Bare-Bones Dependency Parsing

A Case for Occam's Razor?

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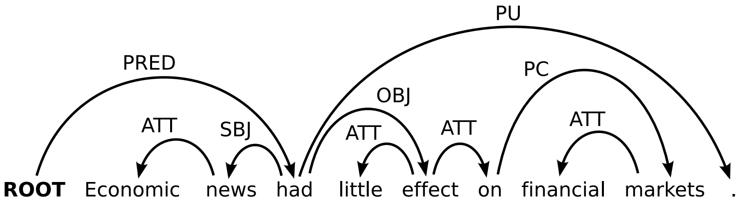
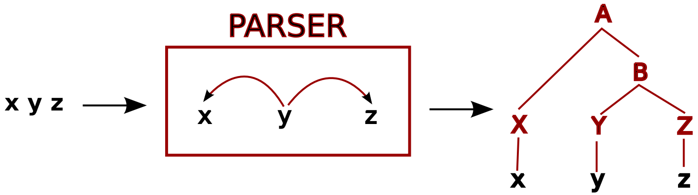
Introduction

- Syntactic parsing of natural language:
  - Who does what to whom?
- Dependency-based syntactic representations
  - Binary, asymmetric relations between words
  - Long tradition in descriptive linguistics
  - Increasingly popular in computational linguistics



Varieties of Dependency Parsing

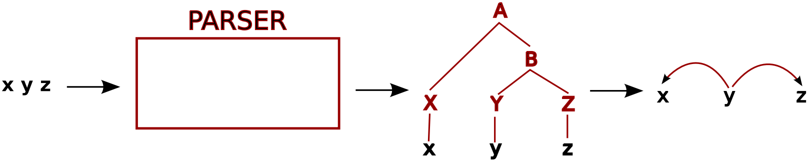
- Dependencies as internal representations (for parsers)
  - Dependency relations useful for disambiguation
  - Incorporated into head-lexicalized grammars



Example: The Collins Parser [Collins 1997]

Varieties of Dependency Parsing

- Dependencies as final representations (for applications)
  - Information extraction [Culotta and Sorensen 2004]
  - Question answering [Bouma et al. 2005]
  - Machine translation [Ding and Palmer 2004]



Example: The Stanford Parser [Klein and Manning 2003]

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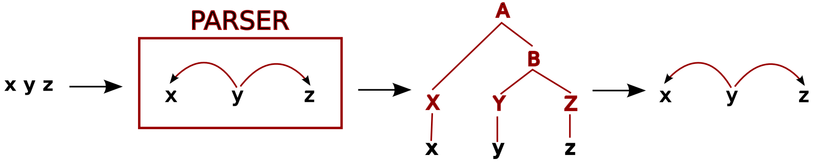
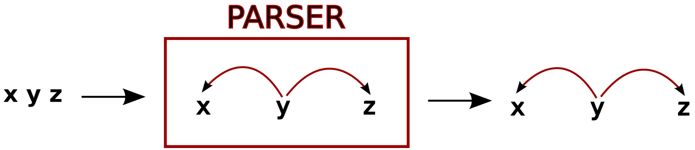


Example: The Stanford Parser [Klein and Manning 2003]

Varieties of Dependency Parsing

- Dependencies as the one and only representation
  - If we only want a dependency tree, why do more?
  - Bare-bones dependency parsing [Eisner 1996]



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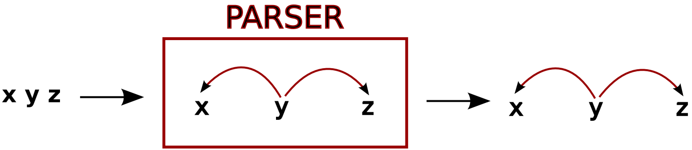


Occam's razor: pluralitas non est ponenda sine necessitate

Outline

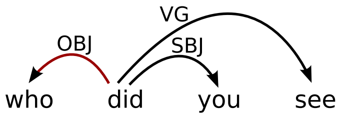
- Basic concepts of dependency parsing
  - Representations, metrics, benchmarks
- Parsing methods for bare-bones dependency parsing
  - Chart parsing techniques
  - Parsing as constraint satisfaction
  - Transition-based parsing
  - Hybrid methods
- Comparative evaluation
  - Different types of parsers evaluated on dependency output
  - Can we really appeal to Occam's razor?

Dependency Graphs

- A dependency graph for a sentence $S = w_1, \ldots, w_n$ is a directed graph $G = (V, A)$, where:
  - $V = \{1, \ldots, n\}$ is the set of nodes, representing tokens,
  - $A \subseteq V \times V$ is the set of arcs, representing dependencies.
- Note:
  - Arc $i \rightarrow j$ is a dependency with head w_i and dependent w_j
  - Arc $i \rightarrow j$ may be labeled with a dependency type $r \in R$

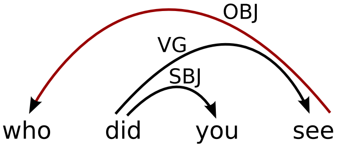
Constraints on Dependency Graphs

- *G* must be a projective tree
  - All subtrees have a contiguous yield
  - Simple conversion from/to phrase structure trees
  - Hard to represent long-distance dependencies



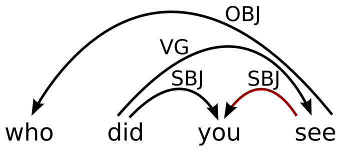
Constraints on Dependency Graphs

- *G* must be a tree
  - Subtrees may have a discontiguous yield
  - Allows non-projective arcs for long-distance dependencies
  - Prague Dependency Trebank [Hajič et al. 2001] (25% trees)



Constraints on Dependency Graphs

- *G* must be connected and acyclic (DAG)
  - A node may have more than one incoming arc
  - Allows multiple heads for deep syntactic relations
  - Danish Dependency Trebank [Kromann 2003]



Parsing Problem

- **Input:** $S = w_1, \ldots, w_n$
- **Output:** $G^* = \operatorname*{argmax}_{G \in \mathcal{G}(S)} \mathcal{F}(S, G)$
- Note:
  - $\mathcal{F}(S, G)$ is the score of G for S
  - $\mathcal{G}(S)$ is the space of possible dependency graphs for S
  - Nodes given by input, only arcs need to be found
  - With tree constraint, assignment of head h_i and relation r_i

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	Relation $r_i \in R$	OBJ	ROOT	SBJ	VG
Output	Head $h_i \in V \cup \{0\}$	4	0	2	2
Input	Node $i \in V$	1	2	3	4
	Word $w_i \in S$	who	did	you	see
	PoS tag	WP	VBD	PRP	VB

Evaluation Metrics

- Accuracy on individual arcs:

$$\text{Recall (R)} = \frac{|\text{PARSED} \cap \text{GOLD}|}{|\text{GOLD}|}$$

$$\text{Precision (P)} = \frac{|\text{PARSED} \cap \text{GOLD}|}{|\text{PARSED}|}$$

$$\text{Attachment score (AS)} = \text{P} = \text{R (only for trees)}$$

- All metrics can be labeled (L) or unlabeled (U)

Benchmark Data Sets

- Penn Treebank (PTB) [Marcus et al. 1993]:
  - Phrase structure annotation converted to dependencies
  - Penn2Malt – projective trees [Nivre 2006]
  - Stanford – projective trees or graphs [de Marneffe et al. 2006]
- Prague Dependency Treebank (PDT) [Hajič et al. 2001]:
  - Native dependency annotation – non-projective trees
- CoNLL Shared Tasks [Buchholz and Marsi 2006, Nivre et al. 2007]:
  - CoNLL-06: 13 languages (trees, mostly non-projective)
  - CoNLL-07: 10 languages (trees, mostly non-projective)

Parsing Methods

- Parsing methods for bare-bones dependency parsing
  - Chart parsing techniques
  - Parsing as constraint satisfaction
  - Transition-based parsing
  - Hybrid methods

Chart Parsing Techniques

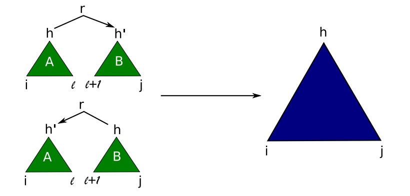
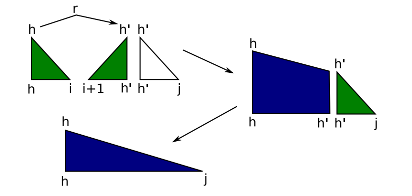
- Context-free dependency grammar:

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

- Parsing methods:
  - Standard chart parsing techniques (CKY, Earley, etc.)
  - Goes back to the 1960s [Hays 1964, Gaifman 1965]
  - Grammar can be augmented/replaced with statistical model
  - Efficiency gains thanks to dependency tree constraints

Eisner's Algorithm

- In standard CKY style parsing, chart items are trees
- Eisner's algorithm [Eisner 1996, Eisner 2000]:
  - Split head representation
  - Chart items are (complete or incomplete) half-trees

<table>
<tr><th>CKY</th><th>Eisner</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>$\mathcal{C}[i, h, l, h', j] \Rightarrow O(n^5)$</td><td>$\mathcal{C}[h, h', j] \Rightarrow O(n^3)$</td></tr>
</table>

Statistical Models

- Chart parsing requires factorized scoring function $\mathcal{F}$:

$$T^* = \underset{T \in \mathcal{T}(S)}{\text{argmax}}\, \mathcal{F}(S, T)$$

$$\mathcal{F}(S, T) = \sum_{g \in T} f(S, g)$$

- Size of subgraph g determines model complexity

Model	Subgraph	TC	PTB	Reference
1st-order		$O(n^3)$	90.9	[McDonald et al. 2005a]
2nd-order		$O(n^3)$	91.5	[McDonald and Pereira 2006]
3rd-order		$O(n^4)$	93.0	[Koo and Collins 2010]

Beyond Projective Trees

- Context-free techniques are limited to projective trees
- Extension to mildly non-projective trees:
  - Well-nested trees with gap degree 1 in $O(n^7)$ time [Kuhlmann and Satta 2009, Gómez-Rodríguez et al. 2009]
- Post-processing techniques:
  - 2nd-order model + hill-climbing [McDonald and Pereira 2006]
  - Can handle non-projective arcs as well as multiple heads
  - Top-scoring model in CoNLL-06 [MSTParser]

Parsing as Constraint Satisfaction

- Constraint dependency grammar [Maruyama 1990]:
  - Variables $h_1, \ldots, h_n$ with domain $\{0, 1, \ldots, n\}$
  - Grammar $\mathcal{G}$ = set of boolean constraints
  - Parsing = search for tree in $\{T \in \mathcal{T}(S) \,|\, \forall c \in \mathcal{G} : c(S, T)\}$
- Adding soft weighted constraints [Menzel and Schröder 1998]:

$$T^* = \operatorname*{argmax}_{T \in \mathcal{T}(S)} \prod_{c : \neg c(S,T)} f(c)$$

- Characteristics:
  - Non-projective trees easily accommodated
  - Constraints not inherently restricted to local subgraphs
  - Exact inference intractable except in restricted cases

Approaches to Inference

- Maximum spanning tree parsing [McDonald et al. 2005b]:
  - First-order model: constraints restricted to single arcs
  - T^* = maximum spanning tree in complete graph
  - Exact parsing with non-projective trees in $O(n^2)$ time
  - "An island of tractability" (D. Smith)
- Approximate inference for higher-order models:
  - Transformational search [Foth et al. 2004]
  - Gibbs sampling [Nakagawa 2007]
  - Loopy belief propagation [Smith and Eisner 2008]
  - Linear programming [Riedel and Clarke 2006, Martins et al. 2009]

Transition-Based Approaches

- Transition-based dependency parsing:
  - Define a transition system for dependency parsing
  - Train a classifier for predicting the next transition
  - Use the classifier to do deterministic parsing
- Open source implementation:
  - MaltParser [Nivre et al. 2006]
    http://maltparser.org
- Characteristics:
  - Highly efficient – linear time complexity for projective trees
  - History-based feature models with unrestricted scope
  - Sensitive to local prediction errors and error propagation

Arc-Eager Shift-Reduce Parsing [Nivre 2003]

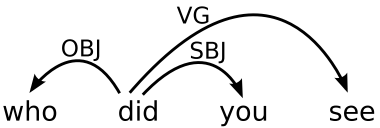
Start state: $([\,], [1, \ldots, n], \{\,\})$

Final state: $(S, [\,], A)$

Shift:	$(S, i\|B, A)$	$\Rightarrow$	$(S\|i, B, A)$
Reduce:	$(S\|i, B, A)$	$\Rightarrow$	$(S, \mathrm{B}, \mathrm{A})$
Right-Arc:	$(S\|i, j\|B, A)$	$\Rightarrow$	$(S\|i\|j, B, A \cup \{i \rightarrow j\})$
Left-Arc:	$(S\|i, j\|B, A)$	$\Rightarrow$	$(S, j\|B, A \cup \{i \leftarrow j\})$

Parsing Example

Stack	Buffer	Arcs
$[\,]_S$	$[\text{who, did, you, see}]_B$	$\{\,\}$



Parsing Example

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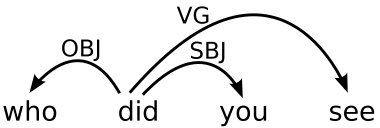
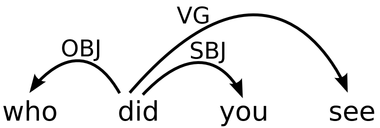


Parsing Example

Stack	**Buffer**	**Arcs**
$[\ ]_S$	$[\text{did, you, see}]_B$	$\{\ \text{who} \xleftarrow{\text{OBJ}} \text{did}\ \}$



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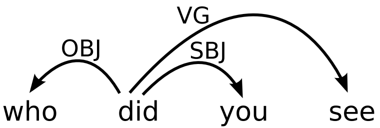
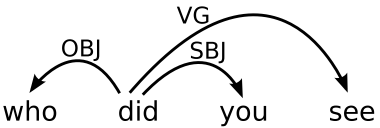


Parsing Example

Stack	Buffer	Arcs
$[\text{did}, \text{you}]_S$	$[\text{see}]_B$	$\{ \text{who} \xleftarrow{\text{OBJ}} \text{did}, \text{did} \xrightarrow{\text{SBJ}} \text{you} \}$



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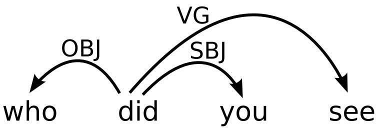
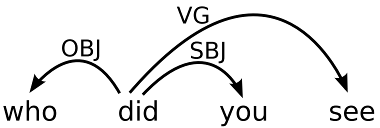


Parsing Example

Stack	**Buffer**	**Arcs**
$[\text{did}, \text{see}]_S$	$[\,]_B$	$\{\text{who} \xleftarrow{\text{OBJ}} \text{did}, \text{did} \xrightarrow{\text{SBJ}} \text{you}, \text{did} \xrightarrow{\text{VG}} \text{see}\}$



Statistical Models

- Parse defined by transition sequence $C = c_0, c_1, \ldots, c_n$
- Local learning [Yamada and Matsumoto 2003, Nivre et al. 2004]:
  - Maximize accuracy of local prediction $f(c_i, c_{i+1})$
  - Deterministic parsing with 1-best configuration
  - Top-scoring model in CoNLL-06 [MaltParser]
- Global learning [Titov and Henderson 2007, Zhang and Clark 2008]:
  - Maximize accuracy over entire sequence $\sum_{i=0}^{n-1} f(c_i, c_{i+1})$
  - Beam search with k-best configurations
  - State of the art on PTB: 82.9 UAS [Zhang and Nivre 2011]

Beyond Projective Trees

- Directed acyclic graphs in linear time [Sagae and Tsujii 2008]:

  Right-Arc: $(S|i, j|B, A) \Rightarrow (S|i, j|B, A \cup \{i \rightarrow j\})$
  Left-Arc: $(S|i, j|B, A) \Rightarrow (S|i, j|B, A \cup \{i \leftarrow j\})$

- Subset of non-projective trees in linear time [Attardi 2006]:

  Right-Arc2: $(S|i|k, j|B, A) \Rightarrow (S|i|k, B, A \cup \{i \rightarrow j\})$
  Left-Arc2: $(S|i|k, j|B, A) \Rightarrow (S|k, j|B, A \cup \{i \leftarrow j\})$

- All non-projective trees in linear expected time [Nivre 2009]:

  Swap: $(S|i|k, j|B, A) \Rightarrow (S|i, j|k|B, A)$

Hybrid Methods

- Parser combination by voting:
  - Majority vote for h_i [Zeman and Žabokrtský 2005]
  - Vote for $f(S, g)$ in MST parsing [Sagae and Lavie 2006]
  - Top-ranked system in CoNLL-07 [Hall et al. 2007]
- Parser combination by stacking:
  - Let P2 learn from output of P1 [Nivre and McDonald 2008]
  - Substantial improvement for best systems in CoNLL-06 [Nivre and McDonald 2008, Torres Martins et al. 2008]
- Parser combination by dual decomposition:
  - Optimize joint score $\mathcal{F}_1(T) + \mathcal{F}_2(T)$
  - 1st-order MST + 3rd-order non-projective chart parsing
  - State of the art for PDT and CoNLL-06 [Koo et al. 2010]

Comparative Evaluation

- Bare-bones dependency parsers against the world
  - Do we need phrase structure to derive dependency trees?
  - How do different parsers compare in terms of efficiency?
  - Do we have a case for Occam's razor?

English: PTB → Penn2Malt

		UAS
[Yamada and Matsumoto 2003]	Trans-Local	90.3
[Collins 1999]*	PCFG	91.5
[Charniak 2000]*	PCFG	92.1

* Result not in original paper

English: PTB $\rightarrow$ Penn2Malt

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[Koo et al. 2010]	Hybrid-Dual	92.5
[Sagae and Lavie 2006]	Hybrid-MST	92.7

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[Sagae and Lavie 2006]	Hybrid-MST	92.7
[Petrov et al. 2006]*	PCFG-Latent	92.8
[Charniak and Johnson 2005]*	PCFG+Rank	93.7

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[Sagae and Lavie 2006]	Hybrid-MST	92.7
[Petrov et al. 2006]*	PCFG-Latent	92.8
[Zhang and Nivre 2011]	Trans-Global	92.9
[Koo and Collins 2010]	Chart-3rd	93.0
[Charniak and Johnson 2005]*	PCFG+Rank	93.7

* Result not in original paper

Czech: PDT

		UAS
[Collins 1999]*	PCFG	82.2
[Charniak 2000]*	PCFG	84.3

* Result not in original paper

Czech: PDT

		UAS
[Collins 1999]*	PCFG	82.2
[McDonald et al. 2005a]	Chart-1st	83.3
[Charniak 2000]*	PCFG	84.3
[McDonald et al. 2005b]	MST	84.4

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[Charniak 2000]*	PCFG	84.3
[McDonald et al. 2005b]	MST	84.4
[Hall and Novák 2005]	PCFG+Post	85.0
[McDonald and Pereira 2006]	Chart-2nd+Post	85.2

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[Charniak 2000]*	PCFG	84.3
[McDonald et al. 2005b]	MST	84.4
[Hall and Novák 2005]	PCFG+Post	85.0
[McDonald and Pereira 2006]	Chart-2nd+Post	85.2
[Zeman and Žabokrtský 2005]	Hybrid-Greedy	86.3
[Koo et al. 2010]	Hybrid-Dual	87.3

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[Hall and Novák 2005]	PCFG+Post	85.0
[McDonald and Pereira 2006]	Chart-2nd+Post	85.2
[Nivre 2009]*	Trans-Local	86.2
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[Koo et al. 2010]	Hybrid-Dual	87.3

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English: PTB $\longrightarrow$ Stanford Dependencies

		LF1	UF1	PTime
MSTParser	Chart-2nd	78.8	82.6	6:01
MaltParser	Trans-Local	81.1	84.8	3:23
Stanford	PCFG	84.2	87.2	11:05
Bikel	PCFG	85.3	88.7	29:57
Charniak	PCFG	87.8	90.5	12:10
Berkeley	PCFG-Latent	87.9	90.5	10:14
Charniak & Johnson	PCFG+Rerank	89.1	91.7	11:18

Cer, D., de Marneffe, M.-C., Jurafsky, D. and Manning, C. (2010) Parsing to Stanford Dependencies: Trade-offs between Speed and Accuracy. In *Proceedings of LREC 2010*.

- Evaluation on collapsed dependencies (lossy conversion)
- Dependency parsers with default settings (unoptimized)

French: FTB $\rightarrow$ Dependencies

		LAS	UAS	PTime
Berkeley	PCFG-Latent	85.6	89.6	12:46
MaltParser	Trans-Local	86.7	89.3	1:25
MSTParser	Chart-2nd	87.6	90.3	14:39

Candito, M. Nivre, J. Denis, P. and Henestroza Anguiano, E. (2010) Benchmarking of Statistical Dependency Parsers for French. In *Coling 2010: Posters*, pp. 108–116.

- Berkeley most accurate PCFG parser [Seddah et al. 2009]
- Very similar accuracy across parsers
- Transition-based parser ten times faster than the others

Conclusion

- Bare-bones dependency parsing:
  - Competitive in terms of parsing accuracy
  - Often superior in terms of run-time efficiency
  - Still a field in very rapid development . . .
- Occam's razor?
  - The jury is still out . . .
  - But if all you want is a dependency tree . . .

- Giuseppe Attardi. 2006. Experiments with a multilanguage non-projective dependency parser. In *Proceedings of the 10th Conference on Computational Natural Language Learning (CoNLL)*, pages 166–170.
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