Comparing cross-language phonological profiles

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How I decided to give this talk?

- During the talk in our Lab with Misha and Ezequiel

Jeff Good: How you came up with the idea of calculating phonological distances? Is it some established procedure?

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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-
researchsquare.com

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The main reason for this talk is that I performed calculation of phonological distances (or caused people to do so) for Circassian languages [Мороз 2021] and Andic branch of East Caucasian languages [Moroz 2020; Давиденко 2021; Tsyzova and Zhang 2021] in order to get a simple less-connected to language phylogeny distance between different idioms.

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

Unlike lexicostatistical distance the phonological distance can be an evidence for language contact, since languages can adopt some feature or property of another (see [Andersson et al. 2017]). This can be possible explained by **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 a work about how to catch contact-induced change in related languages [Bowern 2013].

Materials for the analysis

Materials for the phonological distance calculation can be different:

- segment[1] inventory (and grammar, if you are lucky);
- dictionaries;
- parallel dictionaries;
- corpora;
- parallel corpora.

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[1]Lets leave the phonology vs. phonetics debate aside.

Overview

Criticism by [Simpson 1999]

Complexity based approaches

Distance based approaches

Criticism by [Simpson 1999]

[Simpson 1999] attacks UPSID[1]-like researches:

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    - "The allophone no longer represents the phoneme, it *replaces* it";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

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[1]UPSID 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. Now UPSID can be accessed via PHOIBLE database [Moran and McCloy 2019].

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My metaphor: omelet and pancakes share all ingredients, but they are <u>significantly different meals</u>.

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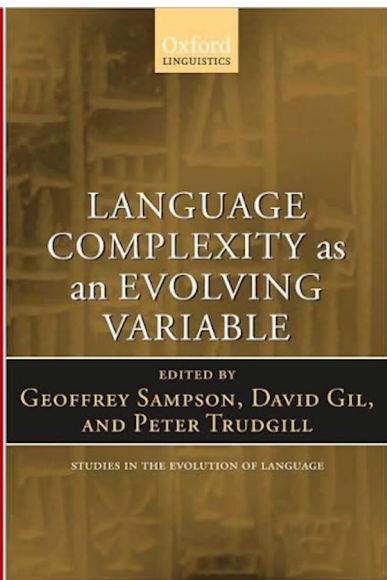
Overview

Criticism by [Simpson 1999]

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Distance based approaches

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

- [Pellegrino et al. 2009]
  - [Ohala 2009]
  - [Maddieson 2009]
  - [Coupé et al. 2009]
- [Sampson et al. 2009]
  - [Nichols 2009]
  - [Deutscher 2009]

[Nichols 2009]

The main goal of this paper is to calculate overall complexity for a typological sample of languages based on phonology, synthesis, classification (gender, numeral classifiers), syntax, and lexicon. The main goal is too 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
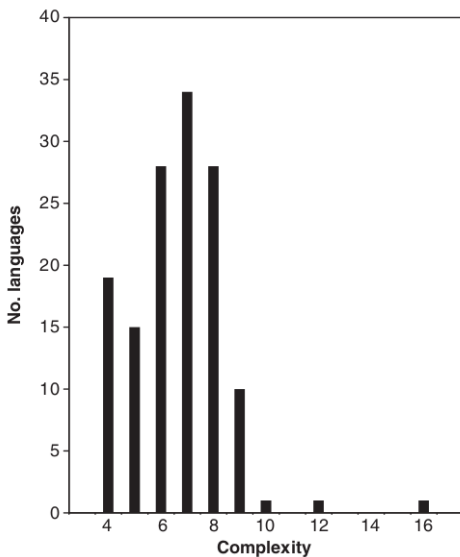
Phonological complexity (N = 137)

'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/: [tʰ] 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 t̪ k ʔ		
						pʰ t̪ʰ kʰ		
b d g			b d g gb			b d̪ g		
						p' t̪' k'		
tʃ dʒ			tʃ dʒ			ts ts'		
f s ʃ x h			f s h			s h		
z			v z			z		
m n ɲ ŋ			m n ŋ			m n̪		
l r			l r			d̪z̪		
w j			w j			j		
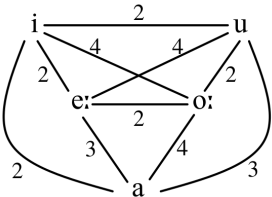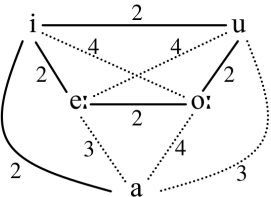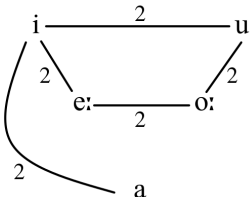
- Merged measure for consonants, vowels, tones and syllable structure;

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

[Maddieson 2009]

- 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 × 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]

[Coupé et al. 2009]

- In this work authors use phonological features as a distances between segments and then use graphs with segments in the nodes and distances in 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.

[Coupé et al. 2009]

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

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[1]Authors motivated their choice, because 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 phonologcial distance values from their graphs.

[Deutscher 2009]

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

Conclusions

Despite of the critics that language 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 authors apply **Jaccard similarity** between two phoneme inventories, that is ratio of similar segments in two languages out of all possible segments in two languages.

[Anderson et al. 2021]

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The reason, why authors do that 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 unit (it can be segments, syllables or phonological features) frequencies from corpora or dictionary.
- The distance between two languages is the sum of the differences between the corresponding unit frequencies.

[Nerbonne and Heeringa 2001] after [Heeringa 2004]

Authors applied the same stratagy as [Hoppenbrouwers and Hoppenbrouwers 2001], but used words as a corpora. So the idiom distance is calculated as an average word distance.

[Heeringa 2004]

Since [Hoppenbrouwers and Hoppenbrouwers 2001] and [Nerbonne and Heeringa 2001] methods does not account for unit order Heeringa decided to use 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:

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

$$(1) \qquad\qquad (2) \qquad\qquad (3) \qquad\qquad (4)$$

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 lack stimuli, then the effect of this stimuli is discounted.
- In case of multiple transcription they are matched according the minimum distance:
  - L1: [hys]; L2: [hys] and [hus]
  - L1: [hys] and [hus]; L2: [hys] and [hus]

[Eden 2018]

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

---

[1]That is just ordered version of Jaccard distance: 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

Cross-entropy measure is used in order to compare 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 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 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)
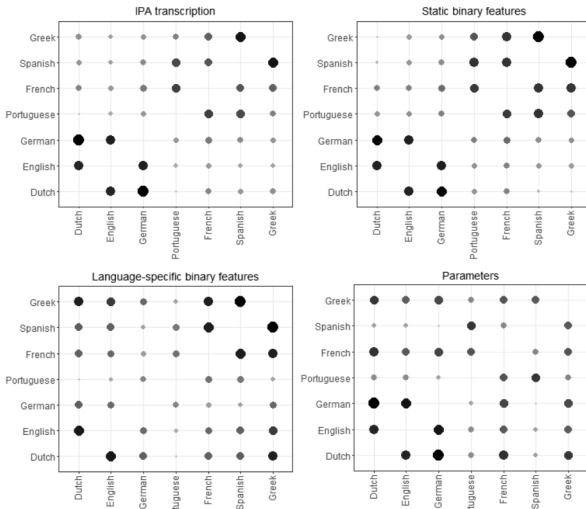
[Eden 2018]: application

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

	Parameter	Entropy: IPA	Entropy: stat
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 feature set that should be chosen by linguists;
- the distance-based approach is better in capturing all phonotactic details present in the data (as [Maddieson 2009] proposed), but it depends on more or less comparable data from different languages.

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Acoustic distances in [Heeringa 2004] and [Eden 2018]!

Thank you for your attention!

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