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EVOLAEMP
Language Evolution:
The Empirical Turn

Uralic and its Neighbors as a Test Case for a Lexical Flow Model of Language Contact

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Table of Contents

NorthEuraLex

Causal Inference

Lexical Flow Inference

Results

Future Work

NorthEuraLex: Overview

- realizations of 1.016 basic concepts across 103 languages of Northern Eurasia compiled from dictionaries (Dellert, 2015)
- advantage compared to existing datasets (like IDS):
  deep coverage of a large continuous geographic area
- data on 26 Uralic languages has been released and is available for inspection and expert feedback (which is very welcome):
  `http://sfs.uni-tuebingen.de/~jdellert/northeuralex`
- Languages used for this study:
  - ▷ 6 Finnic and 6 Saami languages
  - ▷ 2 Mordvinic, 2 Mari, 3 Permian languages
  - ▷ Khanty, Mansi, Hungarian, 4 Samoyedic languages
  - ▷ 4 Turkic languages, and Ket as a contact isolate
  - ▷ 4 Germanic, 2 Baltic, 6 Slavic languages, Romanian

NorthEuraLex: Conversion to IPA

- for every language, we have converters from orthography to IPA
- only based on the literature and readily available recordings; some errors are unavoidable
- accurate enough for modeling historical developments
- infrastructure:
  - ▷ simple formalism based on greedy matching and replacement in freely definable contexts of arbitrary length
  - ▷ description language for defining transducers on X-SAMPA
  - ▷ cascades of between 1 and 6 transducers for each language; for most languages in Cyrillic orthography, one transducer for consonants and one for vowels works reasonably well
  - ▷ should be compilable into finite-state transducers (currently being done as a student project)

NorthEuraLex: Reduction to ASJP classes

- for cross-linguistic comparisons, we will always need to abstract away from some phonetic detail (e.g. exact representation of diphthongs, palatal vs. palatalized)
- full IPA with all diacritics has too many symbols for reliably estimating alignment scores
- popular in computational historical linguistics: **ASJP classes** as used by the Automated Similarity Judgment Program (Brown et al., 2008) across more than 6.000 languages
- 41 classes, no segment length, no coarticulation!
- very suboptimal for Uralic, but ensures that we are not overfitting the method to a single language family

NorthEuraLex: Data Sample

fin	*korva*	[kɔrʋɑ]	korwa
ekk	*kõrv*	[kɤrv]	korv
liv	*kūora*	[ku:orɑ]	kuora
sme	*beallji*	[pe̯æʎ:i]	peEli
smn	*pelji*	[peʎi]	peli
sms	*pe´llj*	[pɛʎ:ʲə]	pEl3
mrj	*пӹлӹш*	[pɯlɯʃ]	puluS
mhr	*пылыш*	[pɤ·lɤʃ]	poloS
mdf	*пиле*	[pilʲe]	pile
myv	*пиле*	[pilʲe]	pile
udm	*пель*	[pelʲ]	pel
kpv	*пель*	[peʎ]	pel
hun	*fül*	[fyl]	fil
mns	*паль*	[paʎ]	pal
sel	*ӄо*	[qo]	qo
yrk	*xa*	[xɑ]	xa
nio	*коу*	[kou]	kou

Table of Contents

NorthEuraLex

Causal Inference

Lexical Flow Inference

Results

Future Work

Causal Inference: Basic Idea

- statistical techniques to infer causal relationships between variables from observational data alone (Pearl, 2009)
- not possible for two variables: “correlation is not causation”
- but: interaction between more than two variables often provides hints about underlying causal scenario
- model causal scenarios as **causal DAGs** (directed acyclic graphs) over the variables, systematically exploit hints to infer properties of the underlying causal DAG
- possible under conditions of sufficiency and faithfulness

Conditional Independence and Causal Graphs

- core building block: a **conditional independence** relation
- $(X \perp\!\!\!\perp Y \mid Z)$ intuitively means:
  "any dependence between the variables X and Y can be explained by the influence of Z"
- PC algorithm: sequence of conditional independence tests reduces a complete graph to a **causal skeleton**, where no link can be explained away by conditioning on other variables
- removal of link $X - Y$ relies on finding a **separating set**, i.e. a set of variables $\{Z_1, \ldots, Z_n\}$ such that $(X \perp\!\!\!\perp Y \mid Z_1, \ldots, Z_n)$

Unshielded Collider Criterion

- directionality inference on the causal skeleton
- for each pattern of the form $X - Z - Y$ (**unshielded collider**), ask whether the central variable was part of the separating set that was used for explaining away the link $X - Y$
- underlying idea: if Z was not necessary to explain away $X - Y$, this excludes all patterns except $X \rightarrow Z \leftarrow Y$ (a **v-structure**)
- reason: we would expect some information flow in all three scenarios $X \leftarrow Z \rightarrow Y$, $X \leftarrow Z \leftarrow Y$, and $X \rightarrow Z \rightarrow Y$
- under certain conditions, we can add additional arrows if they are the only option not to introduce cycles or additional v-structures (stage 3 of PC algorithm)

Table of Contents

NorthEuraLex

Causal Inference

Lexical Flow Inference
- Correlate Detection
- Lexical Flow Independence
- Inferring Directionality
- The Full Algorithm

Results

Future Work

Lexical Flow Inference: Basic Idea

- model **languages as variables**
  - ▷ language is represented by its basic lexicon
  - ▷ for each concept, we get an observation of each language
  - ▷ we will not use phonetic strings directly, but automatically derived correlate judgments
- define a conditional independence measure on languages
  - ▷ leads to an algorithmic test of hypotheses like "does Russian influence explain away all the similarities between Ket and Selkup?"
- apply a custom variant of causal inference
  - ▷ we should get a **graph telling us how languages influenced each other** (e.g. Swedish on Finnish, not in reverse!)
  - ▷ evaluation on Uralic and its contact languages

Lexical Flow Inference: Sound Correspondences

- detection of correlates based on **weighted string distances**
- cognates will have become dissimilar due to regular sound change, but we still want to recognize them
- idea: infer model of ASJP segment correspondences for each language pair, using a variant of the method described by List (2012), and use it to estimate segment distances for each pair
- examples of resulting model:
  - ▷ Finnish `[k]` cheap to align to Hungarian `[h]`
  - ▷ Finnish `[s]` cheap to align to Northern Saami `[C]`
  - ▷ Hungarian `[f]` cheap to align to Northern Saami `[p]`

Lexical Flow Inference: Weighted Alignment

- problem on dictionary forms: string-distance overestimates similarity e.g. between verbs which share an infinitive ending
- solution: for each segment in the ASJP strings, infer information content from trigram models for each language and word class
- use information content as additional weight for alignment (matching of low-information material costs less)
- examples of alignments (transparency = information content):

p	e	E	l	i	SE: beallji "ear"	0.379082
f	i	-	l	-	HU: fül "ear"	

k	o	r	w	a	FI: korva "ear"	0.707607
f	i	-	l	-	HU: fül "ear"	

-	o	t	-	a	FI: ottaa "to take"	0.302580
v	o	t	m	a	ET: võtma "to take"	

Lexical Flow Inference: Correlate Clustering

- an emerging subfield of computational historical linguistics
- Java re-implementation of the LexStat toolchain (List, 2014)
- use UPGMA (Sokal and Michener, 1958) to derive a **hierarchical clustering** of phonetic strings based on their pairwise distances
- cut the tree at a given **threshold to partition** the strings into clusters of similar forms, which we then assume to be correlates
- write $cor(L_1, \ldots, L_n)$ for the correlate sets shared between languages $L_1, \ldots, L_n$, and $c(L_1, \ldots, L_n) := |cor(L_1, \ldots, L_n)|$
- if a dataset has expert cognacy annotation, we can just use it!

Lexical Flow Independence: Problem

- most natural way to define a conditional independence test on correlate sets is based on a mutual information measure:

$$I(L_1, L_2; Z) := \frac{|cor(L_1, L_2) \backslash \{c \mid \exists \{Z_1, \dots, Z_k\} \subseteq Z : c \in cor(Z_1, \dots, Z_k)\}|}{\min\{|cor(L_1)|, |cor(L_2)|\}}$$

- intuitively: ratio of correlates between L_1 and L_2 which cannot be explained by borrowing through any subset of languages in Z
- if $I(L_1, L_2; Z)$ is smaller than chance, assume $(L_1 \perp\!\!\!\perp L_2 \mid Z)$
- assumption of standard PC algorithm (making it tractable): possible separating sets are all subsets of immediate neighbors of L_1 and L_2 in the current skeleton
- true in the fully stochastic case, but problematic in ours (two unconnected neighbors do not constitute a possible transmission path!)

Lexical Flow Independence: Solution

- solution: explicitly model the **lexical flow** for independence testing, i.e. retain a connected subgraph for each correlate set
- only test separating sets which form a union of acyclic paths between L_1 and L_2 in the current skeleton
- implementation uses a depth-first search of the current graph to get all such paths of length ≤ 4, generates all combinations of these paths which lead to separating set candidates of a given cardinality
- longer paths would be necessary in theory, but did not lead to different results on my data, at a much higher computational cost (also, assuming long chains of borrowing events is risky)

Inferring Directionality: Intuition

- causal inference: if Z was not necessary to explain away $X - Y$, this excludes all causal patterns except $X \rightarrow Z \leftarrow Y$
- but: if L_1 borrows from L_2 which in turn borrows from L_3, none of the lexical material from L_3 might appear in L_1!
- idea: for each triple of languages (L_1, L_2, L_3) and a given causal scenario, we can **measure the difference between expected and observed number of correlates**
- do this for each triangle involving L_1 and L_2, derive a **counterevidence score**, weight the scores according the information each triangle contributes
- if counterevidence in one direction is much stronger, add an arrowhead to the link, representing dominant direction of influence

Inferring Directionality: Computation

- $r(L_1, L_2) := c(L_1, L_2) / \min\{c(L_1), c(L_2)\}$
- $r(L_2, L_3) := c(L_2, L_3) / \min\{c(L_2), c(L_3)\}$
- expected number of correlates under assumption $L_1 \leftarrow L_2$: $r(L_1, L_2) \cdot r(L_2, L_3) \cdot \min\{c(L_1), c(L_3)\}$
- amount of information in triangle rises with overlap of L_2 and L_3
- this leads to the **counterevidence score**:

$$sc(L_1 \rightarrow L_2) := \sum_{L_3} c(L_2, L_3)^2 \cdot \frac{c(L_1, L_2, L_3)}{r(L_1, L_2) \cdot r(L_2, L_3) \cdot \min\{c(L_1), c(L_3)\}}$$

- decision depends on ratio of $sc(L_1 \rightarrow L_2)$ and $sc(L_2 \rightarrow L_1)$

The Algorithm

Algorithm 1 infer_network$(L_1, \ldots, L_n)$

$G := (\{L_1, \ldots, L_n\}, \{\{L_i, L_j\} \mid 1 \leq i \neq j \leq n\})$, the complete graph
$s := 0$
while $s < n - 2$ **do**
    for $\{L_i, L_j\} \in G$ by increasing strength of remaining flow **do**
        for each combination $P_1, \ldots, P_k$ of paths from L_i to L_j of length ≤ 4 **do**
            if $|S| = s$ for $S := \bigcup\{P_1, \ldots, P_k\}$ **then**
                if ratio of $c(L_i, L_j)$ not explainable by flow across S is < 0.02 **then**
                    remove $\{L_i, L_j\}$ from G
                end if
            end if
        end for
    end for
    $s := s + 1$
end while
for $\{L_i, L_j\} \in G$ **do**
    if $sc(L_i \to L_j)/sc(L_j \to L_i) < 0.9$ **then**
        add arrow $L_i \to L_j$ to network
    end if
end for
return network consisting of G and arrows

Table of Contents

NorthEuraLex

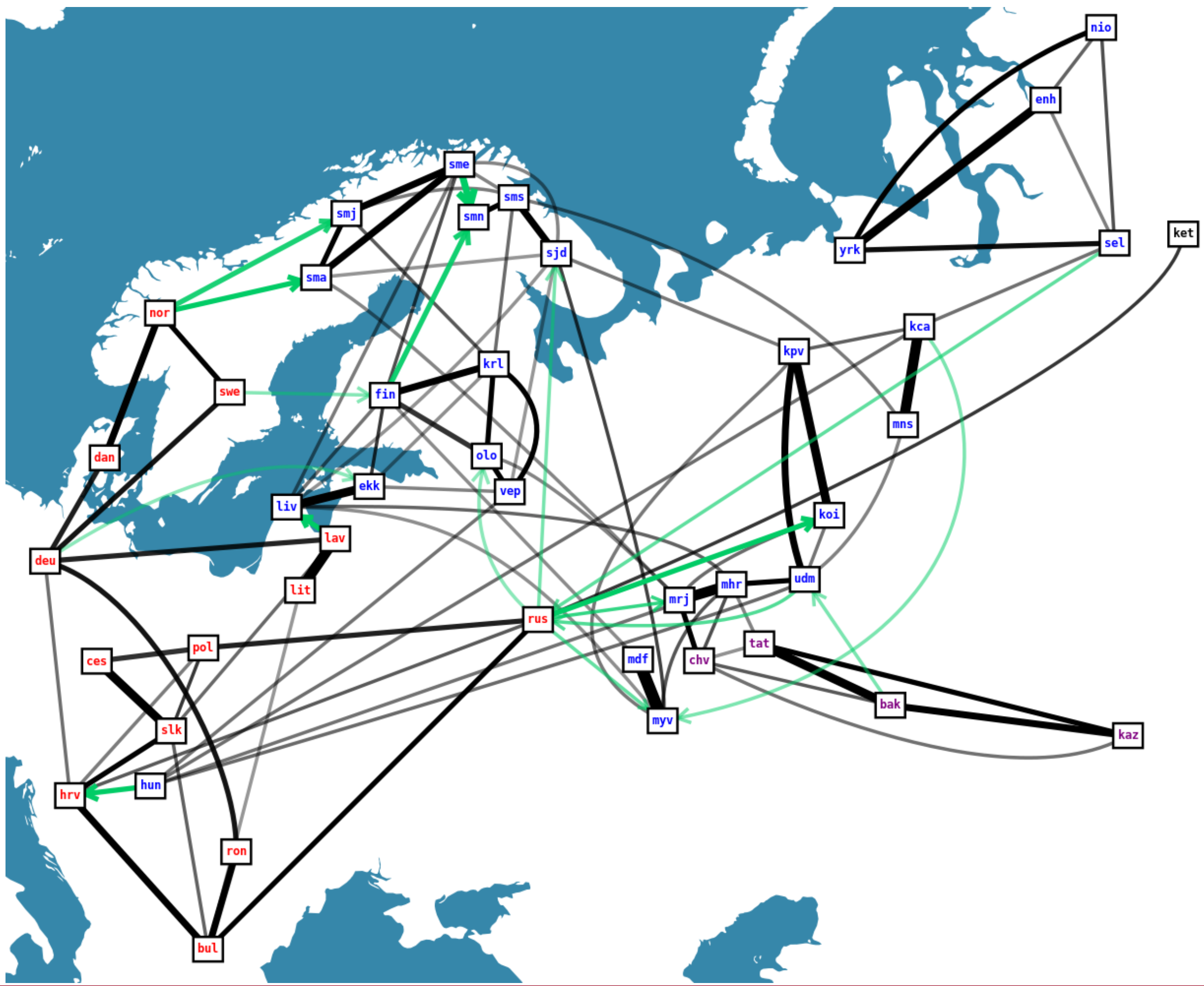
Causal Inference

Lexical Flow Inference

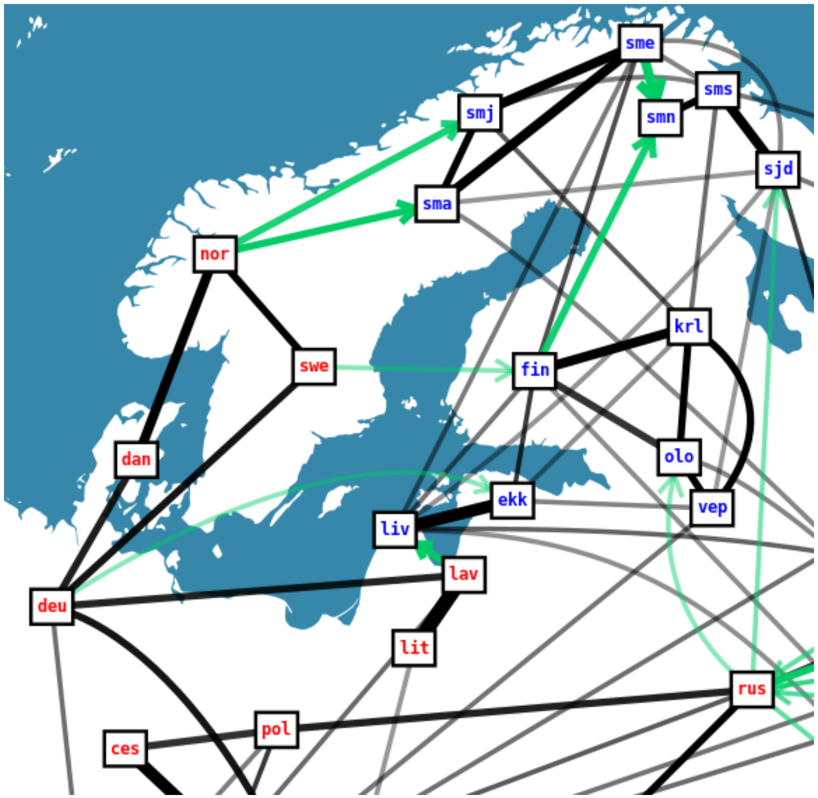
Results

Future Work

Results: Global Picture

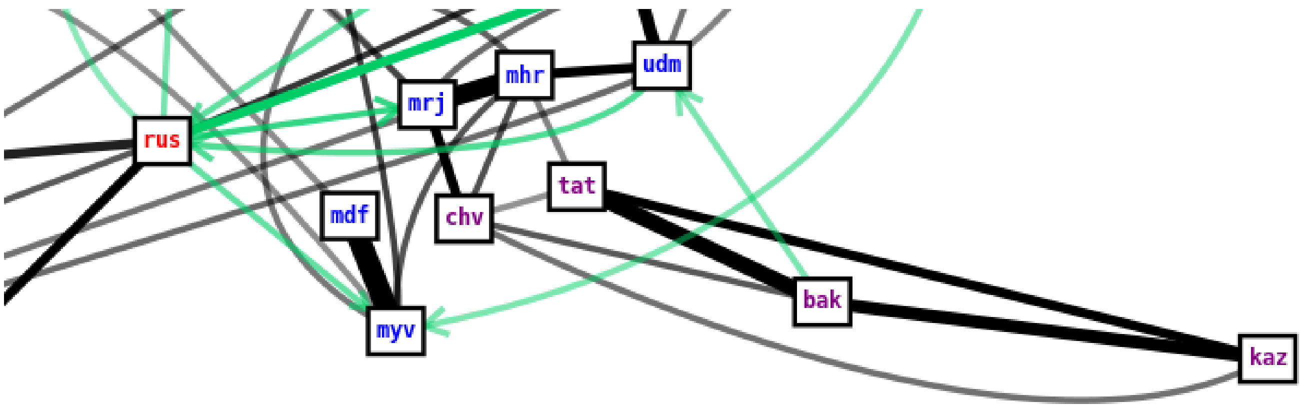


Results: Western Branches



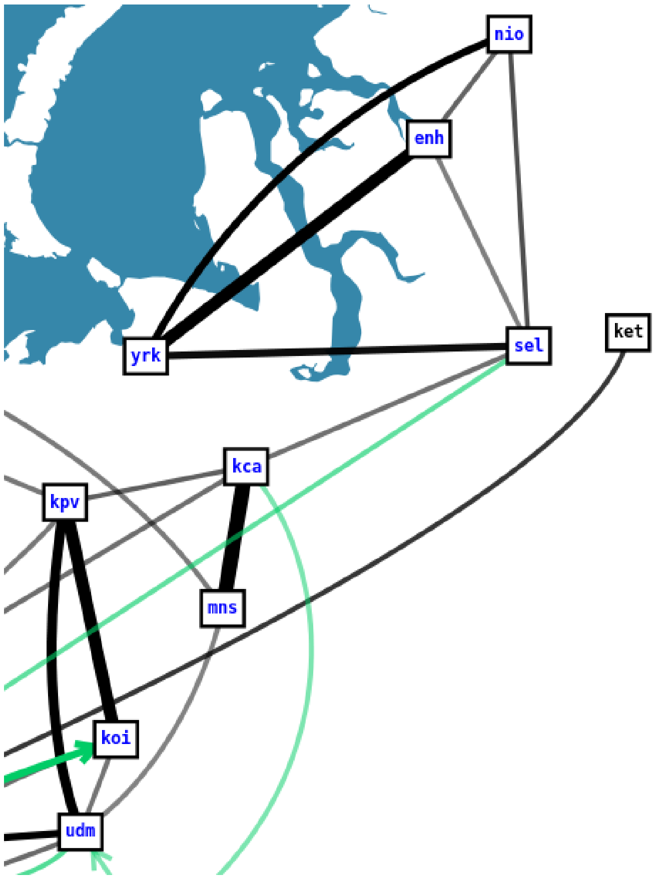
- the causal skeleton is good, shows dialect continua
- all cross-family links are detected as directional, clean split of families
- all inferred arrows point in the correct direction
- slightly questionable: Inari Saami as a mixture of Finnish and Northern Saami

Results: Central Branches



- the causal skeleton is correct (no spurious links)
- wrongly inferred links from Udmurt and Selkup into Russian
- influence of Bashkir on Udmurt is correct
- algorithm does not manage to disentangle contacts of the two Mari languages with the Turkish neighbors Chuvash and Tatar (because most of the contact involved proto-languages?)

Results: Eastern Branches



- the causal skeleton and the strength of links makes sense
- interesting: Selkup is the only Samoyedic language for which an external influence is inferred
- direction of influence between Ket and Russian is not recognized: a problem with isolates, we might need time layering to resolve such cases

Table of Contents

NorthEuraLex

Causal Inference

Lexical Flow Inference

Results

Future Work

Future (and Ongoing) Work

- evaluation on other language families and **simulated data**
- derive explicit models of proto-languages by ancestral state reconstruction on a given phylogeny, use the algorithm to infer **influences between proto-languages**
- explore and evaluate existing techniques for inferring the existence of **hidden common causes**
- move beyond correlate classes, explore conditional independence measures on **realization distances**
- improvements to the data and all its components (IPA transcription, lexical choices, closing gaps)

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References

Brown, C. H., Holman, E. W., Wichmann, S., and Velupillai, V. (2008). Automated classification of the world's languages: A description of the method and preliminary results. *STUF – Language Typology and Universals*, 61(4):285–308.

Dellert, J. (2015). Compiling the Uralic Dataset for NorthEuraLex, a Lexicostatistical Database of Northern Eurasia. *Septentrio Conference Series*, 0(2):34–44.

List, J.-M. (2014). *Sequence comparison in historical linguistics*. Düsseldorf University Press, Düsseldorf.

Pearl, J. (2009). *Causality*. Cambridge University Press.

Sokal, R. R. and Michener, C. D. (1958). A statistical method for evaluating systematic relationships. *University of Kansas Science Bulletin*, 38:1409–1438.