Multiplanarity - a model for dependency structures in treebanks

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Multiplanarity —
a model for dependency structures in treebanks

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TLT 2003, Växjö
1. DEPENDENCY SYNTAX:
   • basic concepts
   • does not capture linear word order (without augmentations)

2. Simple hypotheses for WORD-ORDER:
   • projectivity and planarity

3. Finding a word-order in SYNTACTIC “WONDERLANDS”:
   • the idea of multiplanarity
   • a restriction motivated by the formal language theory
   • modeling treebanks: the algorithm and the coverage evaluation

4. Concluding remarks and possible APPLICATIONS
2 – Dependency Syntax

- An approach to syntax based on links between words which occur together (adapted from Hudson (1984))
- Abstracts away from the linear word-order in the surface strings
- Goes back to Tesnière (1959), and even to the Middle-Ages
• Basic concepts:
  – in the context, each word (or nucleus) has a *syntactic function*;
  – words can be modified or complemented by other words (nuclei)
    ⇒ binary *dependency relation* ("governs") over words;
3 – Dependency Syntax

● Basic concepts:
  – in the context, each word (or nucleus) has a *syntactic function*;
  – words can be modified or complemented by other words (nuclei)
    ⇒ binary *dependency relation* ("governs") over words;

● Assumption of dependency *trees*:
  – a unique *root* word;
  – other words are governed by exactly one other word;
  – all the words are governed by the root ⇒ *acyclic and connected* graph
4 – Dependency syntax and linear word-order

• An example of a dependency syntactic tree:

  ditches \rightarrow \text{flow} \rightarrow \text{into} \rightarrow \text{rivers} \\
  \text{the} \quad \text{small} \quad \text{the} \quad \text{big}

• The dependency trees do not necessarily show the actual word-order (compare to deep structures in transformational grammar)

• Description of the relation between dependency trees and the linearly ordered word sequences requires an extension to dependency syntax:

a model for dependency structures in treebanks
4 – Dependency syntax and linear word-order

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```
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  the   small       the
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                      big
```

- The dependency trees do not necessarily show the actual word-order (compare to deep structures in transformational grammar)

- Description of the relation between dependency trees and the linearly ordered word sequences requires an extension to dependency syntax:
  - simple hypotheses: various kinds of *projectivity*
4 – Dependency syntax and linear word-order

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```
  ditches  flow  into  rivers
     \   /           /     \\
      \ /           /     /  \\
       \ /           /     /   \\
        \ /           /     /    \\
         \ /           /     /     \\
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- The dependency trees do not necessarily show the actual word-order (compare to deep structures in transformational grammar)

- Description of the relation between dependency trees and the linearly ordered word sequences requires an extension to dependency syntax:
  - simple hypotheses: various kinds of projectivity
  - lexicalized constraints: word-order domains, topological fields, etc.

a model for dependency structures in treebanks
Let \(< W_1, W_2, \ldots, W_n >\) be a sequence of words in the surface word-order. The undirected (symmetric) version of the dependency relation *governs* is denoted by *link*.
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**Projective** if, for any linked words $W_i$ and $W_j$, $i < j$, it holds that if there is an intervening word $W_k$, $i < k < j$, then either $W_i$ or $W_j$ transitively \textit{governs} $W_k$. 

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**Projective** if, for any linked words $W_i$ and $W_j$, $i < j$, it holds that if there is an intervening word $W_k$, $i < k < j$, then either $W_i$ or $W_j$ transitiveely **governs** $W_k$.

**Planar** if, for any linked words $W_i$ and $W_j$, $i < j$, it holds that if there is an intervening word $W_k$, $i < k < j$ then either $W_i$ or $W_j$ is transitivity **linked** to $W_k$. 

*a model for dependency structures in treebanks*
In many languages (French, German, Italian, Danish, English, Russian, Swedish, Finnish, Czech), a large percentage of the sentences are projective (Lecerf 1960, etc.).

According to Marcus (1967), there are about 117 000 structured strings which may be formed with seven given words, but only 3876 of these are projective. In other words, projectivity-like hypotheses has a lot of practical importance.
A **plane** is a space with two dimensions. **Planar graph** is a graph that can drawn in a plane without crossing edges.

**Planar dependency graph of a sentence** is a dependency graph that can be drawn above the sentence without crossing dependency links.
7 – Towards generalized projectivity: planarity

A **plane** is a space with two dimensions. **Planar graph** is a graph that can drawn in a plane without crossing edges.

**Planar dependency graph of a sentence** is a dependency graph that can be drawn above the sentence without crossing dependency links.

The following trees are **planar** but they are **not projective** (Figure 1 in the paper).

Moreover, these trees can be made projective by changing the direction of one dependency link only ("holde"—"kan", "det"—"var").
The Research Problem: Quite often extrapositions result into word-orders where the obtained dependency analyses are nonprojective and nonplanar. Is there a generalized projectivity property that captures important word-order regularities in non-planar sentences?
8 – Capturing the word-order in “syntactic wonderlands”

The Research Problem: Quite often extrapositions result into word-orders where the obtained dependency analyses are nonprojective and nonplanar. Is there a generalized projectivity property that captures important word-order regularities in non-planar sentences?

Approach:

• start from an overshoot solution: unrestricted multiplanarity
• make a restriction motivated by the formal language theory
• evaluating the linguistic adequacy of the restricted multiplanarity

a model for dependency structures in treebanks
Multiplanar dependency graph is a finite union of planar dependency graphs drawn above the same sentence.
10 – A restriction motivated by the formal language theory
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- It is generally believed that the language theoretic complexity of natural languages does not exceed the complexity of the so called *mildly context-sensitive languages* (Joshi 1985).
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- It is generally believed that the language theoretic complexity of natural languages does not exceed the complexity of the so called *mildly context-sensitive languages* (Joshi 1985).

- The set of 2-planar trees capture a set of ordered dependency trees that yields the so-called MIX language.
10 – A restriction motivated by the formal language theory

- It is generally believed that the language theoretic complexity of natural languages does not exceed the complexity of the so-called mildly context-sensitive languages (Joshi 1985).

- The set of 2-planar trees capture a set of ordered dependency trees that yields the so-called MIX language.

- The MIX language is not contained into mildly context-sensitive languages; it is more complex.

⇒ We need to restrict multiplanar trees somehow in order to make the multiplanar structures linguistically more interesting.
11 – An example: a two-planar MIX sentence

Legend: The superscript \(^1\) is used for links in the upper plane; [? is used in the head side of each link.

Observe: Both the planes start and end dependency links quite freely.

a model for dependency structures in treebanks
12 – Restricted multiplanarity: alignment constraints

Assume (i) that the words are processed from left to right (i.e. the planes start and end links at certain time moments), and (ii) when needed, additional planes 0, 1, 2, ... are introduced, and the plane with a lower number is used if possible.

A restricted version of multiplanarity is expressed by means of the **Plane Locking** constraint (and some other constraints):

> Links can always end regardless of the plane which they belong to. However, plane $p$ cannot start a new link if there is a plane $r$, $r > p$ such that plane $r$ contains an unended link.
13 – Distributing links to multiple planes: an algorithm

Input: $\langle W_1, W_2, \ldots, W_n \rangle$, and a set of dependency links
Output: a restricted multiplanar representation for the dependency structure
Distributing links to multiple planes: an algorithm

**Input:** \( \langle W_1, W_2, \ldots, W_n \rangle \), and a set of dependency links

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for foreach \( i \) in \([1..n - 1]\) and \( j \) in \([i + 1..n]\)
    if there is a link connecting words \( W_i \) and \( W_j \)
        denote the plane where the link between \( W_i \) and \( W_j \) belongs to with \( p \)
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if, there are two linked words \( W_k \) and \( W_l \) such that \( i < k < j < l \)
Input: \( \langle W_1, W_2, ..., W_n \rangle \), and a set of dependency links

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\[
\text{for } \text{foreach } i \text{ in } [1..n - 1] \text{ and } j \text{ in } [i + 1..n] \\
\text{if } \text{there is a link connecting words } W_i \text{ and } W_j \\
\text{denote the plane where the link between } W_i \text{ and } W_j \text{ belongs to with } p \\
\text{if, there are two linked words } W_k \text{ and } W_l \text{ such that } i < k < j < l \\
\text{minimize } k \text{ and maximize } l \text{ with respect to } k) \\
\text{lift each link encompassed in the range } [k..l] \text{ into the plane } p + 1.
\]
14 – Modeling dependency structures: the evaluation

- Test suite: Danish Dependency Treebank (DDT), 100,000 tokens
- We processed DDT with the presented treebank transformation algorithm
- We examined the resulting representation in order to see how many planes were actually needed and what kind of constructions were involved when more planes were needed.
- Moreover, we developed a very promising local heuristics for proving acyclicity of dependency trees (see the paper)
15 – The results

- Extrapolation and certain grammatical constructions often required an additional plane. Some examples:
  - coordination with two particles (like *both ... and*, *nether ... nor*, etc.)
  - constructions like *it was the same year when* ...

- Three planes were enough to model 99.97% of the corpus (two more complex sentences were found within 5540 sentences)
The linguistic relevance

- The number of required planes correlated with our subjective judgment of the difficulty of the sentence
- Restricted multiplanarity with a fixed number of planes rules out a number of erroneous analyses
- The model captures real examples of cross-serial dependencies in Swiss German.
- A conjecture (not yet formally proven): the model fails to capture many awkward, non-natural languages such as MIX and $a^n b^n c^n$. 
We provided a linguistically interesting generalization of planarity

We provided a specification for a grammarless model for dependency structures

We carried out some tests using the Danish Dependency Treebank

Possible applications:

- treebank validation, data mining, finding non-prototypical analyses,
- a basis for a complexity hierarchy of dependency grammars,
- serves a model-theoretic account of dependency syntax, and
- dependency syntactic parsing (even with finite-state methods).