

Comparative Visual Analysis of Cross-Linguistic Features

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Abstract

Approaches in Visual Analytics have so far been developed for a wide array of research areas, mainly with a focus on industrial or business applications. The field of linguistics, however, has only marginally incorporated visualizations in its research, e.g. using simple tree representations, attribute-value matrices or network analyses. This paper suggests a new interesting field of application demonstrating how Visual Analytics is able to support linguists in their research. We show this with respect to one concrete linguistic phenomenon, named Vowel Harmony, where visual analysis allows an at-a-glance comparison across a variety of languages. Our approach covers the entire pipeline of Visual Analytics methodology: data processing, feature extraction and the creation of an interactive visual representation. Our results allow for a novel approach to linguistic investigation in that we enable an at-a-glance analysis of whether vowel harmony is present in a language and, beyond that, a precise indication of the particular type of vowel interdependence and patterning in a given language.

1. Introduction

Early approaches for the visualization of text data have mainly focused on providing topical overview of document collections [HPK95, WTP*99, Wis99] as well as detailed topical insight into document collections [Hea95, FD00, HHWN02, DZG*07], and are mostly related to the field of Information Retrieval. Since then, a lot of related visualizations have evolved. Some of the recent approaches are based on much more sophisticated text processing methods also involving some linguistic knowledge but still focus on topical content of text documents [CCP09, SOR*09]. In addition, approaches that are concerned with the visual analysis of affective content in large document collections (e.g. news articles, weblog entries or customer reviews) have appeared recently in the field of opinion and sentiment analysis [GPM*07, GBB*08, WRM*09, OHR*09].

While all of the mentioned work primarily deals with extracting and visualizing the topical content of text data, little work has been dedicated to the visual exploration of other text features and natural language phenomena. [HKLK97] have obtained visual syntactic category clusters by generating self-organizing maps based on word context vectors. [KO07] have extracted and visualized diverse statistical text properties on different hierarchy levels for literature analysis and authorship attribution, and [AC07] have extracted and visualized detailed text features to enable a visual classifica-

tion of documents that is not only based on the topic content but also on style and sentiment. [WV08] created the “Word Tree” visualization that was primarily aimed at visualizing the content structure of texts but can also be used to visualize language features as shown by the example of a tree containing Greek nominal suffixes. Recently [AHM09] have introduced an interactive tool for the correction of erroneous machine translation output with visual components.

However, to the best of our knowledge there are no published approaches in the field of the visualization and visual analysis that try to visually compare a large set of languages with respect to linguistic properties. This paper is devoted to fill this gap by visually analyzing one exemplary cross-linguistic feature called Vowel Harmony for a large set of languages.

Vowel Harmony (VH) is an assimilatory phonological process by which vowels are pronounced in accordance (or harmony) with their environment (see [vdHvdW95] for an overview). Most often, preceding vowels trigger the shape of the vowel that follows them, leading to a kind of domino effect within a certain linguistic domain (usually the phonological word). Languages differ as to whether they have harmonic processes or not and which features are involved, with closely related languages mostly sharing the same (or similar) features. A famous instance of VH is found in Turkish, where grammatical markers are pronounced differently in

harmony with the preceding vowel. For example, the Turkish plural suffix is pronounced *-ler* or *-lar* depending on the last vowel of the stem. If the vowel has the feature [FRONT], i.e., if it is articulated in the front of the mouth, the plural marker is realized as *ler* (e.g., *evler* ‘houses’, *çöler* ‘deserts’, *örtüler* ‘coverings’, *kediler* ‘cats’); if it is [BACK], i.e., if it is articulated in the back of the mouth the plural marker has the form *lar* (e.g., *adamlar* ‘men’, *toplar* ‘balls’, *komsular* ‘neighbors’, *kapılar* ‘doors’). However, most languages do not contain VH and even VH languages always also show cases of disharmony. Besides, they differ with respect to how many and which features are active in the harmony process. In this paper we demonstrate how Visual Analytics can support linguists in detecting the degree and kind of VH involved in a language and readily compare different languages with respect to vowel harmonic processes. One important point is the automatic data analysis involving data preprocessing, statistical feature extraction and vowel ordering which are described in Section 2. As a next step, two matrix-visualizations are designed that help to track the probability and association strength of vowel successions within words and provide an insightful visual fingerprint for the vowel distributions in a language (Section 3). Next, in Section 4 a case study is provided that shows that accurate hypotheses about VH can be derived from the matrix visualizations without any prior knowledge about a language. Finally, in Section 5 a conclusion as well as a research outlook are provided.

2. Automatic Processing

2.1. Data gathering and processing

The data used as a basis for our work was extracted from Bible texts — using Bible texts means that we have data available for languages for which texts are not otherwise readily available. For each investigated language a type list was compiled containing all the different word forms appearing in the Bible. It is better to work on the Bible types instead of using a dictionary, because VH is best detected in inflected word forms, which are usually not contained in dictionaries. Moreover, it is better to work on a type rather than on token level, because otherwise highly frequent tokens are able to bias the results. For each list of types of a language, all vowel successions within the types are counted and analyzed. Vowels have been automatically determined with Sukhotin’s algorithm [Suk73] and manually edited for each language. We define a vowel succession as a binary sequence of vowels within a word. Consecutive vowels have to be separated by at least one consonant, otherwise they will be ignored. For example, the word “harmonic” would contribute to the count of the vowel succession “o follows a” which we will refer to as (a->o) and to the count of the vowel succession (o->i). The resulting sums are saved in a matrix, an example is provided in Table 1.

	a	ä	e	i	o	ö	u	y
a	3548	20	1940	1893	831	0	944	24
ä	35	944	806	820	10	138	33	266
e	1623	1144	1495	1608	419	56	497	187
i	1580	854	1514	1044	376	46	355	135
o	1384	7	1032	902	284	0	294	8
ö	7	125	54	39	0	3	1	18
u	1464	6	1085	850	315	1	547	8
y	39	656	368	368	35	75	4	251

Table 1: Example of a matrix with vowel succession counts for the Finnish Bible. The successions go from the row letter to the column letter. The succession (a->e) for instance occurred 1940 times.

2.2. Statistics

The simple matrix with the counts of vowel successions gives a rather general overview. Some high or low values are salient and usually it can be seen that some vowels appear with a much higher overall frequency than others. For most languages the strong variance between the overall frequencies of distinct vowels is the dominating effect visible in the matrix.

In order to provide more detailed insight into the relevant patterns, we calculated the succession probabilities. That means that if a certain vowel is observed, then it is calculated with which probability (in percent) certain other vowels are expected to be observed next. The values for succession probabilities are then saved in a probability matrix, analog to the matrix of absolute succession counts. Of course, still highly-frequent vowels in most cases have a higher probability of succeeding any other vowel than low-frequent vowels. This leads us to apply a test for the statistical significance of deviations in the distribution of vowel successions. The aim is to find out if the deviation of an observed vowel succession from an expected vowel succession is statistically significant. To get a significance value the fourfold χ^2 for-

	e	not(e)
a	A = 1940	B = 7260
not(a)	C = 6354	D = 19861

Table 2: Example of the fourfold matrix for the succession (a->e) in Finnish. The expression “not(a)” stands for the set of all vowels except “a” and the same with “not(e)”. Note that the four cells of the matrix have names (A, B, C and D) that are important for the formulas 1 and 2.

mula (see Formula 1, [Rum70]) is applied. The higher the values, the more significant in a statistical sense is the deviation of observed frequencies from expected frequencies. The test quantifies the influence of the independent variable (e.g. “a” in Table 2) on the dependent variable (e.g. “e” in Table 2).

$$\chi^2 = \frac{(A+B+C+D) \cdot (A \cdot D - C \cdot B)^2}{(A+C) \cdot (B+D) \cdot (A+B) \cdot (C+D)} \quad (1)$$

The χ^2 value depends on the sample size and therefore is not easily interpretable and comparable among sets of different size. To overcome this problem the correlation coefficient ϕ was applied (see Formula 2, [Rum70]).

$$\phi = \sqrt{\frac{\chi^2}{(A+B+C+D)}} \quad (2)$$

The ϕ coefficient represents the association strength and, when calculated directly from the fourfold matrix, the ϕ values lie between -1 and +1, where a negative sign indicates a negative association among the two binary variables. Consequently, another matrix is created containing these association strength values, which we denote as ϕ matrix.

2.3. Matrix Arrangement

To render the relations between vowels with similar behavior maximally visible, it is essential to sort the rows and columns of the matrices in a meaningful way. Interesting vowel succession patterns will only become evident if a certain pixel coherence can be guaranteed [Ber83, HF06]. To enable a sorting of vowels first of all a numerical dissimilarity between vowels needs to be calculated. To do so, for each vowel a feature vector is created that corresponds to the ϕ -values of its matrix row. Next, a distance function between feature vectors has to be defined that quantifies the dissimilarity of the ϕ -values of two vowels at a time. Different distance functions were created and tested and the one that yielded the best results can be found in Formula 3. The rationale behind the formula is that pairs of vectors containing different signs at the same index are considered rather dissimilar.

$$\text{dist}(x, z) = \sum_{i=1}^n d(x_i, z_i), \quad (3)$$

$$\text{where } d(x_i, z_i) = \begin{cases} 1 & \text{if } \text{sign}(x_i) \neq \text{sign}(z_i), \\ (x_i - z_i)^2 & \text{else.} \end{cases}$$

The distance measure in Formula 3 is then used in the sorting process. The first row in the matrix of any language is fixed as the row belonging to the vowel with the smallest Unicode value (usually the vowel [a]). Then a nearest neighbor sorting is done: The most similar vowel row in the ϕ -matrix (vector in high-dimensional feature space) to the /a/-vector is searched and the corresponding vowel is placed in the second position. Next, to this second vowel again the most similar vector is searched among the remaining ones. This procedure is iteratively repeated until there is no vowel left.

After sorting the vowel rows, the vowel columns are sorted in exactly the same order. We also tried to sort columns and rows independently but came to the conclusion that this was not desirable as the diagonal of the matrix lost its general meaning (self-successions). Our tests showed that having the same row and column order is an important visual clue that

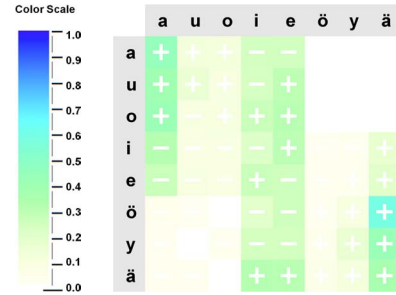


Figure 1: The visualization represents the probability matrix for the Finnish Bible types that has been sorted automatically. The “+” and “-” signs indicate whether a vowel succession occurred more or less frequently than expected when assuming vowel independence. One interesting finding that can be deduced from the visualization is that there are two blocks of vowels that almost never combine, viz. the block {a,u,o} and the block {ö,y,ä}.

helps in understanding the matrix and is more beneficial for the analysis process than an independent sorting of rows and columns.

3. Visualization and Visual Analysis

The numerical matrices generated with the analysis methods described in Section 2 were then transformed into visualizations for further analysis. Therefore, a straight forward visual representation was designed, maintaining the basic matrix metaphor and mapping the numerical entries to colors (see Section 3.1). Most importantly, the matrix rows and columns were sorted according to vowel similarity as described in Section 2.3 in order to make patterns become visible.

3.1. Data mapping and design

In the matrix with the succession probabilities all values inherently lie in the interval [0,1] and thus can be directly mapped to a color scale. In order to get many distinguishable color shades a bipolar color scale was chosen, ranging from bright yellow to dark blue (see Figure 1 for an example). For the matrix with the statistical association strength (ϕ) values of vowel successions two unipolar color scales were used. Vowel successions occurring more frequently than expected (positive ϕ) were colored in blue and vowel successions that were less frequently observed than expected (negative ϕ) got a red color. The higher the ϕ value was, the more saturated the color. Because of the skewed data distribution with many values close to 0, a square root transfer function was applied. Thus, a larger color range was reserved for the densely populated area of low absolute ϕ values. See Figure 2 for the Finnish example. Again, it has to be pointed out that a meaningful sorting of the matrix rows and columns is crucial for

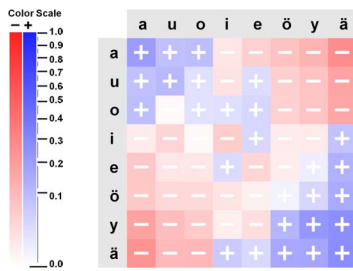


Figure 2: The visualization represents the ϕ matrix for the Finnish Bible. In this case the “+” and “-” symbols provide a redundant mapping. Now, blocks of vowels that belong together can clearly be seen. As before, {a,u,o} build one block, {ö,y,ä} another independent block, and {i,e} cannot unambiguously be assigned to any of them. In fact, this conforms nicely to the categorization linguists have for Finnish vowels: {a,u,o} are back vowels, {ö,y,ä} are front vowels, and {i,e} are neutral vowels, which explains that they do not adhere to one of the blocks.

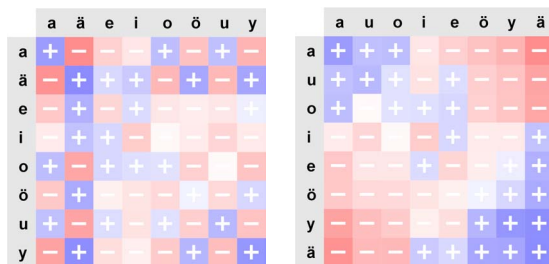


Figure 3: The left visualization has a default vowel sorting (alphabetical order) and shows no easily perceivable pattern at all. The right matrix which was automatically sorted, in contrast, reveals that there exists an interesting pattern.

the visual analysis process. Figure 3 reveals that many interesting features are no longer clearly visible without sorting.

3.2. Comparative Visual Analysis

When performing the described analysis for a large number of different languages vowel harmonic patterns become easily visible (see Figure 4). Apart from Maori and Tagalog, all of the top 7 languages actually contain different kinds of VH. The strongly colored diagonal in Maori stands out and is actually due to a process of syllable reduplication, which leads to a statistically salient amount of self successions. The strongest effect can be perceived in Turkish which is known to have rather strict and complex harmony patterns that rendered clearly visible with our approach.

4. Case Study: Udihe

We conducted a case study in order to examine to what extent our approach is potentially able to help researchers in

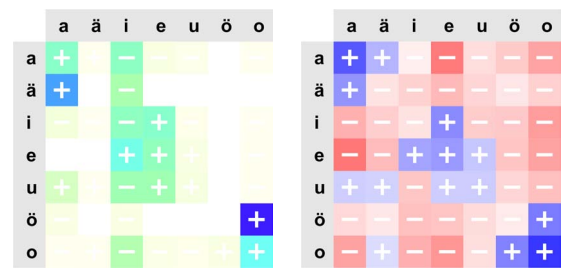


Figure 5: The probability matrix (left) and the ϕ -matrix (right) for the Udihe text fragment containing about 2450 words.

detecting VH and predicting the involved features. We therefore chose to investigate Udihe, a language that might be suspected of containing VH because it is related to other VH languages. Yet we did not know beforehand what kinds of harmonic patterns would be active in the language, if the language did indeed have VH. We were able to get hold of a text with a length of 2450 words which, according to previous experiments we conducted, we established as being enough material for detecting reliable patterns under our approach.

In order to generate a hypothesis about possible vowel harmonic patterns, the first question to be investigated is whether there is VH present at all. Under our approach, we found three indicators for harmony:

- The average ϕ -value of Udihe (0.097) is the third highest after Turkish and Hungarian. This indicates that a strong VH-like effect is present in the language.
- A look at the probability matrix (Figure 5, left) reveals that some successions are very probable and others very improbable which is a characteristic of vowel harmonic languages.
- There are blue blocks along the diagonal of the ϕ matrix as can be seen in Figure 5, right.

If a vowel succession is very probable and at the same time has a highly positive association (ϕ value) this is an indication for a harmonic pattern. Clearly, this is the case for the transitions (a- \rightarrow a) and (ä- \rightarrow a) as well as (o- \rightarrow o) and (ö- \rightarrow o) as can be seen in Figure 5. In both matrices the same block in the /e/ column is salient and indicates the harmonies (i- \rightarrow e), (e- \rightarrow e) and (u- \rightarrow e). The hypotheses were derived from the visualizations without any prior knowledge about Udihe. A comparison with published information on this language shows that our results are very good in that they correspond well to what has been independently established about the language [NT01, p. 74]. Our case study thus shows that it is possible to readily generate accurate hypotheses about VH in languages on the basis our visualization method. Crucially, no previous knowledge about the language under investigation is required.

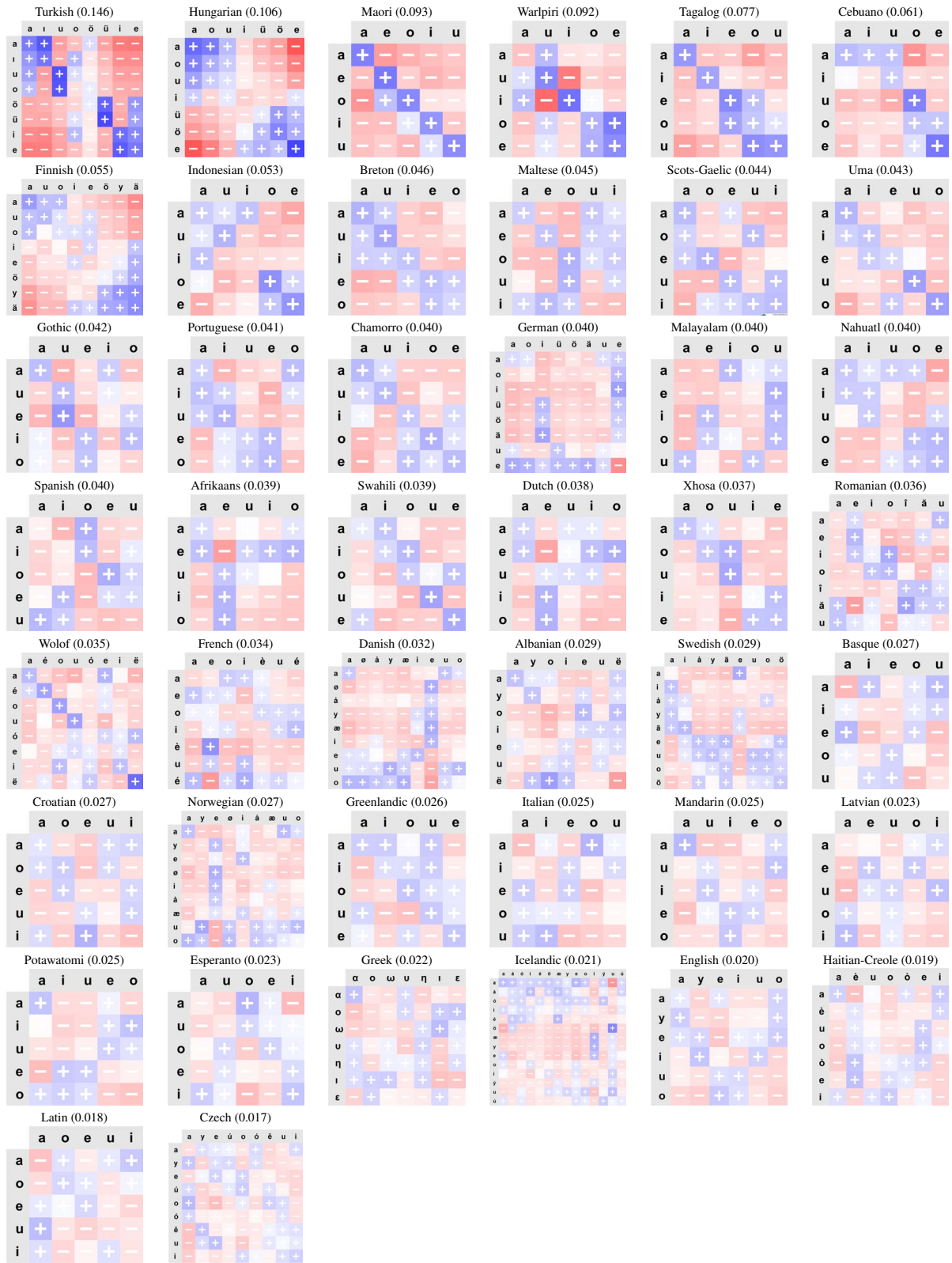


Figure 4: The ϕ matrices for 44 languages ordered according to decreasing average ϕ values (rounded average in parentheses) from left to right and top to bottom.
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5. Conclusions

Our successful visual analysis of crosslinguistic patterns points to a promising new field for research within Visual Analytics. Our aim is to complement established linguistic methodology with automatic methods within visual analysis, thus allowing for a deeper and more multifaceted insight into crosslinguistic patterns. Our approach also provides the linguist with the possibility of uncovering previously unrecognized patterns by throwing a new perspective on the crosslinguistic data. We used the phenomenon of VH as a case study for an application of Visual Analytics to linguistic patterns. Our statistical analysis allows for a first approximation of the degree of VH in a language. Moreover, the visualization enables linguists to compare a large set of languages with respect to VH patterns. Finally, based on the visual impression from the ϕ -matrix and the probability matrix accurate hypotheses can be derived about exactly which vowel harmonic dependences are involved. This was shown with respect to the language Udihe, where VH patterns were correctly predicted with our method of visual analysis.

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