Morphological Analysis
Unification Grammars

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December 9, 2021

EUROPEAN UNION
European Structural and Investment Fund
Operational Programme Research,
Development and Education

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Unification Grammars

- Based on
  - context-free grammars
  - feature structures
  - their unifiability
- Feature structure
  - Sort of database record, or a variable of a structured type: `record` in Pascal, `struct` in C. Description of an object, list of features
  - features (attributes) … names of fields
  - values
  - Examples of attribute-value pairs: [number: plural], [case: nominative]

Feature Structure

entity	
NAME	FF UK
PHONE	258562

entity	
NAME	Dan
PHONE	221914225

faculty	
NAME	MFF UK
DEAN	Rokyta
PHONE	221911111

Feature Structure

entity	
NAME	FF UK
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POS	noun
GEN	masculine
NUM	singular
CASE	dative

POS	adjective
GEN	masculine
NUM	plural
CASE	accusative
DEG	comparative
NEG	affirmative

Feature Structure

- Partial function mapping the set of features to the set of values

$$\begin{bmatrix} \textbf{type} & \\ \text{FEATURE}_1 & \text{VALUE}_1 \\ \text{FEATURE}_2 & \text{VALUE}_2 \\ \text{FEATURE}_3 & \text{VALUE}_3 \end{bmatrix}$$

Unifiability

- Two feature structures are **unifiable** if their values of the features they share are identical
- Example: structures 1 and 2 are unifiable, so are 2 and 3, while 1 and 3 are not

$$1 \begin{bmatrix} \text{GENDER} & \text{masculine} \\ \text{NUMBER} & \text{singular} \\ \text{CASE} & \text{dative} \end{bmatrix} \; 2 \begin{bmatrix} \text{POS} & \text{verb} \\ \text{NUMBER} & \text{singular} \\ \text{TENSE} & \text{present} \end{bmatrix}$$

$$3 \begin{bmatrix} \text{GENDER} & \text{masculine} \\ \text{NUMBER} & \text{singular} \\ \text{CASE} & \text{instrumental} \end{bmatrix}$$

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- Two feature structures are **unifiable** if their values of the features they share are identical
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GENDER	masculine
NUMBER	singular
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TENSE	present

3

GENDER	masculine
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CASE	instrumental

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NUMBER	singular
CASE	dative

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POS	verb
NUMBER	singular
TENSE	present

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GENDER	masculine
NUMBER	singular
CASE	instrumental

Unification

- **Unification** is an operation over two unifiable feature structures. It results in a new feature structure

$$1 \begin{bmatrix} \text{GENDER} & \text{masculine} \\ \text{NUMBER} & \text{singular} \\ \text{CASE} & \text{dative} \end{bmatrix} + 2 \begin{bmatrix} \text{PERSON} & \text{third} \\ \text{NUMBER} & \text{singular} \\ \text{TENSE} & \text{present} \end{bmatrix}$$

$$= 3 \begin{bmatrix} \text{GENDER} & \text{masculine} \\ \text{NUMBER} & \text{singular} \\ \text{CASE} & \text{dative} \\ \text{PERSON} & \text{third} \\ \text{TENSE} & \text{present} \end{bmatrix}$$

Unification as a Tool for Morphological Generation?

- Input: feature structures “lemma” and “tag”
- Search lexicon for all structures “entry” that are unifiable with “lemma”
- For each “entry” found, look up a “paradigm” structure that is unifiable with both the “entry” and the “tag” structures
- Unify the corresponding structures “entry”, “paradigm”, and “tag”. The resulting structure is “form”
- Output: for each “form”, concatenate its values of “paradigm” and “suffix”

Unification as a Tool for Morphological Generation?

- Input: feature structures "lemma" and "tag"

$$\begin{bmatrix} \textbf{lemma} & \\ \text{LEMMA} & \text{háček} \end{bmatrix} \begin{bmatrix} \textbf{tag} & \\ \text{NUMBER} & \text{plural} \\ \text{CASE} & \text{nominative} \end{bmatrix}$$

- Czech noun *háček* has two meanings and belongs to two inflection classes:
  - "small hook" ... masculine inanimate class *hrad* "castle"
  - "bowman" ... masculine animate class *pán* "gentleman"

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LEMMA	háček

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NUMBER	plural
CASE	nominative

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- Search lexicon for "entry" structures unifiable with "lemma"

entry	
LEMMA	háček
PARADIGM	hrad

entry	
LEMMA	háček
PARADIGM	pán

Unification as a Tool for Morphological Generation?

- For each “entry”, find a “paradigm” structure unifiable with both “entry” and “tag”

entry	
LEMMA	háček
PARADIGM	hrad

entry	
LEMMA	háček
PARADIGM	pán

paradigm	
PARADIGM	hrad
NUMBER	plural
CASE	nominative
SUFFIX	y

paradigm	
PARADIGM	pán
NUMBER	plural
CASE	nominative
SUFFIX	i

paradigm	
PARADIGM	pán
NUMBER	plural
CASE	nominative
SUFFIX	ové

Unification as a Tool for Morphological Generation?

- Unify the corresponding structures "entry", "paradigm", and "tag". Call the resulting structure "form"

form	
LEMMA	háček
PARADIGM	hrad | pán
NUMBER	plural
CASE	nominative
SUFFIX	y | i | ové

Unification as a Tool for Morphological Generation?

- Unification resembles database operations
- It does not tell how the “form” structure is to be interpreted
- Rule: output = form.lemma + form.suffix
- The rule does not solve phonological changes (and unification cannot help us with this):
  - We get: **háčeky*, **háčeki*, **háčekové*
  - We want: *háčky, háčci, háčkové*
- Possible workaround: shorter stem, longer suffix
  - *háč+ky, háč+ci, háč+kové*

Unification as a Tool for Morphological Analysis???

- Non-unification part: find all possible affixes recognizable in the word ⇒ set of “form” structures
- The “paradigm” structures tell us what is the set of known suffixes

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- The "paradigm" structures tell us what is the set of known suffixes
- Somehow solve phonological changes (stem-final palatalization, stem-internal ablaut etc.)
- Then take the dual procedure to the generation:
  - Unify form with paradigm
  - Unify the result with lexicon
  - Entries found in lexicon are the possible analyses

  - E.g. cs: *běžím* "I am running" = *běžet* (verb:trpět) + person (1st) ≠ *běží* (noun:stavení) + case (7)

Unification as a Tool for Morphological Analysis???

- Non-unification part: find all possible affixes recognizable in the word $\Rightarrow$ set of "form" structures
- The "paradigm" structures tell us what is the set of known suffixes
- Somehow solve phonological changes (stem-final palatalization, stem-internal ablaut etc.)
- Then use unification...
  - In fact, this is what PC Kimmo v.2 does:
  - It combines two-level morphology with a unification grammar

Unification Morphology Grammar (UMG)

- **Jan Hajič:** *Unification Morphology Grammar (PhD thesis).* Univerzita Karlova, Praha, 1994
- **Stuart Shieber:** *An Introduction to Unification-based Approaches to Grammar.* CSLI Lecture Notes No. 4, Stanford, California, USA, 1986

- Based on a context-free grammar
- A feature structure is attached to each constituent (label + span)
- Rule: left-hand side (LHS) $\rightarrow$ right-hand side (RHS) $:=$ operation over feature structures
- Operations can block a rule by requiring unifiability
- Unification-based chart parser, PATR-II (Shieber)
- Similarly to CFGs, unification grammars were originally designed for sentence syntax analysis and subsequently applied to word analysis as well

UMG Syntax

- LHS $\rightarrow$ RHS := operation over feature structures
  - grammar rule
- <X>
  - non-terminal symbol X. Terminals are written without angle brackets
- #
  - unification operator (it also places requirement on unifiability)
- ^
  - reference operator (it delimits non-terminals / parts of paths to the feature structure we are referencing)
- +
  - concatenation operator
- |
  - disjunction operator. A disjunction of feature structures contains all structures that fulfill the constraints (are unifiable). A disjunction can represent alternate analyses of the same thing

Example of UMG Rule

```
<N> --> <L> := [l = <L>^l, umlaut = <L>^umlaut # no]
```

- Interpretation:
  - If:
    - we recognized constituent <L> and
    - value of the `umlaut` attribute in the feature structure attached to this constituent is "no"

Example of UMG Rule

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<N> --> <L> := [l = <L>^l, umlaut = <L>^umlaut # no]
```

- Interpretation:
  - If:
    - we recognized constituent <L> and
    - value of the `umlaut` attribute in the feature structure attached to this constituent is "no"
  - Then:
    - we also recognized constituent <N> with the same span
    - we must copy the attributes `l` and `umlaut` from the feature structure of <L> to the feature structure of <N>

Theoretical View of the Lexicon

- A rule that generates the empty string but it provides a gigantic feature structure with the entire lexicon in it

```
<LEX> --> "" :=
    [stem=mat,  hw=matka,     pos=N, x=zn6e] |
    [stem=atom, hw=atom,      pos=N, x=hd1]  |
    [stem=nov,  hw=nový,      pos=A, x=reg]  |
    [stem=prac, hw=pracovat, pos=V, x=ovatn] |
    … ;
```

Theoretical View of the Lexicon

- How the lexicon is bound to the rest of the grammar:

```
<R> --> <S>u <LEX> := <LEX> #
    [x=hd1, stem=<S>, case=gen|dat|loc, num=sg]
```

- The rule describes formation of singular noun genitive, dative and locative according to the Czech masculine paradigm `hd1` (*hrad* “castle”)
- `<R>` represents a word unified with the lexicon
- `<S>` is the part of the input that corresponds to the stem of the word. The suffix is shown literally, the `<LEX>` that follows corresponds to empty string
- Operation after `:=` says we are interested in those structures from `<LEX>` whose stem corresponds to `<S>` and which inflect according to paradigm `hd1`
- Lexicon entries that pass this filter will form the set of feature structures bound to the non-terminal `<R>`. Additionally, they will bear information on number and case

UMG Example

```
<L> --> a := [l=a];
<L> --> b := [l=b];
...
```

- Copy input letters to the feature structure

UMG Example

```
<L> --> a := [l=a];
<L> --> b := [l=b];
...
<N> --> <L> := [l=<L>^l];
<N> --> <L> <N> := [l=<L>^l+<N>^l];
```

- Copy input letters to the feature structure
- Define string <N> as a sequence of letters <L>

UMG Example

```
<L> --> a := [l=a];
<L> --> b := [l=b];
...
<N> --> <L> := [l=<L>^l];
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<S> --> <N> := <N>;
```

- Copy input letters to the feature structure
- Define string <N> as a sequence of letters <L>
- <S> is a potential word stem

UMG Example

```
<L> --> a := [l=a];
<L> --> b := [l=b];
…
<N> --> <L> := [l=<L>^l];
<N> --> <L> <N> := [l=<L>^l+<N>^l];
<S> --> <N> := <N>;
<R> --> <S> <LEX> := <LEX> # [stem=<S>^l, x=hd1, num=sg, case=nom|acc, …];
<R> --> <S>u <LEX> := <LEX> # [stem=<S>^l, x=hd1, num=sg, case=gen|dat|loc,
<LEX> --> "" := … | [stem=hrad, x=hd1, …] | …
```

- Copy input letters to the feature structure
- Define string <N> as a sequence of letters <L>
- <S> is a potential word stem
- <R> is a recognized word form checked against lexicon

The Lexicon in Practice

- It is not efficient to treat the lexicon as part of grammar
- Real implementation looks different:
  - Store the lexicon in a separate data structure with fast search access
  - Cover rules containing `<LEX>` by the algorithm accessing the data structure
  - Use the unifying chart parser to process the rest of the grammar

UMG Example

- Lexicon
  `mat zn6e =matka`
  - `mat` ... stem
  - `zn6e` ... paradigm
  - `=matka` ... lemma

- Typical system with many paradigms
  - School paradigm *žena* “woman” corresponds to 44 distinct paradigms in the system
  - Even so, the paradigms do not solve shortening of stem-internal vowel

UMG Example

- Paradigm = *stavení* “building”, neuter gender; omitting LHS, always the same

```
<_><í>$ := [key=<_>í, x=(st|rž), cat=[pos=n],
          morf=[infl=[pf=([gnd=n, num=sg, case=(nom|gen|dat|acc|voc|loc)] |
                           [gnd=n, num=pl, case=(nom|gen|acc|voc)])]]];
<_><í><m>$ := [key=<_>í, x=(st|rž), cat=[pos=n],
          morf=[infl=[pf=([gnd=n, num=sg, case=ins] |
                           [gnd=n, num=pl, case=dat])]]];
<_><í><c><h>$ := [key=<_>í, x=(st|rž), cat=[pos=n],
          morf=[infl=[pf=[gnd=n, num=pl, case=loc]]]];
<_><í><m><i>$ := [key=<_>í, x=(st|rž), cat=[pos=n],
          morf=[infl=[pf=[gnd=n, num=pl, case=ins]]]];
```

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```

$$
\begin{bmatrix}
\text{key} & \text{<\_>í} \\
\text{x} & \text{st} \mid \text{rž} \\
\text{cat} & \begin{bmatrix} \text{pos} & \text{n} \end{bmatrix} \\
\text{morf} & \begin{bmatrix} \text{infl} & \begin{bmatrix} \text{pf} & \begin{bmatrix} \text{gnd} & \text{n} \\ \text{num} & \text{sg} \\ \text{case} & \text{nom} \mid \text{gen} \mid \text{dat} \\ & \mid \text{acc} \mid \text{voc} \mid \text{loc} \end{bmatrix} \mid \begin{bmatrix} \text{gnd} & \text{n} \\ \text{num} & \text{pl} \\ \text{case} & \text{nom} \mid \text{gen} \\ & \mid \text{acc} \mid \text{voc} \end{bmatrix} \end{bmatrix} \end{bmatrix}
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$$

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$$\begin{bmatrix} \text{key} & <\_>\text{í} \\ \text{x} & \text{st} \\ \text{cat} & \begin{bmatrix}\text{pos} & \text{n}\end{bmatrix} \\ \text{morf} & \begin{bmatrix}\text{infl} & \begin{bmatrix}\text{pf} & \begin{bmatrix}\text{gnd} & \text{n} \\ \text{num} & \text{sg} \\ \text{case} & \text{nom}\end{bmatrix}\end{bmatrix}\end{bmatrix}\end{bmatrix}$$

Comparison of UMG and CFG

- ☺ The feature structure contains the required output (tag) ⇒ no need for supplementary non-terminal naming convention

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- ☺ Disjunction of structures represents homonymous analyses

Comparison of UMG and CFG

- ☺ The feature structure contains the required output (tag) ⇒ no need for supplementary non-terminal naming convention
- ☺ The features and their unifiability constrain rule application ⇒ no need to split non-terminals
- ☺ Disjunction of structures represents homonymous analyses
- ☹ Phonology is still an issue. Either combinatorial explosion of paradigms (UMG) or use in tandem with two-level rules (see below)

PC-Kimmo Word Grammar

- Unification grammar by Stuart Shieber
- Rule syntax somewhat different from UMG, application is similar
- Lexicon
  - Recognize possible morphemes in the word
- Rules
  - Phonological changes, especially on morpheme boundary
- Grammar
  - Analysis of inter-morpheme relations
  - Derivation of word features from morpheme features
  - Constraints on morphotactics (what morphemes can combine and in what order)

PC-Kimmo Word Grammar

Analyze *enlargements*:

en	+‘large	+ment	+s
VR1a	+‘large	+NR25	+PL

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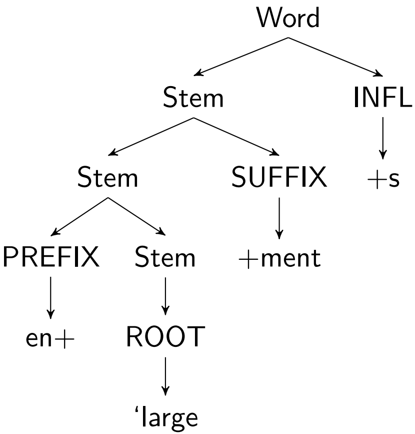

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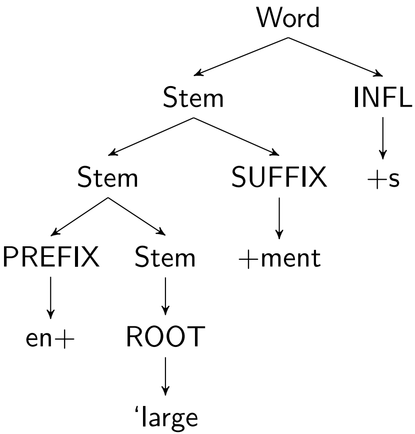

Word:

cat	Word		
head	agr	3sg	–
	number	PL	
	pos	N	
root	'large		
root_pos	AJ		
clitic	–		
drvstem	–		

PC-Kimmo Word Grammar

- First the old part of PC-Kimmo segments the word into morphemes
- Then the new part parses the sequence of morphemes using the grammar
  - Grammar can reject some morpheme sequences
  - Grammar assigns interpretation (feature structure) to accepted sequences
    - The old PC-Kimmo could gloss morphemes
    - But it could not tell how to combine morpheme glosses into interpretation of the whole word (e.g. that the suffix *-able* changes a verb to an adjective)
- A grammar rule looks like this:

```
Word -> Stem INFL
        <Stem head pos> = <INFL from_pos>
        <Word head>     = <INFL head>
```

Grammar Rule

```
Word -> Stem INFL
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- The morpheme symbols `Stem`, `INFL` are pre-terminals and they correspond to the names of sublexicons where the morphemes were found

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- The rule cannot be used if the feature `pos` of the substructure `head` of the morpheme `Stem` is not equal to the feature `from_pos` of the morpheme `INFL`

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- The morpheme symbols `Stem`, `INFL` are pre-terminals and they correspond to the names of sublexicons where the morphemes were found
- The rule cannot be used if the feature `pos` of the substructure `head` of the morpheme `Stem` is not equal to the feature `from_pos` of the morpheme `INFL`
- If the rule is used it shall copy the value of the `head` feature from the `INFL` constituent to the `head` feature of the `Word` constituent

Grammar Rule

```
RULE <rule>
        <rule constraints>
```

- Left-hand side is separated from right-hand side by `->` or `=`

```
RULE Stem_1 = Stem_2 SUFFIX
```

- `X` represents any terminal or non-terminal
- Characters `()[]{}<>=:/` are special
  - Underscore is used only to append an index to a symbol
- Left-hand side of the first rule is the start symbol of the grammar

```
N = Nstem {Sing / Plur}
```

Advantages of the Grammar

- Czech examples:
  - Grammar blocks combination of incompatible stem and suffix
    - E.g., stem belongs to the *žena* "woman" paradigm, suffix belongs to the *růže* "rose" paradigm

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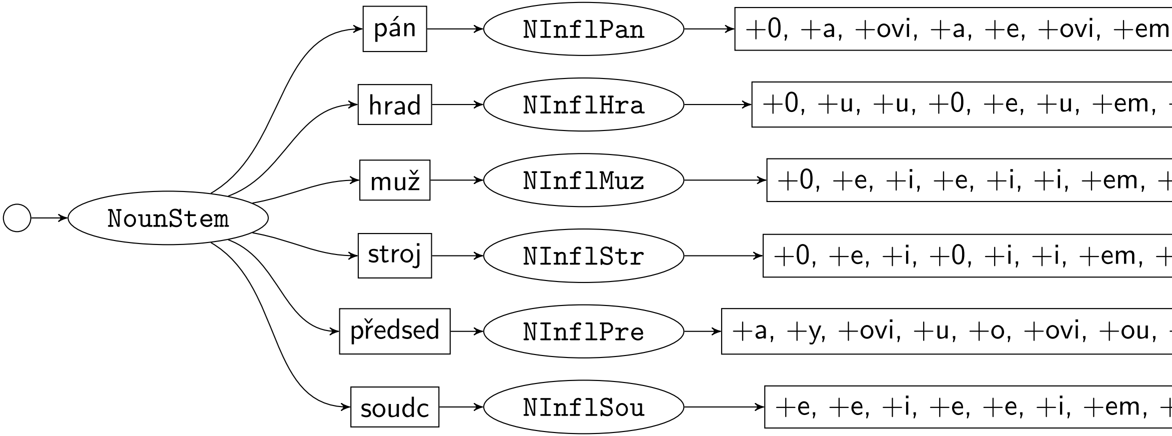
  - It can check long-distance dependencies such as
    - *nejchytřejší* "smartest"
  - Take feminine noun *žena* "woman". Derive possessive adjective *ženin* "woman's"
    - Change gender from feminine to masculine (the suffix says that the possessed object is masculine)
    - Store the original gender as lexical possessor's gender

Czech Nouns without Grammar



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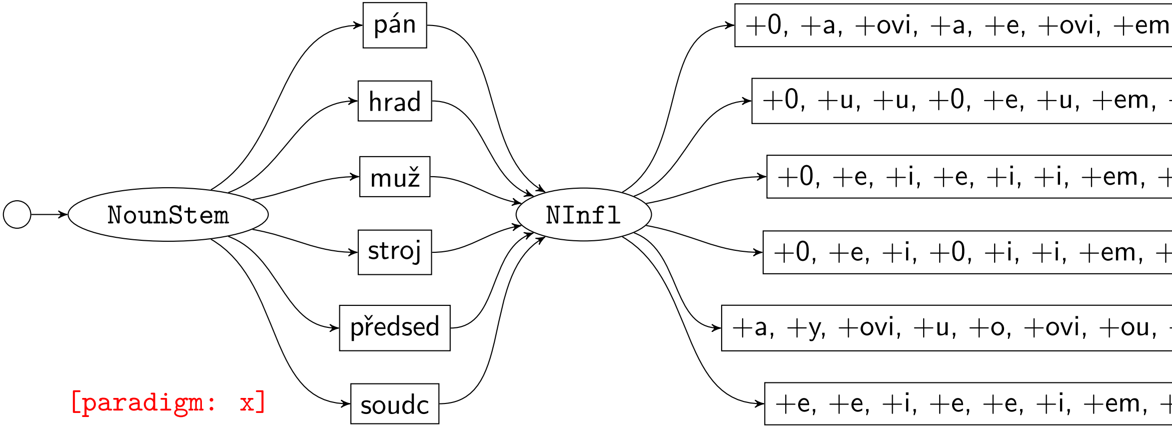
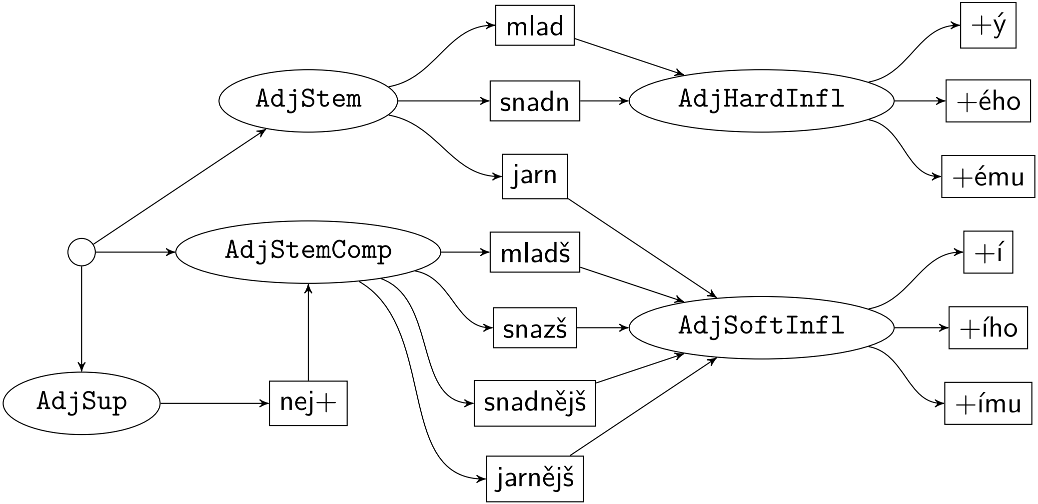
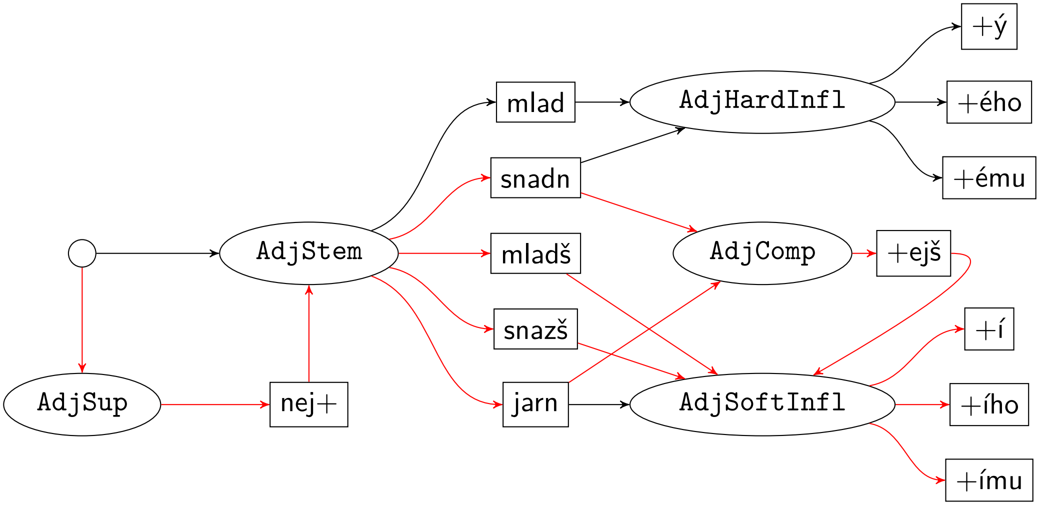


Czech Adjectives without Grammar



Czech Adjectives with Grammar



Grammar Cannot Interact with Phonology

- Phonological rule of consonant softening in Czech imperative:
  - *meteš* "you sweep" → *meť(-me, -te)* "sweep!"
  - `t:ť ⇔ _ +:0 λ:0` or `m:m e:e` or `t:t e:e`
- The rule must not apply in genitive plural form of feminine nouns:
  - *kóta* "spot elevation" → **kóť*
- Phonological rules cannot read the feature structures to constrain their application
- There have been extensions other than PC-Kimmo that combined phonological rules with feature structures, e.g., Trost (1990)

Automatic Features

- Every lexicon entry automatically receives the following features:
  - cat = name of sublexicon (\lx)
  - lex = morpheme, lexical string (\lf)
  - gloss = gloss from the lexicon entry (\gl)

Assigning Values to Features

- Abbreviations of feature assignments
  - If we are going to assign a value to thousands of lexicon entries we want it to be as short as possible
  - `LET <shortcut | category> be <definition>`
  - e.g.
  - `Let pl be [number: PL]`
  - `Let pl be <number> = PL`
  - `Let 3sg be [tense: PRES`
    `agr: 3SG]`
- Disjunction:
  - `Let sg/pl be {[number:SG] [number:PL]}`
  - `Let sg/pl be <number> = {SG PL}`
- Default values:
  - `Let N be <number> = !SG`
  - Unless someone explicitly assigns the value of number to a noun, the noun is assumed to be in singular

Lexical Rules

- Not shortcuts but systematic transformation of features for groups of lexicon entries. They transform a feature structure to another one
- DEFINE <lexical rule name> as <mapping>
- The example in the on-line documentation is invalid
- When the analysis is done and the feature structure for the whole word is ready, we can apply a lexical rule that will modify the structure

Parameter Setting

- PARAMETER <name> is <value>
  - `Parameter Start symbol is Word`
  - `Parameter Attribute order is cat head root`
    - In which order shall PC-Kimmo display the features?
  - `Category feature` (default: `cat`)
  - `Lexical feature` (default: `lex`)
  - `Gloss feature` (default: `gloss`)
    - What are the names of important features with special meaning?