Regression Analysis on Levenshtein-Pointwise Mutual Information Segment Distances Across Languages and Acoustic Distances

Eliza Margaretha
Martijn Wieling
John Nerbonne

Rijksuniversiteit Groningen

Outline

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- Techniques
- Data
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Overview

- Compare phonetic segment distances
  - Dutch, German, Bulgarian
- Compare Levenshtein-Pointwise Mutual Information (PMI) distances to acoustic distances
- Regression analysis
  - Correlation
  - Prediction power

Techniques: Levenshtein-PMI (1/3)

- Segment Distance
  - How often segment x is aligned with segment y
- Levenshtein
  - Insertion: a segment with a gap
  - Deletion: a gap with a segment
  - Substitution: 2 segment

Techniques: Levenshtein-PMI (2/3)

- Pointwise Mutual Information (Church and Hanks, 1995)

$$PMI(x,y) = \log_2\left(\frac{p(x,y)}{p(x)p(y)}\right)$$

- Wieling, et al. (2009)
  - p(x,y) is the number of the x and y occurrences at the same position in 2 aligned strings of X and y, divided by the total number of aligned segments
  - p(x) or p(y) the number of the occurrences of x or y divided by the total number of segment occurrences

Techniques: Levenshtein-PMI (2/3)

- Training Wieling, et al. (2009)
  1. Align string with Levenshtein algorithm (w/o vocal-consonant)
  2. Compute PMI values and transform (subtract from 0 + max value)
  3. Apply Levenshtein to PMI-segment distances
  4. Repeat 2 and 3 till convergence is reached

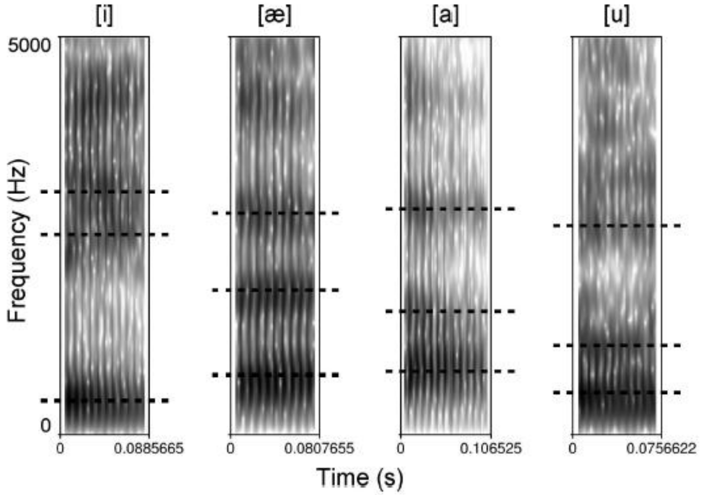
	ɑ	ə	ɛ
ɑ	0	2331	1880
ə	2331	0	64905
ɛ	1880	64905	0

Techniques: Formant Measurements (1/3)

- Vowel quality (McArthur, 1998)
  - the property that makes vowels different, e.g. /iː/ as in sheep from /ɪ/ as in ship
  - determined by the position of the vocal tracts during pronunciation
- Formants
  - measure vowel quality by means of acoustic signals
  - specify the energy concentration positions in the acoustic signals, i.e. the lowest resonance frequencies (Peterson & Barney, 1952)

Techniques: Formant Measurements (2/3)

- Formants: darker bands
  - 2 first formants are the most distinguishing
  - 3rd formants and lip position
- $/i/$ and $/u/$ has similar first formants but the second formant of $/i/$ is much higher than that of $/u/$



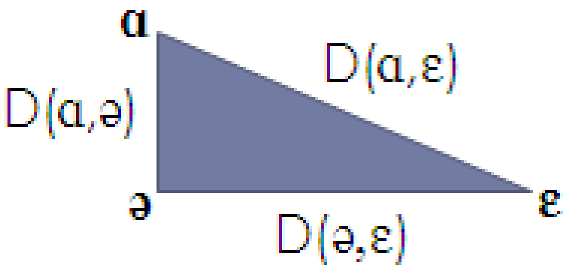
Picture from (Leinonen, 2010)

Techniques: Formant Measurements (3/3)

- Acquiring acoustic distances
  - Compute Euclidean distances of formant values between vowel pairs (Wieling, et al., 2007)
- Normalizing non-linguistic speaker-dependent differences
  - Pitch, gender, shape & size of vocal tracts
  - transforms Hertz frequency to the Bark or the Mel scales

Techniques: Mantel Test (1/2)

- Triangle inequality
  - Dependent: D(ɑ,ɛ) is dependent to D(ɑ,ə) and D(ə,ɛ)
    - D(ɑ,ɛ) < D(ɑ,ə) + D(ə,ɛ)
    - Acoustic distance
  - Independent
    - Levenshtein PMI



- Mantel test
  - Significance Test of a Correlation Coefficient of Distance Matrices

Techniques: Mantel Test (2/2)

- Random permutation test
- H Null = No relation between 2 matrices
  - R should be equally likely to be larger or smaller
- Steps
  1. Permutate rows and columns of one of the matrices randomly
  2. Compute correlation between the permutated matrix and the other matrix
  3. Repeat 1 and 2
- Observation value:
  - Add 1 for every r(PD1,D2) > r(D1,D2)
  - Divided by number of repetition

Dataset (1/5)

Language	Locations	Words	Segment Types
Dutch	424	562	82
German	186	196	78
Bulgarian	197	152	67

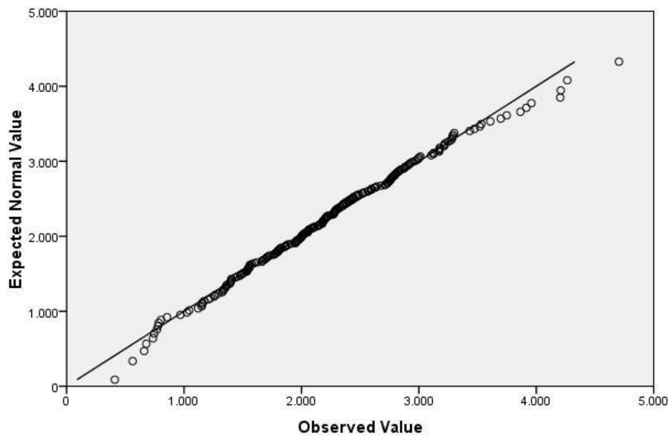
- **Dutch**: Goeman-Taeldean-Van Reenen-Project
- **German** : Kleiner Deutscher Lautatlas project
- **Bulgarian**: students' theses at the University of Sofia, published monographs, dictionaries, and the archive of the Ideographic Dictionary of Bulgarian Dialects (Prokić, et al., 2009)

Dataset (2/5)

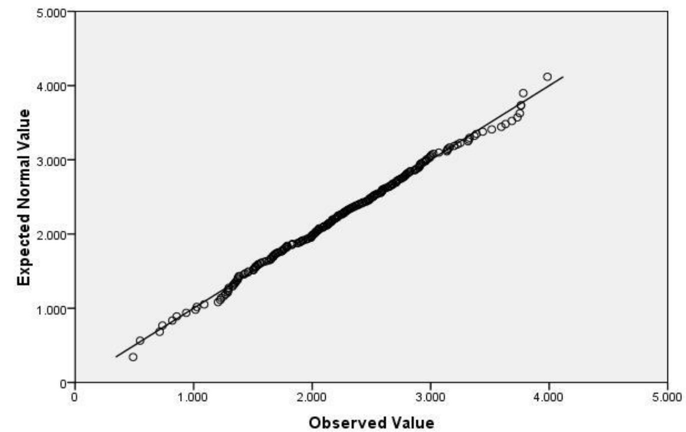
Language Pair	Shared Types	Segment Alignments	Vowel Alignments	Consonant Alignments
Dutch and Bulgarian	43	235	92	143
Dutch and German	71	870	261	609

Dataset (3/5)

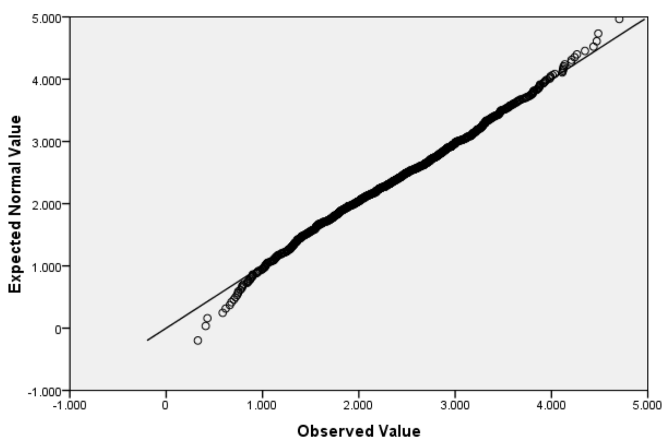
Normal Q-Q Plot of NL



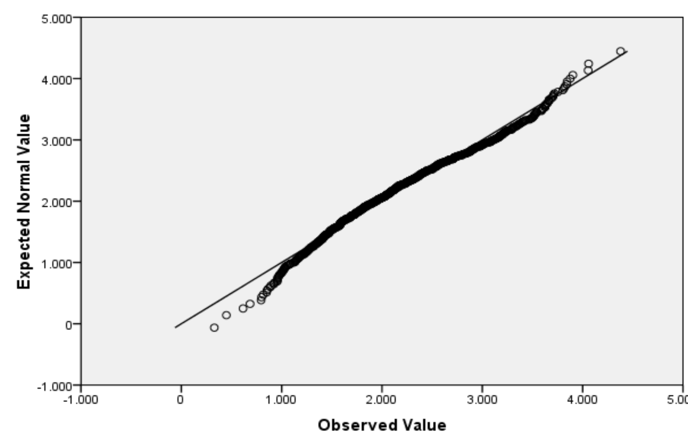
Normal Q-Q Plot of BUL



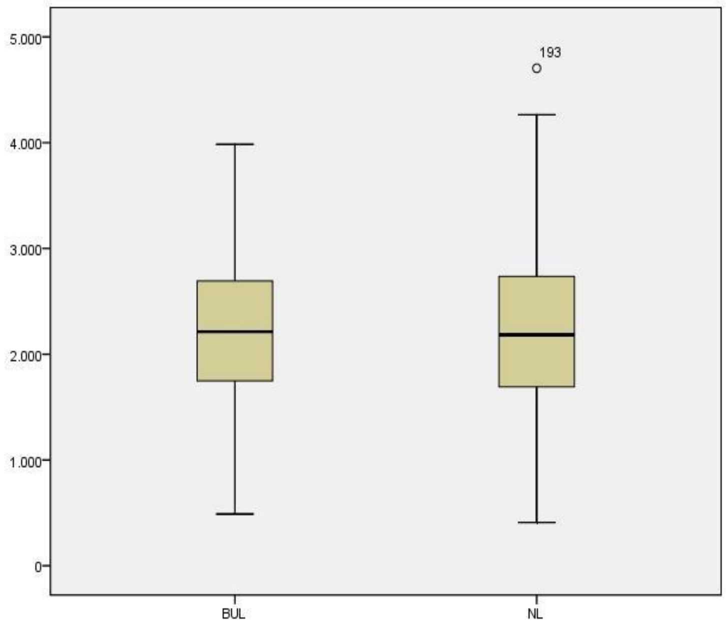
Normal Q-Q Plot of NL

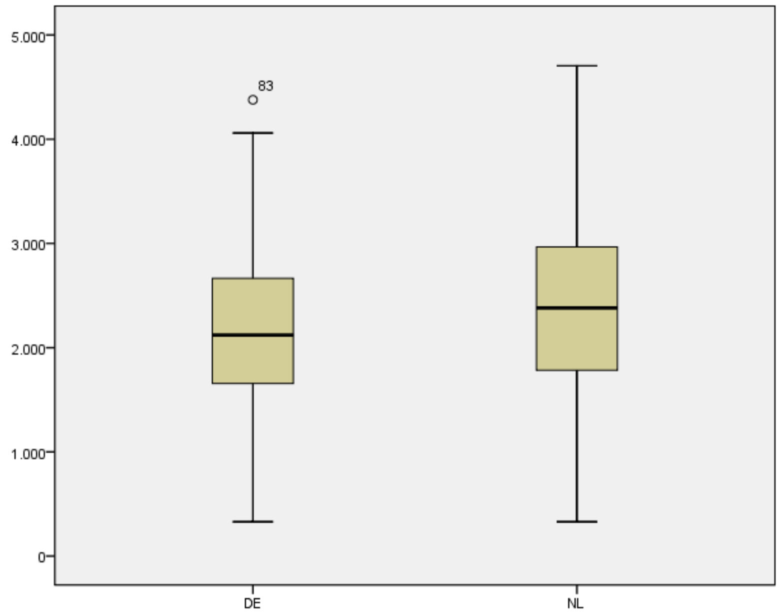


Normal Q-Q Plot of DE



Dataset (4/5)


5.000
4.000
3.000
2.000
1.000
0
193
BUL
NL


5.000
4.000
3.000
2.000
1.000
0
83
DE
NL

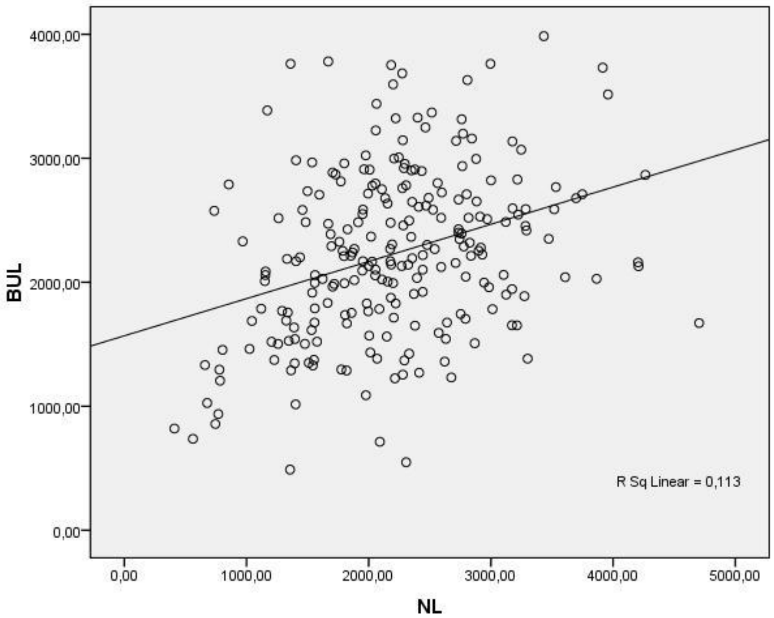
Dataset (5/5)

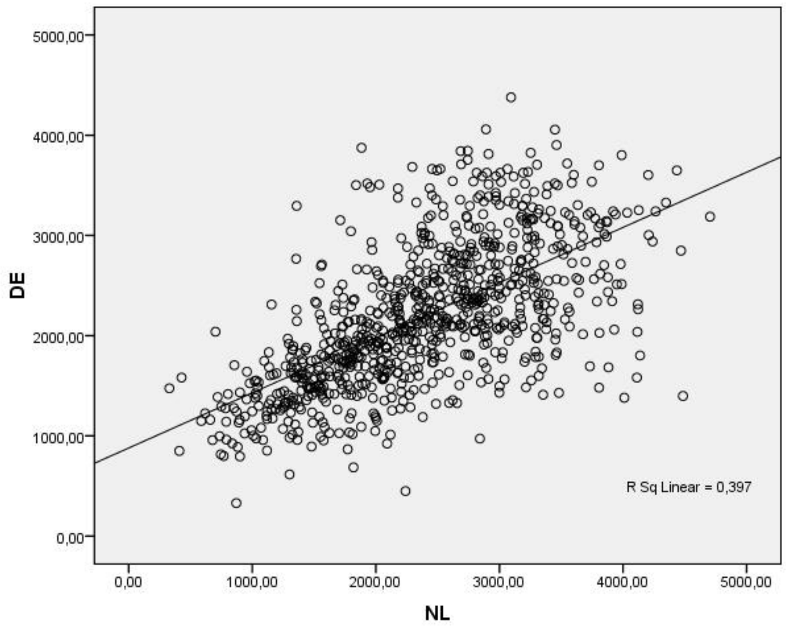
- Acoustic data was obtained from Pols, et al. (1973) and Van Nierop, et al. (1973),
  - three first formants
  - 50 male and 25 female Dutch speakers
  - 36 acoustic vowel alignments
  - All alignments appear in Levenshthein-PMI Dutch matrix

Analysis: Lev-PMI Distance Across Languages (1/5)

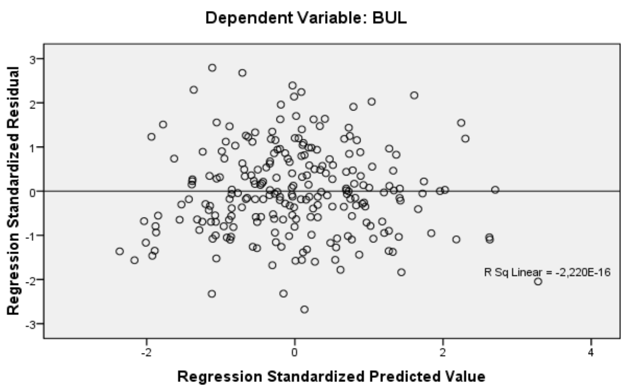
- Regression analysis setup
  - Variables
    - Dutch (independent/explanatory) and Bulgarian (dependent/response)
    - Dutch and German
  - Cases
    - Segment alignments
  - Values
    - Levenshtein-PMI distance

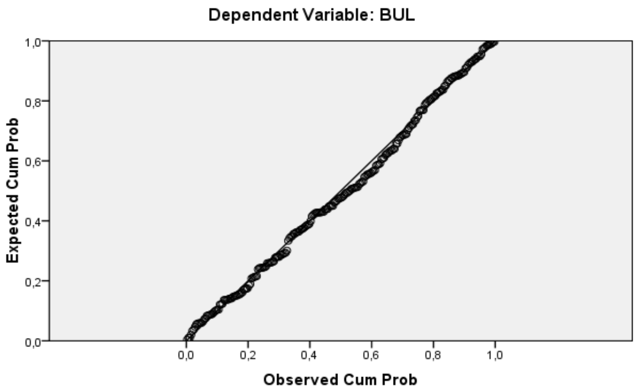
Analysis: Lev-PMI Across Languages (2/5)

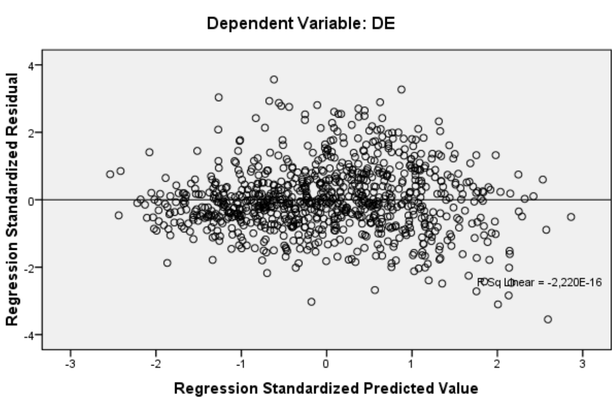


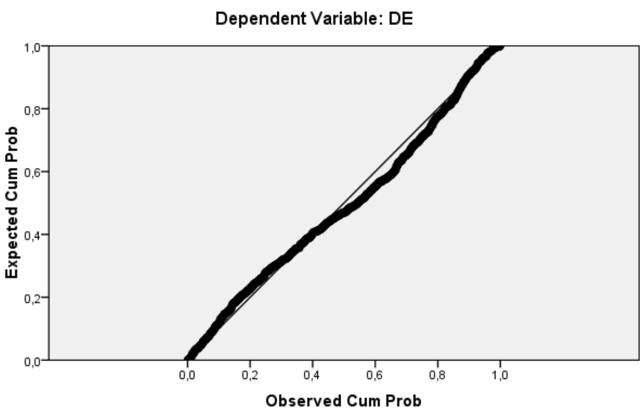


Analysis: Lev-PMI Across Languages (3/5)









Analysis: Lev-PMI Across Languages (4/5)

Language Pair	Alignment Sets	Pearson Correlation	Effect size (r^2)
Dutch and Bulgarian	All	0,336	0.113
	Vowel	0,418	0.178
	Consonant	0,339	0.115
Dutch and German	All	0,630	0,397
	Vowel	0,620	0.384
	Consonant	0.587	0.345

Analysis: Lev-PMI Across Languages (5/5)

- Computing regression line
  - y = 1586, 562 + 0,300x
  - T ratio 5,454 (p < 0,001)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1568,562	128,322		12,224	,000
	NL	,300	,055	,336	5,454	,000

a. Dependent Variable: BUL

Analysis: Example (1/2)

- How does the prediction work?
- Lev-PMI distance between ɑ and ε in Dutch, $x = 1556$
- Predicted ɑ-ε distance in Bulgarian:
  - $\hat{y} = 1586.562 + 0.300\,(1556) = 2053.362$

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,336[a]	,113	,109	639,39919

a. Predictors: (Constant), NL

b. Dependent Variable: BUL

Descriptive Statistics

	Mean	Std. Deviation	N
BUL	2230,4298	677,53592	235
NL	2207,7872	760,44125	235

Analysis: Example (2/2)

$$\mathrm{SE}_{\hat{y}} = s \cdot \sqrt{\frac{1}{n} + \frac{(x^* - \bar{x})^2}{\sum_i^n (x_i - \bar{x})^2}}$$

- $SE_{\hat{y}} = 639.4 \times \sqrt{\frac{1}{235} + \frac{(1556 - 2207.8)^2}{578270.9}} = 549.6$
- t for $(\mathrm{df} = 200) = 1.97$ $(\alpha = 0.05)$
- $Confidence\ Interval\ 95\% = \hat{y} \pm t \times SE_{\hat{y}} = 2053.362 \pm 1.97 \times 549.6 = 2053.362 \pm 1083$
- With 95% certainty, mean of α-ε distance in Bulgarian given the distance in Dutch = 1556, lies in the interval (970,3136).
- Real distance = 1675

Analysis: Lev-PMI and Acoustic Distances (1/3)

- Response Variable
  - Lev-PMI distance for Dutch segments
- Explanatory variables (acoustic distance variations)
  - Hertz: raw hertz measurements of formants
  - Bark: hertz values transformed to Bark scale
  - Mel: hertz values transformed to Mel scale
  - Z-score
    - hertz values transformed to Z-scores per speaker, normalizing over all the vowels for each speaker
    - average the Z-scores per vowel of all speakers

Analysis: Lev-PMI and Acoustic Distances (2/3)

Acoustic variation	Number of first formants	Pearson Correlation	Effect Size (r^2)	Significance
Hertz	2	0.481	23 %	0.003
	3	0.426	18 %	0.010
Z-score	2	0.720	**52 %**	0.000
	3	0.640	**41 %**	0.000
Bark Scale	2	0.616	38 %	0.000
	3	0.517	27 %	0.001
Mel Scale	2	0.603	36 %	0.000
	3	0.507	26 %	0.002

Analysis: Lev-PMI and Acoustic Distances (3/3)

- Mantel test with 9999 replicates
- H0 = No relation between Lev-PMI distance with Acoustic distance
- Positive observations shows positive relationships

Acoustic variation	Observation value	Significance (p-value)
Hertz 2	0.168	0.0134
Hertz 3	0.132	**0.035**
Z2	0.410	1e-04
Z3	0.317	3e-04
Bark 2	0.303	2e-04
Bark 3	0.206	0.0027
Mel 2	0.286	2e-04
Mel 3	0.195	0.0036

Discussion

- Why is the correlation between Dutch and Bulgarian smaller than that between Dutch and German?
- Why do Z-scores yield better results than other variations (Hertz, Bark, Mel)?
- How are the relationships between Levenshtein-PMI distances and acoustic distances of other languages?

Summary

- Our results show that Levenshtein-PMI distances of Dutch are able to predict those of Bulgarian and German.
- Prediction of languages in the same category / with similar characteristics (Dutch-German) is better than those with different characteristics (Dutch-Bulgarian).
- Vowel quality as represented by acoustic distances correlate reasonably highly with Levenshtein-PMI distances, particularly in our Dutch case, the former can predict up to 52% of the latter.