Universität Konstanz

Visualizing Linguistic Change as Dimension Interactions

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SFB-TRR 161
Quantitative Methods for Visual Computing
Transregional Collaborative Research Center

Methodological challenges for historical linguistics

- Ever increasing availability of digitized data and annotated corpora for historical linguistic research (e.g., Penn Treebanks, Dependency Treebanks, etc.)

```
(IP-MAT-SPE (NP-SBJ (PRO-D Mér-mér))
          (VBPI finnst-finna)
          (CP-ADV-SPE (WADVP-1 0)
            (C sem-sem)
            (IP-SUB-SPE (ADVP *T*-1)
                    (NP-SBJ (PRO-N ég-ég))
                    (BEPS sé-vera) (VBN sloppinn-sleppa)
                    (PP (P úr-úr) (NP (NP-POS (ONE+Q-G einhvers-einhver)
                    (N-G konar-konar)) (N-D fangelsi-fangelsi)))))
            (. .-.))
  (ID 1882.TORFHILDUR.NAR-FIC,.603))
```

Annotation sample from IcePaHC (Wallenberg et al. 2011)

- Increased use of **quantitative methods** to analyze and evaluate data
- Programming languages specialized for text processing and statistical analysis (Python, R, …)

Methodological challenges for historical linguistics

- **Standard procedure:** calculation of co-occurrence frequencies and statistical significances for a multitude of different linguistic features across different time stages
- Generation of a multitude of high-dimensional data tables of varying size containing numbers computed for different linguistic features

Texts	Indefinite NPs			Definite NPs			NPs as proper names		
	OV	VO	% OV	OV	VO	% OV	OV	VO	% OV
14th century	28	33	45.9%	11	57	16.2%	3	8	27.3%
15th century	23	30	43.4%	10	25	28.6%	1	3	25.0%
16th century	15	28	34.9%	17	26	39.5%	1	5	16.7%
17th century	28	59	32.2%	18	50	26.5%	0	20	0.0%
18th century	6	28	17.6%	7	31	18.4%	1	7	12.5%
19th century	34	425	7.4%	14	351	3.8%	4	68	5.6%
	134	603	18.2%	77	540	12.5%	10	111	8.3%

Definiteness distribution of NPs across different word orders in Icelandic (Hróarsdóttir 2000, 136)

- **Aim:** **identify** the linguistic features and structures involved in a change; understand how they **interact** across the **temporal dimension**

Methodological challenges for historical linguistics

- Finding significant patterns and feature interactions is challenging:
  - Pair-wise comparison of the relevant bits of information across various tables
  - Statistical significances are often calculated on the basis of only very few occurrences of the actual observation (data sparsity)
  - Interesting patterns may stay hidden when the temporal episodes chosen for the statistical analysis are too fine or too coarse grained
  - The factors causing a change are often unknown (or at least highly debated)

- **Opportunity: Visual Analytics for Linguistics (LingVis)**

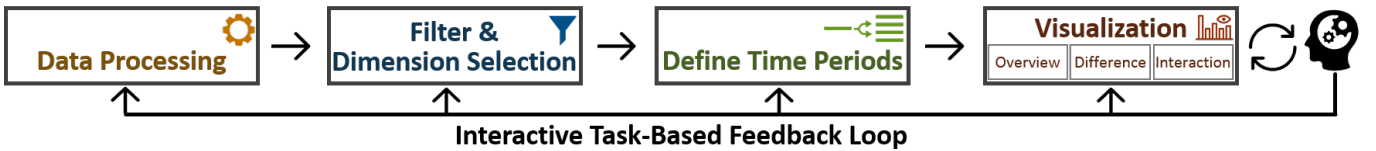
  $\longrightarrow$ turn complex data sets and their relationships into at-a-glance visualizations

  $\longrightarrow$ provide an interactive exploratory access to the data

"Analyze first, show the important, zoom, filter and analyze further, details on demand"
(Keim et al. 2008)

HistoBankVis: a multilayer visualization system

- Generically applicable system for **historical linguistic research**
- Flexible investigation of a potentially high number of interacting linguistic features stored in an SQL database



- Combination of different visualization layers and filtering techniques with a structured statistical analysis process $\longrightarrow$ exploratory access to a high-dimensional data set
  - **Overview:** Compact Matrix Visualization
  - **Difference** Histograms Visualization
  - **New component:** Dimension **Interaction** Visualization

HistoBankVis: a multilayer visualization system

- **On-going work:** investigation of **syntactic change in Icelandic** based on the Icelandic Parsed Historical Corpus (IcePaHC; Wallenberg et al. 2011)
- Automatic extraction of the relevant linguistic factors from the IcePaHC annotation
  $\longrightarrow$ verb type, voice, subject case, word order, subject position, V1 (verb-first)

ID	VERB	VERB_TYPE	MODAL/ASP	VOICE	SBJ_CASE	OBJ_CASE	OBJ2_CASE	WORD_ORDER	SUBJ_POSITION	V1
1150.FIRSTGRAMMAR.SCI-LIN,.1	setja	VB	-	active	sbj_NOM	obj1_ACC	-	VSO1	postfinite	no
1150.FIRSTGRAMMAR.SCI-LIN,.2	setja	VB	-	active	sbj_NOM	obj1_ACC	-	O1VS	postfinite	no
1150.FIRSTGRAMMAR.SCI-LIN,.3	hafa	HV	þurfa	active	sbj_NOM	obj1_ACC	-	SVO1	prefinite	no
1150.FIRSTGRAMMAR.SCI-LIN,.4	rita	VB	-	active	sbj_NOM	obj1_ACC	-	VSO1	postfinite	yes
1150.FIRSTGRAMMAR.SCI-LIN,.5	verða	RD	-	active	sbj_GEN	-	-	VS	postfinite	no
1150.FIRSTGRAMMAR.SCI-LIN,.6	ganga	VB	-	active	sbj_NOM	-	-	VS	postfinite	no
1150.FIRSTGRAMMAR.SCI-LIN,.7	rita	VB	-	active	sbj_NOM	obj1_ACC	-	VSO1	postfinite	no
1150.FIRSTGRAMMAR.SCI-LIN,.8	hafa	HV	-	active	sbj_NOM	-	-	VS	postfinite	no
1150.FIRSTGRAMMAR.SCI-LIN,.9	taka	VB	-	active	sbj_NOM	obj1_ACC	-	O1VS	postfinite	no
1150.FIRSTGRAMMAR.SCI-LIN,.10	rita	VB	-	active	sbj_NOM	obj1_ACC	obj2_DAT	VSO2O1	postfinite	no
1150.FIRSTGRAMMAR.SCI-LIN,.11	taka	VB	-	passive	sbj_NOM	-	-	VS	postfinite	no

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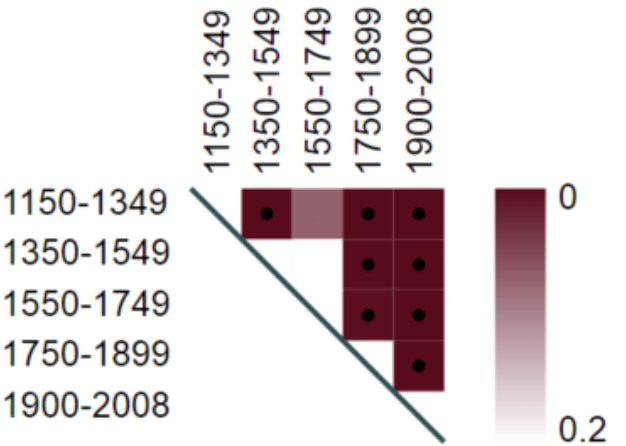
Features

Compact Matrix Visualization

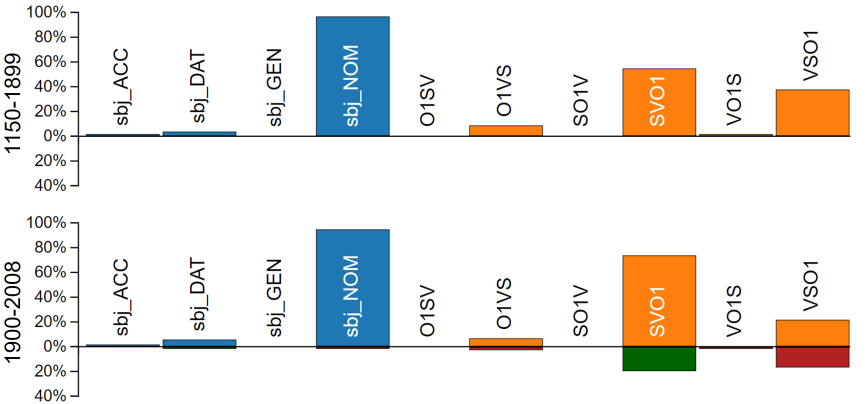
- Visualizes **differences between dimensions** across time stages
- Differences mapped onto a colormap
- Comparison of consecutive periods along the diagonal
- Two comparison modes:
  - χ^2-test
    - Statistical significance ($\alpha \leq 0.05$)
    - Absence of necessary preconditions ×
    - p-value is mapped to colormap (red $p = 0$, white $p \geq 0.2$)
  - Euclidean distance
    - Colormap indicates high (red) or low (white) distance
    - High Euclidean distance → large difference (high significance)



Difference Histograms Visualization

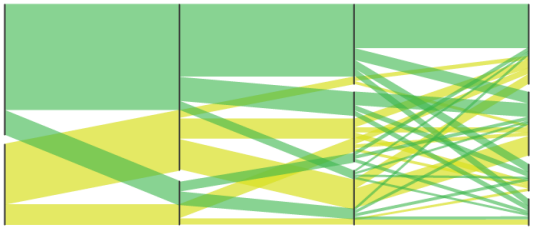
- Difference histograms provide **details on diachrony of features and dimensions**
- Each time period is visualized as one composed **bar chart/histogram**
- Dimensions are encoded via different colors for parallel inspection
- Each bar represents an individual feature of a dimension
- Bar height corresponds to the percentage of sentences containing a feature

- Differences between neighboring time periods as separate bar chart below feature bar:
  - red → feature decrease
  - green → feature increase
- Different comparison modes available



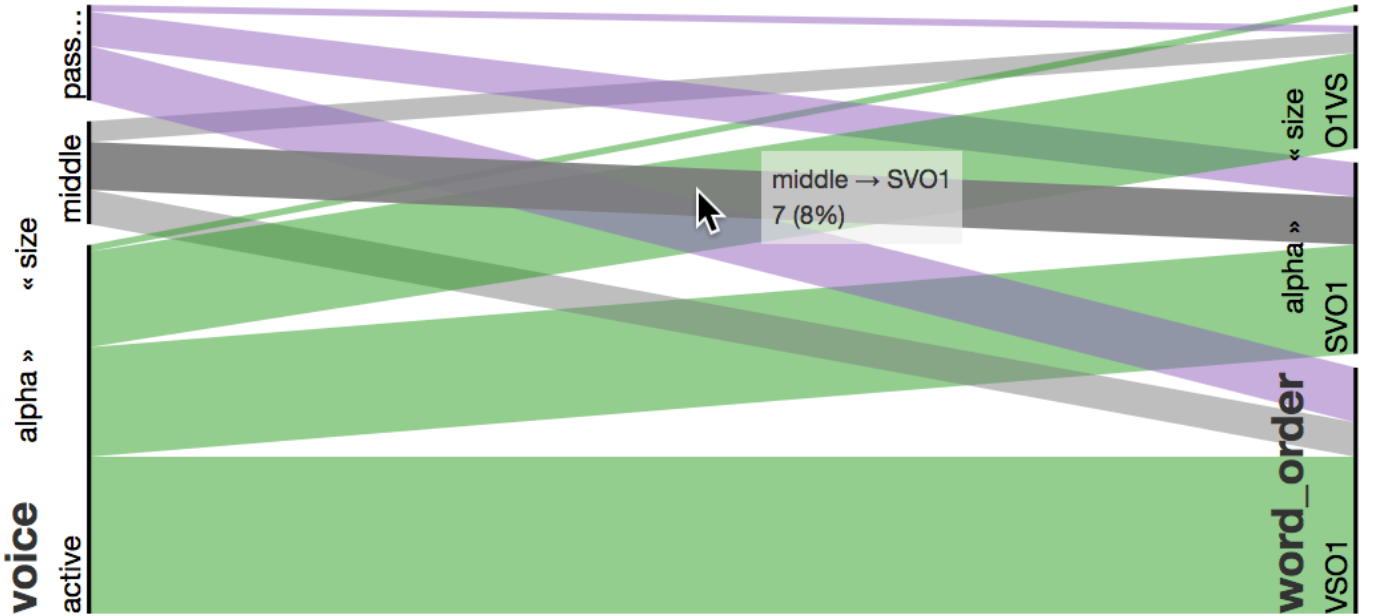
Dimension Interaction Visualization

- Dimension interactions provide insights into the **interrelation between multiple features** of different dimensions
- Application of the **Parallel Sets** technique (Bendix et al. 2005, Kosara et al. 2006)
  - Feature frequencies are visualized as proportions of equally spaced vertical lines (data dimensions)
  - Dimensions are connected by colored ribbons
  - Size of a ribbon $\rightarrow$ share which a feature holds of a feature from another dimension



- Each time period is visualized as one Parallel Sets visualization
  - Dimensions can be reordered via drag&drop
  - Features can be sorted according to their size or alphabetically
  - Details about feature correspondences can be accessed via mouse over

Dimension Interaction Visualization



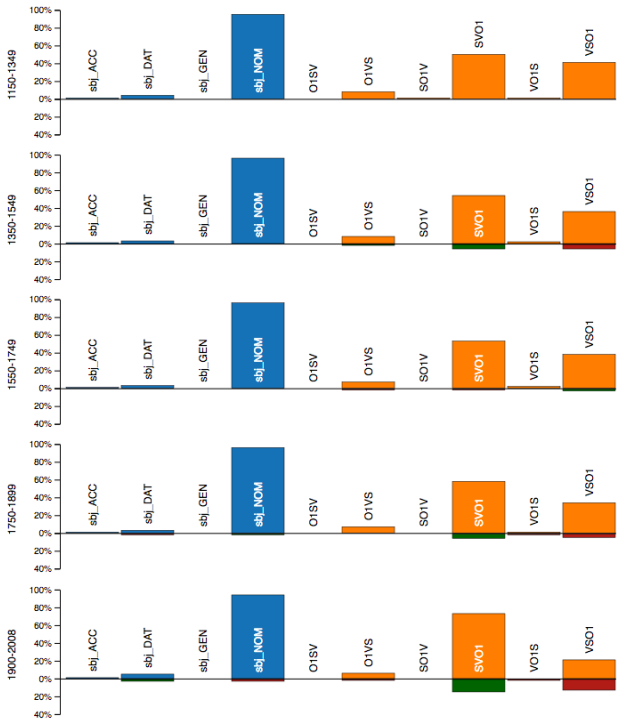
Tracking syntactic change with HistoBankVis

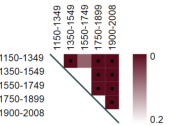
- **Case study:** interaction between **subject case** and **word order** in IcePaHC
- Previous studies on syntactic change in Icelandic:
  - Use of dative subjects increases diachronically (e.g., Barðdal 2011)
  - Word order becomes more rigid over time (e.g., Rögnvaldsson 1996)

  $\Longrightarrow$ **Are these changes interrelated?**

- **Investigation using HistoBankVis:**
  - Dimension selection: subject case & word order
  - Filtering for transitive sentences: sentences with a subject (S), verb (V), and a direct object (O1)
  - Time periods: 1150-1349, 1350-1549, 1550-1749, 1750-1899, 1900-2008

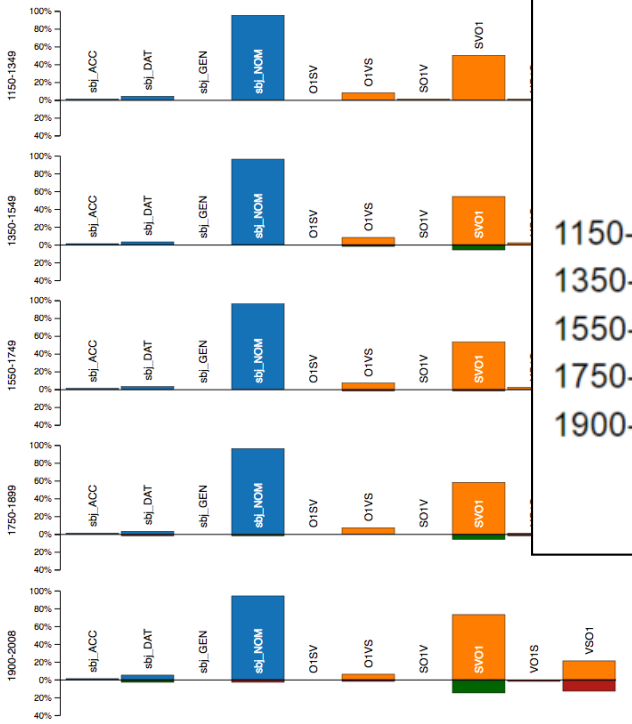
Subject case and word order in IcePaHC

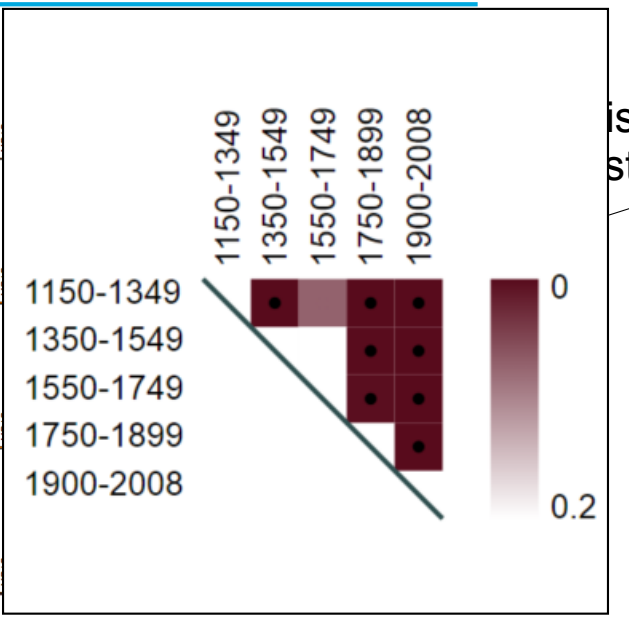




- **Compact matrix:** Distribution changes significantly in the last two periods

Subject case and word order in IcePaHC





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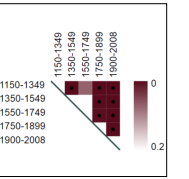
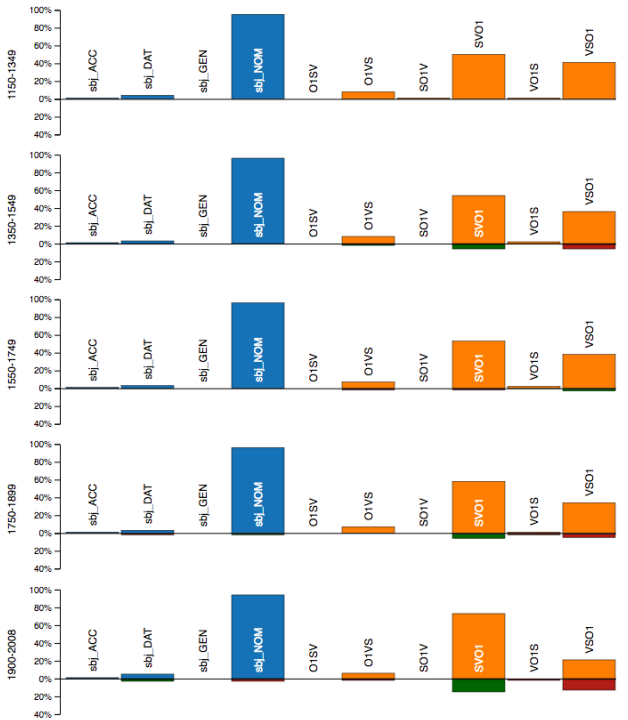
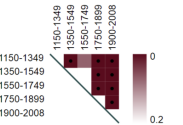


Subject case and word order in IcePaHC





- **Compact matrix:** Distribution changes significantly in the last two periods
- **Difference histograms:**
  - SVO1 most frequent word order
  - **SVO1 increases** over time; largest increase in the period 1900-2008
  - VSO1 decreases concomitantly
  - Subjects are most often nominative
  - **Dative subjects increase** strikingly after 1900

Subject case and word order in IcePaHC

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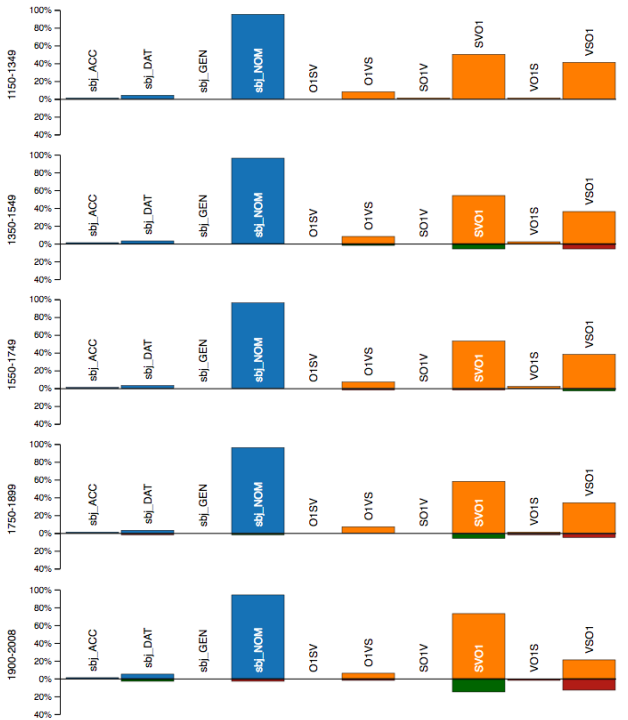

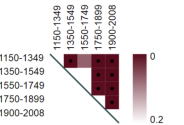

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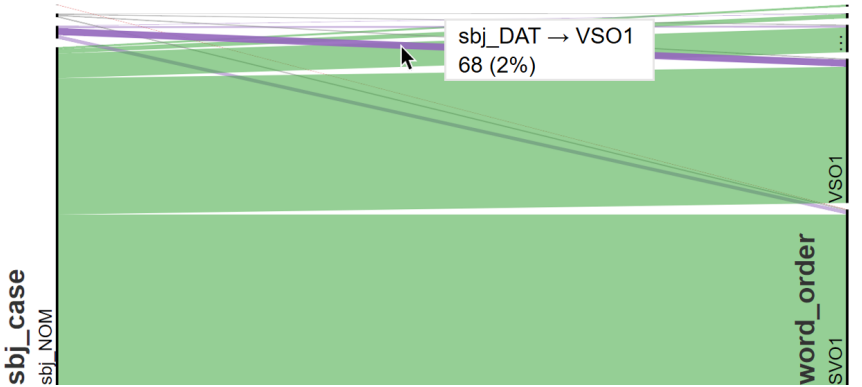
- Subject case and word order change at the same time $\Longrightarrow$ **Interrelation?**

Dimension interactions – subject case and word order

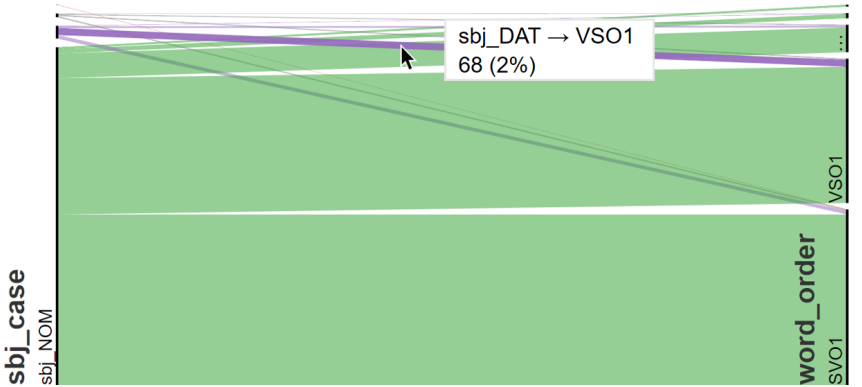


Dimension interaction subject case & word order 1150-1349

Dimension interaction 1150-1349:

- Nominative subjects: shares of SVO1 and VSO1 equal
- **Dative subjects:** large majority are **VSO1**

Dimension interactions – subject case and word order



Dimension interaction subject case & word order 1150-1349

Dimension interaction 1900-2008:

- SVO1 dominant word order overall
- Share of **SVO1 with dative subjects smaller** than with nominatives

Dimension interaction 1150-1349:

- Nominative subjects: shares of SVO1 and VSO1 equal
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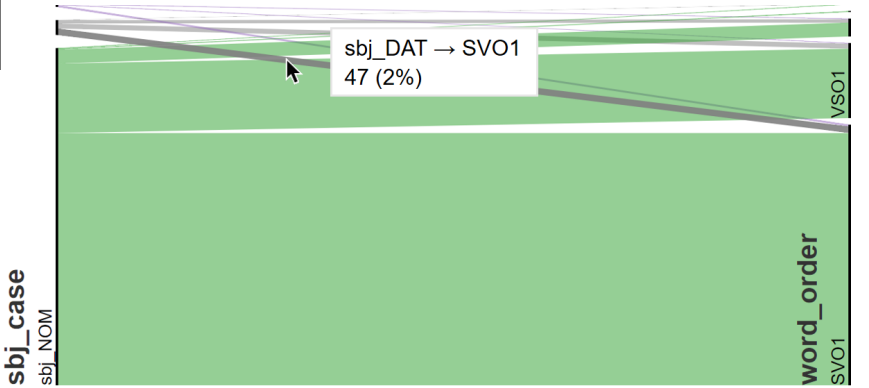

Dimension interaction subject case & word order 1900-2008

Dimension interactions – subject case, word order, and voice

- Dative subjects lag behind with respect to the overall word order changes
- Voice (i.e., passivization, middle formation) influences the occurrence of dative subjects in Icelandic (see Zaenen et al. 1985, Sigurðsson 1989)

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$\Longrightarrow$ **Correlation between voice, subject case, and word order?**

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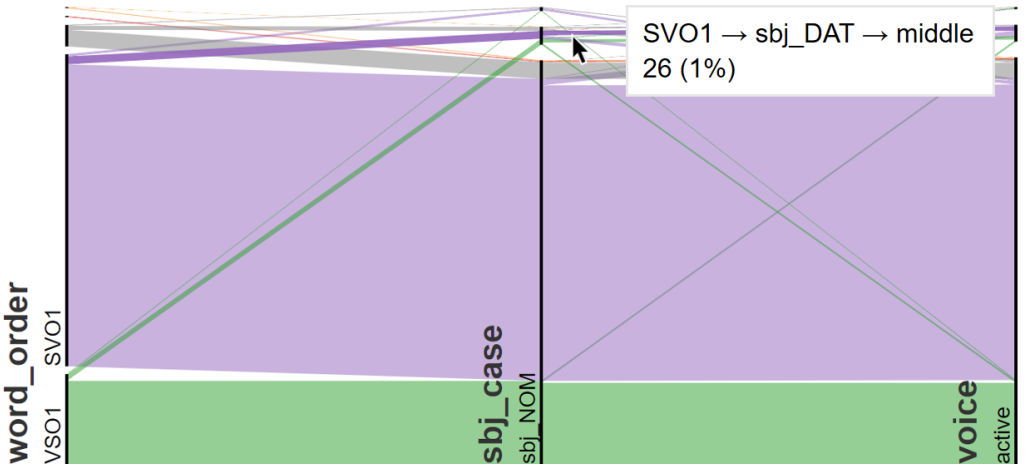
⟹ **Correlation between voice, subject case, and word order?**



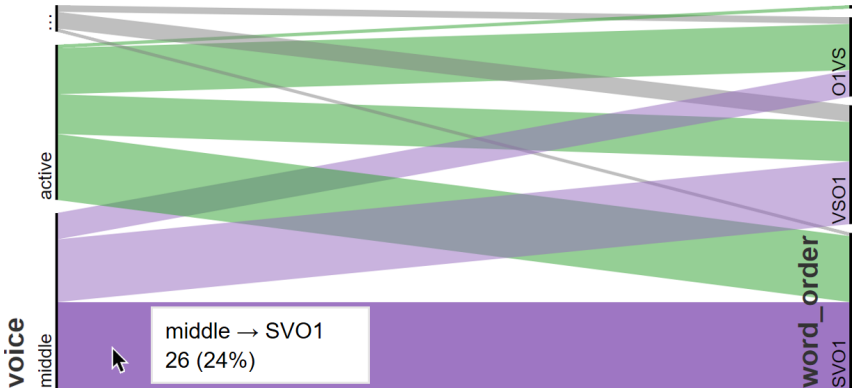
Dimension interaction word order, subject case & voice 1900-2008

- **Nominative subjects:** SVO1 most often in **active** constructions
- **Dative subjects:** SVO1 mainly with **middles**

⇓

Closer look at dative subjects and voice

Dimension interactions – Dative subjects and voice

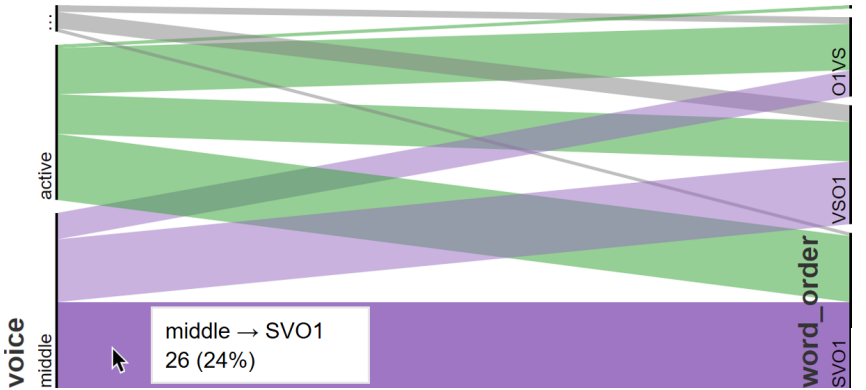


Dimension interaction voice & word order 1900-2008 (dative subjects)

Dimension interaction 1900-2008:

- Dative subjects most frequently with **middle voice**
- **SVO1** most prominent order with all voices

Dimension interactions – Dative subjects and voice



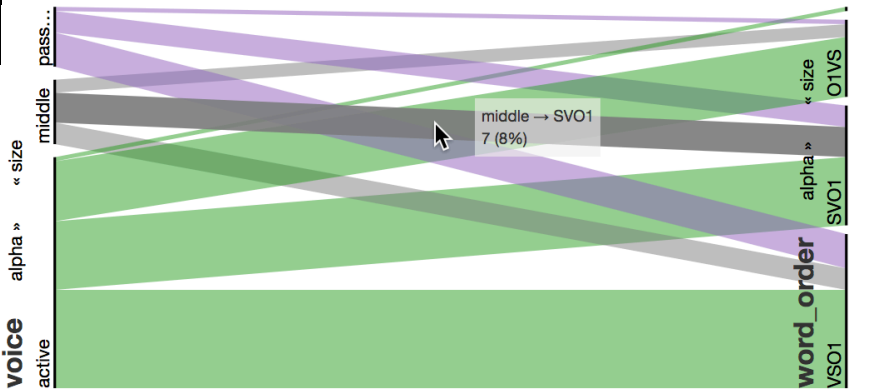
Dimension interaction voice & word order 1900-2008 (dative subjects)

Dimension interaction 1750-1899:

- Dative subjects most frequently in **active constructions**
- **VSO1** is most prominent
- **Middles** most often with **SVO1**

Dimension interaction 1900-2008:

- Dative subjects most frequently with **middle voice**
- **SVO1** most prominent order with all voices



Dimension interaction voice & word order 1700-1899 (dative subjects)

Summary and conclusion

- Dative subjects **lag behind nominative subjects** with respect to their realization in the preverbal position (SVO1)
- Increasing use of dative subjects in the preverbal position correlates with an **increase of dative subjects with middle voice**
- HistoBankVis is an efficient and powerful tool for historical linguistic investigations
  - provides multiple perspectives of the data at different levels of detail
  - fosters iterative process of hypothesis testing and generation
- **Dimension interaction visualization:**
  - Interactive visualization of complex interactions across different dimensions
  - First use of **Parallel Sets** in LingVis
  - Effective new means for historical linguistic research

  $\Longrightarrow$ Identification of previously unknown link between dative subjects, word order, and voice within minutes

Thank you!
Questions?

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http://histobankvis.dbvis.de/

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