how the frequency with which constructions (viz., words, phrases, patterns) are used impacts phonological structure.

The focus of this manuscript is an analytical approach which adopts a usage-based perspective to the description of vowel systems and provides a visual representation of relationships between and among elements in the system as a means by which to study potential repercussions of sound mergers. In order to properly situate the work, established practices will be reviewed before usage-based perspectives and what they can contribute to current understanding are addressed. Subsequently, a usage-based framework for description will be introduced and an analysis which exemplifies its application will be presented.

1.1. History

The IPA charts were originally presented by the International Phonetic Association in 1949 and the aims were formulated in the following way:

> The alphabet of the Association Phonétique Internationale is an alphabet on romanic basis designed primarily to meet practical linguistic needs, such as putting on record the phonetic or phonemic structure of languages, furnishing learners of foreign languages with phonetic transcriptions to assist them in acquiring the pronunciation, and working out romanic orthographies for languages written in other systems or for languages hitherto unwritten. (International Phonetic Association, 2010, p. 1)

Although the charts have been revised periodically, it is worth noting that the principles originally outlined by the Association are still being used to guide decisions regarding how sounds are represented. As Ladefoged and Roach (1986, p. 25) explain, these principles indicate that:

- each distinctive sound should correspond to a separate symbol
- the same symbol should be used for “similar shades of sound” found across languages
- the IPA should exploit ordinary orthographic letters as much as possible and avoid the introduction of new letters
- sound-symbol correspondences should be decided by international usage
- the use of diacritics should be avoided

The current version of the vowel chart presents 25 vowels along three dimensions, as shown in Figure 1. The front-back dimension is depicted along the horizontal from left to right and the close-open dimension from high to low along the vertical. The rounded-unrounded dimension is illustrated by presenting sounds as pairs with rounded sounds to the right of the unrounded. (International Phonetic Association, 1999, p. Foreword)

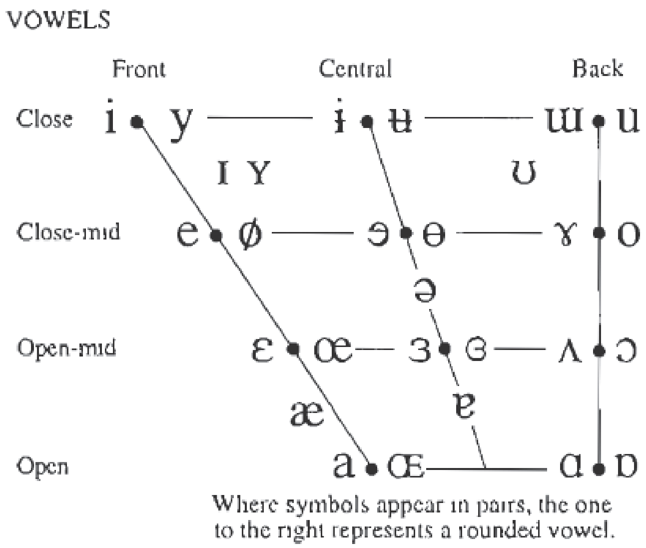

Figure 1. The IPA vowel chart

1.2. Function of the charts

The charts have provided a means by which to produce standardized phonetic and phonemic transcriptions that can be interpreted systematically. Their utility has made them an essential component of introductory linguistics textbooks and, importantly, the method of representation adopted by referential works (e.g., Dryer & Haspelmath, 2013; Kortmann & Schneider, 2004; Ladefoged & Maddieson, 1996).

The fact that researchers use the IPA has facilitated descriptive precision, comparison, and generalization about sound systems in the world's languages. Indeed, seminal typological studies have been founded on data sets which make use of the IPA symbols (e.g., Lindblom & Maddieson, 1988; Maddieson, 1984; Schwartz et al., 1997). The UPSID database, for example, contains distributional information on 919 different sound segments found in 451 languages (Maddieson, 1984). *The World Atlas of Language Structures* (Dryer & Haspelmath, 2013) available online includes structural information on 2,676 languages. The sections on vowel and consonant inventories, in particular, include 564 languages. It merits mention that *The Handbook of Varieties of English* (Kortmann & Schneider, 2004) contains categorical descriptions of 60 varieties spoken around the world, making it possible to compare structural properties within and across regions.

1.3. Limitations

These referential resources allow for observations based on the presence (or absence) of a given feature in the systems surveyed. When it comes to vowel systems, for instance, De Boer (1999, p. 83) observes that vowels /i/, /a/, /u/ occur in more than 80% of all the languages in UPSID while the vowel /ʌ/ occurs in 2% of them. Observations such as these have fueled the notion that human vowel systems are maximally dispersed throughout the vowel space (Liljencrants & Lindblom, 1972; Schwartz et al., 1997).

It is thus noteworthy that when corpus-based probabilities are taken into consideration, it becomes apparent that certain sounds are used noticeably more than others. Gilner (2020) presents results from analysis of the vowel systems of several English varieties which show that, on average, five vowel phonemes account for more than 60% of all instances of vowels in the corresponding corpus. Furthermore, a preference for anterior-based articulations was revealed across the varieties despite rather symmetrical structural descriptions. In other words, usage-based probabilities revealed characteristics of sound systems that have gone unnoticed due to inherent limitations of structural descriptions.

2. Usage-based approaches to phonetic and phonological representation

2.1. Premises

This manuscript provides an illustration of how usage data extracted from corpora can contribute to the study of language sound systems. Usage data is becoming increasingly important to efforts geared toward understanding the interplay of cognitive, social, and evolutionary forces that shape the mind of the individual and the linguistic conventions of the community (Baird et al., 2014; Brdar et al., 2011; Caldwell-Harris et al., 2012; Gries, 2011, 2013; Hruschka et al., 2009). Linguistic description is consequently becoming more sophisticated, drawing on data obtained from corpus analysis, neuroscience techniques, and experimental methods. New types of data obtained by means of innovative analytical approaches are encouraging scholars to expand established frameworks in light of findings outside of any one specific domain. Cumulative evidence is encouraging scholars across various subdisciplines of linguistics such as psycholinguistics, sociolinguistics, evolutionary linguistics, cognitive linguistics to explore the descriptive and explanatory potential of usage-based theories in understanding the role of communicative experience in the creation of mental representations and how linguistic conventions emerge from contact among individuals (Mauranen, 2018; Mufwene & Vigouroux, 2012; The Five Graces Group et al., 2009; Wedel, 2012).

Usage-based theories posit that linguistic constructions (i.e., grammar) emerge from communicative functions conveyed by means of form-meaning mappings, that is to say, words. “The lexicon is the central locus of association between form and meaning” (Pierrehumbert, 2012, p. 173). By including both cognitive and social dimensions within the framework, usage-based theory has provided the field with various models of mental representation. These include prototype models (Lakoff, 1993), probabilistic models (Frisch et al., 2000), and exemplar models (Bybee, 2001; Pierrehumbert, 2001), all of which presume some kind of abstraction process that groups individual instances of usage into cognitive categories. From a usage-based perspective, previous experience guides present and informs future usage. Goldinger (1998) reports results which indicate that each experience with a spoken word adds a memory trace, or echo, to the mental lexicon. Speaker-specific repetition effects have been found to contribute to talker identification and indexical inferencing while abstracting across exemplars provides stability and permanence to the system of relationships (Pierrehumbert, 2003, 2012). It is worthy to note that Eulitz and Lahiri (2004) found that event-related brain responses are sensitive to abstract phoneme representations. These researchers state that their results “…can be interpreted as neurobiological evidence that the human brains uses phonologically underspecified mental representations during vowel perception” (Eulitz & Lahiri, 2004, p. 581). Similarly, confirmation of neural representation of articulatory features during passive speech perception has been provided by means of brain imaging studies (Archila-Meléndez et al., 2018; Chang, 2015; Correia et al., 2015).

A shared premise across usage-based models is that cognitive categories are constantly being updated based on exposure to and tracking of distributional properties of form-meaning mappings in the speech signal. Communicative encounters provide language users with the material they need to figure out the language, as Ellis (2006) explains it. Divjak and Caldwell-Harris (2015) present arguments which support the view that learning is frequency-sensitive, resulting in mental representations that are optimized to the environments from which they are created. The role of sequential learning of statistical tendencies in language usage events has been demonstrated for segmentation of the speech stream, discovery of syllabic structure, and locating phrase boundaries (see Christiansen & Chater, 2008 for discussion). Results reported by Kessler and Treiman (1997) document distributional dependencies among phonemes in relation to syllabic sequencing, finding that in English vowel-consonant sequences are more strongly associated than consonant-vowel sequences. Kang's (2015) study concurs and reports a relationship between statistical tendencies in linguistic input and processing biases.

Usage-based phonology considers exposure and experience with situated and embodied meaning relevant to understanding mental representations of phonological systems. A central concern is understanding and explaining how phonological categories are formed from highly variable speech tokens (Silverman, 2013). Contextual, physiological, and psychological factors conspire to produce "dramatic" acoustic invariance (Taylor, 2009, p. 23) that makes understanding how verbal communication succeeds "a major challenge" (Pitt, 2009, p. 19). Accumulated evidence demonstrates that a usage-based framework accommodates the invariance problem by positing that mental representations of phonological targets and patterns gradually build up over time and with experience (Bybee, 1994; McQueen et al., 2006, 2006; Norris, 2003; Pierrehumbert, 2001; Wedel, 2012). Pierrehumbert (2003) likens the phonetic space to a high-dimensional cognitive map that includes acoustic and articulatory properties as well as probability distributions of experienced exemplars. Wedel (2012) proposes the metaphor of a continually updating multi-dimensional network from which generalizations can emerge and exist with detailed encounters of variant pronunciations. Wedel presents a model that incorporates usage-based experimental and theoretical contributions from various fields and is able to account for how usage can drive development, propagation, and consolidation of phonological patterns over time. Work undertaken by Norris and colleagues indicates phonetic retuning (i.e., categorization of novel input) is ongoing and occurs after very little exposure (McQueen et al., 1999, 2006; Norris, 2003). These perspectives support the observation that: "Because this categorization is ongoing during language use, even adult grammars are not fixed but have the potential to change as experience changes" (The Five Graces Group et al., 2009, p. 7).

2.2. Informational value

Gries and Ellis (2015, p. 230) identify frequency of recurrence in usage as "the most fundamental factor" driving learning since it influences strength of entrenchment, ease of access, and automatization of processing. It is also the basis upon which other statistical measures such as probabilities, dispersion, suprisal, informativity, and functional load (FL) are derived. In this way, corpus data are an indispensable resource to usage-based approaches as they provide a means by which to estimate frequency of recurrence and thus facilitate the study of relationships between distributional characteristics of linguistic units and cognitive and psycholinguistic processes.

The study by Gilner (2020) mentioned previously used corpus recurrence measures to estimate FL for the vowel phonemes in each of 10 English varieties. As will be discussed in more detail shortly, FL provides a measure of relative amount of work for units in a linguistic class and results of these analyses made it possible to discern usage-driven hierarchies among sounds. Figure 2 displays results for the monophthong phonemes of Irish English in the vowel chart. The circles around the phonemes are proportional to their FL values. The figure illustrates that the phoneme /eː/ does the greatest relative amount of work followed by the phoneme /ɪ/ and so on. This visual representation shows one way that usage statistics can augment structural descriptions in relevant and informative ways.

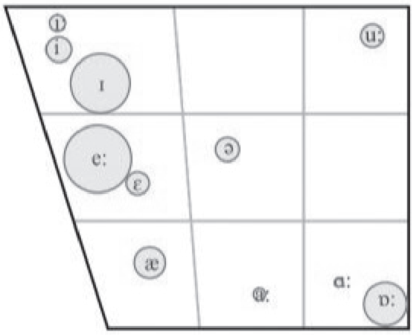

Figure 2. Visual representation of FL of Irish English monophthongs

Oh et al. (2015) provide another example of usage-driven visual representation of vowel systems. Figure 3 is a reproduction from Oh et al. of the illustration of the British Received Pronunciation according to decreasing usage frequency based on FL computations derived from the CELEX corpus (van Gerven, 2013). The authors refer to the figure on the right as a “functional network-based representation” and explain that the thickness of the edges of the connecting lines reflect the FL associated with each vowel pair (Oh et al., 2015, p. 155).

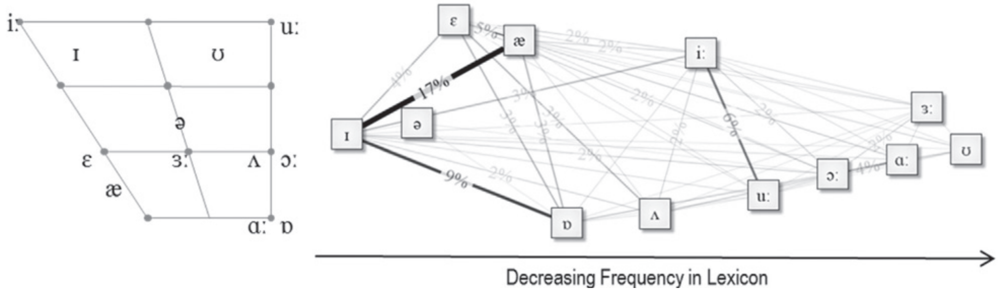

Figure 3. Standard and functional visual representations of British RP vowel system. Reproduced from Oh et al. (2015).

This representation illustrates another way in which usage data augments structural descriptions. The functional network-based representation displays a usage-driven hierarchy by positioning phonemes in order of decreasing frequency. The phoneme /ɪ/ on the left recurs with relative greatest frequency followed by the phonemes /ə/, /ɛ/, /æ/, /ɒ/ and so on. In addition, the network representation provides some indication of the relative amount of work carried by phoneme contrasts. The line connecting the pair /ɪ - æ/ is the thickest, representing its dominant position in a usage-driven hierarchy of contrasts. The connection between /ɪ/ and /ɒ/ is also relatively thicker than the others. The percentages associated with the pairs /ɪ - æ/ and /ɪ - ɒ/ indicate a significant difference between them, intimating a markedly uneven distribution of work among the pairs in the representation. It is noted that the large number of phoneme contrasts displayed in this reproduction makes it difficult to discern all of them clearly and thus a great amount of information is not readily apparent. It is not possible to speculate on, for instance, the dynamics of the system in terms of how change in one aspect might affect others.

3. Introduction to the principal APP approach to representation

This section describes a framework that uses visual representations to explore repercussions of potential mergers. The analytical methodology estimates FL for phoneme contrasts, hereafter referred to as active phoneme pairings (APPs), observed in a spoken corpus and then examines relationships among APPs. The discussion that follows first outlines the history and pertinent applications of FL and then introduces the terminology required to understand the framework.

3.1. FL as a descriptive parameter

Contemporary applications of FL draw on information theory, which proposes that information can be quantified mathematically in terms of *entropy* (Shannon & Weaver, 1949). From this perspective, the speech stream is viewed as comprised of bits of information organized sequentially. Understanding an utterance implies decoding the sequence of elements that comprise its meaningful units. Uncertainty, or entropy, is reduced as more bits are made available. When listening to an utterance, for example, there is a large amount of uncertainty after hearing just the initial word or phrase. As more words are uttered, meaning unfolds and uncertainty (i.e., entropy) is reduced. Similar processes are at play at sub-lexical levels as demonstrated by findings from investigations into spoken word recognition which indicate lexical competitors are reduced as more segments are recognized (Goldinger et al., 1992; Luce & Pisoni, 1998; Magnuson et al., 2007; McQueen et al., 1999).

Entropy-based FL measures use corpus frequencies to calculate the relative contributions that constituents of a linguistic class make to a system. This method was initially formulated by Hockett (1966) who proposed that phonemic constituents do not simply disappear rather they coalesce and that this process results in the redistribution of the work among the remaining elements. The contribution of a constituent to the class of elements is assessed in terms of the difference between two entropy measures: one that corresponds to the entropy of the system containing all of its elements and one that corresponds to the entropy of the system without a given element. Surendran and Niyogi (2003, 2006) have demonstrated that this formulation is informative across linguistic classes including phonemic oppositions, distinctive features, suprasegmental features, and phonological rules.

The information-theoretic approach to estimating FL views language (L) as sequences of word-forms (w) taken from a finite set of size N_L. Equation 1 shows the entropy H of language L calculated over its lexicon N_L.

$$\mathrm{H(L)} = -\sum_{i=1}^{N_L} p_{w_i} * \log_2(p_{w_i})$$

Equation 1. Amount of information or entropy in language L

Equation 1 calculates the probability of word-forms (p_{w_i}) as a factor of the recurrence of a word in a corpus. The measure $H(L)$ corresponds to the entropy of the system (Shannon & Weaver, 1949).

$$FL_{\varphi,\psi} = H(L) - H(L^*_{\varphi\psi})$$

Equation 2. Functional load of the contrast between two phonemes φ and ψ

The FL of a phoneme pairing φ-ψ is defined (as shown in Equation 2) as the difference between the entropy $H(L)$ of the initial system and the entropy $H(L^*_{\varphi\psi})$ of the post-merger system.

The usefulness of FL as a descriptive parameter for studying sound change, and possibly an explanatory one, is seen in the work of Wedel and colleagues (e.g., Wedel, Jackson et al., 2013; Wedel, Kaplan et al., 2013). These researchers adopted corpus-based information-theoretic approaches to the assessment of FL of phonological systems in diverse languages, namely, Dutch, English, French, German, Hong Kong Cantonese, Korean, Slovak, Spanish, and Turkish. A series of statistical analyses revealed that high FL, that is to say, active information transmission, predicted greater stability of a given phoneme and greater resistance to merger between two phonemes. These researchers suggested that differentiative power hence contributes to phoneme contrast preservation. Working within a variationist/usage-based/evolutionary framework, findings were interpreted as supporting the view of a speaker's mental lexicon as a "…steadily-updating multi-dimensional network, in which experienced phonetic detail can be represented redundantly at multiple levels of analysis and where generalizations can emerge from and coexist with that detail" (Wedel, Jackson et al., 2013, p. 398).

3.2. Increasing information value by narrowing complexity

The examples of representation presented in Figure 2 and Figure 3 suggest that usage measures such as probabilities of recurrence can complement structural descriptions in informative ways. The focus of this manuscript is a study which estimates FL of phoneme contrasts based on probabilities extracted from spoken corpora and graphically displays systemic repercussions of the merging of two phonemes. This study implements an information-theoretic approach to the calculation of FL and thus makes it possible to quantify the relative amount of work that particular phonemic contrasts do and, furthermore, to envision how FL would be redistributed in the event of a merger.

The discussion of mergers and their consequences is not without complication. A method of visualization, in the form of diagrams, has been developed in order to assist the interpretation of results. Each diagram is meant to depict a particular APP, hereafter referred to as the *principal* APP, together with its *associated* APPs in a manner that makes it possible to easily resolve post-merger outcomes. This section will gradually introduce these diagrams and their proposed interpretation. The APP with the highest FL in Canadian English (CanE), formed by phonemes /eɪ/ and /ɑɪ/ (for brevity's sake APPeɪ-ɑɪ), will be used as the principal APP in all the examples below.

3.3. APPeɪ-ɑɪ and its associated APPs

The inventory of CanE has 21 phonemes and, thus, the maximum number of possible phoneme pairings is 210 ($= \frac{21 \times 20}{2}$). Minimal pairs (MPs) for 116 phoneme pairings (PPs) were found in the spoken component of the ICE-Canada corpus. No MPs were found for 94 PPs. In short, 116 PPs have non-zero FL (thus, 116 APPs) while 94 PPs have zero FL (thus, 94 NAPPs). As mentioned, APPeɪ-ɑɪ has the highest FL of these 116 APPs.

Now, each of the constituent phonemes of APPeɪ-ɑɪ form APPs with other phonemes. Specifically, /eɪ/ forms APPs with /ɒ, æ, ɑɪ, aʊ, ɔ, ɔɪ, ə, ɛ, ɪ, ɪi, ɵʊ, ʊ, ʉʊ, ʌ, ʌɪ, ʌʊ/ and /ɑɪ/ forms APPs with /ɑ, ɒ, ɒ:, æ, aʊ, ɔ, ɔɪ, eɪ, ɛ, ɜ, ɪ, ɪi, ɵʊ, ʊ, ʉʊ, ʌ/.

The leftmost diagram in Figure 4 shows the principal APPeɪ-ɑɪ and its associated APPs (NAPPs are not displayed in any diagram)[1]. The phonemes in between the two principals, namely, /ɪi, ɵʊ, ʉʊ, ɪ, ɛ, ʌ, ɒ, æ, ʊ, ɔ, aʊ, ɔɪ/ form APPs with both /eɪ/ and /ɑɪ/ and are referred to as the *shared* phonemes in this framework. To the left and right, are the phonemes that form APPs with either /eɪ/ or /ɑɪ/. In the case of /eɪ/, the *non-shared* phonemes are /ə, ʌʊ, ʌɪ/ while in the case of /ɑɪ/, the *non-shared* phonemes are /ɒ:, ɜ, ɑ/.

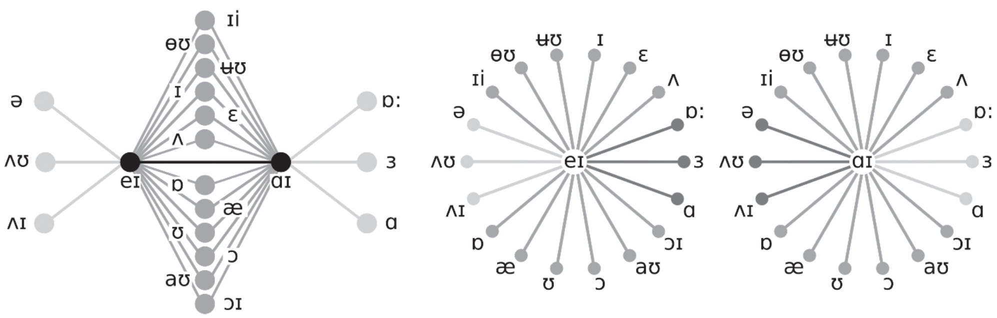

Figure 4. Initial and post-merger states of APPeɪ-ɑɪ

Two mergers of APPeɪ-ɑɪ are possible, the first $M\frac{\text{eɪ}}{\text{ɑɪ}}$ where all instances of /ɑɪ/ are replaced with /eɪ/ and the second $M\frac{\text{ɑɪ}}{\text{eɪ}}$ where all instances of /eɪ/ are replaced with /ɑɪ/. The central and rightmost diagrams in Figure 4 show these two post-merger states, respectively.

Consider for example that, in the initial state, APPɑɪ-ɒ: implies there are MPs formed by /ɑɪ/ and /ɒ:/ while NAPPeɪ-ɒ: (or the absence of APPeɪ-ɒ:, thus, not shown) implies there are no MPs formed by /eɪ/ and /ɒ:/. Following $M\frac{\text{eɪ}}{\text{ɑɪ}}$, the replacement of all instances of /ɑɪ/ with /eɪ/ turns the MPs formed by /ɑɪ/ and /ɒ:/ into MPs formed by /eɪ/ and /ɒ:/, effectively turning APPɑɪ-ɒ: into APPeɪ-ɒ: (or simply creating a new APPeɪ-ɒ:), displayed on the right in the central diagram in Figure 4. Similarly, APPeɪ-ɜ and APPeɪ-ɑ come to be new APPs following $M\frac{\text{eɪ}}{\text{ɑɪ}}$. Note that just as the non-shared phonemes /ɒ:, ɜ, ɑ/ of /ɑɪ/ come to form new APPs in $M\frac{\text{eɪ}}{\text{ɑɪ}}$ with the replacing phoneme /eɪ/, the non-shared phonemes /ə, ʌʊ, ʌɪ/ of /eɪ/ come to form new APPs in $M\frac{\text{ɑɪ}}{\text{eɪ}}$ with the replacing phoneme /ɑɪ/, specifically APPaɪ-ə, APPaɪ-ʌʊ, and APPaɪ-ʌɪ (all 3 shown on the left in the rightmost diagram in Figure 4).

3.4. Window of consideration

The FL values of APPs vary greatly within and across systems. Figure 5 shows the complete FL ranking for CanE. LDRN, plotted on the vertical axis, stands for

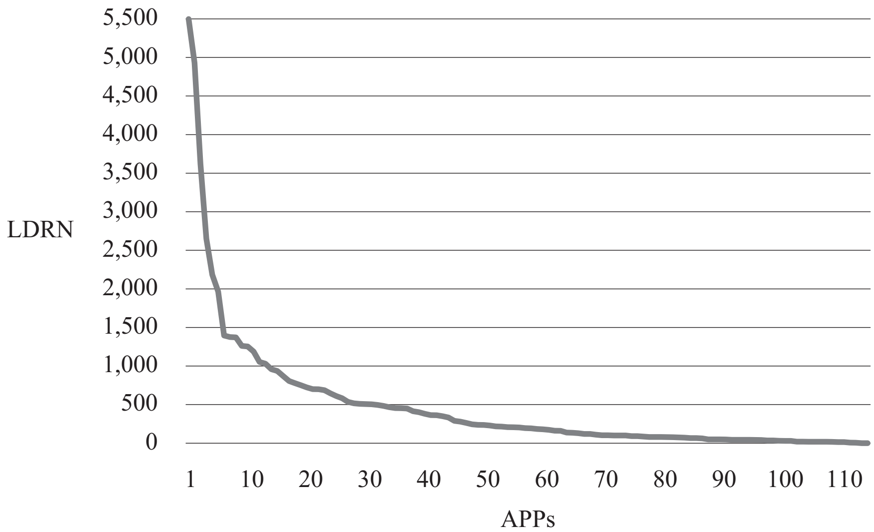

Figure 5. FL ranking of the 116 APPs in CanE

least-dominant relative normalization. LDRN assigns the lowest FL a value of 1 and expresses all others as magnitudes of this one. A markedly uneven distribution of FL is apparent. The 1st ranked APP in Figure 5 has a FL ~5,500 times that of the 116th (the last ranked). The 10th and 20th ranked have FLs ~1,260 times and ~750 times that of the 116th, respectively. In short, the chart shows that the amount of variation is considerable and that, consequently, the amount of information (or FL) lost can be quite different depending on the APP undergoing a merger.

As shown in Figure 5, the top ranked APPs do substantially more work than others but the threshold of relevance remains unclear, as is the case with all so-called frequency based studies (Biber, 1999, 2006; Biber & Barbieri, 2007; Breeze, 2013; Bybee, 2000; Conrad & Biber, 2004; Cortes, 2004; Hyland, 2008, 2009). What is common among these studies is that once a threshold has been established, observations are confined to that *window of consideration*. Scrutiny of the results of this investigation suggests a threshold that limits the discussion to the top 20 ranked APPs for this window of consideration is manageable, informative, and works reasonably well with the diagrams introduced in the previous section.

Despite their differences, both Figure 4 and Figure 6 show the principal APPeɪ-ɑɪ and its associated APPs as well as the two post-merger states. Figure 4 uses a window of consideration of 116 (and thus displays 12 shared and 6 non-shared phonemes) while Figure 6 uses a window of consideration of 20 (and thus displays 1 shared and 3 non-shared phonemes). The attentive reader will notice a reduction and redistribution of phonemes. This is due to the low FL of most of the associated APPs of APPeɪ-ɑɪ, that is, APPs that fall outside the window of consideration of 20. The end result is that Figure 6, in effect, shows the APPs with the greatest FL in CanE.

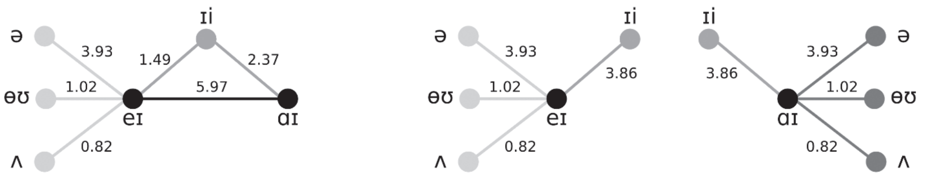

Figure 6. A window of consideration of 20

The diagrams in Figure 6 show the FL of each APP (multiplied by 100). A distinguishing characteristic of a shared phoneme is that its two associated APPs become a single one after a merger, its FL becoming the addition of the FL values of these two associated APPs. For example, in the case of $M\frac{\text{eɪ}}{\text{ɑɪ}}$, the FL of APPeɪ-ɪi has changed from 1.49 to 3.86 while, in the case of $M\frac{\text{eɪ}}{\text{ɑɪ}}$, the FL of APPɑɪ-ɪi has changed from 2.37 to 3.86. Note that although in both cases the post-merger FL is the same (3.86 = 1.49 + 2.37), the APP affected is different, each undergoing an *absolute change* in FL, from 1.49 and from 2.37, respectively.

A distinguishing characteristic of a non-shared phoneme is that, depending on the merger, it might create a new APP with the replacing phoneme of the principal APP. For example, in the case of $M\frac{\text{eɪ}}{\text{ɑɪ}}$, the non-shared phonemes /ə, ɵʊ, ʌ/ come to create APPɑɪ-ə, APPɑɪ-ɵʊ, and APPɑɪ-ʌ, each with their pre-merger FL values, all displayed on the right of the rightmost diagram in Figure 6.

Note also that the loss of the FL of the principal APP decreases the FL of the system accordingly (by 5.97 in the case of Figure 6). As a result, the *relative values* of the FL of the non-shared phonemes, while not changing in an absolute manner, become proportionally greater. Indeed, this is a system wide phenomenon that affects all post-merger APPs.

4. Further inspection of CanE using the window of consideration

With the principal APP framework in mind, we will now take a closer look at the FL ranking of CanE APPs. The FL values have been estimated from probabilities obtained from the spoken component of the ICE-Canada corpus (Newman & Columbus, 2015). Phonemic transcriptions were manufactured according to Boberg (2004)[2]. The dataset contained transcriptions of 551,775 word forms. Recall that a total of 116 APPs were found in the corpus. Table 1 presents the FL ranking for the APPs that fall within the window of consideration, that is to say, the top 20.

FL values range from 0.0597 for the APPeɪ-ɑɪ to 0.0082 for the APPeɪ-ʌ. The data shows that 5 of the 21 vowel phonemes in CanE do not form APPs that rank among the top 20, namely /ɔɪ, i, ɪ, ʊ, ʌɪ/. The phonemes /eɪ/ and /ɪi/ form the most APPs (n = 5) while the phonemes /aʊ, ɑ, ɒ, ɒː, ɔ/ form the least (n = 1). Note that the phonemes /æ, ɛ, ɜ/ form 4 APPs each.

When using an entropy-based measure of FL, as in this study, the consequence of a merger is a *decrease* in information due a decrease in contrastiveness and consequently

Table 1. Functional load ranking of the top 20 active phoneme pairings in CanE

Rank	APP		FL
1	eɪ	ɑɪ	0.0597
2	ɪ	æ	0.0536
3	eɪ	ə	0.0393
4	ə	ʉʊ	0.0288
5	ɑɪ	ɪi	0.0237
6	ɪ	ɒ:	0.0213
7	ɔ	ɑ	0.0152
8	eɪ	ɪi	0.0149
9	ɪ	ʌʊ	0.0149
10	ɛ	ɒ	0.0137
11	ɪi	ɵʊ	0.0136
12	ɪ	ɛ	0.0129
13	ɪi	ʉʊ	0.0114
14	æ	ɛ	0.0112
15	ɵʊ	aʊ	0.0104
16	eɪ	ɵʊ	0.0102
17	ɪi	æ	0.0095
18	ɛ	ʌ	0.0087
19	æ	ʌʊ	0.0085
20	eɪ	ʌ	0.0082

the transformation of MPs into homophones. This loss of information is equal in amount to the FL of the merging APP and is taken from the replacing phoneme which is deprived not only a contrast but of its corresponding FL. In short, a merger necessarily implies a decrease in information of the replacing phoneme.

Given this key observation regarding the information loss sustained by the replacing phoneme and given the knowledge that APPs can have associated APPs (as shown visually via the diagrams introduced previously), it is relevant to probe into the FL values of the replacing phoneme and its APPs as a consequence of merger. Of particular interest would be outcomes that result in an increase in FL of the replacing phoneme despite the stated inevitable loss as well as the nature of this increase, if any. Moreover, it would be important to note those cases involving a significant alteration to the FL ranking. These concerns lend to the formulation of three research questions (RQs) that will guide the discussion of this analysis:

RQ1. Which principal phonemes gain more FL than they lose as a result of a merger?
RQ2. Which mergers lead to at least one APP which has a FL greater than the FL lost?
RQ3. Which mergers come to have APPs with a FL greater than the top ranked APP?

Figure 7 provides the visual representation for the top 5 APPs along with their associated APPs within the window of consideration. It is interesting to observe that each APP creates a unique constellation of relationships and that these tend to be asymmetrical, indicating rather different outcomes depending on which principal phoneme is replaced. Even in the case of symmetrical constellations as in ❷ and ❹, there is an evident differential in the FL of associated APPs with non-shared phonemes. The simplest example is ❹ where both ❹ $M\frac{\text{ə}}{\text{ʉʊ}}$ and ❹ $M\frac{\text{ʉʊ}}{\text{ə}}$ would result in one new APP. Yet, the FL of the new APPʉʊ-eɪ associated with ❹ $M\frac{\text{ʉʊ}}{\text{ə}}$ is great enough to rank it among the top 5 while that of the new APPə-ɪi is not.

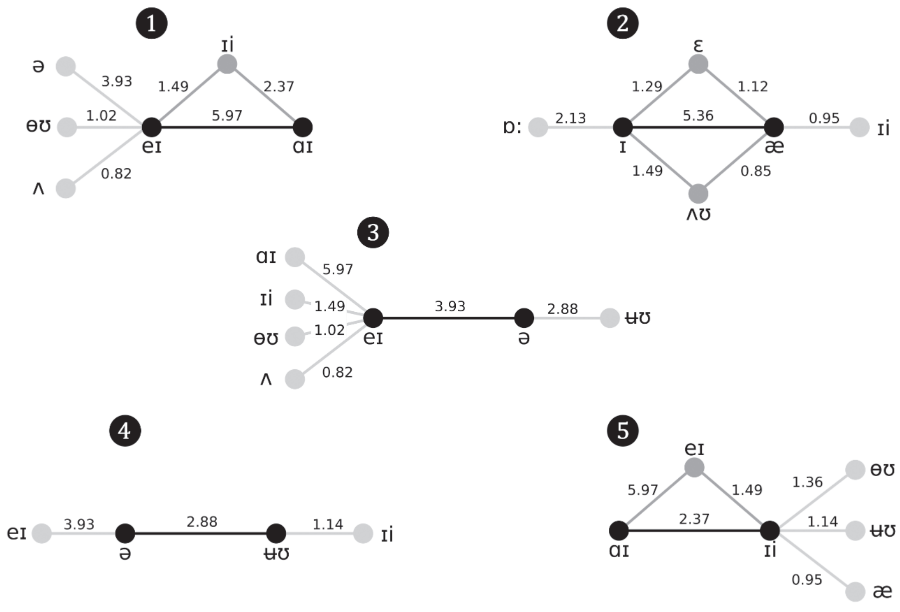

Figure 7. Top 5 ranked APPs and their associated APPs in the top 20 in CanE

Given Figure 7, answers to the RQs can be formulated:

RQ1. Which principal phonemes gain more FL than they lose as a result of a merger?
The following do: ❶/ɑɪ/[3], ❸/ə/, ❹/ʉʊ/, ❺/ɑɪ/, and ❺/ɪi/.

RQ2. Which mergers lead to at least one APP which has a FL greater than the FL lost?
The following do: ❸$M\frac{\text{ə}}{\text{eɪ}}$, ❹$M\frac{\text{ʉʊ}}{\text{ə}}$, and ❺$M\frac{\text{ɪi}}{\text{ɑɪ}}$. Note that ❺$M\frac{\text{ɑɪ}}{\text{ɪi}}$ does not since it already had such an APP before the merger and no other is so formed.

RQ3. Which mergers come to have APPs with a FL greater than the top ranked APP (FL = 5.97)?
❺$M\frac{\text{ɑɪ}}{\text{ɪi}}$ and ❺$M\frac{\text{ɪi}}{\text{ɑɪ}}$ form such APPs with /eɪ/ (FL = 7.46).

Additionally, certain observations can be made:

- 7 out of the 21 phonemes in the inventory act as principal phonemes. Four diphthongs are included, three of these are anterior-closing and one is posterior-closing.
- The phoneme /eɪ/ is present in 4 out of 5 diagrams. It has 5 APPs in the top 20, 2 of which are in the top 5 and are therefore principal (see ❶ and ❸). Mergers where /eɪ/ is the replaced phoneme would result in a noticeable transfer of FL and creation of new APPs.
- The phoneme /ɪi/ is present in all 5 diagrams. It is shared in ❶, non-shared in ❷❸❹ and principal in ❺.
- The principal phonemes of ❷ have limited presence across the diagrams because none or few of the constituent phonemes with which they form associated APPs form themselves other APPs with a FL high enough to fall within the top 5 (see Table 1). The phoneme /ɪ/ is present only as a principal phoneme while the phoneme /æ/ is also present as a non-shared phoneme in ❺.
- As a whole, these 10 mergers would exert a substantial change in occupation of the vowel space since all principal phonemes, as arranged according to their APPs, have a noticeably distinct composite of articulatory features.

- From a complementary perspective, both principal phonemes of ❶ are anterior-closing diphthongs and share the articulatory features corresponding to the offglide. In the event of merger, the differences in the initial target phonemes imply change along both the open-close and front-back articulatory dimensions. The principal phonemes of ❷ are both anterior-based sounds so a merger would involve change in only the open-close articulatory dimension. The principal phonemes of ❸ differ along two primary articulatory dimensions so a merger would involve change in both the front-back and the open-close articulatory dimensions. Reduction is also at play. The same observation holds for the principal phonemes of ❹ with the addition of secondary articulation of rounding. The principal phonemes in ❺ are both anterior-closing diphthongs and thus share certain features corresponding to the offglide. A difference in tenseness should be noted. The initial segments occupy diametrically opposed quadrants in the vowel space so a merger would involve change along both the open-close and front-back articulatory dimensions.

5. Closing remarks

The visual representations introduced in this manuscript have added resolution to our understanding of phonemic contrasts in a variety of ways. The mapping out of the upper echelons of the usage-driven hierarchy of contrasts in CanE has shown, for instance, that each APP ascribes a unique configuration of entanglements with shared and non-shared phonemes. Furthermore, these configurations tend not to be symmetrical, indicating distinct post-merger outcomes depending on the direction of the merger. By including FL values of each APP in the diagrams, it has been possible to quantify the amount of change a particular merger would yield. In the case of CanE, for example, it was observed that merger of one APP in particular, ❺APPɑɪ-ɪi, would result in an increase in FL of both principal phonemes, would produce at least one APP with greater FL than that lost, and would establish a new maximum FL. This combination of repercussions could be described as highly disruptive to the dynamics of this vowel system and suggests a venue for future research. Wedel et al. (2013, p. 397) provided “the first statistical evidence” that phoneme contrasts which distinguish more minimal pairs were significantly less likely to merge. The method of visual representation presented here encourages speculation that the degree of disruption caused by a particular merger might act as a kind of inhibitor due to the complications surrounding information transfer. More work needs to be done.

Maddieson (2011) points out that both structural and usage-based perspectives have contributions to make to phonological description and theory. Examination of components within and across languages has encouraged speculation and theorization regarding structural patterns as well as speech processing, (e.g., Lindblom & Maddieson, 1988; Schwartz et al., 2012). At the same time, usage-based approaches offer perspectives in line with experiential and statistical models of learning. These perspectives propose that language users form mental representations of phonological categories from analysis of actually encountered instances of usage and that representations influence speech perception and processing. This manuscript has introduced an analytical approach which demonstrates how corpus-driven quantification augments categorical descriptions along with a method of representations which reveals potential repercussions of sound merger otherwise not evident. These results suggest that the approach constitutes an informative means by which to contribute empirical data for consideration when developing theories of language learning and cognition.

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Notes

1 Full color version of this manuscript is available at: https://www.researchgate.net/publication/360255243_Usage-based_visual_representation_of_phonological_systems

2 The complete vowel inventory consists of /eɪ ɪ ɑɪ ɪi æ ɛ ə ɵʊ ʉʊ aʊ ɔ ɒ ʌ ɒ: ʌʊ ɑ ʌɪ ʊ ɜ ɔɪ i/. See Gilner (2020) for details on methodology and results.

3 As a result of ❶ $M \frac{\text{ɑɪ}}{\text{eɪ}}$ t the gained FL of APPs formed by /ɑɪ/ is 3.93 + 1.02 + 0.82 from acquired non-shared phonemes and 1.49 from shared phonemes, the sum of which is greater than 5.97.

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