

Morphological Analysis Unification Grammars

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unless otherwise stated

- 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

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

type	
FEATURE ₁	VALUE ₁
FEATURE ₂	VALUE ₂
FEATURE ₃	VALUE ₃

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	<table><tr><td>GENDER</td><td>masculine</td></tr><tr><td>NUMBER</td><td>singular</td></tr><tr><td>CASE</td><td>dative</td></tr></table>	GENDER	masculine	NUMBER	singular	CASE	dative	2	<table><tr><td>POS</td><td>verb</td></tr><tr><td>NUMBER</td><td>singular</td></tr><tr><td>TENSE</td><td>present</td></tr></table>	POS	verb	NUMBER	singular	TENSE	present
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Unification

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

$$\begin{aligned} 1 \begin{bmatrix} \text{GENDER} & \text{masculine} \\ \text{NUMBER} & \text{singular} \\ \text{CASE} & \text{dative} \end{bmatrix} + 2 \begin{bmatrix} \text{PERSON} & \text{third} \\ \text{NUMBER} & \text{singular} \\ \text{TENSE} & \text{present} \end{bmatrix} \\ = 3 \begin{bmatrix} \text{GENDER} & \text{masculine} \\ \text{NUMBER} & \text{singular} \\ \text{CASE} & \text{dative} \\ \text{PERSON} & \text{third} \\ \text{TENSE} & \text{present} \end{bmatrix} \end{aligned}$$

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”

lemma		tag	
LEMMA	háček	NUMBER	plural
		CASE	nominative

- 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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- “small hook” ... masculine inanimate class *hrad* “castle”
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- Search lexicon for “entry” structures unifiable with “lemma”

entry		entry	
LEMMA	háček	LEMMA	háček
PARADIGM	hrad	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: *háč*ek*ky, *háč*ek*i, *háč*ek*ové
 - 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 \Rightarrow 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)
 \neq *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
- **Somewhat 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
- $\langle X \rangle$
 - non-terminal symbol X. Terminals are written without angle brackets
- $\#$
 - unification operator (it also places requirement on unifiability)
- \wedge
 - 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

$\langle N \rangle \rightarrow \langle L \rangle := [l = \langle L \rangle^l, \text{umlaut} = \langle L \rangle^{\text{umlaut}} \# \text{no}]$

- Interpretation:
 - If:
 - we recognized constituent $\langle L \rangle$ and
 - value of the `umlaut` attribute in the feature structure attached to this constituent is “no”

Example of UMG Rule

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- Interpretation:
 - If:
 - we recognized constituent $\langle L \rangle$ and
 - value of the `umlaut` attribute in the feature structure attached to this constituent is “no”
 - Then:
 - we also recognized constituent $\langle N \rangle$ with the same span
 - we must copy the attributes `l` and `umlaut` from the feature structure of $\langle L \rangle$ to the feature structure of $\langle N \rangle$



- 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] |  
    ... ;
```


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

$\langle R \rangle \rightarrow \langle S \rangle_u \langle LEX \rangle := \langle LEX \rangle \#$
[$x=hd1$, $stem=\langle S \rangle$, $case=gen|dat|loc$, $num=sg$]

- The rule describes formation of singular noun genitive, dative and locative according to the Czech masculine paradigm *hd1* (*hrad* “castle”)
- $\langle R \rangle$ represents a word unified with the lexicon
- $\langle S \rangle$ is the part of the input that corresponds to the stem of the word. The suffix is shown literally, the $\langle LEX \rangle$ that follows corresponds to empty string
- Operation after $:=$ says we are interested in those structures from $\langle LEX \rangle$ whose stem corresponds to $\langle S \rangle$ 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 $\langle R \rangle$. Additionally, they will bear information on number and case

UMG Example

$\langle L \rangle \rightarrow a := [l=a];$

$\langle L \rangle \rightarrow b := [l=b];$

...

- Copy input letters to the feature structure

UMG Example

$\langle L \rangle \rightarrow a := [l=a];$

$\langle L \rangle \rightarrow b := [l=b];$

...

$\langle N \rangle \rightarrow \langle L \rangle := [l=\langle L \rangle^1];$

$\langle N \rangle \rightarrow \langle L \rangle \langle N \rangle := [l=\langle L \rangle^1 + \langle N \rangle^1];$

- Copy input letters to the feature structure
- Define string $\langle N \rangle$ as a sequence of letters $\langle L \rangle$

UMG Example

$\langle L \rangle \rightarrow a := [l=a];$

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...

$\langle N \rangle \rightarrow \langle L \rangle := [l=\langle L \rangle^1];$

$\langle N \rangle \rightarrow \langle L \rangle \langle N \rangle := [l=\langle L \rangle^1 + \langle N \rangle^1];$

$\langle S \rangle \rightarrow \langle N \rangle := \langle N \rangle;$

- Copy input letters to the feature structure
- Define string $\langle N \rangle$ as a sequence of letters $\langle L \rangle$
- $\langle S \rangle$ is a potential word stem

UMG Example

```
<L> --> a := [l=a];  
<L> --> b := [l=b];  
...  
<N> --> <L> := [l=<L>^1];  
<N> --> <L> <N> := [l=<L>^1+<N>^1];  
<S> --> <N> := <N>;  
<R> --> <S> <LEX> := <LEX> # [stem=<S>^1, x=hd1, num=sg, case=nom|acc, ...];  
<R> --> <S>u <LEX> := <LEX> # [stem=<S>^1, 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



- 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

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

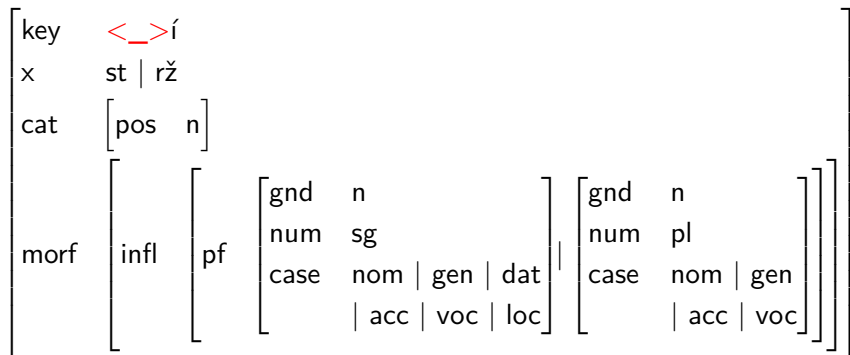
```
<_><i>$ := [key=<_>i, x=(st|rž), cat=[pos=n],  
            morf=[infl=[pf=( [gnd=n, num=sg, case=(nom|gen|dat|acc|voc|loc)] |  
                             [gnd=n, num=pl, case=(nom|gen|acc|voc)])]]];  
  
<_><i><m>$ := [key=<_>i, x=(st|rž), cat=[pos=n],  
            morf=[infl=[pf=( [gnd=n, num=sg,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




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)])]]];
```





UMG Example

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

```
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             morf=[infl=[pf=( [gnd=n, num=sg, case=(nom|gen|dat|acc|voc|loc)] |
                               [gnd=n, num=pl, case=(nom|gen|acc|voc)])]]];
```

$$\left[\begin{array}{cc} \text{key} & \text{<_>í} \\ \text{x} & \text{st} \\ \text{cat} & \left[\begin{array}{cc} \text{pos} & \text{n} \end{array} \right] \\ \text{morf} & \left[\begin{array}{cc} \text{infl} & \left[\begin{array}{cc} \text{pf} & \left[\begin{array}{cc} \text{gnd} & \text{n} \\ \text{num} & \text{sg} \\ \text{case} & \text{nom} \end{array} \right] \end{array} \right] \end{array} \right] \end{array} \right]$$

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- 😊 The feature structure contains the required output (tag) \Rightarrow no need for supplementary non-terminal naming convention

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Comparison of UMG and CFG

- 😊 The feature structure contains the required output (tag) \Rightarrow no need for supplementary non-terminal naming convention
- 😊 The features and their unifiability constrain rule application \Rightarrow 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)

- 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)



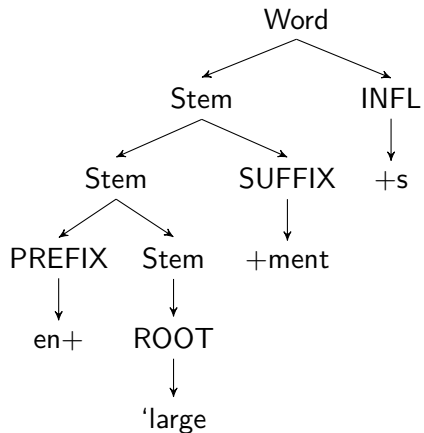
Analyze *enlargements*:

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



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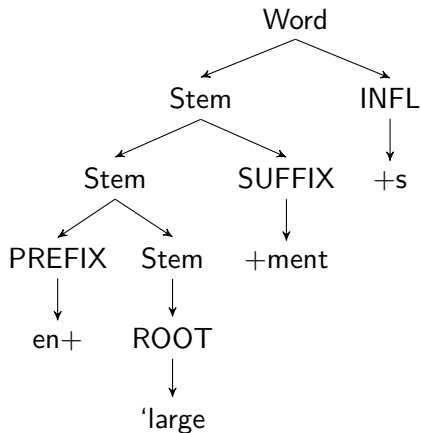
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Analyze *enlargements*:

en + 'large + ment + s
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Word:

cat	Word
head	$\left[\begin{array}{cc} \text{agr} & \left[\begin{array}{cc} 3\text{sg} & - \end{array} \right] \\ \text{number} & \text{PL} \\ \text{pos} & \text{N} \end{array} \right]$
root	'large
root_pos	AJ
clitic	—
drvstem	—

- 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>

Word \rightarrow Stem INFL
 <Stem head pos> = <INFL from_pos>
 <Word head> = <INFL head>

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

Word \rightarrow Stem INFL

$\langle \text{Stem head pos} \rangle = \langle \text{INFL from_pos} \rangle$

$\langle \text{Word head} \rangle = \langle \text{INFL head} \rangle$

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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 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 \rightarrow 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



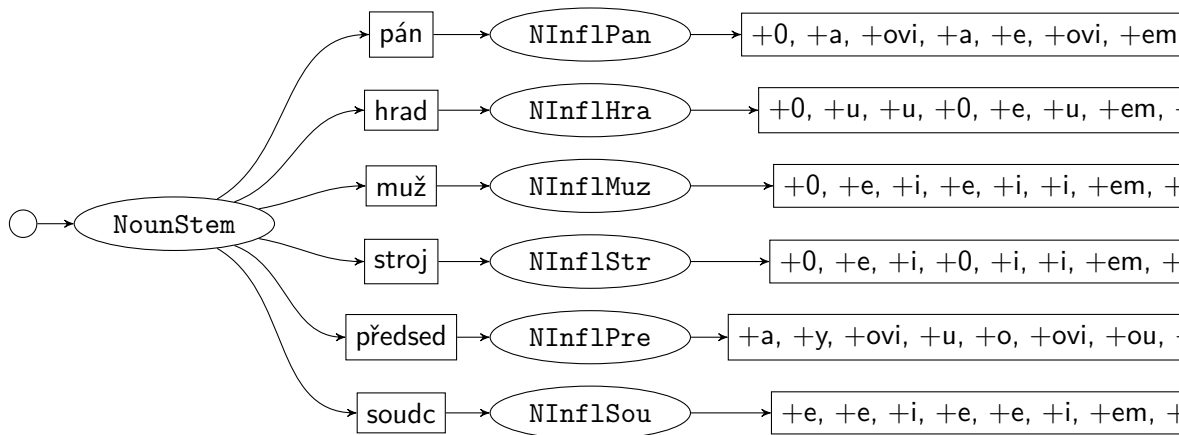
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 - *nejchytřejší* “smartest”



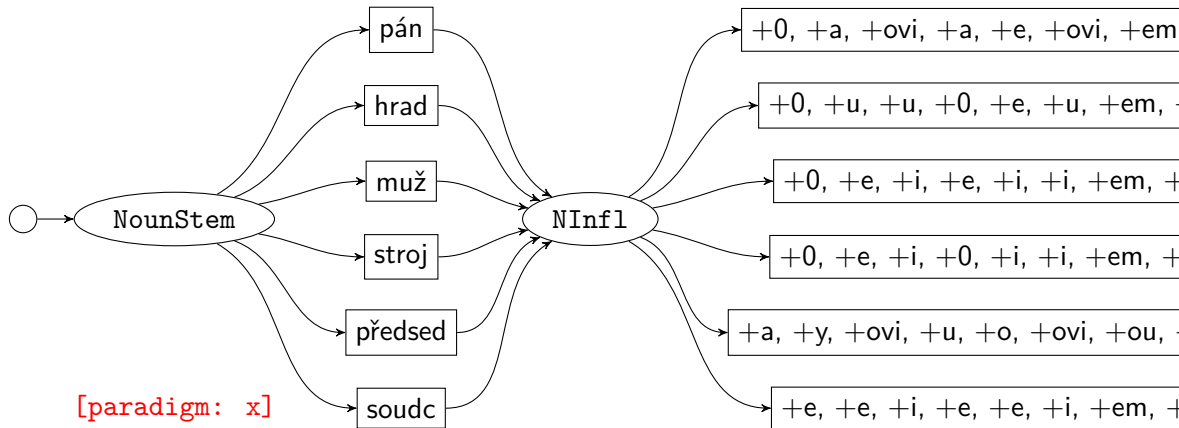
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 - It can check **long-distance dependencies** such as
 - *nejchytřejší* “smartest”
 - Take feminine noun *žena* “woman”. Derive possessive adjective *ženin* “woman’s”
 - Change gender from feminine to masculine (the suffix says that the possessed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



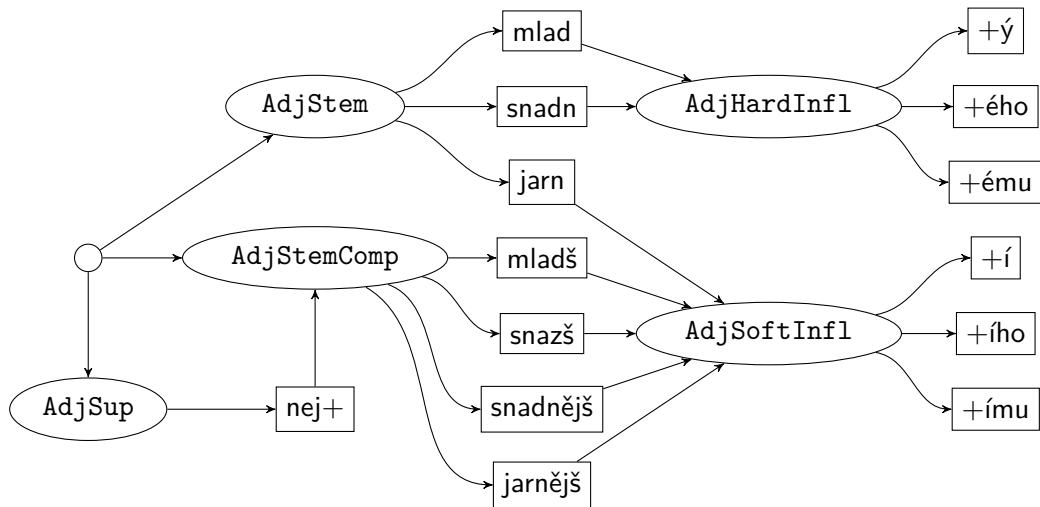


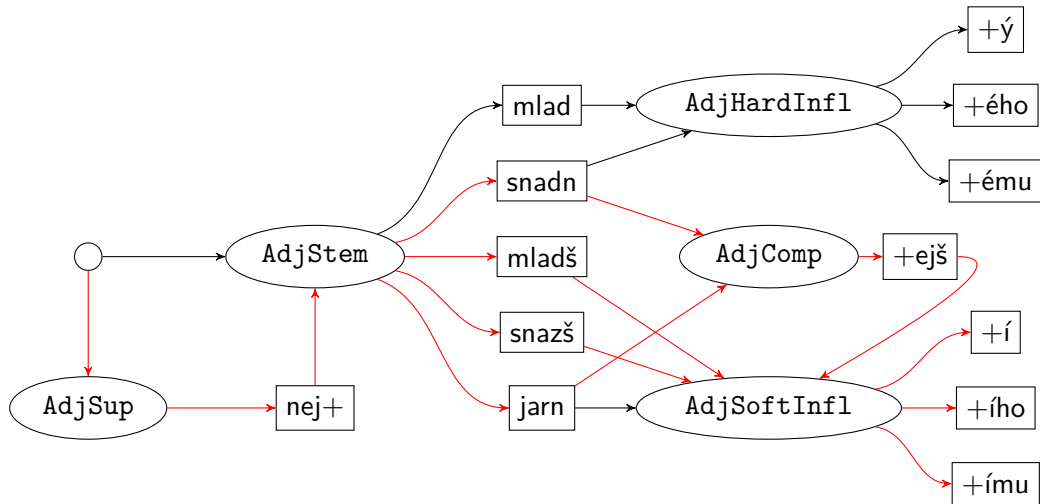
Czech Nouns with Grammar






Czech Adjectives without Grammar





Grammar Cannot Interact with Phonology

- Phonological rule of consonant softening in  Czech imperative:
 - *meteš* “you sweep” → *met̚(-me, -te)* “sweep!”
 - $t:t̚ \Leftrightarrow _ +:0 \ \lambda:0$ 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” → **kót̚*
- 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)

- 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

- 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?