

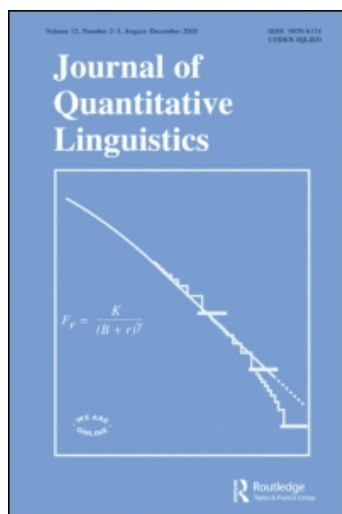
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Automated Word Stability and Language Phylogeny*

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ABSTRACT

The idea of measuring distance between languages seems to have its roots in the work of the French explorer Dumont D’Urville (1832). He collected comparative word lists of various languages during his voyages aboard the *Astrolabe* from 1826 to 1829 and, in his work about the geographical division of the Pacific, he proposed a method to measure the degree of relationship among languages. The method used by modern glottochronology, developed by Morris Swadesh in the 1950s (Swadesh, 1952), measures distances from the percentage of shared cognates, which are words with a common historical origin. Recently, we proposed a new automated method which uses normalized Levenshtein distance among words with the same meaning and averages on the words contained in a list.

Another classical problem in glottochronology is the study of the stability of words corresponding to different meanings. Words, in fact, evolve because of lexical changes, borrowings and replacement at a rate which is not the same for all of them. The speed of lexical evolution is different for different meanings and it is probably related to the frequency of use of the associated words (Pagel et al., 2007). This problem is tackled here by an automated methodology only based on normalized Levenshtein distance.

INTRODUCTION

Glottochronology tries to estimate the time at which languages diverged with the implicit assumption that vocabularies change at a constant average rate. The concept seems to have its roots in the work

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of the French explorer Dumont D'Urville. He collected comparative word lists of various languages during his voyages aboard the *Astrolabe* from 1826 to 1829 and, in his work about the geographical division of the Pacific (D'Urville 1832) he introduced the concept of lexical cognates and proposed a method to measure the degree of relation among languages. He used a core vocabulary of 115 basic terms which, impressively, contains all but three of the terms of the Swadesh 100-item list. Then, he assigned a distance from 0 to 1 to any pair of words with the same meaning and finally he was able to resolve the relationship for any pair of languages. His conclusion is famous: "*La langue est partout la même*".

The method used by modern glottochronology, was developed by Morris Swadesh (1952) in the 1950s. The idea is to consider the percentage of shared cognates in order to compute the distance between pairs of languages. These lexical distances are assumed to be, on average, logarithmically proportional to divergence times. In fact, changes in vocabulary accumulate year after year and two languages initially similar become more and more different. A recent example of the use of Swadesh lists and cognates to construct language trees are the studies of Gray and Atkinson (2003) and Gray and Jordan (2000).

We recently proposed an automated method which uses Levenshtein distance among words in a list (Serva & Petroni, 2008; Petroni & Serva, 2008). To be precise, we defined the distance of two languages by considering a normalized Levenshtein distance among words with the same meaning and we averaged on all the words contained in a list.¹ The normalization, which takes into account word length, plays a crucial role, and no sensible results would have been found without it. We applied our method to the Indo-European and the Austronesian groups considering, in both cases, 50 different languages (Serva & Petroni, 2008; Petroni & Serva, 2008).

Almost at the same time, the automated method described above was used and developed by another large group of scholars (Bakker et al., 2008; Holman et al., 2008). In their work, they used lists of 40 words while we used lists of 200. Their choice was taken according to a careful study of the stability of different words (Wichmann, 2009).

¹The database, modified by the authors, is available at the following web address: <http://univaq.it/~serva/languages/languages.html>. Readers are welcome to modify, correct and add words to the database.

Another classical problem in glottochronology is the study of the stability of words corresponding to different meanings. Words, in fact, evolve because of lexical changes, borrowings and replacement at a rate which is not the same for all of them. The speed of lexical evolution is different for different meanings and it is probably related to the frequency of use of the associated words (Pagel et al., 2007). The study of word stability has an interest in itself since it may give strong information on the activities which are at the core of the behaviour of a social or ethnic group, but it is also necessary for a proper choice of the input lists for language comparisons.

The idea of inferring the stability of an item from its similarity in related languages goes back a long way in the lexicostatistical literature (Thomas, 1960; Kroeber, 1963; Oswalt, 1971). In this paper we tackle this problem with an automated methodology based on normalized Levenshtein distance. To reach the goal, it is necessary to obtain a measure of the typical distance of all pairs of words corresponding to a given meaning in a language family. The distance between words is computed as in Serva and Petroni (2008) and Petroni and Serva (2008), avoiding the use of cognates. For any meaning, and any language family, we are able to find a number which measures its stability (or rate of evolution) in a completely objective and reproducible manner provided that the database used for the analysis is the same, being this the only subjective choice in the analysis.

In the next section we define the lexical distance between words. Section 3 is the core of the paper; there we define the automated stability of the meanings and we study the distribution and ranking of stability for the Indo-European family and for the Austronesian family. In Section 4 we compare the stability ranking of items. Conclusions and outlook are in Section 5.

LEXICAL DISTANCE

Our definition of lexical distance between two words is a variant of the Levenshtein distance which is simply the minimum number of insertions, deletions, or substitutions of a single character needed to transform one word into the other. Our definition is taken as the Levenshtein distance divided by the number of characters of the longer of the two words compared.

More precisely, given two words α_i and β_i corresponding to the same item i in two languages α and β , their distance $D(\alpha_i, \beta_i)$ is given by

$$D(\alpha_i, \beta_i) = \frac{D_1(\alpha_i, \beta_i)}{L(\alpha_i, \beta_i)} \quad (1)$$

where $D_1(\alpha_i, \beta_i)$ is the Levenshtein distance between the two words and $L(\alpha_i, \beta_i)$ is the number of characters of the longer of the two words α_i and β_i . Therefore, the distance can take any value between 0 and 1. Obviously $D(\alpha_i, \alpha_i) = 0$ since both the item and the language coincide.

The normalization is an important innovation and it plays a crucial role; no sensible results can be obtained without it. The reason why we normalize can be understood from the following example. Consider the case in which a single substitution transforms one word into the other with the same length. If they are short, let's say two characters, they are very different. On the contrary, if they are long, let's say eight characters; it is reasonable to say that they are very similar. Without normalization, their distance would be the same and equal to 1, regardless of their length. Instead, introducing the normalization factor, in the first case the distance is 1/2, whereas in the second, it is much smaller and equal to 1/8.

In Serva and Petroni (2008) and Petroni and Serva (2008), we used distance between pairs of words, as defined above, to construct the lexical distances of languages. For any pair of languages, the first step was to compute the distance between words corresponding to the same meaning. The lexical distance between each pair of languages was defined as the average of the distance between all words in the Swadesh list. As a result we obtained a number between 0 and 1 which is the lexical distance between two languages. Then, we performed a logarithmic transformation of lexical distances into separation times with a formula analogous to the adjusted fundamental formula of glottochronology (Starostin, 1999). Finally, the phylogenetic trees for the Austronesian and Indo-European families could be straightforwardly constructed.

Criticism has been made of our proposal (Nichols & Warnow, 2008) on the basis that our reconstructed trees present some incongruence as, for example, the early separation of Armenian which is not grouped together with Greek (which in our Indo-European tree separates just after Armenian). Nevertheless, the structure of the top of the tree is debated and no universally accepted conclusion exists.

STABILITY OF MEANINGS

We now make decisions concerning stability of meanings. Our aim is to obtain an automated procedure, which avoids, also at this level, the use of cognates. For this purpose, it is necessary to obtain a measure of the typical distance of all pairs of words corresponding to a given meaning in a language family.

Assume that the number of languages in the family under consideration is N and the list of words for any language contains $M = 200$ items. Any language in the group is labelled with a Greek letter (say α) and any word of that language by α_i with $1 \leq i \leq M$. Then, two words α_i and β_i in the languages α and β have the same meaning.

Therefore, we define the stability as:

$$S(i) = 1 - \frac{2}{N(N-1)} \sum_{\alpha > \beta} D(\alpha_i, \beta_i) \quad (2)$$

where the sum is over all possible $N(N-1)/2$ language pairs α, β in the family using the fact that $D(\alpha_i, \beta_i) = D(\beta_i, \alpha_i)$.

With this definition, $S(i)$ is inversely proportional to the average of the distances $D(\alpha_i, \beta_i)$ and it takes a value between 0 and 1. The averaged distance is smaller for those words corresponding to meanings with a lower rate of lexical evolution since they tend to remain more similar in two languages. Therefore, to a larger $S(i)$ corresponds a greater stability.

We computed the $S(i)$ for 200 meanings averaging over 50 languages of the Indo-European family and the same for the Austronesian family.

To have a first qualitative understanding we plot the two associated histograms shown in Figure 1. We can see that, in both cases, there is a fat tail on the right of the histograms indicating that there are some meanings with great stability. This tail is at very variance with a standard Gaussian behaviour.

We remark that similar plots were computed in Pagel et al. (2007), where the rates of lexical evolution are obtained by the standard glottochronological approach.

To understand better the behaviour of the stability distribution, we plot $S(i)$, in a decreasing rank, for the 200 meanings taken from the Swadesh list. In Figure 2 we report the data concerning the

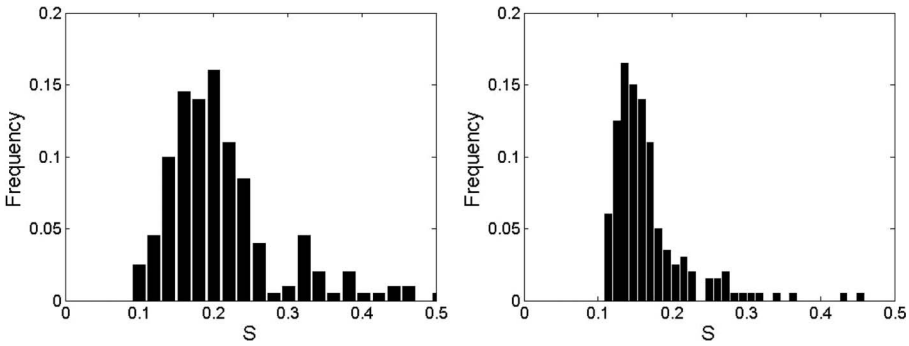


Fig. 1. Stability histogram of meanings for Austronesian (left) and Indo-European (right) languages. The fat tail on the right of the histograms indicates that some items have a very large stability. The qualitative behavior of the two families is the same.

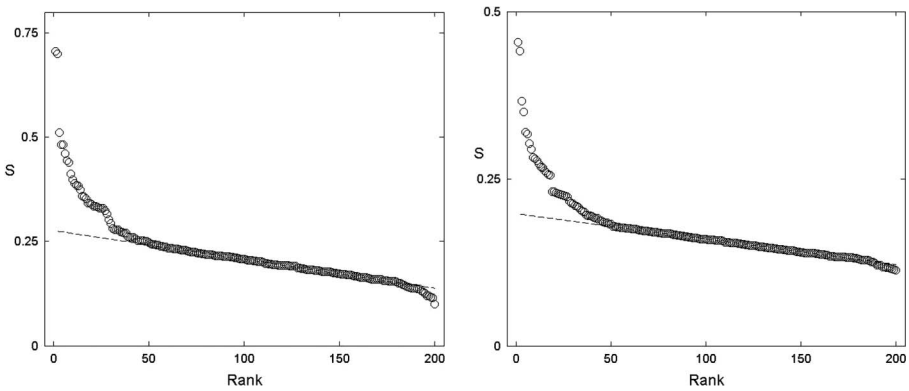


Fig. 2. Stability in a decreasing rank for the 200 meanings of the Austronesian (left) and Indo-European (right) languages. At the beginning stability has large values but drops rapidly, then, between the 50th and the 180th position it decreases linearly, then finally it drops again. The straight line between position 51 and position 180 underlines the initial and final deviation from the linear behaviour. Also in this case the qualitative behaviour of the two groups is the same.

Indo-European and Austronesian families. For both families, the stability drops rapidly at the beginning, then, between the 50th position and the 180th, it decreases slowly and almost linearly with rank, and finally at the end stability drops again. In both figures we fit by a straight line the central part of the data between position 51 and position 180, in order to highlight the initial and final deviation from the linear

behaviour. One can easily conclude that both families have 50 meanings, with particularly high information content and 20 meanings with a particularly low one.

COMPARISON

We study the stability correlations between same items in the two language families and we also compare the stability ranking of items. We found that the correlation coefficient between the stability index computed for the two groups is roughly 0.21. This number is positive and it evidences a certain correlation between ranking in the two families. Nevertheless, its low value suggests that the stability of items depends strongly on the family studied. Only looking at the overall correlation, we are not able to understand its origin, since it could be a consequence of the strong correlation of a few items or a weak correlation of many items. In other words, it could be that the most stable terms in the two lists show a large coincidence, while the other a lower or vanishing one. Or it also could be possible that a small coincidence can be found both for very stable and low stability items.

To better understand this point we considered the first n items in the ranking list for both families, and we computed the number $m(n)$ of common items in the two lists. To underline the non-casual behaviour, $m(n)$ has to be compared with n^2/N which is the average number of common items if one randomly chooses n items from either of the two lists. Then, it is natural to define $p(n)$ as $m(n)$ divided by n^2/N . If there is no relation between stability in the two families, $p(n)$ must be close to 1 for every n . The behaviour of $p(n)$ as a function of n can be seen in Figure 3 which shows that indeed there is a non-trivial overlapping of the two lists of the n most stable items since $p(n)$ is always larger than 1. This fact confirms the correlation between the two rankings, but also shows that this effect is strong only for small n (n less than 50). For larger n the overlapping is much closer to 1 and random coincidences prevail. This means that the most stable terms in the two lists are those to show a larger coincidence.

To give an example of the lists found with our approach, we show here a table of the 20 most stable items for the Indo-European and Austronesian languages families. Together with any of the items, we report its stability record within the family.

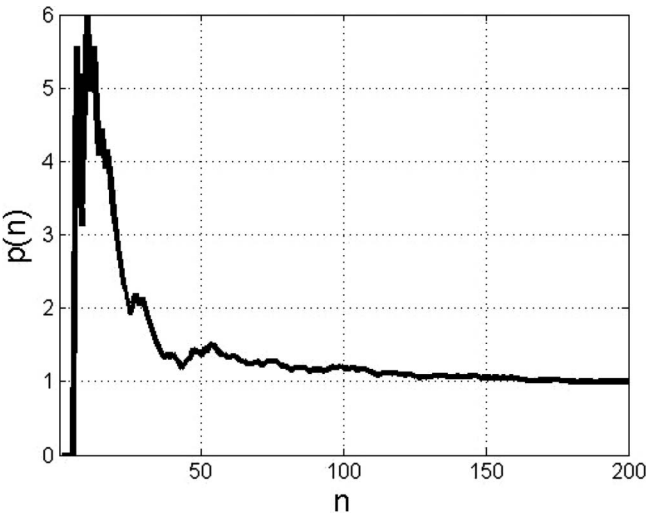


Fig. 3. In this figure it is shown that the number of common items in the two lists of the n most stable items obtained for the Austronesian and Indo-European families. The number is normalized by the random coincidence $n^2/200$.

Table 1. The table shows the 20 most stable words for the Indo-European and Austronesian language families. Together with any of the items, we report its stability record within the family.

Indo-European	S(i)	Austronesian	S(i)
YOU	0.45395	EYE	0.70646
THREE	0.44102	FIVE	0.70089
MOTHER	0.36627	FATHER	0.51095
NOT	0.35033	DIE	0.48157
NEW	0.31961	STONE	0.48157
NOSE	0.3169	THREE	0.46087
FOUR	0.30226	TWO	0.44411
NIGHT	0.29403	LOUSE	0.43958
TWO	0.28214	ROAD	0.41217
NAME	0.27962	FOUR	0.39798
TOOTH	0.27677	HAND	0.38997
STAR	0.27269	NAME	0.38493
SALT	0.26792	LIVER	0.38375
DAY	0.26695	PUSH	0.37444
GRASS	0.26231	MOTHER	0.35821
SEA	0.25906	WE	0.35749
DIE	0.25602	EAT	0.3529
SUN	0.25535	STICK	0.34242
ONE	0.23093	I	0.34208
FEATHER	0.23055	VOMIT	0.33861

CONCLUSIONS

The novelty of the approach we have proposed is that almost everything can be done automatically. One has only to choose a group of languages for which the relative lists of words exist. Then, stability can be computed automatically by using simple objective arguments. We do not claim that our method produces better results than the standard glottochronological approach, but surely they are at least comparable, the advantage being only that it avoids almost all of the subjectivity since all results can be replicated by other scholars assuming that the database is the same. With this respect we stress that part of the subjectivity remains, in fact, scholars have to choose a list of meanings and the corresponding words for each language. Furthermore, it allows for rapid comparison of items of a very large number of languages. In fact, the only work is to prepare the lists, while all the remaining work is done by a computer program. In this way the difficult and lengthy task of cognate identification is avoided.

We applied our method here to the Indo-European and Austronesian families of languages considering 200 item lists of words according to the original choice of Swadesh. The output was a stability measure for all items computed separately for the two families. The histogram of stability shows identical qualitative behaviour in the two cases with a fat tail corresponding to items with very high stability. The ranking plot also shows that the two families behave in the same way, with the higher stability items deviating from the linear interpolation because of their very large values. We speculate that this phenomenology we observe both for Indo-European and Austronesian languages, could be a universal characteristic of stability distributions, common to all families.

On the contrary, it turns out that the most stable items are not the same even if there is a positive correlation between the stability computed for Indo-European and Austronesian groups. We do not know, at this stage, why items may be stable within a family and unstable in another. We can only speculate, according to a recent study (Pagel et al., 2007), that this is related to the different frequency of use of words in different cultural contexts.

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