Dependency Parsing

L445 / L545

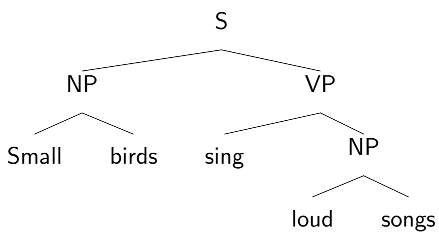
With thanks to Joakim Nivre and Sandra Kübler

Dependency Syntax

- Basic idea:
  - Syntactic structure consists of lexical items, linked by binary asymmetric relations called dependencies.
- In the (translated) 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]

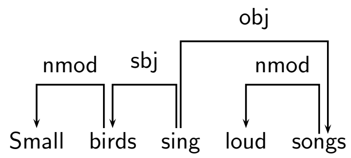
Overview: constituency

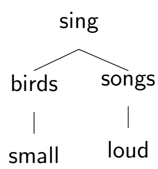
(1) Small birds sing loud songs



Overview: dependency

The corresponding dependency tree representations [Hudson(2000)]:

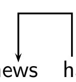




Dependency Structure

Economic news had little effect on financial markets .

Dependency Structure



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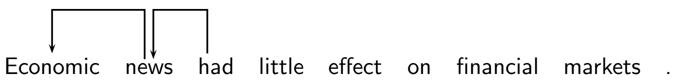
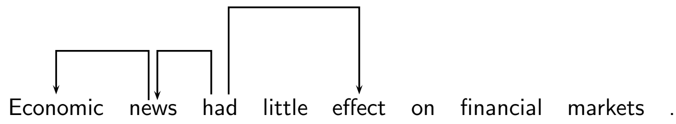
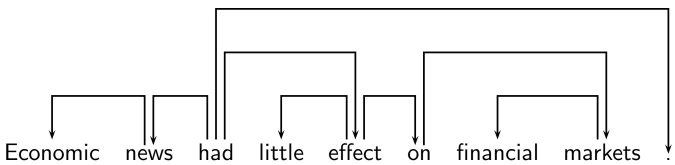


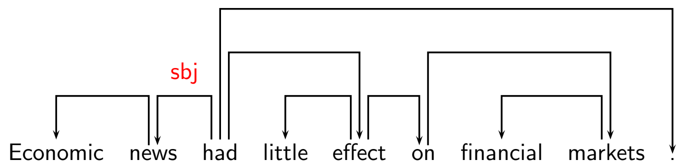
Dependency Structure



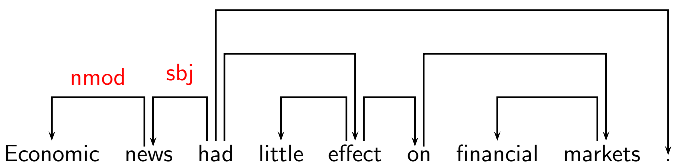
Dependency Structure



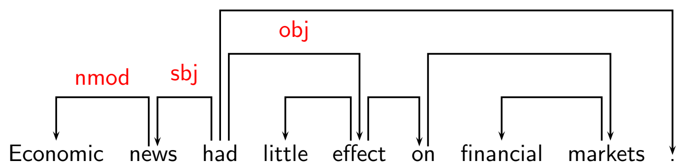
Dependency Structure



Dependency Structure



Dependency Structure



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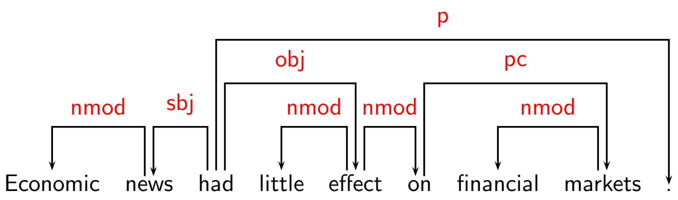


Terminology

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

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)]
- Functional Generative Description (FGD) [Sgall et al.(1986)Sgall, Hajičová and Panevová]
- Dependency Unification Grammar (DUG) [Hellwig(1986), Hellwig(2003)]
- Meaning-Text Theory (MTT) [Mel'čuk(1988)]
- (Weighted) Constraint Dependency Grammar ([W]CDG) [Maruyama(1990), Harper and Helzerman(1995), 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)Debusmann, Duchier and Kruijff]

Dependency Graphs

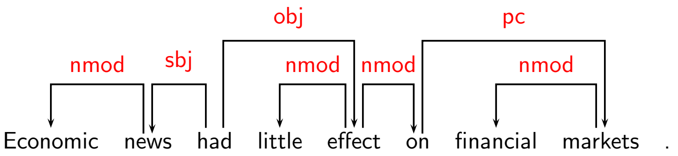
- A dependency structure can be defined as a directed graph G, consisting of
  - A set V of nodes,
  - A set E of arcs (edges),
  - A linear precedence order $<$ on V.
- Labeled graphs:
  - Nodes in V are labeled with word forms (and annotation).
  - Arcs in E are labeled with dependency types.
- Notational conventions ($i, j \in V$):
  - $i \to j \;\equiv\; (i, j) \in E$
  - $i \to^* j \;\equiv\; i = j \vee \exists k : i \to k, k \to^* j$

Formal Conditions on Dependency Graphs

- G is (weakly) connected:
  - For every node i there is a node j such that $i \to j$ or $j \to i$.
- G is acyclic:
  - If $i \to j$ then not $j \to^* i$.
- G obeys the single-head constraint:
  - If $i \to j$, then not $k \to j$, for any $k \neq i$.
- G is projective:
  - If $i \to j$ then $i \to^* k$, for any k such that $i < k < j$ or $j < k < i$.

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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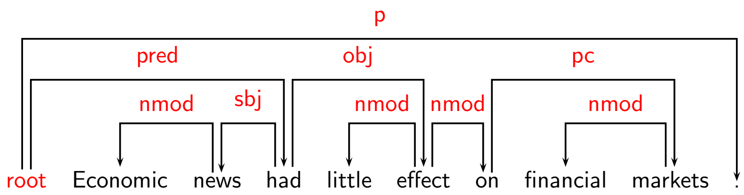
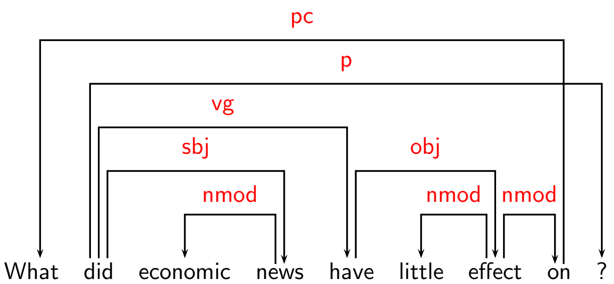


Projectivity

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



Where we're going

- Dependency parsing:
  - Input: Sentence $x = w_1, \ldots w_n$
  - Output: Dependency graph G
- Focus:
  - Computational methods for dependency parsing
  - Resources for dependency parsing (parsers, treebanks)

Parsing Methods

- Three main traditions:
  - Deterministic parsing (specifically: **Transition-based parsing**)
  - Dynamic programming (specifically: **Graph-based parsing**)
  - Constraint satisfaction (not covered today)
- Special issue:
  - Non-projective dependency parsing

Deterministic Parsing

- Basic idea:
  - Derive a single syntactic representation (dependency graph) through a deterministic sequence of elementary parsing actions
  - Sometimes combined with backtracking or repair
- Motivation:
  - Psycholinguistic modeling
  - Efficiency
  - Simplicity

Covington's Incremental Algorithm

- Deterministic incremental parsing in $O(n^2)$ time by trying to link each new word to each preceding one [Covington(2001)]:

```
PARSE(x = (w_1, ..., w_n))
for i = 1 up to n
    for j = i − 1 down to 1
        LINK(w_i, w_j)
```

$$\textsc{Link}(w_i,\ w_j) = \begin{cases} E \leftarrow E \cup (i,j) & \text{if } w_j \text{ is a dependent of } w_i \\ E \leftarrow E \cup (j,i) & \text{if } w_i \text{ is a dependent of } w_j \\ E \leftarrow E & \text{otherwise} \end{cases}$$

- Different conditions, such as Single-Head and Projectivity, can be incorporated into the LINK operation.

Shift-Reduce Type Algorithms

Transition-based parsing

- Data structures:
  - Stack $[\ldots, w_i]_S$ of partially processed tokens
  - Queue $[w_j, \ldots]_Q$ of remaining input tokens
- Parsing actions built from atomic actions:
  - Adding arcs ($w_i \rightarrow w_j$, $w_i \leftarrow w_j$)
  - Stack and queue operations
- Left-to-right parsing in $O(n)$ time
- Restricted to projective dependency graphs

Yamada's Algorithm

- Three parsing actions:

$$\text{Shift} \quad \frac{[\ldots]_S \quad [w_i, \ldots]_Q}{[\ldots, w_i]_S \quad [\ldots]_Q}$$

$$\text{Left} \quad \frac{[\ldots, w_i, w_j]_S \quad [\ldots]_Q}{[\ldots, w_i]_S \quad [\ldots]_Q \quad w_i \rightarrow w_j}$$

$$\text{Right} \quad \frac{[\ldots, w_i, w_j]_S \quad [\ldots]_Q}{[\ldots, w_j]_S \quad [\ldots]_Q \quad w_i \leftarrow w_j}$$

- Algorithm variants:
  - Originally developed for Japanese (strictly head-final) with only the Shift and Right actions [Kudo and Matsumoto(2002)]
  - Adapted for English (with mixed headedness) by adding the Left action [Yamada and Matsumoto(2003)]
  - Multiple passes over the input give time complexity $O(n^2)$

Nivre's Algorithm

- Four parsing actions:

$$\text{Shift} \quad \frac{[\ldots]_S \quad [w_i, \ldots]_Q}{[\ldots, w_i]_S \quad [\ldots]_Q}$$

$$\text{Reduce} \quad \frac{[\ldots, w_i]_S \quad [\ldots]_Q \quad \exists w_k : w_k \rightarrow w_i}{[\ldots]_S \quad [\ldots]_Q}$$

$$\text{Left-Arc}_r \quad \frac{[\ldots, w_i]_S \quad [w_j, \ldots]_Q \quad \neg\exists w_k : w_k \rightarrow w_i}{[\ldots]_S \quad [w_j, \ldots]_Q \quad w_i \xleftarrow{r} w_j}$$

$$\text{Right-Arc}_r \quad \frac{[\ldots, w_i]_S \quad [w_j, \ldots]_Q \quad \neg\exists w_k : w_k \rightarrow w_j}{[\ldots, w_i, w_j]_S \quad [\ldots]_Q \quad w_i \xrightarrow{r} w_j}$$

- Characteristics:
  - Integrated labeled dependency parsing
  - Arc-eager processing of right-dependents
  - Single pass over the input gives time complexity $O(n)$

Example

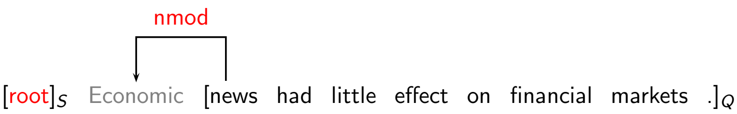
$[\text{root}]_S$ [Economic news had little effect on financial markets $.]_Q$

Example

$[\text{root Economic}]_S$ [news had little effect on financial markets $.]_Q$

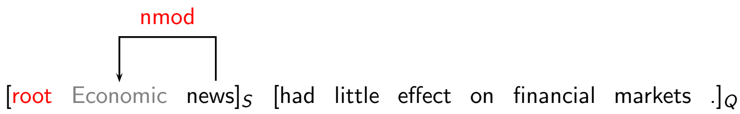
Shift

Example



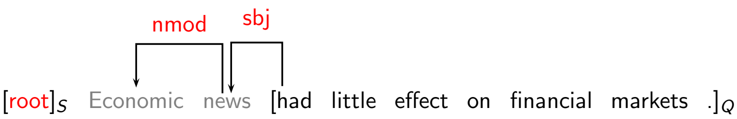
Left-Arc$_{nmod}$

Example



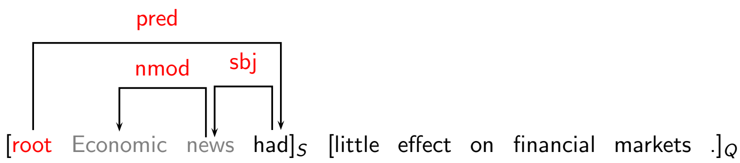
Shift

Example



Left-Arc$_{sbj}$

Example

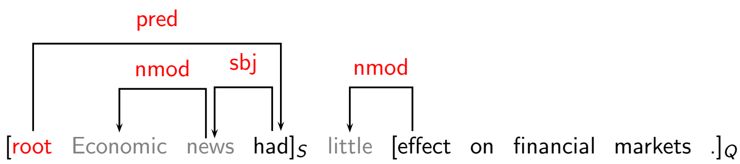


Right-Arc$_{pred}$

Example

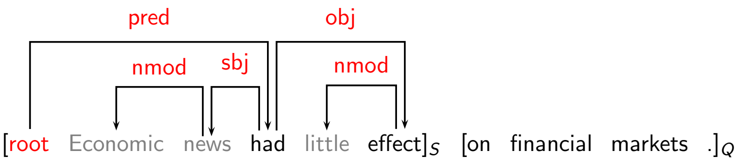
Shift

Example



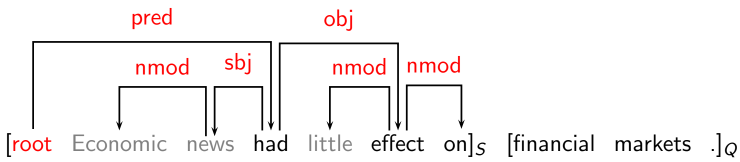
Left-Arc$_{nmod}$

Example



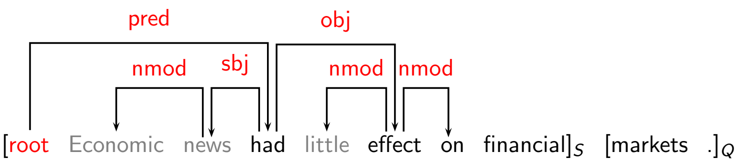
Right-Arc$_{obj}$

Example



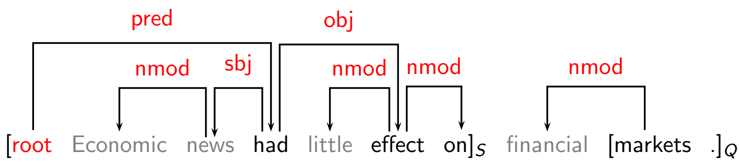
Right-Arc$_{nmod}$

Example



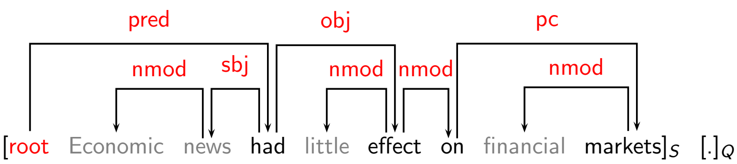
Shift

Example



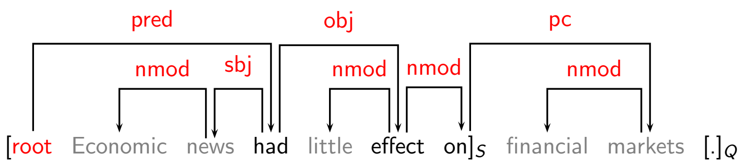
Left-Arc$_{nmod}$

Example



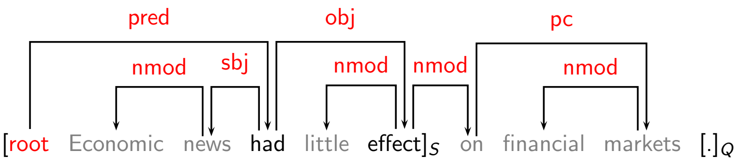
Right-Arc$_{pc}$

Example



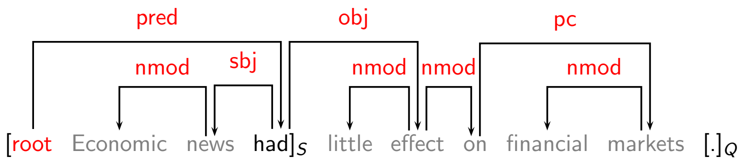
Reduce

Example



Reduce

Example



Reduce

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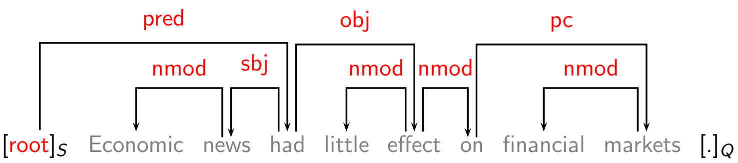
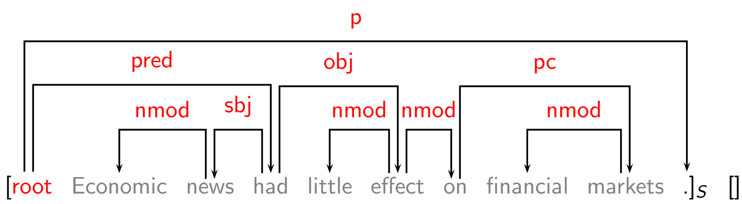


Reduce

Example



Right-Arc$_p$

Classifier-Based Parsing

- Data-driven deterministic parsing:
  - Deterministic parsing requires an oracle.
  - An oracle can be approximated by a classifier.
  - A classifier can be trained using treebank data.
- Learning methods:
  - Support vector machines (SVM)
    [Kudo and Matsumoto(2002), Yamada and Matsumoto(2003), Isozaki et al.(2004)Isozaki, Kazawa and Hirao, Cheng et al.(2004)Cheng, Asahara and Matsumoto, Nivre et al.(2006)Nivre, Hall, Nilsson, Eryiğit and Marinov]
  - Memory-based learning (MBL)
    [Nivre et al.(2004)Nivre, Hall and Nilsson, Nivre and Scholz(2004)]
  - Maximum entropy modeling (MaxEnt)
    [Cheng et al.(2005)Cheng, Asahara and Matsumoto]

Feature Models

- Learning problem:
  - Approximate a function from parser states, represented by feature vectors to parser actions, given a training set of gold standard derivations.
- Typical features:
  - Tokens:
    - Target tokens
    - Linear context (neighbors in S and Q)
    - Structural context (parents, children, siblings in G)
  - Attributes:
    - Word form (and lemma)
    - Part-of-speech (and morpho-syntactic features)
    - Dependency type (if labeled)
    - Distance (between target tokens)

Comparing Algorithms

- Parsing algorithm:
  - Nivre's algorithm gives higher accuracy than Yamada's algorithm for parsing the Chinese CKIP treebank [Cheng et al.(2004)Cheng, Asahara and Matsumoto].
- Learning algorithm:
  - SVM gives higher accuracy than MaxEnt for parsing the Chinese CKIP treebank [Cheng et al.(2004)Cheng, Asahara and Matsumoto].
  - SVM gives higher accuracy than MBL with lexicalized feature models for three languages [Hall et al.(2006)Hall, Nivre and Nilsson]:
    - Chinese (Penn)
    - English (Penn)
    - Swedish (Talbanken)

Graph-Based Parsing

From here, we'll look at some slides from NASSLLI 2010 ...

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