Introduction to Natural Language Processing

a course taught as B4M36NLP at Open Informatics

by members of the Institute of Formal and Applied Linguistics

Today: **Week 6, lecture**

Today's topic: **Syntactic Analysis**

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Level of (Surface) Syntax

- Relations between sentence parts
- Sentence part = token (word, number, punctuation)
  - Practical reasons:
    - Easily recognizable.
    - Unit of previous (morphological) level of processing.
    - We don't restore elided constituents, nor do we collapse nodes of function words; this can be done later on a deep-syntactic level.
  - On the other hand:
    - We must now also define relations between function words (prepositions, auxiliary verbs etc.), punctuation and the rest of the sentence.

Level of Surface Syntax

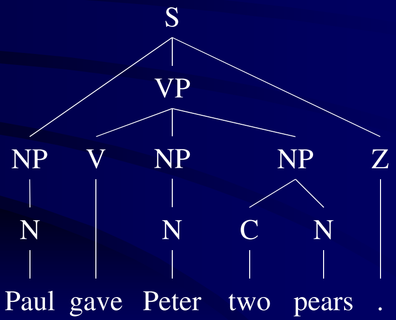
- Between morphology and meaning.
- Morphology provides / requires:
  - lemmas (it's time to obtain syntactic info from the dictionary)
  - tags (part of speech and morphosyntactic features)
  - word order (now it starts to play a role)
- Typical input is ambiguous
  - ambiguous morphological analysis
- Typical output is ambiguous
  - several syntactic structures for one sentence (several readings of the sentence)

Syntactic Structure

- Different shapes in different theories
- Typically a tree
  - Phrasal (constituent) tree, parse tree
  - Dependency tree

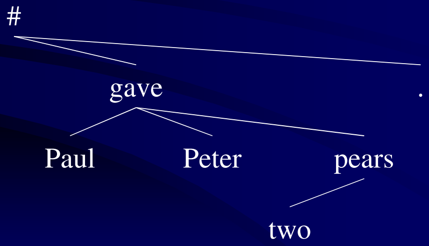
Example of Constituent Tree

- ((Paul (gave Peter (two pears))) .)



Example of Dependency Tree

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



Words and Phrases

- Word (token)
  - smallest unit of the syntactic layer
  - grammatical (function, synsemantic) words (e.g. *and* in coordination *Paul and Peter*, *to be* in compound verb forms *he is scared*, *he will be scared*)
  - lexical (content, autosemantic) words (e.g. *dog*; *to be* in the sentence *I think, therefore I am*. (René Descartes))
- Phrase
  - composed of words and/or other phrases **(immediate constituents)**

Words

- Relation to other words
  - Lexicon contains information on words and possible relations among them.
    - Subcategorization of verbs and other words (do they require an object? if so, should it be marked for a particular case?)
    - Semantic features (a noun has color, has size, can act as the subject of a particular set of verbs…)
- Idioms, multi-word expressions
  - Fixed, indivisible phrases may act as one word (e.g. compound prepositions *(in spite of)*, foreign citations and named entities *(Rio de Janeiro)*, compound nouns written as separate tokens *(stock exchange)*)

Phrase Replaceability

- A phrase can be replaced by another phrase of the same type. Specifically, it can be replaced by its head.
  - This is related to the generation of the sentence.

⇒ The 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 because it cannot be replaced by another noun phrase, e.g. *man*: *"*This is the man talked about."*

Phrase

- Phrase
  - Sequence of immediate constituents (words or phrases).
  - May be discontinuous in some languages. `cs:` *„Soubor se nepodařilo otevřít.“* (lit. *File oneself one-was-not-able to-open*) contains the phrase *“open file”*.
- 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*
  - Verb phrase: *to catch a ball*

Noun Phrase

- 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*

Adjective Phrase

- An adjective or a determiner (attributive pronoun) is the head.
- Simple ADJPs are very frequent, complex ones 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 (*who, what*, *somebody*, *something*, *nothing*).
- Attributive pronouns (determiners): similar behavior as adjectives
  - Possessive pronouns (*my*, *your*, *his*, *whose*).
  - Articles (*the, a, an*).
  - Attributively used demonstrative, interrogative, relative and negative pronouns (*which, some, every, no*).

Numeral Phrases

- In Slavic languages not always clear what should be the head: the number, or the counted noun phrase?
  - The numeral inherits the gender of the counted noun. The noun gets its grammatical number from the numeral.
    - *jeden muž (one man), jedna žena (one woman), jedno dítě (one child)*
    - *dva muži (two men), dvě ženy (two women), dvě děti (two children)*
  - The numeral governs the case of the counted noun.
    - *pět mužů (five men*: noun in genitive, numeral in nominative, accusative or vocative)
  - Both the counted noun and the numeral have a case required by their governing preposition or verb.
    - *pěti ženami (five women*: instrumental)

Adverbial Phrases

- An adverb is the head.
  - *quickly*
  - *much more*
  - *how*
  - *louder than you can imagine*
  - *yesterday*

Prepositional (Postpositional) Phrase

- The preposition serves as head (because it determines the case of the rest of the phrase).
- Often have a function similar to adverbial phrases (adverbiale) or noun phrases (object of a verb).
  - *<u>in</u> the city center*
  - *<u>in</u> God*
  - *<u>around</u> five o'clock*
  - *<u>to</u> a better future*
  - *up <u>to</u> a situation where neither of them could back out*
  - *with respect <u>to</u> his nonage*

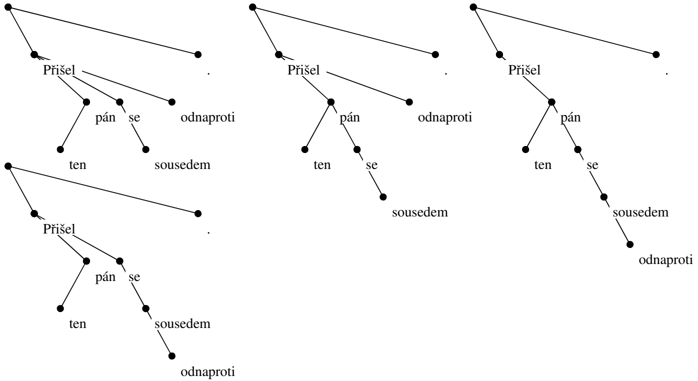
Prepositional Phrases

- Classic English example:
  - *I saw the man with a telescope.*
    1. *Viděl jsem ho dalekohledem.*
    2. *Viděl jsem ho s dalekohledem.*

Prepositional Phrases: Czech Example

Lit.: *Came the man with neighbor from-across-the-road.*

- *„Přišel ten pán se sousedem odnaproti.“*



Prepositional Phrases and Syntactic Ambiguities

- *V **letech** 1991 – 1993 jsem **absolvovala kurzy** řízení a marketingu na Collège Bart v kanadském Québecu.*
- *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.)

Prepositional Phrases and Syntactic Ambiguities

- *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...*

Prepositional Phrases and Syntactic Ambiguities

- *In years 1991 – 1993 I attended classes of management and marketing at Collège Bart in Canadian Québec.*
  - *attended (class (of (mngmt and market))) (at Bart)*
  - *attended (class (of (mngmt and market)) (at Bart))*
  - *attended (class (of ((mngmt and market) (at Bart))))*
  - *attended (class (of (mngmt and (market (at Bart)))))*
  - *… ((at Bart) (in Québec))*
    - Is Bart in Québec or Québec in Bart?

Prepositional Phrases and Syntactic Ambiguities

- *„říjnové jednání OSN o klimatických změnách v Kodani“ (Události ČT, 27.2.2009)*
- *“October UNO summit about climatic changes in Copenhagen” (Czech TV news, 2-27-2009)*

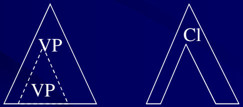
- Question:
  Were there climatic changes in Copenhagen?

Verb Phrase

- The underlined finite verb form is the head.
- The repertory depends on the rules for analytical verb forms and varies greatly cross-linguistically.
  - *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*
  - *prohibits smoking in this room*
  - *give Mary the beads that we brought from the vacation in Morocco*
  - *the file could not be opened*

Clause

- Group of words with 1 predicate, e.g.:
  - *John loves Mary.*
  - *…that you are right.*
- Not necessarily same as a verb phrase (VP).
  - Nested VPs are part of the main VP.
  - Nested clauses are not parts of the main clause.



Clause and Sentence

- Clause
  - simple sentence or part of compound sentence
  - e.g. *John loves Mary*. or "*that you are right*".
- Sentence
  - simple sentence or compound sentence
  - consists of one or more clauses
  - e.g. *John loves Mary*. or "*I realized that you were right.*"

Clause

- Predicative function
  - Certain activity of certain subjects and objects in certain time under certain conditions
- Main clause
  - Independent of other clauses in the sentence
- Nested clause, relative clause
  - Depends on another clause, carries out a function in that clause (as a dependent phrase)
- Functions of clauses:
  - Same as phrases plus some special, e.g. direct speech.

Sentence

- Consists of one or more main clauses.
- If there are more than one main clause then they are usually coordinated.
- A written sentence begins with a capital letter (if the script distinguishes case). Sometimes begins with a parenthesis or a quotation mark. An uppercase letter can occur inside of the sentence, too.
- It ends with a period, exclamation or question mark. Sometimes ends with a parenthesis or a quotation mark. A period can occur inside of the sentence, too.
- Depending on human decision, semicolons and colons may or may not terminate a sentence. It is usually possible to view them as coordinating conjunctions.

Coordination

- There is no real head. Technically, the conjunction, comma etc. can be proclaimed a head.
- The coordinated phrases 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*

Apposition

- Similarly to coordination, joins two phrases none of which depends on the other.
- Unlike coordination, apposition has never more than two members.
- The combined meaning is also different:
  - *Charles IV, Roman Emperor and Czech King*
- Coordination: multiple different phrases carry out the same function together.
- Apposition: semantically only one entity; on surface, it is described by two different ways.
  - *and the most — 40 percent — befalls to family homes*
  - *factors, especially depreciation*
  - *caretaker — natural or legal person determined by the owner of the building*
  - *costs and increase of taxes — these are matters that…*

Elision

- A phrase omitted from the (surface of the) sentence although it is present in the underlying meaning (deep structure).
- Frequently in dialogues: the elided phrase is known from context.
  - *Whom did you see there? — Peter.* (Missing verb.)
- In written text often occurs in coordination.
  - *Czech and German researchers discussed…* (There was probably no researcher that was Czech and German at the same time. Instead, there were *Czech researchers and German researchers*.)
  - *The Penguins are leading 4:0, while the Colorado Avalanches only 3:2.* (verb in the second part)
- Systemic elision of subject in pro-drop languages (it is marked on the verb and can be deduced in the form of a pronoun).
  - *Sedím.* (*já*) = *"(I) sit."*

Gaps and Discontinuous Phrases

- A constituent (phrase) was moved from the position where it is expected.
- Nothing special in free-word-order languages. The terms *gap* and *trace* are typically used in English (see the Penn Treebank).
- In Czech: *gap* is a term related to non-projective constructions and its meaning is different!
- English questions and relative clauses:
  - *Who do you work for <gap>*$_{\textit{whom}}$*?*
  - *I don't know why we have got so much rain <gap>*$_{\textit{why}}$*.*
  - *On Sundays, I usually work <gap>*$_{\textit{on sundays}}$ *but I stay at home on Tuesdays.*
  - *the story he never wrote <gap>*$_{\textit{the story}}$

Summary of Phrase-Based Model

- Sentence is divided to phrases (constituents).
- Phrase may be divided to even smaller phrases.
- The largest phrase is the whole sentence.
- The smallest phrase is a word.
- Phrases are named and labeled according to their type.

Observation: Phrases Are Related to Context-Free Grammars

- Phrase structure of a sentence corresponds to the derivation tree under the grammar that generates / recognizes the sentence.
- Example:
  - S → NP VP (a sentence has a subject and a predicate)
  - NP → N (a noun is a noun phrase)
  - VP → V NP (a verb phrase consists of a verb and its object)
- Lexicon part of the grammar:
  - N → dog | cat | man | car | John …
  - V → see | sees | saw | bring | brings | brought | …

Lexicon

- In practice the lexical part can (and should) be implemented separately from the grammar.
- The nonterminals of the lowest level (immediately above the terminals) might be POS tags.
  - Then morphological analysis and tagging (disambiguation of MA) solves the lowest level of the phrase tree.
    - In fact, disambiguation is not necessary. There will be other ambiguities in the tree anyway. The parser can take care of them.
  - The grammar works only with POS tags.
  - This is why we sometimes talk about *preterminals* (the nonterminals immediately above the leaf nodes).

An Extended Grammar Example for Czech (7 Cases!)

- NP → N | AP N
- AP → A | AdvP A
- AdvP → Adv | AdvP Adv

- NP_{nom} → N_{nom}
- NP_{nom} → AP_{nom} N_{nom}
- NP_{nom} → N_{nom} NP_{gen}

- NP_{gen} → N_{gen}
- NP_{gen} → AP_{gen} N_{gen}
- NP_{gen} → N_{gen} NP_{gen}

- N → *pán* | *hrad* | *muž* | *stroj* …
- A → *mladý* | *velký* | *zelený* …
- Adv → *velmi* | *včera* | *zeleně* …

- N_{nom} → *pán* | *hrad* | *muž* …
- N_{gen} → *pána* | *hradu* | *muže* …
- N_{dat} → *pánovi* | *hradu* | *muži* …
- N_{acc} → *pána* | *hrad* | *muže* …
- N_{voc} → *pane* | *hrade* | *muži* …
- N_{loc} → *pánovi* | *hradu* | *muži* …
- N_{ins} → *pánem* | *hradem* …

An Extended Grammar Example for Czech (Verbs)

- $VP \rightarrow VP_{obligatory}$
- $VP \rightarrow VP_{obligatory}\ VP_{optional}$

- $VP_{obligatory} \rightarrow V_{intr}$
- $VP_{obligatory} \rightarrow V_{trans}\ NP_{acc}$
- $VP_{obligatory} \rightarrow V_{bitr}\ NP_{dat}\ NP_{acc}$
- $VP_{obligatory} \rightarrow V_{mod}\ VINF$

- $VP_{optional} \rightarrow AdvP_{location} \mid AdvP_{time} \ldots$

- $V_{intr} \rightarrow$ *šedivět* | *brzdit* …
- $V_{trans} \rightarrow$ *koupit* | *ukrást* …
- $V_{bitr} \rightarrow$ *dát* | *půjčit* | *poslat* …
- $V_{mod} \rightarrow$ *moci* | *smět* | *muset* …

- … (tens to hundreds of frames)

Unification Grammar

- An alternative to nonterminal splitting
- Instead of seven context-free rules:
  - $NP_{nom} \longrightarrow AP_{nom}\ N_{nom}$
  - $NP_{gen} \longrightarrow AP_{gen}\ N_{gen}$
  - $NP_{dat} \longrightarrow AP_{dat}\ N_{dat}$
  - $NP_{acc} \longrightarrow AP_{acc}\ N_{acc}$
  - $NP_{voc} \longrightarrow AP_{voc}\ N_{voc}$
  - $NP_{loc} \longrightarrow AP_{loc}\ N_{loc}$
  - $NP_{ins} \longrightarrow AP_{ins}\ N_{ins}$
- One unification rule:
  - NP $\longrightarrow$ AP N := [case = AP^case # N^case]

Syntactic Analysis (Parsing)

- Automatic methods of finding the syntactic structure for a sentence
  - Symbolic methods: a phrase grammar or another description of the structure of language is required. Then: the chart parser.
  - Statistical methods: a text corpus with syntactic structures is needed (a treebank).
  - Hybrid methods: a simple grammar, ambiguities solved statistically with a corpus.
    - Chunking / shallow parsing

Parsing with a Context-Free Grammar

- Hierarchy of grammars:
  - Noam Chomsky (1957): *Syntactic Structures*
- Couple of classical algorithms.
  - CYK (Cocke-Younger-Kasami) … complexity $O(n^3)$
    - John Cocke (“inventor”)
    - Tadao Kasami (1965), Bedford, MA, USA (another independent “inventor”)
    - Daniel H. Younger (1967) (computational complexity analysis)

    - Constraint of CYK: grammar is in CNF (Chomsky Normal Form), i.e. the right-hand side of every rule consists of either two nonterminals or one terminal. (CFGs can be easily transformed to CNF.)

Parsing with a Context-Free Grammar

- **Chart parser**: CYK requires a data structure to hold information about partially processed possibilities. Turn of 1960s and 1970s: the *chart* structure proposed for this purpose.
- Jay Earley (1968), PhD thesis, Pittsburgh, PA, USA
  - A somewhat different version of chart parsing.
- For details on chart parser, see the earlier lecture about morphology and context-free grammars.

Practical Phrase-Based Parsing

- Rule-based parsers, e.g. Fidditch (Donald Hindle, 1983)
- Collins parser (Michael Collins, 1996–1999)
  - Probabilistic context-free grammars, lexical heads
  - Labeled precision & recall on Penn Treebank / Wall Street Journal data / Section 23 = 85%
  - Reimplemented in Java by Dan Bikel ("Bikel parser"), freely available
- Charniak parser (Eugene Charniak, NAACL 2000)
  - Maximum entropy inspired parser
  - P ~ R ~ 89.5%
  - Mark Johnson: reranker => over 90%
- Stanford parser (Chris Manning et al., 2002–2010)
  - Produces dependencies, too. Initial P ~ R ~ 86.4%

Dependency Parsing

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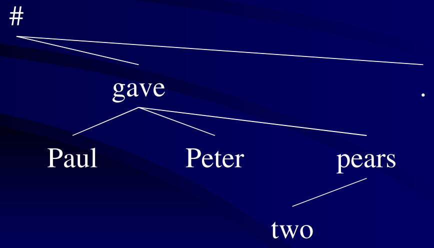
Dependency Model of Syntax

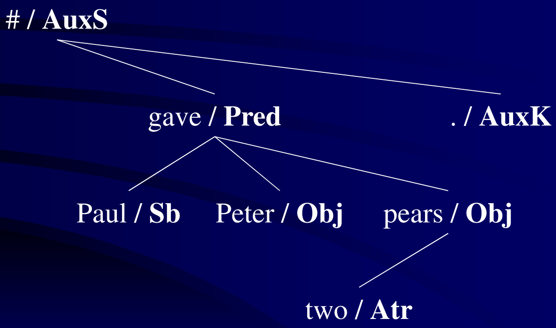
- Summary of syntactic relations:
- Sentence divided to **phrases** (constituents).
  - Cornerstone of the phrase-based (constituent-based) model.
- Phrase head, **dependency** of other phrase members on the head.
  - Head = governing node (token), the other nodes are dependent.
  - Cornerstone of a dependency tree.
- We can talk of dependencies even if we work with constituent trees and vice versa.

Example of Dependency Tree

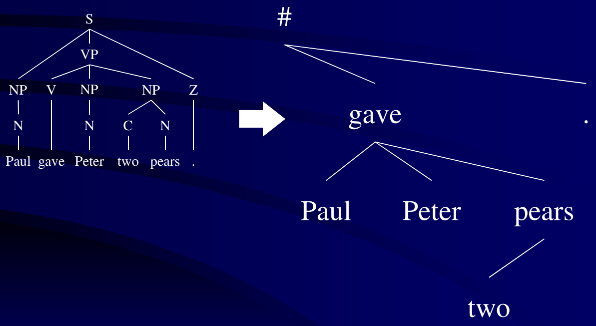
- [#,0] ([gave,2] ([Paul,1], [Peter,3], [pears,5] ([two,4])), [.,6])



Dependency Labels



Phrase vs. Dependency Trees



Phrase vs. Dependency Trees

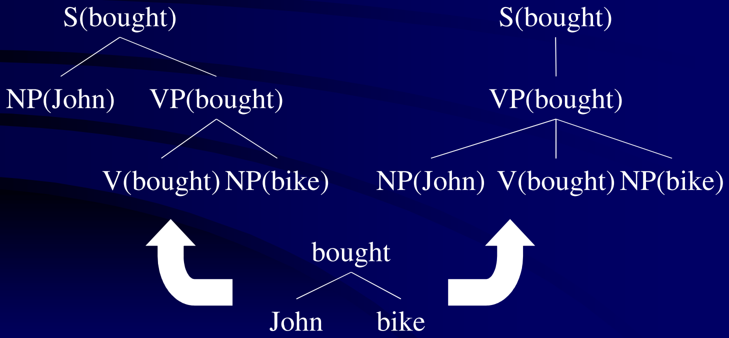
- Phrase (constituent) trees
  - Show decomposition of sentence to phrases and label them.
  - Don't stress what is head and which word depends on which.
  - Needn't specify function, dependency type.
- Dependency trees
  - Show dependencies between words and label them.
  - Don't capture similarity of construction of different sentence parts, recursion.
  - Don't capture progress of sentence generation, proximity of dependent nodes to the head.
  - Don't contain nonterminals, phrase types—these can be only estimated from parts of speech of the heads.

Differences between Phrase and Dependency Model

- We want to convert a phrase tree P to a dependency tree D or vice versa.
- Phrase tree does not tell what is the phrase head.
  - To convert P → D we need a selection function that for every grammar rule select a right-hand symbol to serve as the head.
- Dependency tree does not show how the sentence arose (recursion), nor does it necessarily cover the complete phrase decomposition.
  - It does not tell what has been added “sooner” and what “later”.
  - Several phrase structures may lead to the same dependency structure ⇒ back conversion (D → P) is ambiguous.

Example

- Several phrase trees lead to the same dependency tree.

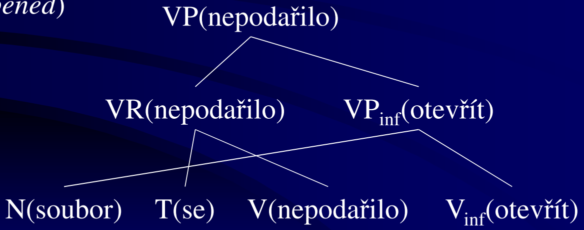


Differences between Phrase and Dependency Model

- Dependency tree does not know phrase labels (nonterminals—because it does not even know what the phrases are, see previous slide).
  - We need a function that determines the label according to the phrase head.
  - Really we need it? To understand the meaning, one needs the relations and **their type** but not what has been generated sooner and what later.
- Phrase tree does not know the type of the relation between the head and the other members—**function**. (But cf. functional tags in Penn Treebank.)
  - We need a function that determines the dependency label for every non-head member of the phrase. (We can tell that while selecting the head.)
- A significant difference: phrase trees are **tightly bound to the word order!**

Discontinuous Phrases

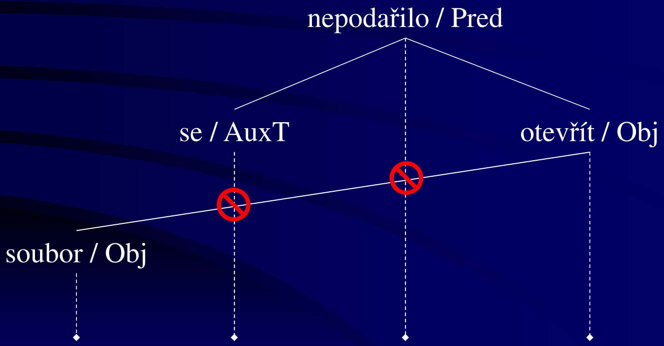
- Classical context-free grammar cannot describe them!
- They cannot be represented by bracketing.
- *(Soubor (se nepodařilo) otevřít).* (`cs:` *File couldn't be opened*)



Nonprojectivity

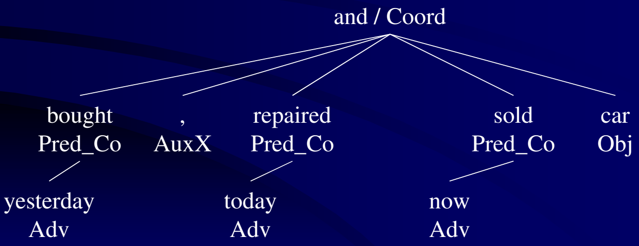
- Dependency tree including word order (horizontal coordinate of nodes).
- Projection to the base: the vertical from the node crosses a dependency (**nonprojective edge**).
- Formally:
  - Dependency ([g,x_g],[d,x_d]). x_w is the order of the word w in the sentence.
  - There exists a node [n,x_n] that $x_g < x_n < x_d$ or $x_d < x_n < x_g$ and [n,x_n] is not in subtree rooted by [g,x_g].
- Informally: The string spanned by the subtree of the governing node is discontinuous, contains gaps.

Nonprojectivity: Can Be Handled by a Dependency Tree!

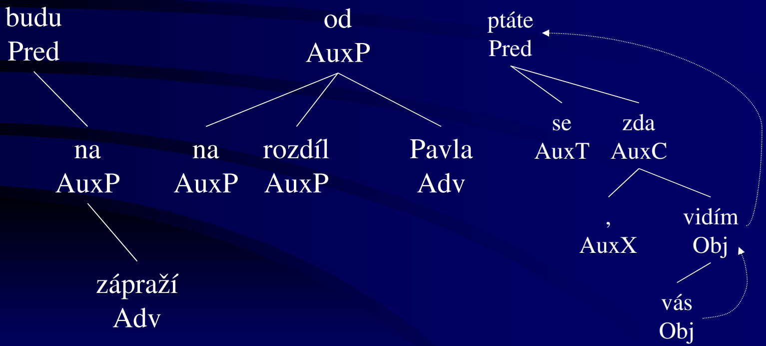


Problem: Not Everything is Dependency

- Coordination and apposition.
  - Modifying coordination × modifying a coordination member.
  - Auxiliary nodes (punctuation etc.)



Prepositional Phrases, Nested Subjoined Clauses



Nested Relative Clauses

Phrases, Dependencies and Other Models

- Phrases (constituents, immediate constituents).
  - Originally more widespread, suitable for English.
  - Context-free grammars.
- Dependencies.
  - Originally popular e.g. in Czech (and also in Far East), now widespread.
  - Especially suitable for free-word-order languages.
  - Dependency grammars, grammars of dependency trees.
- Categorial grammars.
- Tree-adjoining grammars (TAGs).
- And many more…

Dependency Grammar

- In contrast to phrase model, relation to grammar is artificial ("dependency tree does not demonstrate how it was generated").
- No implementation for Czech.
- Context-free grammar + head-selection function (only projective constructions).
- Grammar rules that rewrite a nonterminal to a whole subtree *(grammar of dependency trees)*.
- Related to link grammars, tree-adjoining grammars, categorial grammars.
- HPSG, unification.

MST Parser

- McDonald et al., HLT-EMNLP 2005
- http://sourceforge.net/projects/mstparser/
- MST = maximum spanning tree = `cs:` nejlépe ohodnocená kostra (orientovaného) grafu
- Start with a total graph.
  - We assume that there can be a dependency between any two words of the sentence.
- Gradually remove poorly valued edges.
- A statistical algorithm will take care of the valuation.
  - It is trained on edge features.
  - Example features: lemma, POS, case… of governing / dependent node.

MST Parser

- Feature engineering (tell the parser what features to track) by modifying the source code (Java).
- Not easy to incorporate *2nd order features*
  - I.e. edge weight depends e.g. on POS tag of its grandparent.
- Parser can be run in nonprojective mode.
- Training on the whole PDT reportedly takes about 30 hours.
  - It is necessary to iterate over all feature combinations and look for the most useful ones.
- In comparison to that, the parsing proper is quite fast.

Malt Parser

- 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, dependencies and dependency labels)
- Transitions:
  - Shift: move word from buffer to stack
  - Larc: left dependency between two topmost words on stack
  - Rarc: right dependency between two topmost words on stack

Malt Parser

- Parser driven by oracle that selects the transition operation based on the current configuration.
- Training: decompose the tree from training data to a sequence of configurations and transitions
  - Sometimes there are more than one possibility
    - Various learning strategies: e.g. create dependencies eagerly, as soon as possible.
- 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

- Again, a machine learning algorithm is 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 is relatively faster (~ 1 sentence / second) and can be parallelized.

Example of Malt Parsing

• stack	=	#
• buffer	=	Pavel dal Petrovi dvě hrušky .
• *English*	=	*Paul gave to-Peter two pears .*

Example of Malt Parsing

- stack = #
- buffer = Pavel dal Petrovi dvě hrušky .
- tree =

SHIFT

- stack = # Pavel
- buffer = dal Petrovi dvě hrušky .
- tree =

Example of Malt Parsing

- stack = # Pavel
- buffer = dal Petrovi dvě hrušky .
- tree =

SHIFT

- stack = # Pavel dal
- buffer = Petrovi dvě hrušky .
- tree =

Example of Malt Parsing

- stack = # Pavel dal
- buffer = Petrovi dvě hrušky .
- tree =

LARC

- stack = # dal
- buffer = Petrovi dvě hrušky .
- tree = dal(Pavel)

Example of Malt Parsing

- stack = # dal
- buffer = Petrovi dvě hrušky .
- tree = dal(Pavel)

SHIFT

- stack = # dal Petrovi
- buffer = dvě hrušky .
- tree = dal(Pavel)

Example of Malt Parsing

- stack = # dal Petrovi
- buffer = dvě hrušky .
- tree = dal(Pavel)

RARC

- stack = # dal
- buffer = dvě hrušky .
- tree = dal(Pavel,Petrovi)

Example of Malt Parsing

- stack = # dal
- buffer = dvě hrušky .
- tree = dal(Pavel,Petrovi)

SHIFT

- stack = # dal dvě
- buffer = hrušky .
- tree = dal(Pavel,Petrovi)

Example of Malt Parsing

- stack = # dal dvě
- buffer = hrušky .
- tree = dal(Pavel,Petrovi)

SHIFT

- stack = # dal dvě hrušky
- buffer = .
- tree = dal(Pavel,Petrovi)

Example of Malt Parsing

- stack = # dal dvě hrušky
- buffer = .
- tree = dal(Pavel,Petrovi)

LARC

- stack = # dal hrušky
- buffer = .
- tree = dal(Pavel,Petrovi),hrušky(dvě)

Example of Malt Parsing

- stack = # dal hrušky
- buffer = .
- tree = dal(Pavel,Petrovi),hrušky(dvě)

RARC

- stack = # dal
- buffer = .
- tree = dal(Pavel,Petrovi,hrušky(dvě))

Example of Malt Parsing

- stack = # dal
- buffer = .
- tree = dal(Pavel,Petrovi,hrušky(dvě))

RARC

- stack = #
- buffer = .
- tree = #(dal(Pavel,Petrovi,hrušky(dvě)))

Example of Malt Parsing

- stack = #
- buffer = .
- tree = #(dal(Pavel,Petrovi,hrušky(dvě)))

SHIFT

- stack = # .
- buffer =
- tree = #(dal(Pavel,Petrovi,hrušky(dvě)))

Example of Malt Parsing

- stack = # .
- buffer =
- tree = #(dal(Pavel,Petrovi,hrušky(dvě)))

RARC

- stack = #
- buffer =
- tree = #(dal(Pavel,Petrovi,hrušky(dvě)),.)

Nonprojective Mode of Malt

- It can be proved that the above transition system is
  - correct
    - resulting graph is always a tree (continuous, cycle-free)
  - complete for the set of projective trees
    - every projective tree can be expressed as a sequence of transitions
- How to add nonprojective dependencies?
  - New transition operation **`SWAP`**:
  - Take second topmost word from stack and return it to buffer. That will swap the order of the input words.
  - This action is permitted only for words that have not been swapped before (their order on the stack corresponds to their original order in the sentence).

Nonprojective Parsing Example

- stack = #
- buffer = Soubor se nepodařilo otevřít .
- *English* = *File itself it-did-not-succeed to-open .*

Nonprojective Parsing Example

- stack = #
- buffer = Soubor se nepodařilo otevřít .
- tree =

SHIFT

- stack = # Soubor
- buffer = se nepodařilo otevřít .
- tree =

Nonprojective Parsing Example

- stack = # Soubor
- buffer = se nepodařilo otevřít .
- tree =

SHIFT

- stack = # Soubor se
- buffer = nepodařilo otevřít .
- tree =

Nonprojective Parsing Example

- stack = # Soubor se
- buffer = nepodařilo otevřít .
- tree =

SHIFT

- stack = # Soubor se nepodařilo
- buffer = otevřít .
- tree =

Nonprojective Parsing Example

- stack = # Soubor se nepodařilo
- buffer = otevřít .
- tree =

LARC

- stack = # Soubor nepodařilo
- buffer = otevřít .
- tree = nepodařilo(se)

Nonprojective Parsing Example

- stack = # Soubor nepodařilo
- buffer = otevřít .
- tree = nepodařilo(se)

SHIFT

- stack = # Soubor nepodařilo otevřít
- buffer = .
- tree = nepodařilo(se)

Nonprojective Parsing Example

- stack = # Soubor nepodařilo otevřít
- buffer = .
- tree = nepodařilo(se)

SWAP

- stack = # Soubor otevřít
- buffer = nepodařilo .
- tree = nepodařilo(se)

Nonprojective Parsing Example

- stack = # Soubor otevřít
- buffer = nepodařilo .
- tree = nepodařilo(se)

LARC

- stack = # otevřít
- buffer = nepodařilo .
- tree = nepodařilo(se),otevřít(Soubor)

Nonprojective Parsing Example

- stack = # otevřít
- buffer = nepodařilo .
- tree = nepodařilo(se),otevřít(Soubor)

SHIFT

- stack = # otevřít nepodařilo
- buffer = .
- tree = nepodařilo(se),otevřít(Soubor)

Nonprojective Parsing Example

- stack = # otevřít nepodařilo
- buffer = .
- tree = nepodařilo(se),otevřít(Soubor)

LARC

- stack = # nepodařilo
- buffer = .
- tree = nepodařilo(se,otevřít(Soubor))

Nonprojective Parsing Example

- stack = # nepodařilo
- buffer = .
- tree = nepodařilo(se,otevřít(Soubor))

RARC

- stack = #
- buffer = .
- tree = #(nepodařilo(se,otevřít(Soubor)))

Nonprojective Parsing Example

- stack = #
- buffer = .
- tree = #(nepodařilo(se,otevřít(Soubor)))

SHIFT

- stack = # .
- buffer =
- tree = #(nepodařilo(se,otevřít(Soubor)))

Nonprojective Parsing Example

- stack = # .
- buffer =
- tree = #(nepodařilo(se,otevřít(Soubor)))

RARC

- stack = #
- buffer =
- tree = #(nepodařilo(se,otevřít(Soubor)),.)

Malt and MST Accuracy

- Czech (PDT):
  - MST Parser over 85%
  - Malt Parser over 86%
    - Sentence accuracy (“complete match”) 35%, that is high!
  - The two parsers use different strategies and can be combined (either by voting (third parser needed) or one preparing features for the other)
- Other languages (CoNLL shared tasks)
  - MST was slightly better on most languages.
  - Accuracies not comparable cross-linguistically, figures are very dependent on particular corpora.

Features Are the Key to Success

- Common feature of MST and Malt:
  - Both can use large number of input text features.
  - Nontrivial machine learning algorithm makes sure that the important features will be given higher weight.
  - Machine learning algorithms are general classifiers.
    - Typically there is a library ready to download.
    - The concrete problem (here tree building) must be converted to a sequence of classification decisions, e.g. vectors (feature values + answer).