# Learning linearization rules from treebanks

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# Goal

- **Use a treebank to learn rules describing linearization**
  - Restrictions on linearization
  - Variability in linearization
- **Work in progress**

- **Acknowledgments**

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# Why learn rules describing linearization?

- **Practical issues**
  - *Treebank grammar*: CFG productions read off TB trees (Charniak, 1996)
  - ⇒ Is a CFG strong enough?
  - ⇒ Coverage, generalizability with freer word order?
- **Theoretical issues**
  - Cross-linguistic primitives
  - Hierarchy of generative strength or performance complexity

# Overview

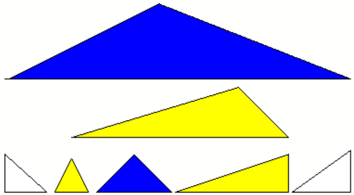
- **Four Type X languages** (Greenberg, 1966; Hawkins, 1983)
  - English, German, Dutch, Czech
  - Different degrees of word order freedom (Steele, 1978; Kruijff, 2001)
- **Empirical investigations**
  - Discontinuous wordgroups (more freedom ⇒ more discontinuity)
  - Scrambling (more freedom ⇒ more scrambling)

  ⇒ Beyond CFG, range of variability
- **Learning linearization rules**
  - Learning problem
  - Approach: General setting, intuitions
  - First experiments
- **Conclusions & outlook**

# Investigation: Discontinuous wordgroups

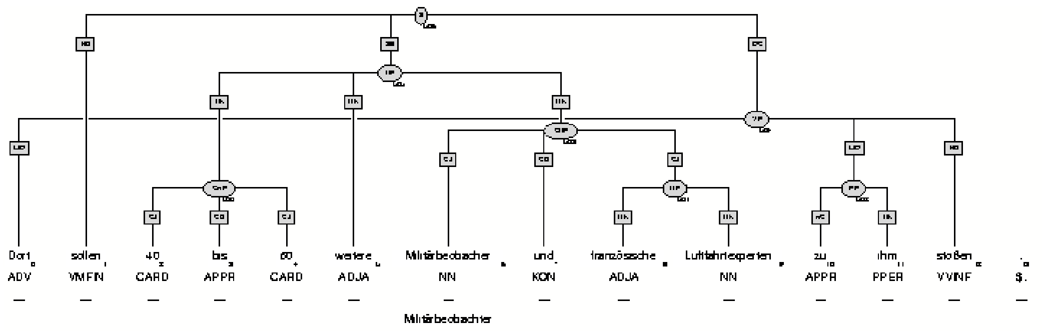
- **Discontinuity in wordgroups**
  - Intervening material from non-dependent wordgroups
  - ⇒ Discontinuous span
- **Null hypothesis**: **More freedom ⇒ more discontinuity**

# Discontinuous wordgroups (once)



- Yellow span interrupted once: intervening blue material

# Discontinuous wordgroups (once)

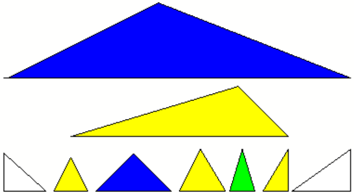



"Dort sollen 40 bis 50 weitere Militärbeobachter und französische Luftfahrtexperten zu ihm stoßen."

(*There, another 40 to 50 military observers and French airline experts should push towards him.*)

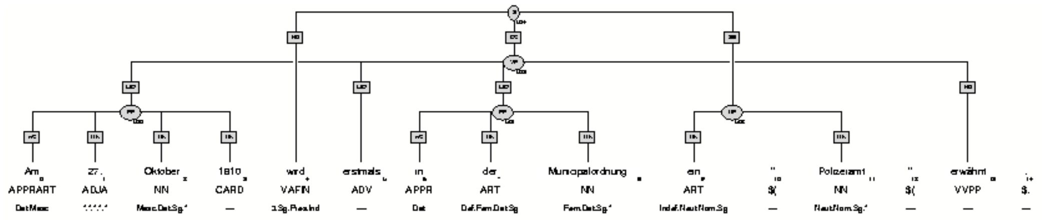
[NEGRA 14876]

# Discontinuous wordgroups (twice)



- Yellow span interrupted twice: intervening blue and green material

# Discontinuous wordgroups (twice)




“Am 27. Oktober 1810 wird erstmals in der Municipalordnung ein Polizeiamt erwähnt.”

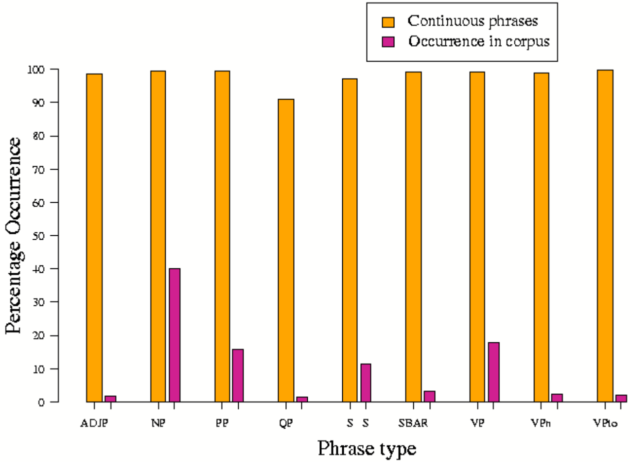
(*On the 27th of October 1810 a police office is mentioned for the first time in the municipality.”*)

[NEGRA 165]

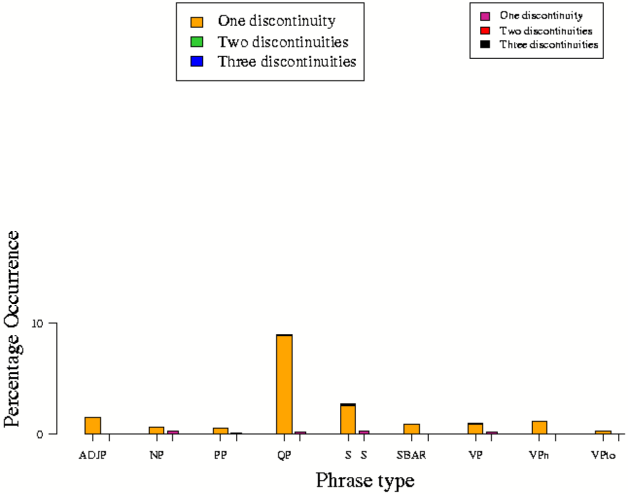
# Experimental setup

- **Four treebanks**
  - English: PTB WSJ section, 49208 trees; (et al, 1995)
  - German: NEGRA, 20602 trees (Skut et al., 1997)
  - Dutch: CGN, 29571 trees (Oostdijk, 2000)
  - Czech: PDT Row 5, 21992 trees (Hajič, 1998)
- **Extract modification context for each head**
  - Dependency tree
  - Includes both complements and adjuncts
- **Count (dis)continuity**
  - Number of interruptions of a head's span
  - 0=continuous, >0 discontinuous
  - Relative freq. (#occ. of head), absolute freq. (#observed nodes)
  - Presentation: Phrases with frequency ≥1%, up to 3 holes (≥0.01%)

# Results: Continuous wordgroups in English (WSJ)



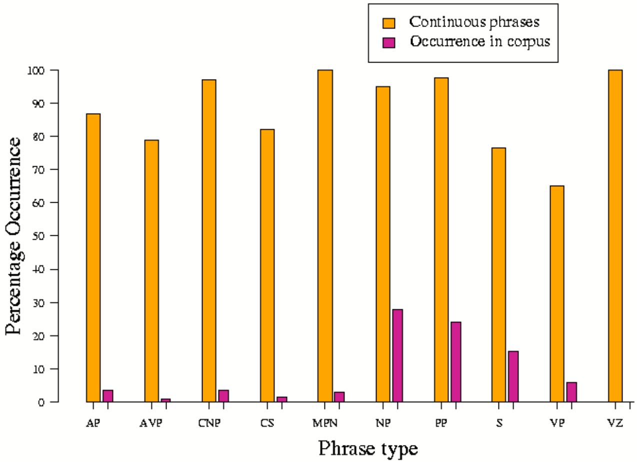
# Results: Discontinuous wordgroups in English (WSJ)



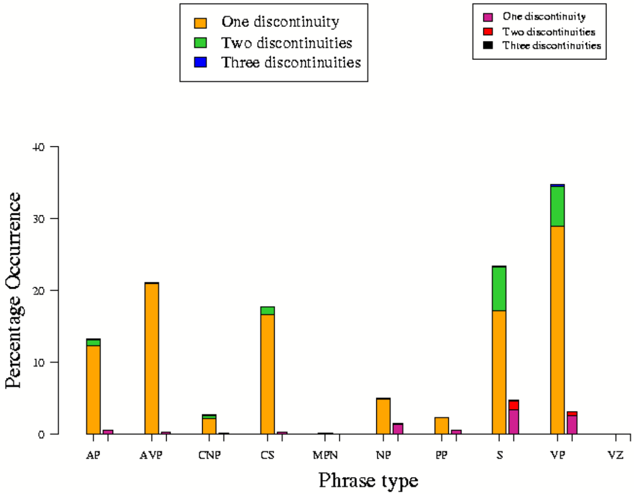
# Frequency (in %) of (dis)continuous occ. per total # occ. (WSJ)

| **Type** | **0 holes** | **1 hole** | **2 holes** | **3 holes** | $\Sigma$ |
|---|---|---|---|---|---|
| ADJP | 1.64% (98.54%) | 0.02% | 0.00% | 0.00% | 0.02% |
| NP | 40.13% (99.39%) | 0.24% | 0.00% | 0.00% | 0.24% |
| PP | 15.69% (99.51%) | 0.08% | 0.00% | 0.00% | 0.08% |
| QP | 1.41% (91.06%) | 0.14% | 0.00% | 0.00% | 0.14% |
| S | 11.56% (97.26%) | 0.31% | 0.00% | 0.00% | 0.31% |
| SBAR | 3.32% (99.11%) | 0.03% | 0.00% | 0.00% | 0.03% |
| VP | 17.99% (99.06%) | 0.16% | 0.01% | 0.00% | 0.17% |
| VPn | 2.47% (98.84%) | 0.03% | 0.00% | 0.00% | 0.03% |
| VPto | 2.17% (99.71%) | 0.01% | 0.00% | 0.00% | 0.01% |
| | $\Sigma^0 = 96.38\%$ | $\Sigma^1 = 1.02\%$ | $\Sigma^2 = 0.01\%$ | $\Sigma^3 = 0.00\%$ | $\Sigma^d = 1.03\%$ |

# Results: Continuous wordgroups in German (NEGRA)



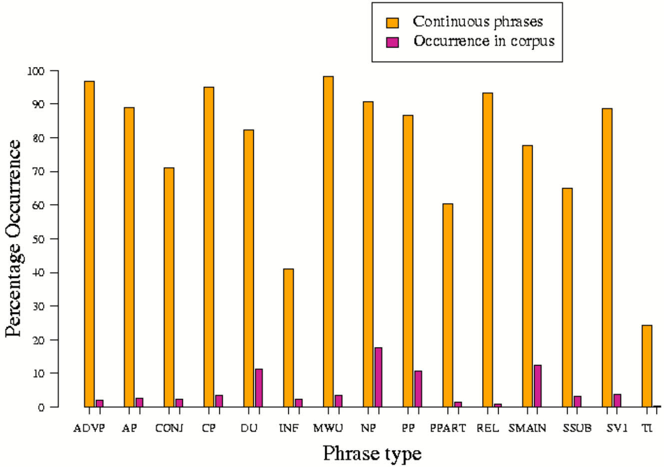
# Results: Discontinuous wordgroups in German (NEGRA)



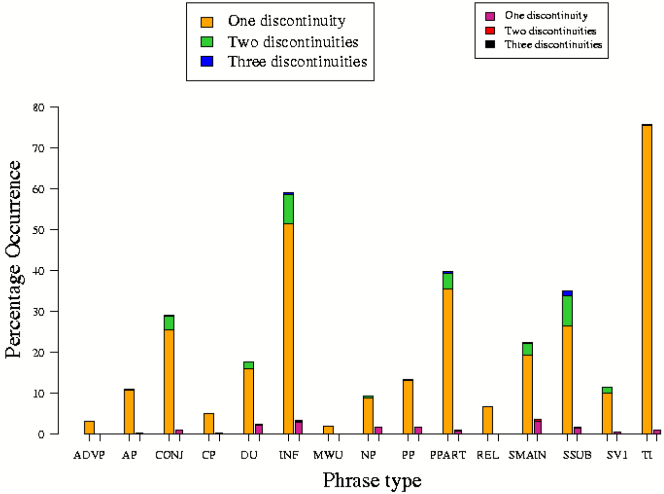
# Frequency (in %) of (dis)continuous occ. per total # occ. (NEGRA)

| **Type** | **0 holes** | **1 hole** | **2 holes** | **3 holes** | $\Sigma$ |
|---|---|---|---|---|---|
| AP | 3.52% (86.80%) | 0.50% | 0.04% | 0.00% | 0.54% |
| AVP | 1.01% (78.90%) | 0.27% | 0.00% | 0.00% | 0.27% |
| CNP | 3.47% (97.17%) | 0.08% | 0.01% | 0.01% | 0.10% |
| CS | 1.45% (82.22%) | 0.29% | 0.02% | 0.00% | 0.31% |
| MPN | 2.87% (99.88%) | 0.00% | 0.00% | 0.00% | 0.00% |
| NP | 27.74% (95.01%) | 1.42% | 0.03% | 0.00% | 1.45% |
| PP | 23.95% (97.63%) | 0.57% | 0.01% | 0.00% | 0.58% |
| S | 15.31% (76.53%) | 3.45% | 1.21% | 0.03% | 4.69% |
| VP | 5.84% (65.18%) | 2.59% | 0.50% | 0.02% | 3.11% |
| VZ | 1.17% (100.0%) | 0.00% | 0.00% | 0.00% | 0.00% |
| | $\Sigma^0 = 86.33\%$ | $\Sigma^1 = 9.17\%$ | $\Sigma^2 = 1.82\%$ | $\Sigma^3 = 0.06\%$ | $\Sigma^d = 11.05\%$ |

# Results: Continuous wordgroups in Dutch (CGN)



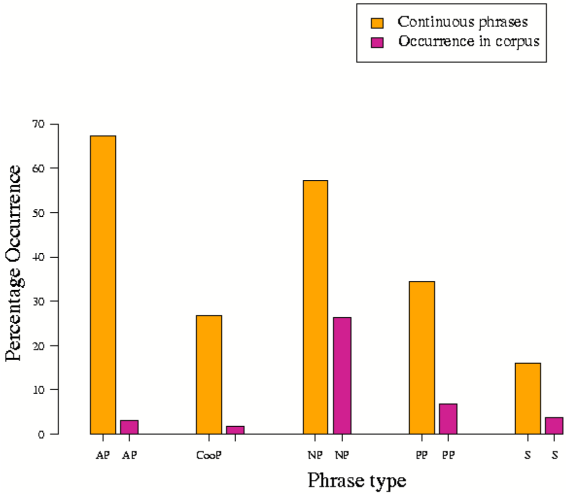
# Results: Discontinuous wordgroups in Dutch (CGN)



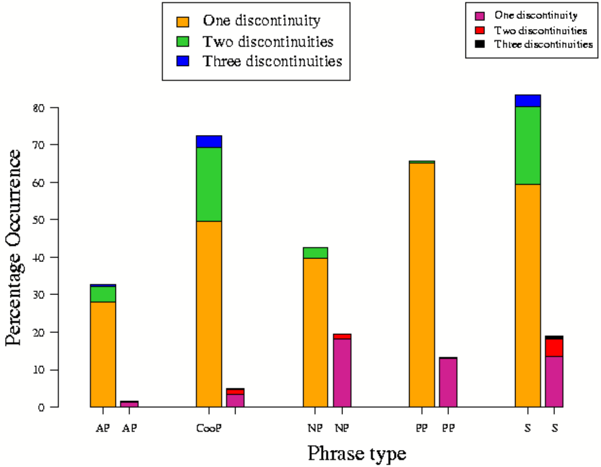
# Frequency (in %) of (dis)continuous occ. per total # occ. (CGN)

| **Type** | **0 holes** | **1 hole** | **2 holes** | **3 holes** | $\Sigma(discont)$ |
|---|---|---|---|---|---|
| ADVP | 2.05% (96.85%) | 0.07% | 0.00% | 0.00% | 0.07% |
| AP | 2.54% (89.07%) | 0.30% | 0.00% | 0.00% | 0.30% |
| CONJ | 2.37% (70.91%) | 0.85% | 0.11% | 0.01% | 0.97% |
| CP | 3.46% (94.92%) | 0.19% | 0.00% | 0.00% | 0.19% |
| DU | 11.33% (82.31%) | 2.21% | 0.21% | 0.02% | 2.44% |
| INF | 2.25% (40.96%) | 2.83% | 0.39% | 0.03% | 3.25% |
| MWU | 3.43% (98.06%) | 0.07% | 0.00% | 0.00% | 0.07% |
| NP | 17.63% (90.77%) | 1.71% | 0.08% | 0.00% | 1.79% |
| PP | 10.78% (86.60%) | 1.64% | 0.03% | 0.00% | 1.67% |
| PPART | 1.32% (60.27%) | 0.78% | 0.09% | 0.01% | 0.88% |
| REL | 0.97% (93.27%) | 0.07% | 0.00% | 0.00% | 0.07% |
| SMAIN | 12.46% (77.60%) | 3.08% | 0.46% | 0.05% | 3.59% |
| SSUB | 3.32% (64.98%) | 1.35% | 0.37% | 0.06% | 1.78% |
| SV1 | 3.70% (88.54%) | 0.42% | 0.06% | 0.00% | 0.48% |
| TI | 0.28% (24.33%) | 0.87% | 0.00% | 0.00% | 0.87% |
| | $\Sigma^0 = 77.89\%$ | $\Sigma^1 = 16.44\%$ | $\Sigma^2 = 1.80\%$ | $\Sigma^3 = 0.20\%$ | $\Sigma^d = 18.42\%$ |

# Results: Continuous wordgroups in Czech (PDT)



# Results: Discontinuous wordgroups in Czech (PDT)



# Frequency (in %) of (dis)continuous occ. per total # occ. (PDT)

| **Type** | **0 holes** | **1 hole** | **2 holes** | **3 holes** | $\Sigma(discont)$ |
|---|---:|---:|---:|---:|---:|
| AP | 3.10% (67.19%) | 1.29% | 0.19% | 0.03% | 1.51% |
| CooP | 1.82% (26.70%) | 3.38% | 1.34% | 0.22% | 4.94% |
| NP | 26.29% (57.29%) | 18.28% | 1.20% | 0.09% | 19.57% |
| PP | 6.90% (34.33%) | 13.10% | 0.11% | 0.00% | 13.21% |
| S | 3.64% (16.10%) | 13.41% | 4.71% | 0.72% | 18.84% |
| | $\Sigma^0 = 41.75\%$ | $\Sigma^1 = 49.46\%$ | $\Sigma^2 = 7.55\%$ | $\Sigma^3 = 1.06\%$ | $\Sigma^d = 58.07\%$ |

# Comparison

| **Language** | $\Sigma^0$ | $\Sigma^1$ | $\Sigma^2$ | $\Sigma^3$ |
|---|---:|---:|---:|---:|
| English | 96.38% | 1.02% | 0.01% | 0.00% |
| German | 86.33% | 9.17% | 1.82% | 0.06% |
| Dutch | 77.89% | 16.44% | 1.80% | 0.20% |
| Czech | 41.75% | 49.46% | 7.55% | 1.06% |

- **Confirmation of null hypothesis**
- **German, Dutch**
  - VZ is continuous (nested) $\Sigma^d$=0.00%
  - INF, TI are mostly 'discontinuous' (cross-serial) ($\Sigma^d$=4.12%)
- **Nominal, verbal groups**
  - Nominal groups mostly continuous in E, G & D (99.39%, 95.01%, 90.77%)
  - Verbal groups show increase in discontinuity with increase in flexibility
- **Prediction: CFG more and more inadequate**

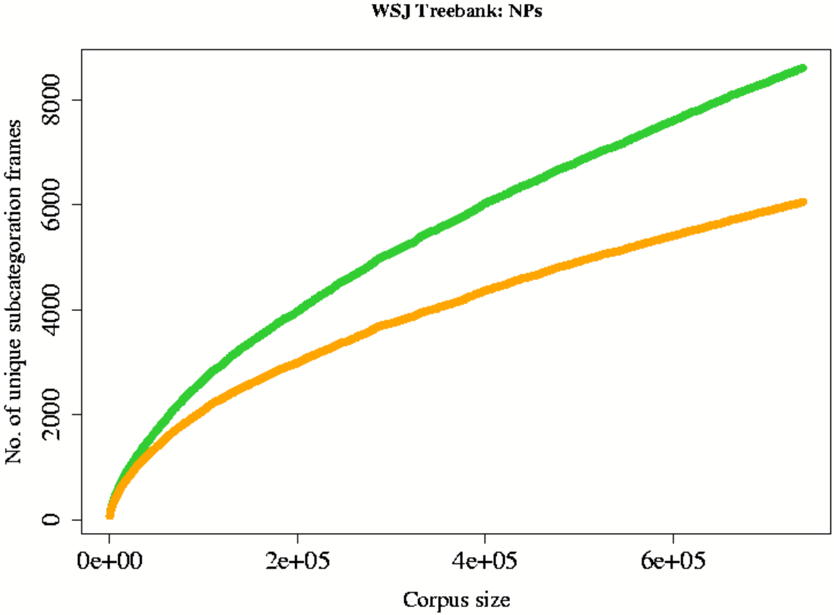
# Investigation: Scrambling

- **Null hypothesis: More freedom $\Rightarrow$ more scrambling**
- **Simple approach**
  - Ordered modification context: Dependency *tree*
  - Unordered modification context: Dependency *mobile*
  - variability factor $= log_2\left(\frac{|\text{unique ordered MCs}|}{|\text{unique unordered MCs}|}\right)$
  - Variability factor: 0 means no scrambling, >0 scrambling
- **Measurements**
  - Variability factor for MCs per head type
  - Growth of $|\text{ordered MCs}|$, $|\text{unordered MCs}|$

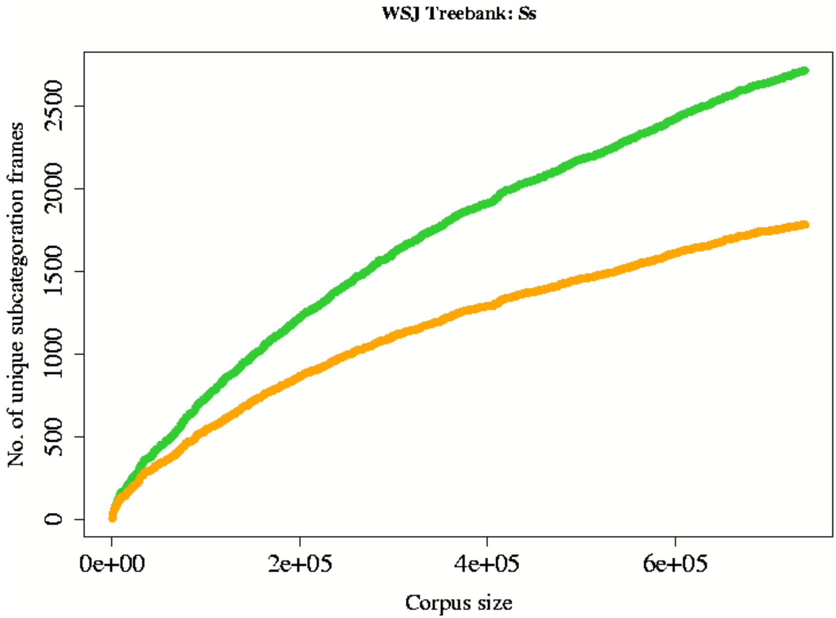
# Results: Variability factors for English (WSJ)

| **Type** | **Unique ordered** | **Unique unordered** | **Var. factor** |
|---|---|---|---|
| ADJP | 23 | 20 | 0.14 |
| NP | 409 | 303 | 0.30 |
| PP | 43 | 33 | 0.26 |
| QP | 95 | 70 | 0.31 |
| S | 445 | 325 | 0.31 |
| SBAR | 33 | 27 | 0.20 |
| VP | 561 | 452 | 0.22 |
| VPn | 99 | 76 | 0.26 |
| VPto | 2 | 1 | 0.69 |

# Results: Growth of unique NP mod.ctxts for English (WSJ)



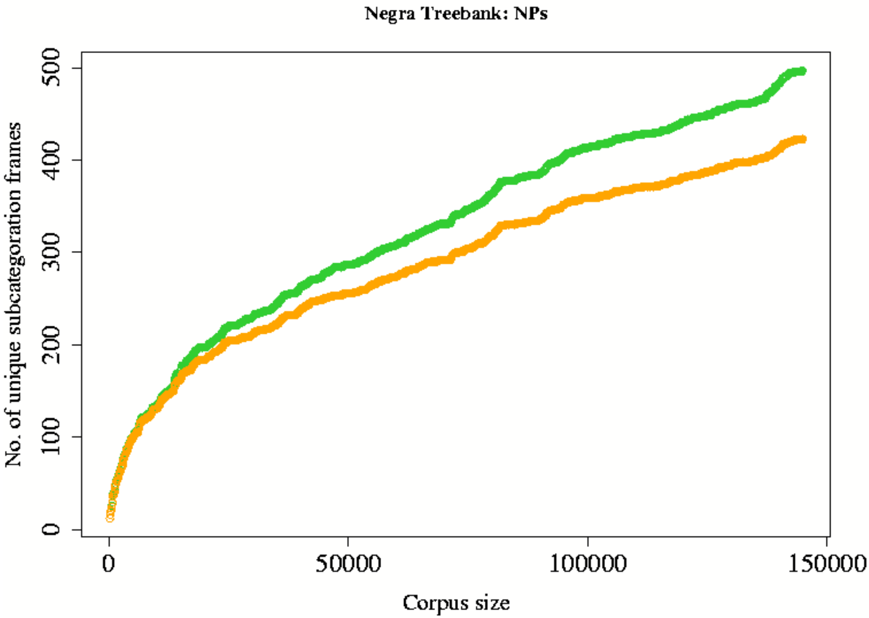
## Results: Growth of unique S mod.ctxts for English (WSJ)



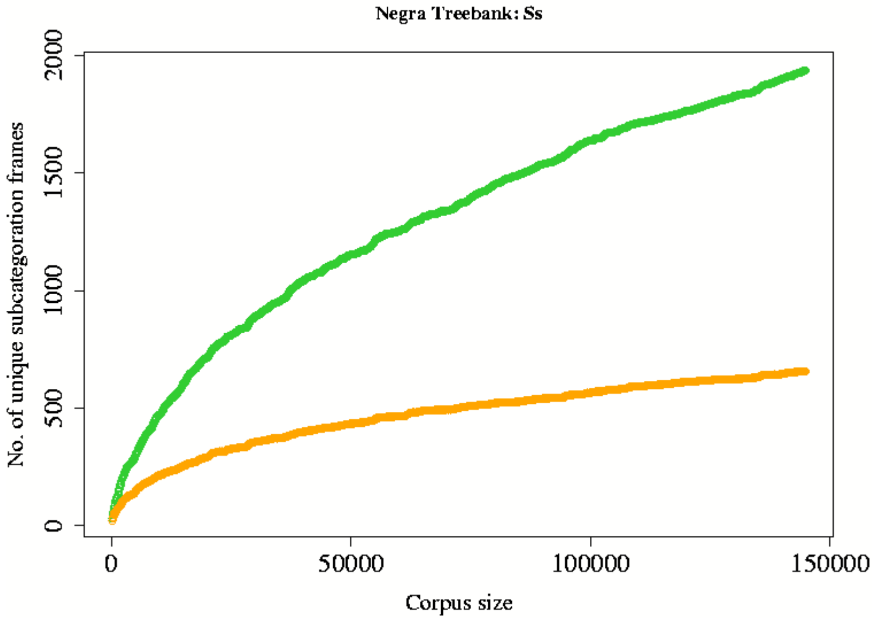
# Results: Variability factors for German (NEGRA)

| Type | Unique ordered | Unique unordered | Var. factor |
|---|---|---|---|
| AP | 77 | 52 | 0.39 |
| AVP | 9 | 8 | 0.12 |
| CNP | 21 | 17 | 0.21 |
| CS | 4 | 1 | 1.39 |
| MPN | 4 | 4 | 0.00 |
| NP | 229 | 193 | 0.17 |
| PP | 127 | 109 | 0.15 |
| S | 688 | 248 | 1.02 |
| VP | 211 | 76 | 1.02 |

# Results: Growth of unique NP mod.ctxts for German (NEGRA)



# Results: Growth of unique S mod.ctxts for German (NEGRA)

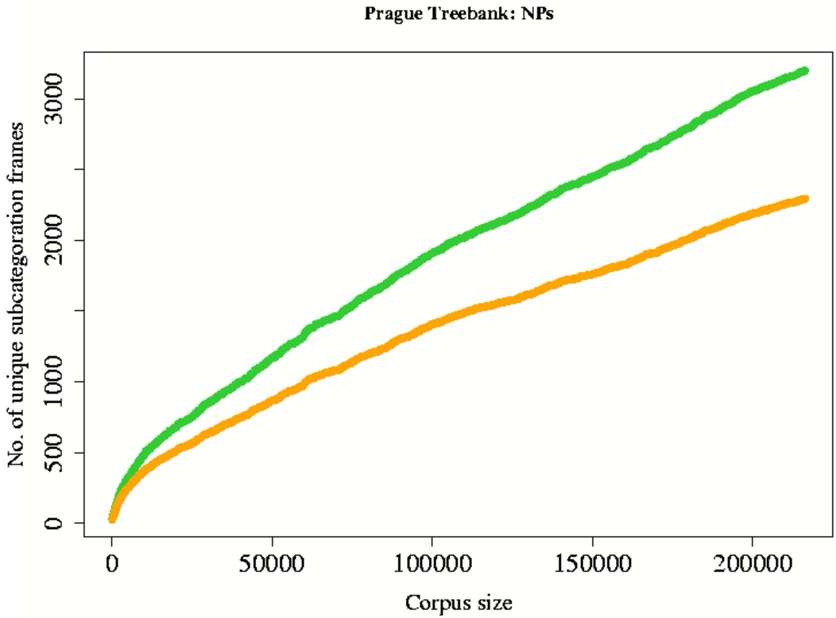


## Results: Variability factors for Czech (PDT)

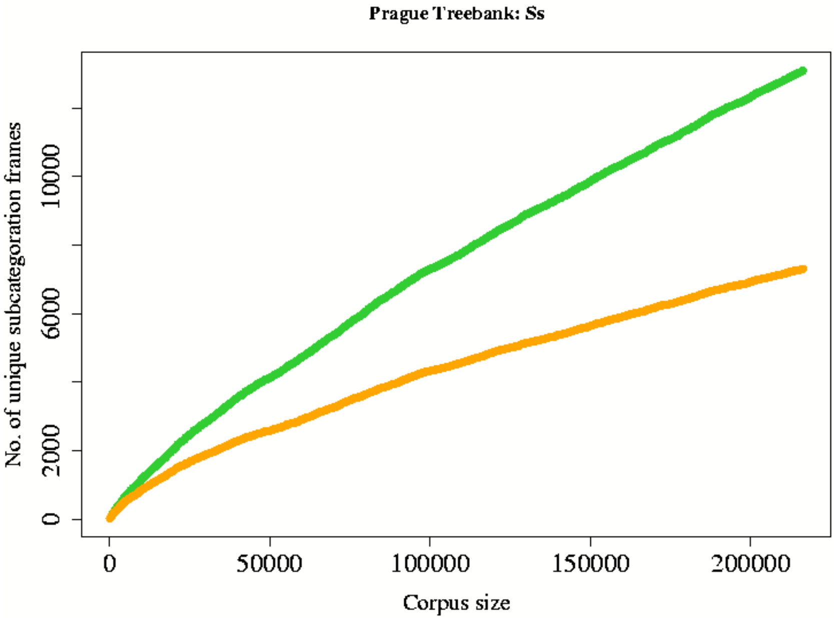
| Type | Unique ordered | Unique unordered | Var. factor |
|---|---|---|---|
| AP | 657 | 576 | 0.13 |
| CooP | 1973 | 1523 | 0.26 |
| NP | 2400 | 1686 | 0.35 |
| PP | 169 | 111 | 0.42 |
| S | 11350 | 6455 | 0.56 |

- **Surprising results**
  - Nominal groups behave similarly to English, German – expected
  - Verbal groups: English $\approx 2.5\times$ but German $\approx 0.5\times$
- **Possible reasons**
  - S class too indiscriminate
  - Genuine division of labor?

# Results: Growth of unique NP mod.ctxts for Czech (PDT)



# Results: Growth of unique S mod.ctxts for Czech (PDT)



- **Division of labor**
  - Long-distance dependencies (nonlocal)
  - Scrambling (local)
- **Compaction**
  - Square-root growth rate for TBG rule set with corpus size (Krotov et al., 1998)
  - Similar observations here
  - Krotov et al's compaction vs. variability in linearization

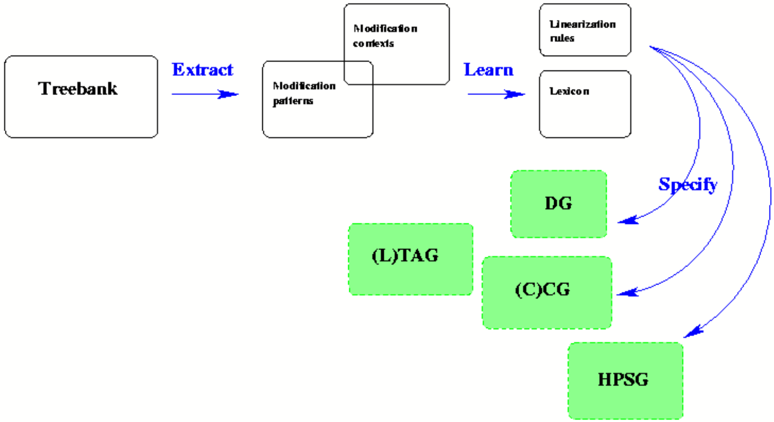
# Parsing results

- **"Treebank grammars"**
- **English**
  - Charniak (CFG), Xia *et al.* (LTAG), Hockenmaier, Clark *et al.* (CCG)
- **German**
  - Becker & Frank (topol.), Neumann (TAG/HPSG)
- **Dutch**
  - Adriaans (stat.), Moortgat & Moot (CTL)
- **Czech**
  - Sarkar & Zeman (stat.)
- **Lack of baseline information**
- **Applicability of formal algorithms**, e.g. Buszkowski & Penn

# Learning linearization rules

- **Data**
  - Discontinuous groups
  - Scrambling
- **Learning problem**
  - Given a set of trees (modification contexts,-patterns)
  - Restrictions ⇒ constancy of (partial) orderings
  - Variability ⇒ variation on canonical ordering
- **Approach**
  - Framework: 3-phase learning
  - Technique: multiple-sequence alignment (bioinformatics)

# 3-Phase Learning



# Robust learning of linearization rules

- **Variability in linearization**
  - Is a given linearization a variation of a canonical order?
- **Similar problem in bio-informatics**
  - Basic problem: *Pairwise alignment*
  - Given two sequences, possibly with gaps
  - Align the sequences
  - Related by chance or through evolution: Significance of scoring

- **Examples** (alignment to human alpha globin) (Durbin et al., 1998)

  *Clear similarity to human beta globin*

```
HBA_HUMAN   GSAQVKGHGKKVADALTNAVAHVDDMPNALSALSDLHAHKL
            G+ +VK+HGKKV  A+++++AH+D++ +++++LS+LH  KL
HBB_HUMAN   GNPKVKAHGKKVLGAFSDGLAHLDNLKGTFATLSELHCDKL
```

  *Structurally plausible alignment to leghaemoglobin from yellow lupin*

```
HBA_HUMAN   GSAQVKGHGKKVADALTNAVAHV---D--DMPNALSALSDLHAHKL
            ++ ++++H+ KV   + +A  ++          +L+ L+++H+ K
LGB2_LUPLU NNPELQAHAGKVFKLVYEAAIQLQVTGVVVTDATLKNLGSVHVSKG
```

  *Spurious high-scoring alignment to a nematode glutathion S-transferase homologue*

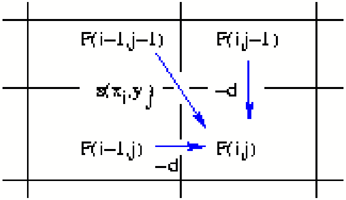
```
HBA_HUMAN GSAQVKGHGKKVADALTNAVAHVDDMPNALSALSD----LHAHKL
          GS+ + G +   +D L  ++ H+ D+  A +AL D     ++AH+
F11G11.2  GSGYLVGDSLTFVDLL--VAQHTADLLAANAALLDEFPQFKAHQE
```

# Pairwise alignment (cont'd)

- **Scoring model**
  - Mutational processes: *substitution* and *insertion*, *deletion* (gaps)
  - Score: $\Sigma$ terms for each aligned pair of residues, plus terms for each gap
- **Examples**
  - Match model $M$, aligned pairs (a,b) have joint probability $p_{ab}$
  - "$a$ and $b$ derived independently from residue $c$ in ancestor"
  - Probability of alignment: $P(x, y|M) = \prod_i p_{x_i y_i}$
  - Gap penalties: linear $\gamma(g) = -gd$, affine $\gamma(g) = -d - (g-1)e$
- **Significance of scores**
  - Distinguish spurious from genuine alignments
  - Data-driven parametrization

# Pairwise alignment (cont'd)

- **Alignment algorithms**
  - Dynamic programming techniques
  - Find highest-scoring alignment of two sequences
  - Fill matrix F using solutions for optimal alignments of smaller subsequences




- **Different alignments**
  - Global alignment: Needleman-Wunsch algorithm
  - Local alignment: Smith-Waterman algorithm
  - Repeated matches (multiple local alignments), overlap matches

⇒ Hybrid match conditions

## Pairwise alignment and linearization

- **Pairwise alignment**
  - Similarity between two sequences (dependency trees)
  - Linguistically motivated gap penalty
- **Families and profiling**
  - Generalize alignment to form *families*
  - Create *profile* over family

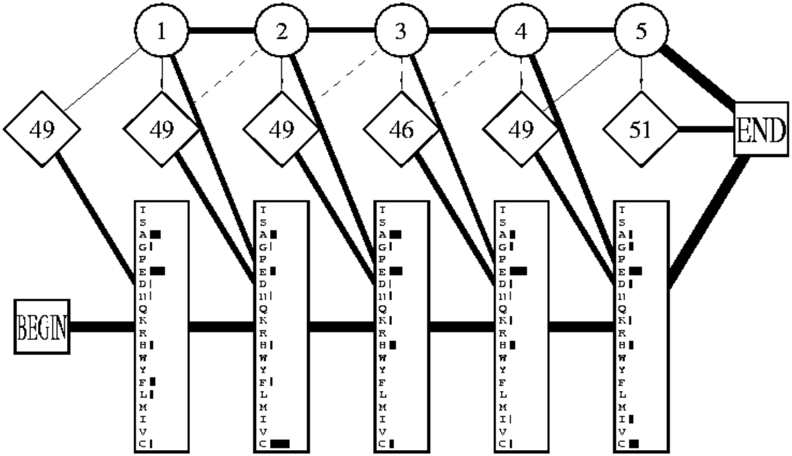
⇒ **Multiple sequence alignment**

- **Alignment of multiple sequences in colums**
  - Aligned substructures are 'homologous' – structurally similar
  - No single optimal alignment
  - Optimality depends on relatedness of training sequences ⇒ families
- **Scoring multiple alignment**
  - Position conservation
  - Sequences are not independent, but related
- **Multiple alignment by profile HMM training**

# Profile Hidden Markov Models

- ***Match***, ***insert*** **and** ***delete*** **states**
- **Key idea**
  - Profile of multiple aligned sequences
  - Transition, emission probabilities capture information about each position in alignment
- **Training**
  - Adaptations of standard model construction methods
  - Aligned or unaligned sequences as input
- **Profile useful for multiple sequence alignment**

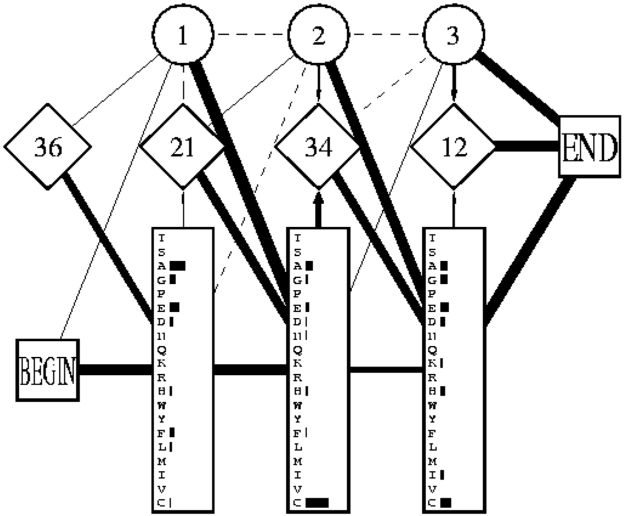
- **Family**
  - Sequences of equal length
  - Sequences of equal type
  - Variations (dep.trees) on dependency mobile
- **Tools**
  - Sequence Alignment Module (SAM) (Hughey and Krogh, 1996)
  - Translation edge-labels → single-characters
  - Treebank Perl scipts and Java classes




| | SB | HD | MO | CP | OC | OA |
|---|---|---|---|---|---|---|
| **Mapping table** | A | C | E | F | G | H |

# Aligned sequences of equal length: S, length 5

| | |
|---|---|
| sequence11 | EFADC |
| sequence32 | HECAE |
| sequence187 | ECAED |
| sequence246 | FHAEC |
| sequence247 | ECNEA |
| sequence284 | EFAGC |
| sequence291 | ECAEE |
| sequence317 | ECNAI |
| sequence392 | ACEHI |
| : | |

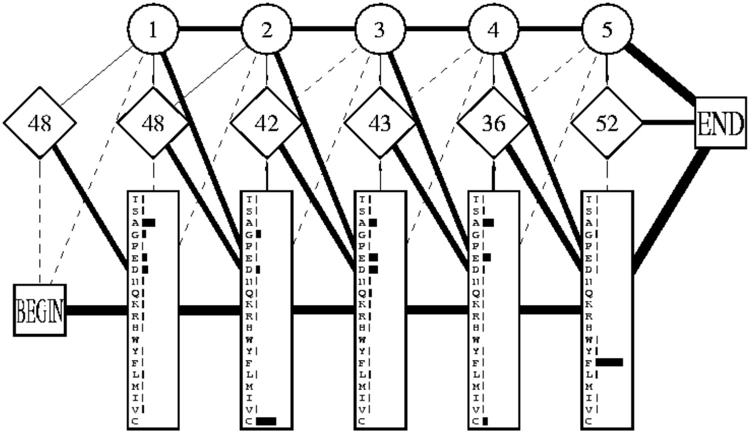



| | SB | HD | MO | CP | OC | OA |
|---|---|---|---|---|---|---|
| **Mapping table** | A | C | E | F | G | H |

# Aligned sequences of equal type: S

```
sequence38     A..C.......G.....
sequence39     A..C.......D.....
sequence46     A..C.......G.....
sequence48     G..C.......A.....
sequence56     A..C.......G.....
sequence58     -..C.......G.....
sequence62     A..C.......G.....
sequence66     A..D.......C.....
              :
```

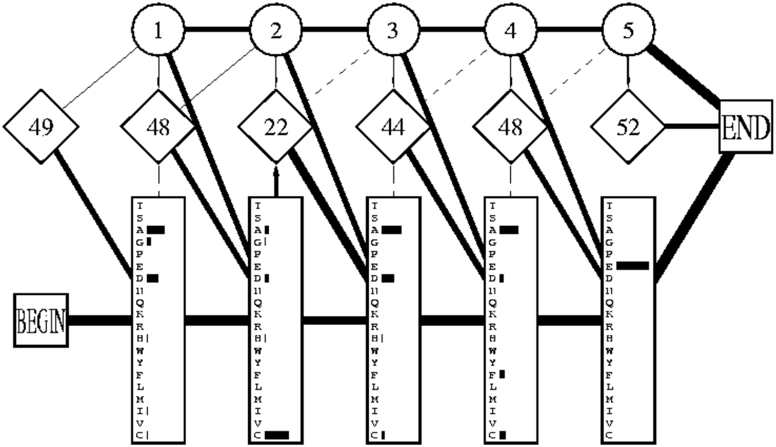
# Sequences of equal dependency mobile I (6 var)




`[HD:VMFIN, MO:ADV, MO:ADV, OC:VP, SB:NP]`

| | SB | HD | MO | CP | OC | OA |
|---|---|---|---|---|---|---|
| **Mapping table** | A | C | E | F | G | H |

# Sequences of equal dependency mobile II (7 var)

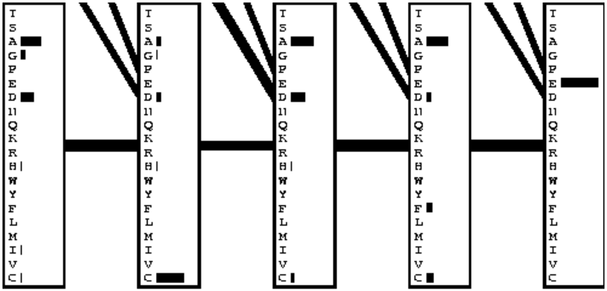



[HD:VVFIN, MO:PP, MO:PP, SB:NP]

| | SB | HD | MO | CP | OC | OA |
|---|---|---|---|---|---|---|
| **Mapping table** | A | C | E | F | G | H |

# Observations

- **From profiles to rules**
  - Soft rules: Use probabilities as preferences
  - Hard rules: discard patterns $\leq$ threshold
- **Example**
  - Hard rules yield classical topological model for II
  - {1 dep} HD {$n$ deps } { CP }
  - Canonical is SB-V order



# Conclusions & outlook

- **Potential approach to learning linearization rules**
  - Robust given scrambling, discontinuity
  - Linguistic intuitions
- **Improving data**
  - Phylogenetic trees $\overset{?}{\leftrightarrow}$ head alternation graphs
  - Sequence weighing (balancing data)
- **Improving computation**
  - Arbitrary sequence encoding
  - Linguistic data-based (affine) gapping scoring

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