Introduction to Dependency Grammar and Dependency Parsing

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Based on previous tutorials with Ryan McDonald

WARNING!

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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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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 constituants 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]

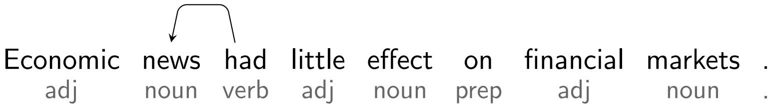
Dependency Grammar

- 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]

Dependency Structure

Economic	news	had	little	effect	on	financial	markets	.
adj	noun	verb	adj	noun	prep	adj	noun	.

Dependency Structure



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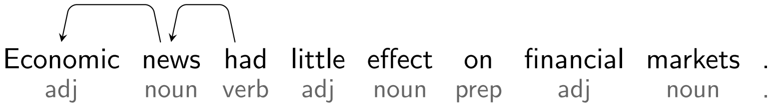

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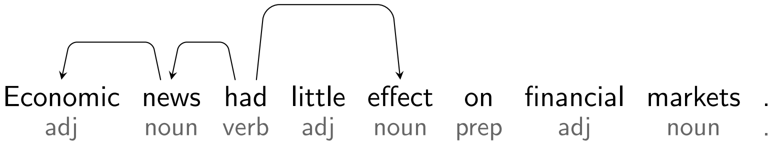

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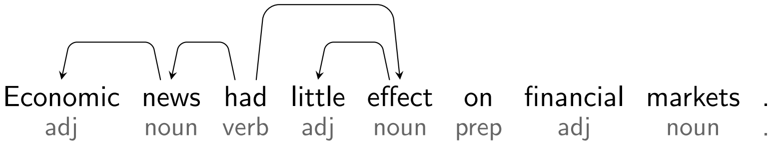

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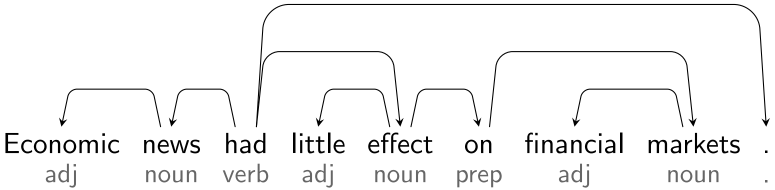

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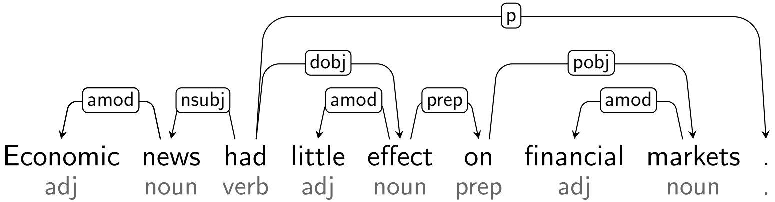

Terminology

Superior	**Inferior**
Head	Dependent
Governor	Modifier
Regent	Subordinate
⋮	⋮

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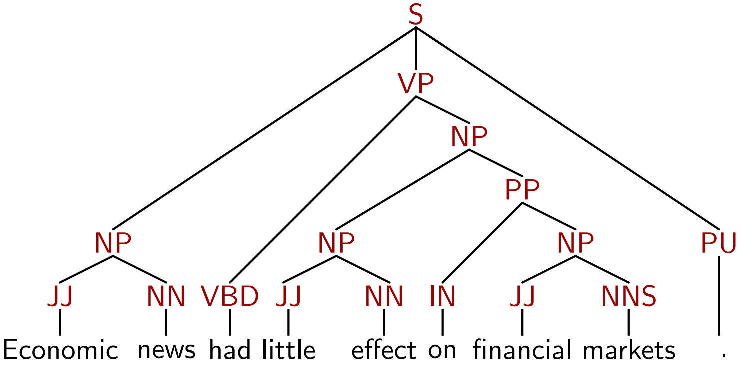
Phrase Structure



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]
- (Weighted) Constraint Dependency Grammar ([W]CDG) [Maruyama 1990, Menzel and Schröder 1998, Schröder 2002]
- 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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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

Construction	Head	Dependent
Exocentric	Verb	Subject (nsubj)
	Verb	Object (dobj)
Endocentric	Verb	Adverbial (advmod)
	Noun	Attribute (amod)

Economic	news	suddenly	affected	financial	markets	.
adj	noun	adv	verb	adj	noun	.

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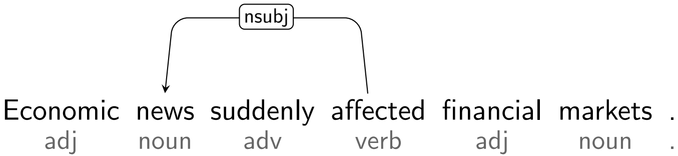

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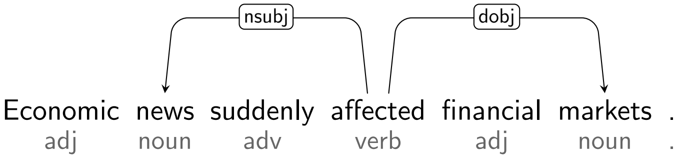

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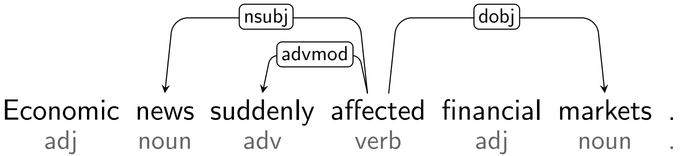

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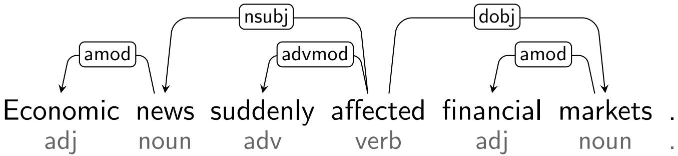

Some Tricky Cases

- 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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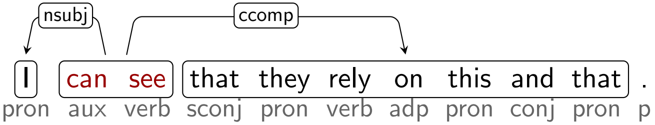

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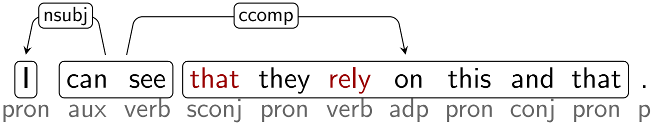

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Dependency Graphs

- 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

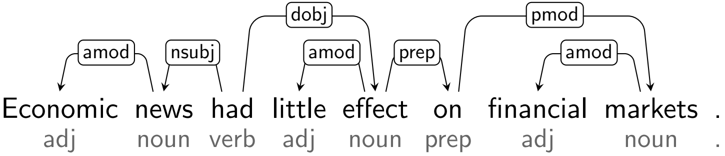
- For a dependency graph $G = (V, A)$
- With label set $L = \{l_1, \ldots, l_{|L|}\}$
  - $i \rightarrow j \;\equiv\; \exists k : (i, j, k) \in A$
  - $i \leftrightarrow j \;\equiv\; i \rightarrow j \vee j \rightarrow i$
  - $i \rightarrow^* j \;\equiv\; i = j \vee \exists i' : i \rightarrow i',\, i' \rightarrow^* j$
  - $i \leftrightarrow^* j \;\equiv\; i = j \vee \exists i' : i \leftrightarrow i',\, i' \leftrightarrow^* j$

Formal Conditions on Dependency Graphs

- G is (weakly) connected:
  - If $i, j \in V$, $i \leftrightarrow^* j$.
- G is acyclic:
  - If $i \to j$, then not $j \to^* i$.
- G obeys the single-head constraint:
  - If $i \to j$, then not $i' \to j$, for any $i' \neq i$.
- G is projective:
  - If $i \to j$, then $i \to^* i'$, 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.



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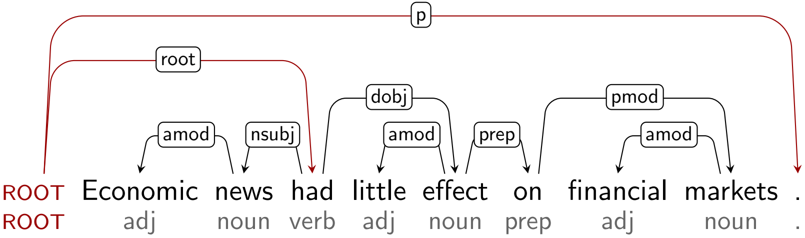
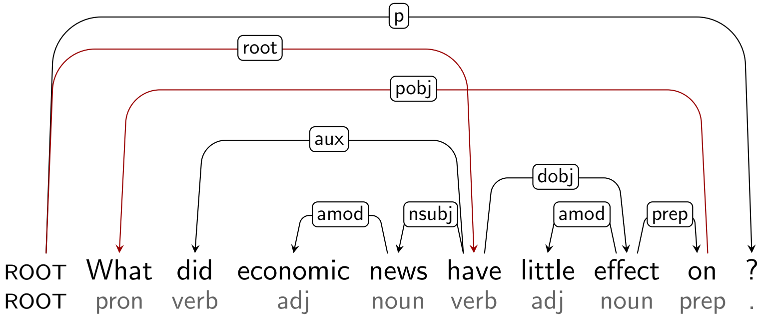


Projectivity

- 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:

$$H \longrightarrow L_1 \cdots L_m \, h \, R_1 \cdots R_n$$

  - 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]
  - Bilexical grammars [Eisner 1996, Eisner 2000]

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 [Harper and Helzerman 1995, Wang and Harper 2004]
  - 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

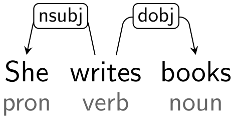
- What are the advantages of dependency-based methods?
- What are the disadvantages?
- Four types of considerations:
  - Complexity
  - Transparency
  - Word order
  - Expressivity

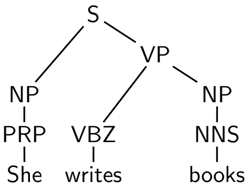
Complexity

- 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]

Transparency

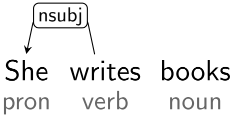
- Direct encoding of predicate-argument structure





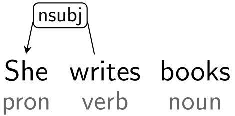
Transparency

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



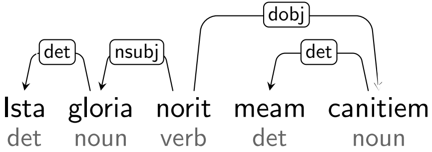
Transparency

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



Word Order

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



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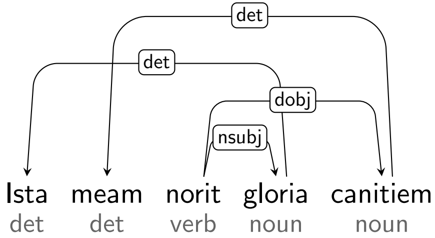

Word Order

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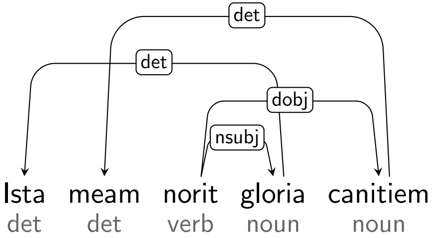
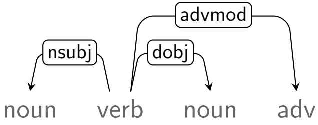
- But only with non-projective dependency graphs



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].



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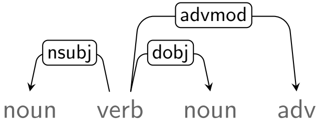

- What about labeled non-projective dependency structures?

Coming Up Next

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References and Further Reading

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