Introduction to Dependency Grammar and Dependency Parsing

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Based on previous tutorials with Ryan McDonald
WARNING!
WARNING!

▶ This is not a course about how to parse multiword expressions
WARNING!

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- It is primarily an introduction to dependency parsing
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- It is primarily an introduction to dependency parsing
- But we will get to multiword expressions . . .
Overview of the Course

1. Introduction to dependency grammar and dependency parsing
2. Graph-based and transition-based dependency parsing
3. Multiword expressions in dependency parsing
4. Practical lab session (MaltParser)
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1. Introduction to dependency grammar and dependency parsing
2. Graph-based and transition-based dependency parsing
3. Multiword expressions in dependency parsing
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Plan for this Lecture

- Dependency grammar:
  - Basic concepts
  - Terminology and notation
  - Dependency graphs

- Dependency parsing
  - Grammar-driven methods
  - Data-driven methods

- Pros and cons of dependency parsing
Dependency Grammar

- The basic idea:
  - Syntactic structure consists of lexical items, linked by binary asymmetric relations called dependencies.

- In the words of Lucien Tesnière [Tesnière 1959]:
  - La phrase est un ensemble organisé dont les éléments constitutants sont les mots. [1.2] Tout mot qui fait partie d’une phrase cesse par lui-même d’être isolé comme dans le dictionnaire. Entre lui et ses voisins, l’esprit aperçoit des connexions, dont l’ensemble forme la charpente de la phrase. [1.3] Les connexions structurales établissent entre les mots des rapports de dépendance. Chaque connexion unit en principe un terme supérieur à un terme inférieur. [2.1] Le terme supérieur reçoit le nom de régissant. Le terme inférieur reçoit le nom de subordonné. Ainsi dans la phrase Alfred parle […], parle est le régissant et Alfred le subordonné. [2.2]
Dependency Grammar

The basic idea:

- Syntactic structure consists of *lexical items*, linked by binary asymmetric relations called *dependencies*.

In the words of Lucien Tesnière [Tesnière 1959]:

- The sentence is an *organized whole*, the constituent elements of which are *words*. [1.2] Every word that belongs to a sentence ceases by itself to be isolated as in the dictionary. Between the word and its neighbors, the mind perceives *connections*, the totality of which forms the structure of the sentence. [1.3] The structural connections establish *dependency* relations between the words. Each connection in principle unites a *superior* term and an *inferior* term. [2.1] The superior term receives the name *governor*. The inferior term receives the name *subordinate*. Thus, in the sentence *Alfred parle [ . . . ]*, *parle* is the governor and *Alfred* the subordinate. [2.2]
Economic news had little effect on financial markets.
Economic news had little effect on financial markets.
Economic news had little effect on financial markets.
Economic news had little effect on financial markets.

**Dependency Structure**

- Economic: adj
- news: noun
- had: verb
- little: adj
- effect: noun
- on: prep
- financial: adj
- markets: noun
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## Terminology

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<thead>
<tr>
<th>Superior</th>
<th>Inferior</th>
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Comparison

- Dependency structures explicitly represent
  - head-dependent relations (directed arcs),
  - functional categories (arc labels),
  - possibly some structural categories (parts-of-speech).

- Phrase structures explicitly represent
  - phrases (nonterminal nodes),
  - structural categories (nonterminal labels),
  - possibly some functional categories (grammatical functions).

- Hybrid representations may combine all elements.
Some Theoretical Frameworks

- Word Grammar (WG) [Hudson 1984, Hudson 1990, Hudson 2007]
- Functional Generative Description (FGD) [Sgall et al. 1986]
- Dependency Unification Grammar (DUG) [Hellwig 1986, Hellwig 2003]
- Meaning-Text Theory (MTT) [Mel’čuk 1988, Milićević 2006]
- Functional Dependency Grammar (FDG) [Tapanainen and Järvinen 1997, Järvinen and Tapanainen 1998]
- Topological/Extensible Dependency Grammar ([T/X]DG) [Duchier and Debusmann 2001, Debusmann et al. 2004]
Some Theoretical Issues

- Dependency structure sufficient as well as necessary?
- Mono-stratal or multi-stratal syntactic representations?
- What is the nature of lexical elements (nodes)?
  - Morphemes?
  - Word forms?
  - Multiword expressions?
- What is the nature of dependency types (arc labels)?
  - Grammatical functions?
  - Semantic roles?
- What are the criteria for identifying heads and dependents?
- What are the formal properties of dependency structures?
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  - Semantic roles?
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- What are the formal properties of dependency structures?
Criteria for Heads and Dependents

Criteria for a syntactic relation between a head $H$ and a dependent $D$ in a construction $C$ [Zwicky 1985, Hudson 1990]:

1. $H$ determines the syntactic category of $C$; $H$ can replace $C$.
2. $H$ determines the semantic category of $C$; $D$ specifies $H$.
3. $H$ is obligatory; $D$ may be optional.
4. $H$ selects $D$ and determines whether $D$ is obligatory.
5. The form of $D$ depends on $H$ (agreement or government).
6. The linear position of $D$ is specified with reference to $H$.

Issues:

- Syntactic (and morphological) versus semantic criteria
- Exocentric versus endocentric constructions
## Some Clear Cases

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Economic news suddenly affected financial markets .

adj  noun    adv  verb    adj  noun
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Some Tricky Cases

- Complex verb groups (auxiliary ↔ main verb)
- Subordinate clauses (complementizer ↔ verb)
- Coordination (coordinator ↔ conjuncts)
- Prepositional phrases (preposition ↔ nominal)
- Punctuation

I can see that they rely on this and that.

pron aux verb sconj pron verb adp pron conj pron p
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I
pron
 aux
verb
sconj
pron
verb
adp
pron
conj
pron
p

nsubj
ccomp

can see
that
they
rely
on
this
and
that
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Dependency Graphs

- A dependency structure can be defined as a directed graph $G$, consisting of:
  - a set $V$ of nodes (vertices),
  - a set $A$ of arcs (directed edges),
  - a linear precedence order $<$ on $V$ (word order).

- Labeled graphs:
  - Nodes in $V$ are labeled with word forms (and annotation).
  - Arcs in $A$ are labeled with dependency types:
    - $L = \{l_1, \ldots, l_{|L|}\}$ is the set of permissible arc labels.
    - Every arc in $A$ is a triple $(i, j, k)$, representing a dependency from $w_i$ to $w_j$ with label $l_k$. 
Dependency Graph Notation

- For a dependency graph \( G = (V, A) \)
- With label set \( L = \{l_1, \ldots, l_{|L|}\} \)
  - \( i \rightarrow j \equiv \exists k : (i, j, k) \in A \)
  - \( i \leftrightarrow j \equiv i \rightarrow j \lor j \rightarrow i \)
  - \( i \rightarrow^* j \equiv i = j \lor \exists i' : i \rightarrow i', i' \rightarrow^* j \)
  - \( i \leftrightarrow^* j \equiv i = j \lor \exists i' : i \leftrightarrow i', i' \leftrightarrow^* j \)
Formal Conditions on Dependency Graphs

- $G$ is (weakly) connected:
  - If $i, j \in V$, $i \leftrightarrow^* j$.

- $G$ is acyclic:
  - If $i \rightarrow j$, then not $j \rightarrow^* i$.

- $G$ obeys the single-head constraint:
  - If $i \rightarrow j$, then not $i' \rightarrow j$, for any $i' \neq i$.

- $G$ is projective:
  - If $i \rightarrow j$, then $i \rightarrow^* i'$, for any $i'$ such that $i < i' < j$ or $j < i' < i$. 
Connectedness, Acyclicity and Single-Head

- **Intuitions:**
  - Syntactic structure is complete (*Connectedness*).
  - Syntactic structure is hierarchical (*Acyclicity*).
  - Every word has at most one syntactic head (*Single-Head*).
- Connectedness can be enforced by adding a special root node.
Connectedness, Acyclicity and Single-Head

▶ Intuitions:
  ▶ Syntactic structure is complete (Connectedness).
  ▶ Syntactic structure is hierarchical (Acyclicity).
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▶ Connectedness can be enforced by adding a special root node.
Projectivity

- Most theoretical frameworks do not assume projectivity.
- Non-projective structures are needed to account for
  - long-distance dependencies,
  - free word order.
Dependency Parsing

- **Input:** Sentence $x = w_0, w_1, \ldots, w_n$ with $w_0 = \text{ROOT}$
- **Output:** Dependency graph $G = (V, A)$ for $x$
  - $V = \{0, 1, \ldots, n\}$ is the node set,
  - $A$ is the arc set, i.e., $(i, j, k) \in A$ iff $w_i \xrightarrow{l_k} w_j$

- Grammar-based parsing
  - Context-free dependency grammar
  - Constraint dependency grammar

- Data-driven parsing
  - Graph-based models
  - Transition-based models
Evaluation Metrics

- **Standard setup:**
  - Test set $\mathcal{E} = \{(x_1, G_1), (x_2, G_2), \ldots, (x_n, G_n)\}$
  - Parser predictions $\mathcal{P} = \{(x_1, G'_1), (x_2, G'_2), \ldots, (x_n, G'_n)\}$

- **Evaluation on the word (arc) level:**
  - Labeled attachment score (LAS) = head and label
  - Unlabeled attachment score (UAS) = head
  - Label accuracy (LA) = label

- **Evaluation on the sentence (graph) level:**
  - Exact match (labeled or unlabeled) = complete graph

- **NB:** Evaluation metrics may or may not include punctuation
Context-Free Dependency Grammar

- Dependency grammar as lexicalized context-free grammar:

\[ H \rightarrow L_1 \cdot \cdot \cdot L_m \ h \ R_1 \cdot \cdot \cdot R_n \]

- Standard context-free parsing algorithms (CKY, Earley, etc.)
- Projective, unlabeled dependency trees only
- Weakly equivalent to arbitrary CFGs [Hays 1964, Gaifman 1965]

- Related approaches:
  - Link Grammar [Sleator and Temperley 1991]
Constraint Dependency Grammar

- Parsing as constraint satisfaction [Maruyama 1990]:
  - Variables $h_1, \ldots, h_n$ with domain $\{0, 1, \ldots, n\}$
  - Grammar $G =$ set of boolean constraints
  - Parsing = search for dependency graph satisfying $G$
  - Handles non-projective labeled dependency graphs
  - Parsing intractable in the general case

- Recent developments:
  - Weighted Constraint Dependency Grammar
    [Menzel and Schröder 1998, Foth et al. 2004]
  - Probabilistic Constraint Dependency Grammar
  - Topological/Extensible Dependency Grammar
    [Duchier and Debusmann 2001, Debusmann et al. 2004]
Graph-Based Models

- Basic idea:
  - Define a space of candidate dependency graphs for a sentence.
  - **Learning:** Induce a model for scoring an entire dependency graph for a sentence.
  - **Parsing:** Find the highest-scoring dependency graph, given the induced model.

- Characteristics:
  - Global training of a model for optimal dependency graphs
  - Exhaustive search/inference
Transition-Based Models

- Basic idea:
  - Define a transition system (state machine) for mapping a sentence to its dependency graph.
  - **Learning:** Induce a model for predicting the next state transition, given the transition history.
  - **Parsing:** Construct the optimal transition sequence, given the induced model.

- Characteristics:
  - Local training of a model for optimal transitions
  - Greedy search/inference
Pros and Cons of Dependency Parsing

- What are the advantages of dependency-based methods?
- What are the disadvantages?
- Four types of considerations:
  - Complexity
  - Transparency
  - Word order
  - Expressivity
Complexity

▶ Practical complexity:
  ▶ Given the Single-Head constraint, parsing a sentence $x = w_1, \ldots, w_n$ can be reduced to labeling each token $w_i$ with:
    ▶ a head word $h_i$,
    ▶ a dependency type $d_i$.

▶ Theoretical complexity:
  ▶ By exploiting the special properties of dependency graphs, it is sometimes possible to improve worst-case complexity compared to constituency-based parsing:
    ▶ Lexicalized projective parsing in $O(n^3)$ time [Eisner 1996]
    ▶ Arc-factored non-projective parsing in $O(n^2)$ time [McDonald et al. 2005]
Pros and Cons of Dependency Parsing

Transparency

- Direct encoding of predicate-argument structure

```
She writes books
sbj obj
S VP NP NP
PRP VBZ NNS
```

```
She writes books
```

```
S
   VP
      NP
        PRP
           She
               writes
                   NP
                       NNS
                           books
```

Introduction to Data-Driven Dependency Parsing 28(1)

Introduction to Dependency Grammar and Dependency Parsing 28(31)
Pros and Cons of Dependency Parsing

**Transparency**

- Direct encoding of predicate-argument structure
- Fragments directly interpretable

```
She writes books
sbj NP NP
PRP VBZ NNS
```

```
She writes books
pron verb noun
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```

```
She writes books
```

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Introduction to Dependency Grammar and Dependency Parsing 28(31)
Pros and Cons of Dependency Parsing

Transparency

- Direct encoding of predicate-argument structure
- Fragments directly interpretable
- But only with labeled dependency graphs

Example:

She writes books

- She (nsubj)
- writes (verb)
- books (noun)

NP

PRP

VBZ

NNS

She

writes

books
Word Order

- Dependency structure independent of word order
- Suitable for free word order languages

Diagram:

- Ista
  - det
  - nsubj
  - det

- gloria
  - noun

- norit
  - verb

- meam
  - det

- canitiem
  - noun
Word Order

- Dependency structure independent of word order
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Pros and Cons of Dependency Parsing

Word Order

- Dependency structure independent of word order
- Suitable for free word order languages
- But only with non-projective dependency graphs

![Dependency Tree Diagram]

Ista det meam det norit verb gloria noun canitiem noun
Expressivity

- Limited expressivity:
  - Every projective dependency grammar has a strongly equivalent context-free grammar, but not vice versa [Gaifman 1965].
  - Impossible to distinguish between phrase modification and head modification in unlabeled dependency structure [Mel’čuk 1988].
Expressivity

▶ Limited expressivity:

▶ Every projective dependency grammar has a strongly equivalent context-free grammar, but not vice versa [Gaifman 1965].

▶ Impossible to distinguish between phrase modification and head modification in unlabeled dependency structure [Mel’čuk 1988].

▶ What about labeled non-projective dependency structures?
Coming Up Next

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*English Word Grammar.* Blackwell.


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