Syntactic Analysis

Daniel Zeman

March 11, 2020
### Syntactic Annotation

<table>
<thead>
<tr>
<th>ID</th>
<th>FORM</th>
<th>LEMMA</th>
<th>POS</th>
<th>FEATS</th>
<th>HEAD</th>
<th>DEPREL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>They</td>
<td>they</td>
<td>PRON</td>
<td>Case...</td>
<td>2</td>
<td>nsubj</td>
</tr>
<tr>
<td>2</td>
<td>buy</td>
<td>buy</td>
<td>VERB</td>
<td>Mood...</td>
<td>0</td>
<td>root</td>
</tr>
<tr>
<td>3</td>
<td>and</td>
<td>and</td>
<td>CCONJ</td>
<td>_</td>
<td>4</td>
<td>cc</td>
</tr>
<tr>
<td>4</td>
<td>sell</td>
<td>sell</td>
<td>VERB</td>
<td>Mood...</td>
<td>2</td>
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<tr>
<td>5</td>
<td>books</td>
<td>book</td>
<td>NOUN</td>
<td>Number...</td>
<td>2</td>
<td>obj</td>
</tr>
<tr>
<td>6</td>
<td>.</td>
<td>.</td>
<td>PUNCT</td>
<td>_</td>
<td>2</td>
<td>punct</td>
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They buy and sell books.
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<td>prodávat</td>
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<td>Kupují</td>
<td>kupovat</td>
<td>VB-P---3P-AA---</td>
<td>2</td>
<td>Pred_Co</td>
</tr>
<tr>
<td>2</td>
<td>a</td>
<td>a</td>
<td>J^------------</td>
<td>0</td>
<td>Coord</td>
</tr>
<tr>
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<td>prodávat</td>
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<td>kniha</td>
<td>NNFP4------A----</td>
<td>2</td>
<td>Obj</td>
</tr>
<tr>
<td>5</td>
<td>.</td>
<td>.</td>
<td>Z:------------</td>
<td>0</td>
<td>AuxK</td>
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Kupují a prodávají knihy.
Constituents vs. Dependencies
What Is (Surface) Syntax?

- Relations between sentence parts
- Sentence part = token (word, number, punctuation)
  - Advantages:
    - Token is easily recognizable
    - Unit of previous (morphological) level of processing
    - We do not restore elided (missing) constituents at this level
  - Drawbacks:
    - We must define relations for function words and punctuation

- Purpose:
  - Understand how meaning of words combines into meaning of sentence
  - Some theories also want to show how the sentence was generated
**Syntactic Structure**

- Different shapes in different theories
- Typically a hierarchical structure – *tree*
  - Phrasal (constituent) tree, parse tree
  - Dependency tree
Constituent Tree

(S (NP (N Paul)) (VP (V gave) (NP (N Peter)) (NP (C two) (N pears)))))
Paul gave Peter two pears.
Dependency Tree with Labels

[#,0] ([gave,2] ([Paul,1], [Peter,3], [pears,5] ([two,4])), [,6])

# / AuxS
  
gave / Pred
    
Paul / Sb
   
Peter / Obj
    
pears / Obj
      
two / Atr
Paul gave Peter two pears

Dependency Tree with Labels

Syntactic Analysis

Phrases, Their Types and Their Heads  Dependency Parsing
Constituents vs. Dependencies

- The two models are interconnected

- Sentence divided to phrases (constituents)
  - Recursive: phrases divided to smaller phrases
  - The smallest phrases are words

- There are dependencies (relations) between words (constituents)
  - Head of phrase = governing node, parent node
  - The other nodes are dependent nodes, children of the head
Phrase vs. Dependency Trees

Syntactic Analysis

Constituents vs. Dependencies

Phrases, Their Types and Their Heads

Dependency Parsing

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Phrase vs. Dependency Trees

- Phrase trees
  - Usually do not mark the head
  - May not mark the function of the constituent in the superordinate constituent
Phrase vs. Dependency Trees

- **Phrase trees**
  - Usually do not mark the **head**
  - May not mark the **function** of the constituent in the superordinate constituent

- **Dependency trees**
  - Do not show **nonterminals** (phrase types)
    - Nor any other phrase-level features
  - Do not show “how the sentence is generated” (order, recursion, **proximity** of constituents)
Example

Syntactic Analysis

Constituents vs. Dependencies

Phrases, Their Types and Their Heads

Dependency Parsing
Phrases, Their Types and Their Heads
Phrase Replaceability

- A phrase can be replaced by another phrase of the same type
- The sentence stays grammatical
- Specifically, a phrase can be replaced by its head
  - This is related to the generation of the sentence

- Phrases $x, y, z$ can be immediate constituents of a larger phrase $f$ only if they are related to each other. This is however a matter of the particular phrase structure grammar.

- Example sentence: *This is the man that I talked about.*
  - The part *man that I* is not a whole noun phrase.
  - Cannot replace it by another noun phrase, e.g., *man*:
  - *This is the man talked about.*
- Sequence of immediate constituents (words or phrases)
- May be discontinuous in some languages
- Phrase types by their main word—head
  - Noun phrase: the new book of my grandpa
  - Adjectival phrase: brand new
  - Adverbial phrase: very well
  - Prepositional phrase: in the classroom (if preposition is considered the head—somewhat controversial (cannot replace whole phrase by preposition))
  - Verb phrase: to catch a ball
A noun or a (substantive) pronoun is the head.

- *water*
- *the book*
- *new ideas*
- *two millions of inhabitants*
- *one small village*
- *the greatest price movement in one year since the World War II*
- *operating system that, regardless of all efforts by our admin, crashes just too often*
- *he*
- *whoever*
An adjective or a determiner (attributive pronoun) is the head.

Simple adjectives are very frequent, complex ADJPs are rare.

- *old*
- *very old*
- *really very old*
- *five times older than the oldest elephant in our zoo*
- *sure that he will arrive first*
**Pronouns / Determiners**

- **(Substantive) pronouns**: similar behavior as nouns
  - Personal pronouns (*I, you, they, oneself*)
  - Some demonstrative, interrogative, relative and negative pronouns (*who, what, somebody, something, everything, nothing*)

- **Attributive pronouns (determiners)**: similar behavior as adjectives
  - Possessive pronouns in some languages (*my, your, his, whose*)
  - Articles (*the, a, an*)
  - Attributively used demonstrative, interrogative, relative and negative pronouns (*which, some, every, no*)
Numerals and Quantified Noun Phrases

- Slavic languages: not always clear what should be the head: the quantifier (number), or the counted noun?
  - Numeral inherits gender from counted noun.
  - Counted noun gets grammatical number from numeral (or in accord with it).
    - *jeden muž* “one man”, *jedna žena* “one woman”, *jedno dítě* “one child”
    - *dva muži* “two men”, *dvě ženy* “two women”, *dvě děti* “two children”
  - Numeral may govern the case of the counted noun.
    - *pět mužů* “five men” – noun in genitive, numeral in nominative, accusative, or vocative
  - Or both numeral and counted noun have case required by preposition or verb.
    - *pěti ženami* “five women” – instrumental case
An adverb is the head.

Simple adverbs are very frequent, complex ADVPs are rare.

- quickly
- much more
- how
- louder than you can imagine
- yesterday
Many theories: preposition is the head (it determines the case of the rest of the phrase)

But we cannot replace the phrase by the preposition alone! (Nor can we replace it by
the noun without the preposition.)

PPs often have functions similar to adverbial phrases or noun phrases.

Preposition in one language may correspond to case morphology in another language.

- *in* the city center
- *in* January
- *in* God
- *around* five o’clock
- *to* a better future
- *up to* a situation where neither of them could back out
- *with respect to* his nonage
Ambiguity in Attachment of Prepositional Phrases

- Classic English example:
  - *I saw the man with a telescope.*
    - “Viděl jsem muže dalekohledem.”
    - “Viděl jsem muže s dalekohledem.”
Přišel ten pán se sousedem odnaproti. “The gentleman came with his neighbor from across the street.”

(Odnaproti is an adverb arisen as a frozen PP: od + naproti.)
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Ambiguity in Attachment of Prepositional Phrases: Czech Example

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Ambiguity in Attachment of Prepositional Phrases: Czech Example

Přišel ten pán se sousedem odnaproći. “The gentleman came with his neighbor from across the street.”

(*Odnaproći* is an adverb arisen as a frozen PP: *od* + *naproći.* )

Syntactic Analysis

Constituents vs. Dependencies

Dependency Parsing
Prepositional Phrase Attachment Ambiguity: Corpus Example


- “In years 1991 – 1993 I attended classes of management and marketing at Collège Bart in Canadian Québec.”

(A Czech sentence from the Prague Dependency Treebank.)
In years 1991 – 1993 I attended classes of management and marketing at Collège Bart in Canadian Québec.

- attended at Collège Bart
- classes at Collège Bart
- management and marketing at Collège Bart
- marketing at Collège Bart
- Collège Bart in Québec
- marketing in Québec
- management and marketing in Québec
- classes in Québec
- attended in Québec
In years 1991 – 1993 I attended classes of management and marketing at Collège Bart in Canadian Québec.

- attended (classes (of (management and marketing))) (at Collège Bart)
- attended (classes (of (management and marketing)) (at Collège Bart))
- attended (classes (of (management and marketing) (at Collège Bart)))
- attended (classes (of (management and (marketing (at Collège Bart)))))
- … ((at Collège Bart) (in Québec))
  - Is Collège Bart in Québec or Québec in Collège Bart?
Prepositional Phrase Attachment Ambiguity: News Example

- *říjnové jednání OSN o klimatických změnách v Kodani* (Události ČT, 27.2.2009)
- “October UNO summit about climatic changes in Copenhagen” (Czech TV news, 2009-02-27)

- Question:
  Were there climatic changes in Copenhagen?
The repertory depends on the rules for analytical verb forms and varies greatly across languages.

- *it rains*
- *he could at all sight Mr. President*
- *why we got wet so much*
- *Go!*
- *he has been transported to the hospital on Sunday*
- *it began to rain*
- *the law prohibits smoking in this room*
- *give Mary the beads that we brought from the vacation in Morocco*
- *the file could not be opened*
- **One predicate** together with its arguments and modifiers, e.g.:
  - *John loves Mary.*
  - ... *that you are right.*

- Not recursive ⇒ not necessarily the same as a verb phrase (VP).
  - Nested phrases are part of the superordinate phrase.
  - Nested clauses are not parts of the main (‘matrix’) clause.
Coordination

- There is no real head ⇒ difficult to capture in dependency trees.
- The coordinate phrases (conjuncts) are usually of the same type.
  - chickens, hens, rabbits, cats and dogs
  - new or even newer
  - quickly and finely
  - he came to the conclusion that there is no point in hiding any more, so we might hear him here today
  - in the house or outside
  - to and from Prague
  - either now or later
  - not only on Monday and on Wednesday but also tomorrow or the day after tomorrow
  - veni, vidi, vici
Ellipsis

- A phrase omitted from the (surface form of the) sentence although it is present in the underlying meaning (deep structure).
- Often in dialogues: the elided information is known from context.
  - *Whom did you see there? — Peter.* (missing verb)
- Also often in coordination:
  - *Czech and German researchers discussed...* It probably means *Czech researchers and German researchers discussed.* Unlikely that each researcher was Czech and German at the same time.
  - *The Penguins are leading 4:0, while the Colorado Avalanches only 3:2.* (missing verb in the second part)
- Systemic elision of subject pronouns in pro-drop languages (it is marked on the verb).
  - *Sedím.* “(I) sit.”
Dependency Parsing
Dependency Parsing

- Automatically assign a dependency tree to a sentence.
- Machine-learning: manually annotated “gold standard” data needed!

**Chart** (Eisner, CKY)
  - $O(n^3)$
  - Produces only projective parses
    (if $x$ directly depends on $y$, all words between $x$ and $y$ transitively depend on $y$)
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- **Transition-based** (shift-reduce)
  - $O(n)$ (fast!)
  - Can be extended to capture nonprojectivity
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- **Transition-based** (shift-reduce)
  - $O(n)$ (fast!)
  - Can be extended to capture nonprojectivity

- **Graph-based** (MST)
  - $O(n^2)$
  - Can produce projective and nonprojective parses
Transition-Based Parsers: Malt

- Nivre et al., *Natural Language Engineering* 2007
- http://maltparser.org/
- Based on *transitions* from one configuration to another
- Configuration:
  - Input buffer (words of the sentence, left-to-right)
  - Stack
  - Output tree (words, edges, labels)
- Transitions:
  - **Shift**: move word from buffer to stack
  - **Larc**: connect two topmost stack words (higher is parent)
  - **Rarc**: connect two topmost stack words (lower is parent)
Malt Parser

- Driven by oracle
  - Looks at current configuration
  - Selects next transition
Malt Parser

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- Training: decompose the training tree to a sequence of transitions
  - Sometimes more than one possibility
    - Various learning strategies: e.g. create dependencies eagerly, as soon as possible
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- Training: decompose the training tree to a sequence of transitions
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- The oracle learns based on the features of the configuration
  - E.g. word, lemma, POS, case, number...
    - $n^{th}$ word from the top of the stack
    - $k^{th}$ word remaining in the buffer
    - particular node in output tree part created so far
Malt Parser

- Machine learning responsible for training, here the Support Vector Machines (SVM)
  - Classifier. Input vectors: values of all features of the current configuration
  - In addition, during training there is the output value, i.e. action identifier (shift / larc / rarc)
  - The trained oracle (SVM) tells the output value during parsing

- Training on the whole PDT may take weeks!
  - Complexity $O(n^2)$ where $n$ is number of training examples
  - Over 3 million training examples can be extracted from PDT

- Parsing comparatively faster (~ 1 sentence / second) and can be parallelized
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<tr>
<th>STACK</th>
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<tr>
<td>ROOT</td>
<td>Pavel dal Petrovi dvě hrušky .</td>
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Pavel dal Petrovi dvě hrušky .
Pavel gave Petr two pears .
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LARC

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Constituents vs. Dependencies  Phrases, Their Types and Their Heads

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RARC

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Syntactic Analysis
Constituents vs. Dependencies  Phrases, Their Types and Their Heads

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<td>dal dvě hrušky</td>
</tr>
</tbody>
</table>

Pavel dal Petrovi dvě hrušky .
Pavel gave Petr two pears .
Example of Malt Parsing

<table>
<thead>
<tr>
<th>STACK</th>
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<tbody>
<tr>
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<td>.</td>
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</table>

LARC

Pavel dal Petrovi dvě hrušky .
Pavel gave Petr two pears .

Syntactic Analysis  Constituents vs. Dependencies  Phrases, Their Types and Their Heads
Example of Malt Parsing

<table>
<thead>
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Pavel gave Petr two pears.
Example of Malt Parsing

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RARC

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Example of Malt Parsing

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Pavel dal Petrovi dvě hrušky .
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Syntactic Analysis
Constituents vs. Dependencies  Phrases, Their Types and Their Heads
Example of Malt Parsing

STACK | BUFFER
ROOT  dal | .

SHIFT

Pavel dal Petrovi dvě hrušky .
Pavel gave Petr two pears .
Example of Malt Parsing

<table>
<thead>
<tr>
<th>STACK</th>
<th>BUFFER</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROOT dal</td>
<td></td>
</tr>
</tbody>
</table>

Pavel dal Petrově dvě hrušky.
Pavel gave Petr two pears.
Example of Malt Parsing

**STACK** | **BUFFER**
---|---
ROOT dal | 

**RARC**

Pavel dal Petrovi dvě hrušky .
Pavel gave Petr two pears .

Syntactic Analysis

Constituents vs. Dependencies  Phrases, Their Types and Their Heads
Example of Malt Parsing

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Pavel gave Petr two pears.

Pavel dal Petrovi dvě hrušky.
Example of Malt Parsing

Syntactic Analysis
Constituents vs. Dependencies  Phrases, Their Types and Their Heads

STACK  |  BUFFER
ROOT   | dal

RARC

Pavel dal Petrovi dvě hrušky.
Pavel gave Petr two pears.
Example of Malt Parsing

<table>
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Pavel gave Petr two pears.

Syntactic Analysis

Constituents vs. Dependencies  Phrases, Their Types and Their Heads
So Far Only Projective Trees

- It can be proven that the above transition system is correct:
  - resulting graph is always a tree (connected, cycle-free)

- There are extensions that can produce non-projective trees
- Non-projective constructions occur in natural languages but they are rare
So Far Only Projective Trees

- It can be proven that the above transition system is
  - correct
    - resulting graph is always a tree (connected, cycle-free)
  - complete for the set of projective trees
    - every projective tree can be expressed as a sequence of transitions

- There are extensions that can produce non-projective trees
- Non-projective constructions occur in natural languages but they are rare