

Comparing cross-language phonological profiles

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Why did I decide to give this talk?

- During the talk about “Geography and language divergence: the case of Andic languages” at our Lab

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- The second reason:



Johann-Mattis List

@LinguList



New preprint with Cormac Anderson, [@tresoldi](#), [@xrotwang](#), [@SimonJGreenhill](#), and Russell Gray: "Measuring Variation in Phoneme Inventories" doi.org/10.21203/rs.3...



Measuring variation in phoneme inventories

For over a century, the phoneme has played a central role in linguistic research. In recent years, collections of phoneme inventories, originally designed for cross-

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But does this measure make any sense? How can we compare phonological profiles of languages?

Unlike lexicostatistical distance, phonological distance can be evidence for language contact, since languages can adopt some phonological feature or property from a contact language (see [[Andersson et al. 2017](#)]). This can possibly be explained by the **Perceptual Magnet framework** [[Blevins 2017](#)]. In most cases phonological change in unrelated languages is more salient to linguists, however it is worth mentioning that there is at least one study about how to catch contact-induced phonological change in

Materials for the analysis

Materials for the calculation of phonological distance can be different:

- segment¹ inventory (and grammar, if you are lucky);
- dictionaries;
- parallel dictionaries;
- corpora;
- parallel corpora.

¹Let's leave the phonology vs. phonetics debate aside.

Overview

Criticism by [Simpson 1999]

Complexity-based approaches

Distance-based approaches

Criticism by [Simpson 1999]

[Simpson 1999] criticizes UPSID¹-like researches:

- phonemes mask allophones
 - Standard High German /ç/ stands for [ç], [x] and [χ];
 - “The allophone no longer represents the phoneme, it *replaces* it”;
- the phonological relations between segments are lost
 - it is impossible to get information about e.g. vowel harmony by comparing just vowel inventories;
- there is no non-arbitrary way of assigning phonological features (e.g. SPE [Chomsky and Halle 1968]) to segments.

¹UPSID stands for UCLA Phonological Segment Inventory Database [Maddieson and Abramson 1987], which consists of the phonemic systems of a representative sample of 451 (this number changes from publication to publication) of the world's languages in machine-readable form. UPSID can be accessed via the PHOIBLE database [Moran and McCloy 2019].

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My metaphor: omelets and pancakes share the same ingredients, but they are significantly different meals.

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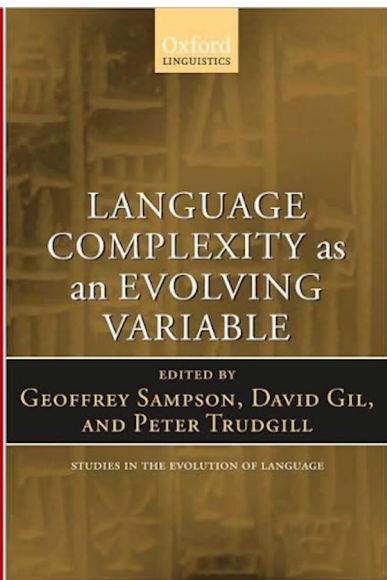
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[Pellegrino et al. 2009] and [Sampson et al. 2009]



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 - [Deutscher 2009]

The main goal of this paper was to calculate the overall complexity for a typological sample of languages based on phonology, synthesis, classification (gender, numeral classifiers), syntax, and lexicon. The main goal was to prove:

- that all languages **are not** equal in complexity;
- that different parts of grammar **do not** compensate for complexity in other parts of grammar.

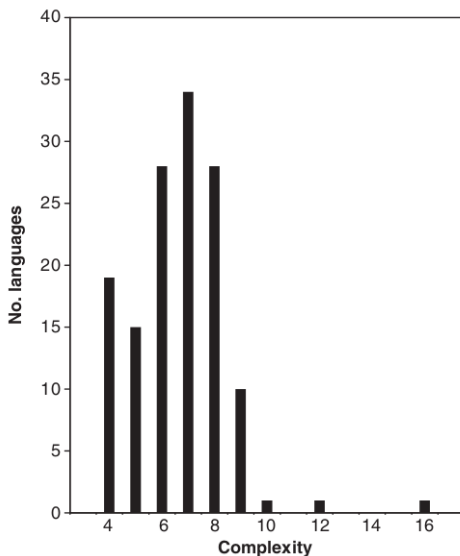
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Phonological features in the

- number of contrastive manners of articulation in stops;
- number of vowel quality distinctions;
- tone system (none/simple/complex, after [Maddieson 2013b]);
- syllable structure (after [Maddieson 2013a]).

[Nichols 2009: 116]: results



Phonological complexity (N = 137)

‘Secondary distinctive features’ are important for phonologization:

- nasals in French: saint [sɛ̃] < Latin sanctus ‘holy’;
- average F₀ contour of vowels following English stops is falling after voiceless and rising after voiced.

They are not captured by the segmental inventories.

Allophones, like English /t/: [t^h] vs [t] vs [ɾ] (cf [Simpson 1999]).

- Merged measure for consonants, vowels, tones and syllable structure;

Indonesian (Austronesian)	Birom (Niger-Congo; Nigeria)	Kiowa (Kiowa-Tanoan; USA)
p t k	p t k kp	p t̚ k ʔ
b d g	b d g gb	p ^h t̚ ^h k ^h
tʃ dʒ	tʃ dʒ	b d̚ g p' t̚' k'
f s ʃ x h	f s h	ts ts'
z	v z	s h
m n ɲ ŋ	m n ŋ	z
l r	l r	m ɲ
w j	w j	d̚ʒ
		j

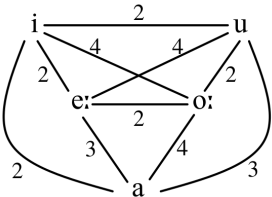
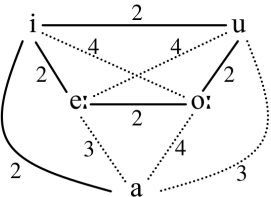
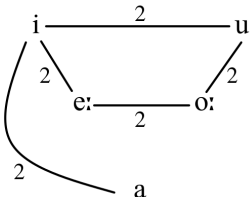
- Merged measure for consonants, vowels, tones and syllable structure;

Indonesian = 24	Birom = 27	Kiowa = 32
1 1 1	1 1 1 2	1 1 1 1
1 1 1	1 1 1 2	2 2 2
1 2	1 2	1 1 1
1 1 1 1 1	1 1 1	2 2 2
2	2 2	1 2
1 1 1 1	1 1 1	1 1 1
1 1	1 1	2
1 1	1 1	1 1 3
		1

- Merged measure for consonants, vowels, tones and syllable structure;
- The number of possible distinct syllables allowed by the language (cf [Shosted 2006]);
- Frequency measures based on lexicon or texts (cf [Давиденко 2021] for Andic):

“To compare these data, it is useful to calculate some kind of index. There are a number of ways this might be done. One possibility is to calculate a summed frequency \times complexity score over the top ten segments, in which each segment contributes decreasingly according to its rank, and increasingly according to its complexity”.
[Maddieson 2009: 97]

- In this work the authors use phonological features as distances between segments and then use graphs with segments as the nodes and distances as the edges:

STEP 1	STEP 2	STEP 3
We compute the <u>direct</u> phonetic distance for each phonemes pair.	Identification of pairs of phonemes for which an <u>indirect</u> path requires smaller "jumps" than the direct one.	Suppression of costly <u>direct</u> paths.
		

- In this work the authors use phonological features as distances between segments and then use graphs with segments as the nodes and distances as the edges:
- Then, the authors use the *off-diagonal complexity* proposed by [Claussen 2007],¹ which makes it possible to disassociate from linguistics and phonology and rely purely on graph structure.

¹Their motivation for this choice, was that this measure

- does not explicitly take into account graph size;
- is sensitive to the presence of hierarchical sub-structures in the network;
- is minimal for regular graphs and maximal for free-scale graphs.

Unfortunately, off-diagonal complexity can not be calculated for valued graphs, so authors were ought to drop phonological distance values from their graphs.

- ‘All Languages are Equally Complex’ — is a myth (actually, a lot of papers from [Sampson et al. 2009] state the same).
- Complexity is a polysemous notion: some scholars focus on the multipartite nature of language, others on the complicated relations within the system.
- Overall complexity is better to present as a vector of values rather than one value.

Conclusions

Despite the criticism that a language's phonological system is a complex system that can not be reduced to the set of its elements [[Simpson 1999](#); [Ohala 2009](#); [Coupé et al. 2009](#); [Deutscher 2009](#)], I think that any phonological complexity measure can be used in order to compare different languages. The sophistication and granularity of this measure will influence the possible effect size gathered by this measure.

Overview

Criticism by [Simpson 1999]

Complexity-based approaches

Distance-based approaches

Distance-based approaches

- [Hoppenbrouwers and Hoppenbrouwers 2001] (after [Heeringa 2004])
- [Nerbonne and Heeringa 2001] (after [Heeringa 2004])
- [Heeringa 2004]
- [Eden 2018]
- [Anderson et al. 2021]

In this paper the authors apply the **Jaccard similarity** between two phoneme inventories, that is a ratio of similar segments in two languages out of all the possible segments in two languages.

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The reason why authors do this, is because their goal is to compare different inventories of the **same** languages across four databases of phonological inventories (UPSID [Maddieson and Abramson 1987], LAPSyD [Maddieson et al. 2013], Core PHOIBLE [Moran and McCloy 2019], JIPA [Baird et al. 2021]). The results are unfavorable: researchers found a high degree of variation across datasets.

[Hoppenbrouwers and Hoppenbrouwers 2001] after [Heeringa 2004]

- Extract frequencies of units (these can be segments, syllables or phonological features) from corpora or dictionaries.
- The distance between two languages is the sum of the differences between the corresponding unit frequencies.

[Nerbonne and Heeringa 2001] after [Heeringa 2004]

The authors applied the same strategy as [Hoppenbrouwers and Hoppenbrouwers 2001], but used words as corpora. So the idiom distance is calculated as an average word distance.

[Heeringa 2004]

Since the methods of [Hoppenbrouwers and Hoppenbrouwers 2001] and [Nerbonne and Heeringa 2001] do not account for unit order, Heeringa decided to use the Levenstein distance [Левенштейн 1965]. The Levenstein distance is the minimum number of unit edits (insertions, deletions or substitutions) that should be applied to the unit string in order to get another:

- the distance between *pancake* and *omelet* is 7
- the distance between *pancake* and *cake* is 3
- the distance between *sing* and *sign* is 1

Shortcoming:

- diphthong vs. vowel + consonant combination (/au/ or /aw/?);
- suprasegmental features;
- sequence length: the longer the sequences, the greater the chance of differences between them.

To address the sequence length problem [Heeringa 2004] uses normalization by the length of the alignment:

$$\begin{array}{ccc} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ \hline 1 & 1 & 1 \end{array}$$

(1)

$$\begin{array}{ccc} a_1 & a_2 & \emptyset \\ b_1 & b_2 & b_3 \\ \hline 1 & 1 & 1 \end{array}$$

(2)

$$\begin{array}{ccc} a_1 & a_2 & \emptyset \\ \emptyset & \emptyset & b_3 \\ \hline 1 & 1 & 1 \end{array}$$

(3)

$$\begin{array}{ccc} a_1 & a_2 & \emptyset \\ \emptyset & b_2 & b_3 \\ \hline 1 & 1 & 1 \end{array}$$

(4)

All four examples are normalized by the value 3.

[Heeringa 2004]: interlanguage stimuli mismatch

- It is possible that for one of the pair of idioms one lacks stimuli, in which case the effect of this stimulus is discounted.
- In case of multiple transcriptions they are matched according the minimum distance:
 - L1: [hys]; L2: [hys] and [hus]
 - L1: [hys] and [hus]; L2: [hys] and [hus]

- Parametric typology:
 - annotate languages according to 27 syllable structure parameters, and 29 inventory parameters;
 - apply Hamming distance,¹
- Cross-entropy of the transcribed example texts

¹This is just an ordered version of the Jaccard distance: the ratio of similar units in two languages out of all possible units in two languages.

[Eden 2018]: Shannon information entropy

Entropy is a measure of randomness or uncertainty proposed by [Shannon 1948].

$$H(X) = - \sum_{i=1}^n P(x_i) \times \log_2 P(x_i)$$

Possible entropy values are $H(X) \in [0, +\infty]$:

dataset	entropy
A-A-A-A-A	0.00
A-A-A-A-B	0.72
A-A-A-B-B	0.97
A-A-B-B-B	0.97
A-A-B-B-C	1.52
A-B-C-A-B	1.52

[Eden 2018]: Cross-entropy

A cross-entropy measure is used in order to compare the two distributions X and Y :

$$H(X, Y) = - \sum_{i=1}^n P(x_i) \times \log_2 P(y_i)$$

first dataset	cross-entropy	second dataset
A-A-A-A-B	0.72	A-A-A-A-B
A-A-A-A-B	0.85	A-A-A-B-B
A-A-A-B-B	1.09	A-A-B-B-B
A-A-A-A-B	1.20	A-A-B-B-B

[Eden 2018]: Kullback-Leibler divergence

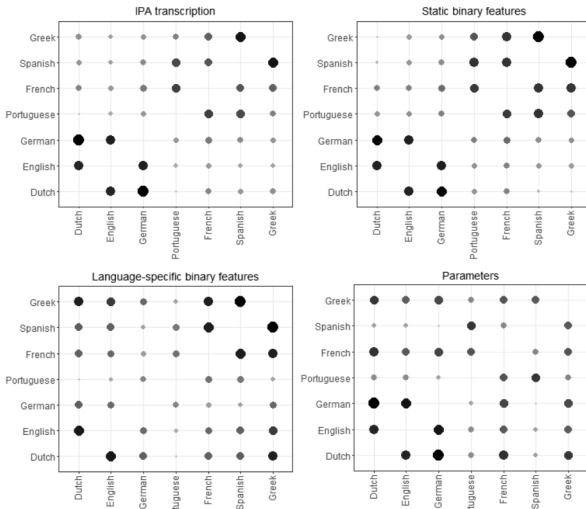
As we have seen, if the distributions X and Y are equal, then the cross-entropy is equal to the entropy of that distribution. So there is a way to normalize it, called the Kullback-Leibler divergence measure:

$$D_{KL}(P \parallel Q) = H(P, Q) - H(P)$$

first dataset	Kullback-Leibler	second dataset
A-A-A-A-B	0.00	A-A-A-A-B
A-A-A-B-B	0.12	A-A-B-B-B
A-A-A-A-B	0.13	A-A-A-B-B
A-A-A-A-B	0.48	A-A-B-B-B

[Eden 2018]: application (greater circles stand for similar languages)

- 7 languages from the corpus of European languages (Portuguese, French, Spanish, German, English, Dutch, Greek)



[Eden 2018]: application

- 7 languages from the corpus of European languages (Portuguese, French, Spanish, German, English, Dutch, Greek)
- Pearson correlation between some metrics:

	Parameter	Entropy: IPA	Entropy: static binary features
Entropy: IPA	0.67		
Entropy: static binary features	0.55	0.94	
Entropy: ls binary features	0.33	0.46	0.38

Conclusions

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Both complexity-based and distance-based approaches are valid for language comparison:

- the complexity-based approach probably is better by design, but it depends on a feature set that should be chosen by linguists;
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Acoustic distances in [[Heeringa 2004](#)] and [[Eden 2018](#)]!

Thank you for your attention!

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