Jonas Kuhn & Stefan Müller

Grammar Development in Constraint-Based Formalisms – HPSG and LFG

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HPSG Background

Head-Driven Phrase Structure Grammar

- developed in the mid 1980s as an alternative to Transformational Grammar
- Pollard and Sag (1987, 1994)

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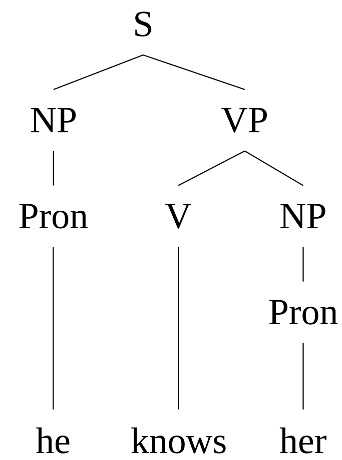
- Websites:
  http://hpsg.stanford.edu/ and http://www.dfki.de/lt/HPSG/ (Literature)
- recent textbooks:
  (Sag and Wasow, 1999)

Outline

- Phrase Structure Grammars
- The Formalism
- Valence and Grammar Rules
- Complementation
- Semantics
- Adjunction
- The Lexicon

A Simple Phrase Structure Grammar for English



S → NP, VP
VP → V, NP
NP → Pron
Pron → *he*
Pron → *him*
Pron → *her*
V → *knows*

(1) a. He knows her.
b. * We knows her.

What is wrong?

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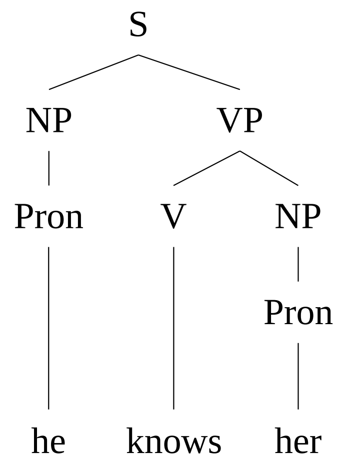

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What is wrong?

Person and number of *we* and verb

Person Number Agreement

(2) a. I/you/we/you/they sleep.

b. He sleeps.

(3) I am / you are / he is / we/you/they are . . .

To capture the fact that subject and verb agree in person and number we have to use more complex symbols:

S $\rightarrow$ NP_1_sg, VP_1_sg

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S → NP_3_sg, VP_3_sg

. . .

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. . .

VP_1_sg → V_1_sg, NP

VP_2_sg → V_2_sg, NP

VP_3_sg → V_3_sg, NP

. . .

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S	→ NP_1_sg, VP_1_sg	NP_1_sg	→ Pron_1_sg
S	→ NP_2_sg, VP_2_sg	NP_2_sg	→ Pron_2_sg
S	→ NP_3_sg, VP_3_sg	NP_3_sg	→ Pron_3_sg
. . .		. . .	
VP_1_sg	→ V_1_sg, NP		
VP_2_sg	→ V_2_sg, NP		
VP_3_sg	→ V_3_sg, NP		
. . .			

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S	→ NP_1_sg, VP_1_sg	NP_1_sg	→ Pron_1_sg
S	→ NP_2_sg, VP_2_sg	NP_2_sg	→ Pron_2_sg
S	→ NP_3_sg, VP_3_sg	NP_3_sg	→ Pron_3_sg
. . .		. . .	
VP_1_sg	→ V_1_sg, NP	Pron_3_sg	→ *he*
VP_2_sg	→ V_2_sg, NP	Pron_3_sg	→ *him*
VP_3_sg	→ V_3_sg, NP	Pron_3_sg	→ *her*
. . .		V_3_sg	→ *knows*

Problems with this Approach

- the number of non-terminal symbols explodes
- in rules like

  VP_1_sg → V_1_sg, NP

  VP_2_sg → V_2_sg, NP

  VP_3_sg → V_3_sg, NP

  what does NP stand for?
  Instead we had to write NP_1_sg or NP_2_sg or . . . in each rule
  → explosion of the number of rules
- missing generalization
- Solution: Features

Person Number Agreement: Rules with Features

(4) a. I/you/we/you/they sleep.

b. He sleeps.

(5) I am / you are / he is / we/you/they are . . .

S → NP(Per,Num), VP(Per,Num)

VP(Per,Num) → V(Per,Num), NP(Per2,Num2)

NP(Per,Num) → Pron(Per,Num)

Pron(3,sg) → *he*

V(3,sg) → *knows*

things in the brackets written in capital letters are variables

the value of Per and Num in the rules does not matter

important: Per and Num of NP and VP are equal

Per2, Num2 do not matter since they do not appear anywhere else

Feature Bundles

- are there rules where Per values have to be identical, but Num values may be not?

  S → NP(Per,Num), VP(Per,Num)

  VP(Per,Num) → V(Per,Num), NP(Per2,Num2)

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  NP(Per,Num) → Pron(Per,Num)

  Pron(3,sg) → *he*

  V(3,sg) → *knows*

- structuring of information: Per and Num are grouped together and referred to with Arg:

  S → NP(Agr), VP(Agr)

  VP(Agr) → V(Agr), NP(Agr2)

  NP(Agr) → Pron(Agr)

  Pron(agr(3,sg)) → *he*

  V(agr(3,sg)) → *knows*

- value of Agr is a complex structure that contains information about person and number
- important in HPSG: information is shared by mothers and daughters or between daughters in a rule

Heads

A head determines the most important features of a phrase/projection.

(6) a. Karl sleeps.
    b. Karl talks about linguistics.
    c. about linguistics
    d. a man

A (finite) sentence is a maximal projection of a (finite) verb.

Heads

A head determines the most important features of a phrase/projection.

(6) a. Karl sleeps.
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    c. about linguistics
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A (finite) sentence is a maximal projection of a (finite) verb.

main categories are:

category	projected features
verb	part of speech, verb form (*fin*, *bse*, . . .)
noun	part of speech, case
preposition	part of speech, form of the preposition
adjective	part of speech

Abstraction over Rules

$\overline{\text{X}}$ -Theory (Jackendoff, 1977):

$\overline{\text{X}}$ – Rule	examples with instantiated part of speech
$\overline{\overline{\text{X}}} \rightarrow \overline{\overline{\text{Specifier}}}\ \overline{\text{X}}$	$\overline{\overline{\text{N}}} \rightarrow \overline{\overline{\text{DET}}}\ \overline{\text{N}}$
$\overline{\text{X}} \rightarrow \overline{\text{X}}\ \overline{\overline{\text{Adjunct}}}$	$\overline{\text{N}} \rightarrow \overline{\text{N}}\ \overline{\overline{\text{REL\_CLAUSE}}}$
$\overline{\text{X}} \rightarrow \overline{\overline{\text{Adjunct}}}\ \overline{\text{X}}$	$\overline{\text{N}} \rightarrow \overline{\overline{\text{ADJ}}}\ \overline{\text{N}}$
$\overline{\text{X}} \rightarrow X\ \overline{\overline{\text{Complement}}}*$	$\overline{\text{N}} \rightarrow \text{N}\ \overline{\overline{\text{P}}}$

X stands for an arbitrary category (the head), ‘*’ for arbitrarily many repetitions

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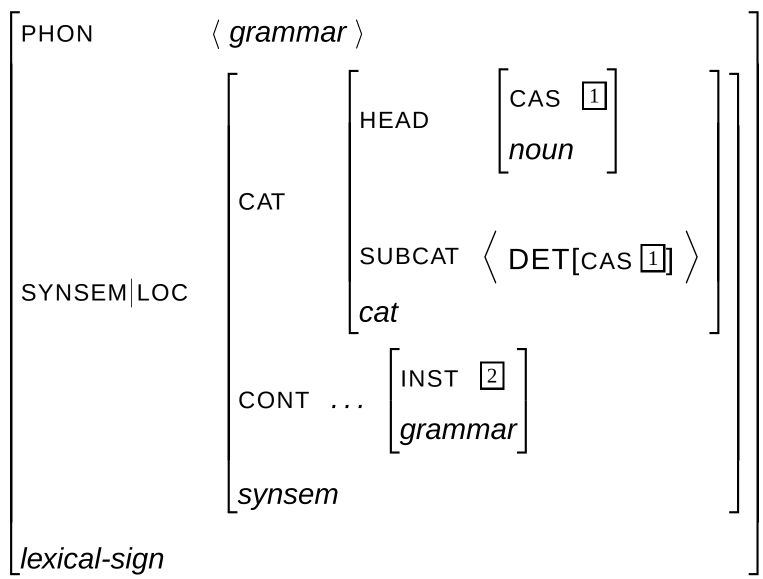
Overall Approach

- Surface-Based
- Monostratal Theory
- Lexicalized (Head-Driven)
- Sign-Based (Saussure, 1915)
- Typed Feature Structures (Lexical Entries, Morphology, Phrases, Principles)
- Multiple Inheritance

  - Phonology
  - Syntax
  - Semantics



Feature Structures

- feature structure
- attribute-value matrix
- feature matrix
- Shieber (1986), Pollard and Sag (1987), Johnson (1988), Carpenter (1992), King (1994)

Def. 1 (Feature Structure—Preliminary Version)
*A feature structure is a set of pairs of the form [*ATTRIBUTE *value].*

ATTRIBUTE *is an element of the set of feature names ATTR.*

The component value *is*

- *atomic (a string)*
- *or again a feature structure.*

Feature Structures – Examples

a simple feature structure:

$$\begin{bmatrix} \text{A1} & \textit{W1} \\ \text{A2} & \textit{W2} \\ \text{A3} & \textit{W3} \end{bmatrix}$$

Feature Structures – Examples

a simple feature structure:

$$\begin{bmatrix} \mathrm{A1} & \mathit{W1} \\ \mathrm{A2} & \mathit{W2} \\ \mathrm{A3} & \mathit{W3} \end{bmatrix}$$

a complex feature structure:

$$\begin{bmatrix} \mathrm{A1} & \mathit{W1} \\ \mathrm{A2} & \begin{bmatrix} \mathrm{A21} & \mathit{W21} \\ \mathrm{A22} & \begin{bmatrix} \mathrm{A221} & \mathit{W221} \\ \mathrm{A222} & \mathit{W222} \end{bmatrix} \end{bmatrix} \\ \mathrm{A3} & \mathit{W3} \end{bmatrix}$$

Example

A feature structure that describes a human being:

FIRST-NAME	*max*
LAST-NAME	*meier*
BIRTHDAY	*10.10.1985*

Example

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$$\begin{bmatrix} \text{FIRST-NAME} & \textit{max} \\ \text{LAST-NAME} & \textit{meier} \\ \text{BIRTHDAY} & \textit{10.10.1985} \end{bmatrix}$$

recursive structures:

$$\begin{bmatrix} \text{FIRST-NAME} & \textit{max} \\ \text{LAST-NAME} & \textit{meier} \\ \text{BIRTHDAY} & \textit{10.10.1985} \\ \text{FATHER} & \begin{bmatrix} \text{FIRST-NAME} & \textit{peter} \\ \text{LAST-NAME} & \textit{meier} \\ \text{BIRTHDAY} & \textit{10.05.1960} \\ \text{FATHER} & \ldots \\ \text{MOTHER} & \ldots \end{bmatrix} \\ \text{MOTHER} & \ldots \end{bmatrix}$$

Example

A feature structure that describes a human being:

$$\begin{bmatrix} \textsc{first-name} & \textit{max} \\ \textsc{last-name} & \textit{meier} \\ \textsc{birthday} & \textit{10.10.1985} \end{bmatrix}$$

recursive structures:

$$\begin{bmatrix} \textsc{first-name} & \textit{max} \\ \textsc{last-name} & \textit{meier} \\ \textsc{birthday} & \textit{10.10.1985} \\ \textsc{father} & \begin{bmatrix} \textsc{first-name} & \textit{peter} \\ \textsc{last-name} & \textit{meier} \\ \textsc{birthday} & \textit{10.05.1960} \\ \textsc{father} & \ldots \\ \textsc{mother} & \ldots \end{bmatrix} \\ \textsc{mother} & \ldots \end{bmatrix}$$

Exercise: How do we represent the daughters or sons of a human being?

Solution I

FIRST-NAME	*max*
LAST-NAME	*meier*
BIRTHDAY	*10.10.1985*
FATHER	...
MOTHER	...
DAUGHTER	...

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DAUGHTER	...

What about persons with several daughters?

FIRST-NAME	*max*
LAST-NAME	*meier*
BIRTHDAY	*10.10.1985*
FATHER	...
MOTHER	...
DAUGHTER-1	...
DAUGHTER-2	...
DAUGHTER-3	...

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BIRTHDAY	*10.10.1985*
FATHER	...
MOTHER	...
DAUGHTER-1	...
DAUGHTER-2	...
DAUGHTER-3	...

How many features do we want? Where is the limit?

Solution II – Lists

$$\begin{bmatrix} \text{FIRST-NAME} & \textit{max} \\ \text{LAST-NAME} & \textit{meier} \\ \text{BIRTHDAY} & \textit{10.10.1985} \\ \text{FATHER} & \ldots \\ \text{MOTHER} & \ldots \\ \text{DAUGHTER} & \left\langle \ldots, \ldots \right\rangle \end{bmatrix}$$

Solution II – Lists

FIRST-NAME	*max*
LAST-NAME	*meier*
BIRTHDAY	*10.10.1985*
FATHER	...
MOTHER	...
DAUGHTER	$\langle \ldots, \ldots \rangle$

What about sons?

Solution II – Lists

FIRST-NAME	*max*
LAST-NAME	*meier*
BIRTHDAY	*10.10.1985*
FATHER	...
MOTHER	...
DAUGHTER	$\langle \ldots, \ldots \rangle$

What about sons?

Do we want to differentiate? Yes, but it is a property of the described objects:

FIRST-NAME	*max*
LAST-NAME	*meier*
BIRTHDAY	*10.10.1985*
SEX	*male*
FATHER	...
MOTHER	...
CHILDREN	$\langle \ldots, \ldots \rangle$

Types

- feature structures are of a certain type
- the type is written in *italics*:

$$\left[\begin{array}{ll}\text{A1} & \textit{W1} \\ \textit{type} & \end{array}\right]$$

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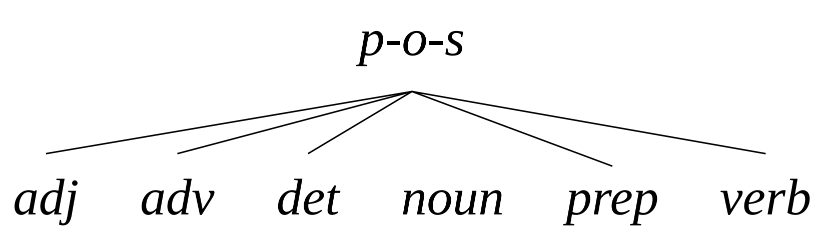
- types are organized in hierarchies
- example: part of speech



Appropriateness

- A type definition says what features are appropriate for a structure of the defined type.
- Example: A feature structure that discribes a human being does not have a feature NUMBER-OF-WHEELS.

Structure Sharing

A1 and A2 are token-identical:

$$\begin{bmatrix} \text{A1} & \boxed{1} \begin{bmatrix} \text{A3} & \textit{W3} \end{bmatrix} \\ \text{A2} & \boxed{1} \end{bmatrix}$$

Identity of values is marked by boxes

similar to variables

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our agreement example

S $\rightarrow$ NP(Agr), VP(Agr)

rewritten with feature descriptions:

$[\textsc{cat}\ \text{S}] \rightarrow [\textsc{cat}\ \text{NP},\ \textsc{agr}\ \boxed{1}],\ [\textsc{cat}\ \text{VP},\ \textsc{agr}\ \boxed{1}]$

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Valence and Grammar Rules: PSG

- huge amount of grammar rules:

VP	$\rightarrow$	V	sleep
VP	$\rightarrow$	V, NP	love
VP	$\rightarrow$	V, PP	talk about
VP	$\rightarrow$	V, NP, NP	give X Y
VP	$\rightarrow$	V, NP, PP	give Y to X

- verbs have to be used with an appropriate rule
- subcategorization is encoded twice: in rules and in lexical entries

Valence and Grammar Rules: HPSG

- complements are specified as complex categories in the lexical representation of the head
- like Categorial Grammar
- verb subcat

verb	subcat
sleep	$<$ NP $>$
love	$<$ NP, NP $>$
talk	$<$ NP, PP $>$
give	$<$ NP, NP, NP $>$
give	$<$ NP, NP, PP $>$

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sleep	$<$ NP $>$
love	$<$ NP, NP $>$
talk	$<$ NP, PP $>$
give	$<$ NP, NP, NP $>$
give	$<$ NP, NP, PP $>$
- specific rules for head complement combinations:

  V[SUBCAT $\boxed{1}$] $\rightarrow$ V[SUBCAT $\boxed{1} \oplus < \boxed{2} >$] $\boxed{2}$

  N[SUBCAT $\boxed{1}$] $\rightarrow$ N[SUBCAT $\boxed{1} \oplus < \boxed{2} >$] $\boxed{2}$

  A[SUBCAT $\boxed{1}$] $\rightarrow$ A[SUBCAT $\boxed{1} \oplus < \boxed{2} >$] $\boxed{2}$

  P[SUBCAT $\boxed{1}$] $\rightarrow$ P[SUBCAT $\boxed{1} \oplus < \boxed{2} >$] $\boxed{2}$

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- complements are specified as complex categories in the lexical representation of the head
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verb	subcat
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  $\text{P[SUBCAT } \boxed{1}] \quad \rightarrow \quad \text{P[SUBCAT } \boxed{1} \oplus < \boxed{2} >] \; \boxed{2}$
- generalized, abstract schema (H = head):

  $\text{H[SUBCAT } \boxed{1}] \quad \rightarrow \quad \text{H[SUBCAT } \boxed{1} \oplus < \boxed{2} >] \; \boxed{2}$

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- a lexical entry consists of:

  gibt (‘gives’ finite form):

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  $$\begin{bmatrix} \text{PHON} & \langle \textit{gibt} \rangle \\ & \\ & \end{bmatrix}$$

  – phonological information

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- a lexical entry consists of:

  gibt ('gives' finite form):

  $\begin{bmatrix} \textsc{phon} & \langle \textit{gibt} \rangle \\ \textsc{part-of-speech} & \textit{verb} \\ & \end{bmatrix}$

  – phonological information

  – information about part of speech

Representation of Valence in Feature Descriptions

- a lexical entry consists of:

  gibt ('gives' finite form):

PHON	⟨ *gibt* ⟩
PART-OF-SPEECH	*verb*
SUBCAT	⟨ NP[*nom*], NP[*acc*], NP[*dat*] ⟩

  – phonological information

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  – valence information: a list of feature descriptions

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  gibt (‘gives’ finite form):

$$\begin{bmatrix} \text{PHON} & \langle \textit{gibt} \rangle \\ \text{PART-OF-SPEECH} & \textit{verb} \\ \text{SUBCAT} & \left\langle \text{NP}[\textit{nom}], \text{NP}[\textit{acc}], \text{NP}[\textit{dat}] \right\rangle \end{bmatrix}$$

  - phonological information
  - information about part of speech
  - valence information: a list of feature descriptions

- NP[*nom*] is an abbreviation for a feature description

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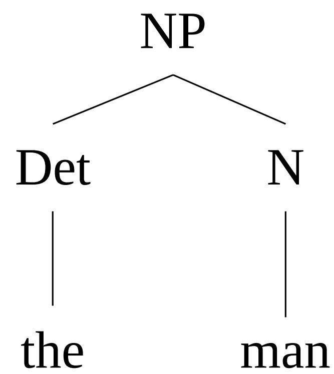
Representation of Grammar Rules (I)

- same description inventory for
  - morphological schemata,
  - lexical entries, and
  - phrasal schemata

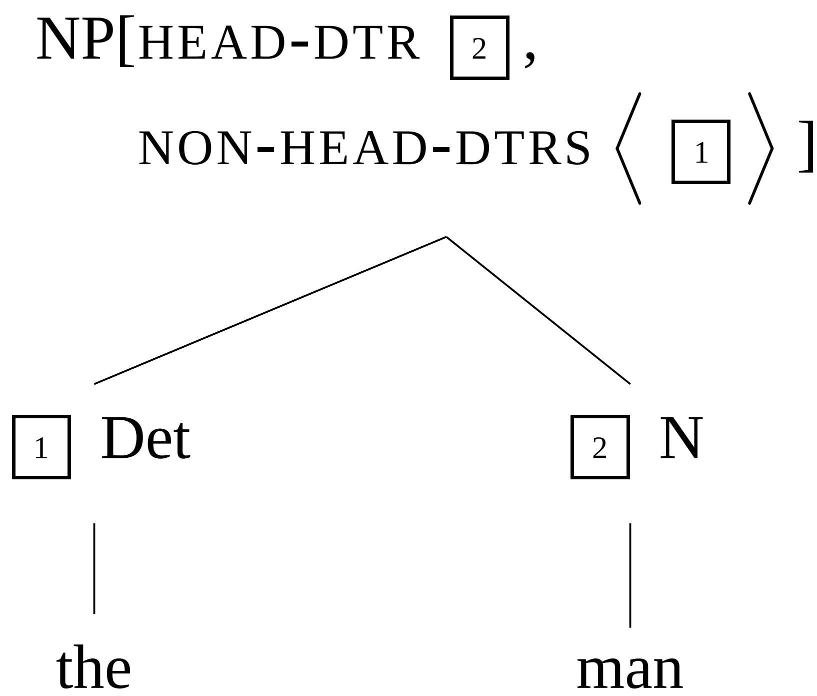
  everything is modeled in feature structures
- distinction between immediate dominance and linear precedence
- dominance is encoded in the daughter features of a structure (heads, non-heads)
- precedence is contained implicitly in the PHON value of a sign

Part of the Structure in Feature Structure Representation – PHON Values (I)



$$\begin{bmatrix} \text{PHON} & \langle \textit{the man} \rangle \\ \text{HEAD-DTR} & \begin{bmatrix} \text{PHON} \langle \textit{man} \rangle \end{bmatrix} \\ \text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix} \text{PHON} \langle \textit{the} \rangle \end{bmatrix} \right\rangle \end{bmatrix}$$

Tree with DTRS Values (I)



Representation of Grammar Rules (II)

- dominance rule:

Schema 1 (Head Complement Schema (binary branching))

$$\begin{bmatrix} \text{SUBCAT } \boxed{1} & \\ \text{HEAD-DTR} & \begin{bmatrix} \text{SUBCAT } \boxed{1} \oplus \left\langle \boxed{2} \right\rangle \\ \textit{sign} \end{bmatrix} \\ \text{NON-HEAD-DTRS} & \left\langle \boxed{2} \right\rangle \\ \textit{head-complement-structure} & \end{bmatrix}$$

$\oplus$ stands for *append*, i.e., a relation that concatenates two lists

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$\oplus$ stands for *append*, i.e., a relation that concatenates two lists

- alternative formulation, similar to $\overline{\text{X}}$ -Schema:

$\text{H[SUBCAT } \boxed{1}\text{]} \quad \rightarrow \quad \text{H[SUBCAT } \boxed{1} \oplus < \boxed{2} > \text{] } \boxed{2}$

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  Schema 1 (Head Complement Schema (binary branching))

$$\begin{bmatrix} \text{SUBCAT } \boxed{1} & \\ \text{HEAD-DTR} & \begin{bmatrix} \text{SUBCAT } \boxed{1} \oplus \left\langle \boxed{2} \right\rangle \\ \textit{sign} \end{bmatrix} \\ \text{NON-HEAD-DTRS} & \left\langle \boxed{2} \right\rangle \\ \textit{head-complement-structure} & \end{bmatrix}$$

  $\oplus$ stands for *append*, i.e., a relation that concatenates two lists

- alternative formulation, similar to $\overline{\text{X}}$ -Schema:

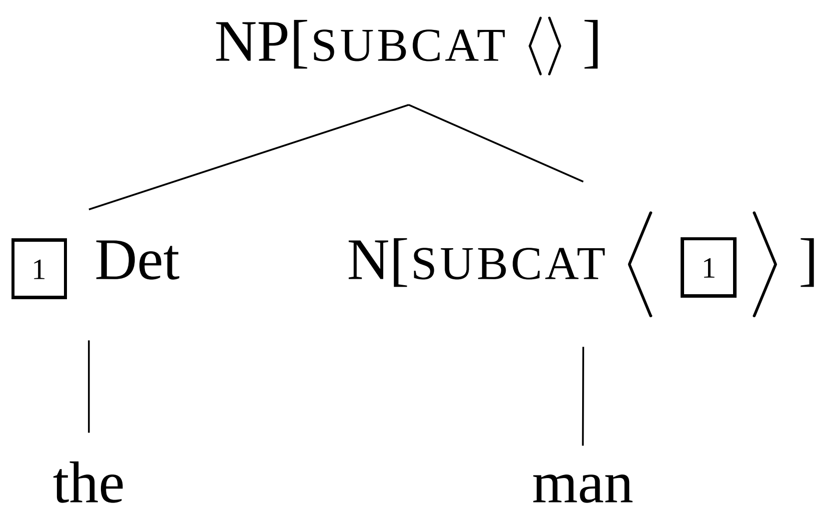
  $\text{H[SUBCAT } \boxed{1}\text{]} \quad \rightarrow \quad \text{H[SUBCAT } \boxed{1} \oplus < \boxed{2} > \text{] } \boxed{2}$

- possible instantiation:

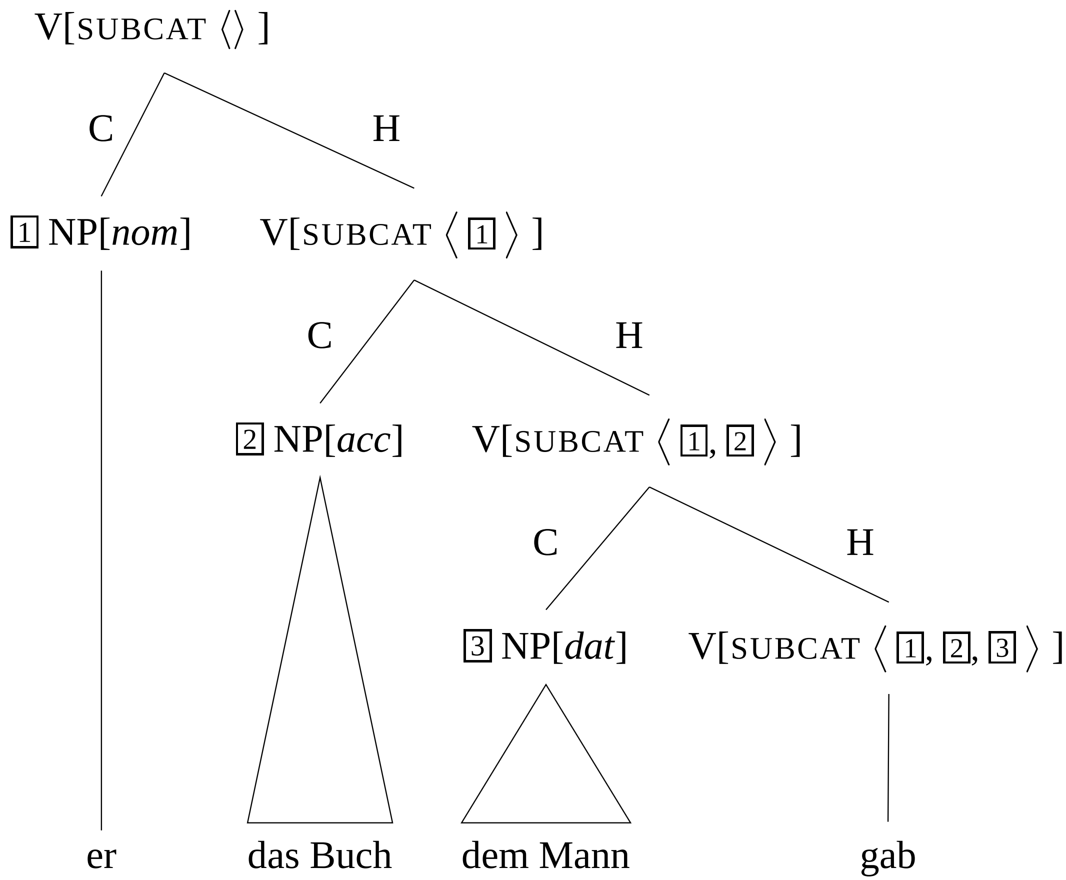
  $\text{N[SUBCAT } \boxed{1}\text{]} \quad \rightarrow \quad \text{Det N[SUBCAT } \boxed{1} \oplus < \text{Det} > \text{]}$

  $\text{V[SUBCAT } \boxed{1}\text{]} \quad \rightarrow \quad \text{V[SUBCAT } \boxed{1} \oplus < \text{NP[}\textit{dat}\text{]} > \text{] NP[}\textit{dat}\text{]}$

An Example



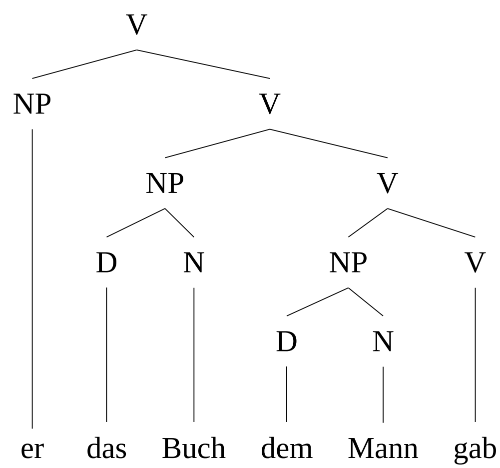
A More Complex Example



Binary Branching Head Complement Structure for ‘He gave the man the book.’

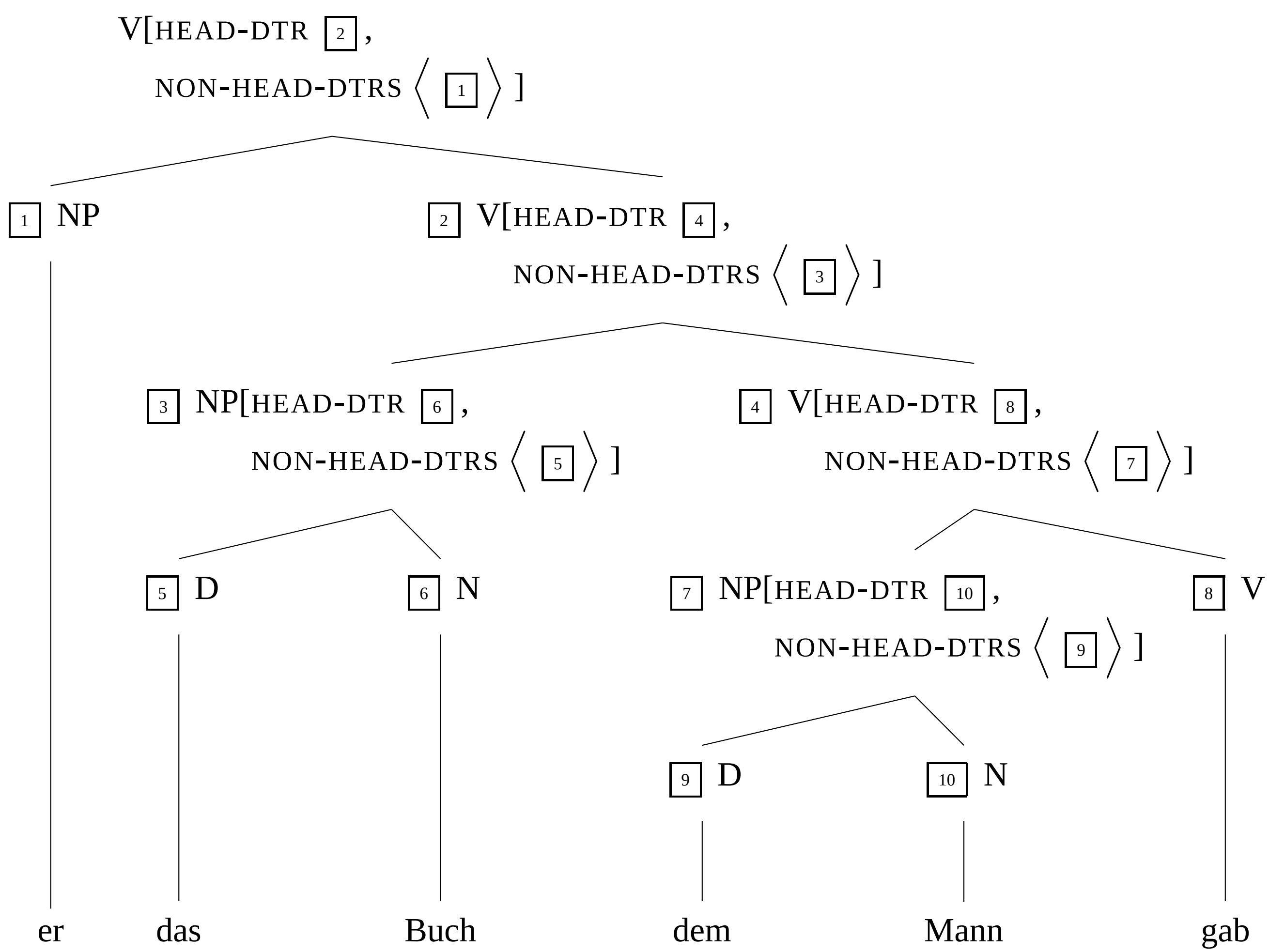
H = Head, C = Complement (= Non-Head)

Representation with Feature Structure – PHON Values (II)



$$\begin{bmatrix} \text{PHON} & \langle \textit{dem Mann gab} \rangle \\ \text{HEAD-DTR} & \begin{bmatrix} \text{PHON} \langle \textit{gab} \rangle \end{bmatrix} \\ \text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix} \text{PHON} & \langle \textit{dem Mann} \rangle \\ \text{HEAD-DTR} & \begin{bmatrix} \text{PHON} \langle \textit{Mann} \rangle \end{bmatrix} \\ \text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix} \text{PHON} \langle \textit{dem} \rangle \end{bmatrix} \right\rangle \end{bmatrix} \right\rangle \end{bmatrix}$$

Tree with DTRS Values (II)



Representation with Feature Structure – PHON values (III)

$$
\begin{bmatrix}
\text{PHON} & \langle \textit{er das Buch dem Mann gab} \rangle \\
\text{HEAD-DTR} & \begin{bmatrix}
\text{PHON} & \langle \textit{das Buch dem Mann gab} \rangle \\
\text{HEAD-DTR} & \begin{bmatrix}
\text{PHON} & \langle \textit{dem Mann gab} \rangle \\
\text{HEAD-DTR} & \begin{bmatrix} \text{PHON} & \langle \textit{gab} \rangle \end{bmatrix} \\
\text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix}
\text{PHON} & \langle \textit{dem Mann} \rangle \\
\text{HEAD-DTR} & \begin{bmatrix} \text{PHON} & \langle \textit{Mann} \rangle \end{bmatrix} \\
\text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix} \text{PHON} & \langle \textit{dem} \rangle \end{bmatrix} \right\rangle
\end{bmatrix} \right\rangle
\end{bmatrix} \\
\text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix}
\text{PHON} & \langle \textit{das Buch} \rangle \\
\text{HEAD-DTR} & \begin{bmatrix} \text{PHON} & \langle \textit{Buch} \rangle \end{bmatrix} \\
\text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix} \text{PHON} & \langle \textit{das} \rangle \end{bmatrix} \right\rangle
\end{bmatrix} \right\rangle
\end{bmatrix} \\
\text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix} \text{PHON} & \langle \textit{er} \rangle \end{bmatrix} \right\rangle
\end{bmatrix}
$$

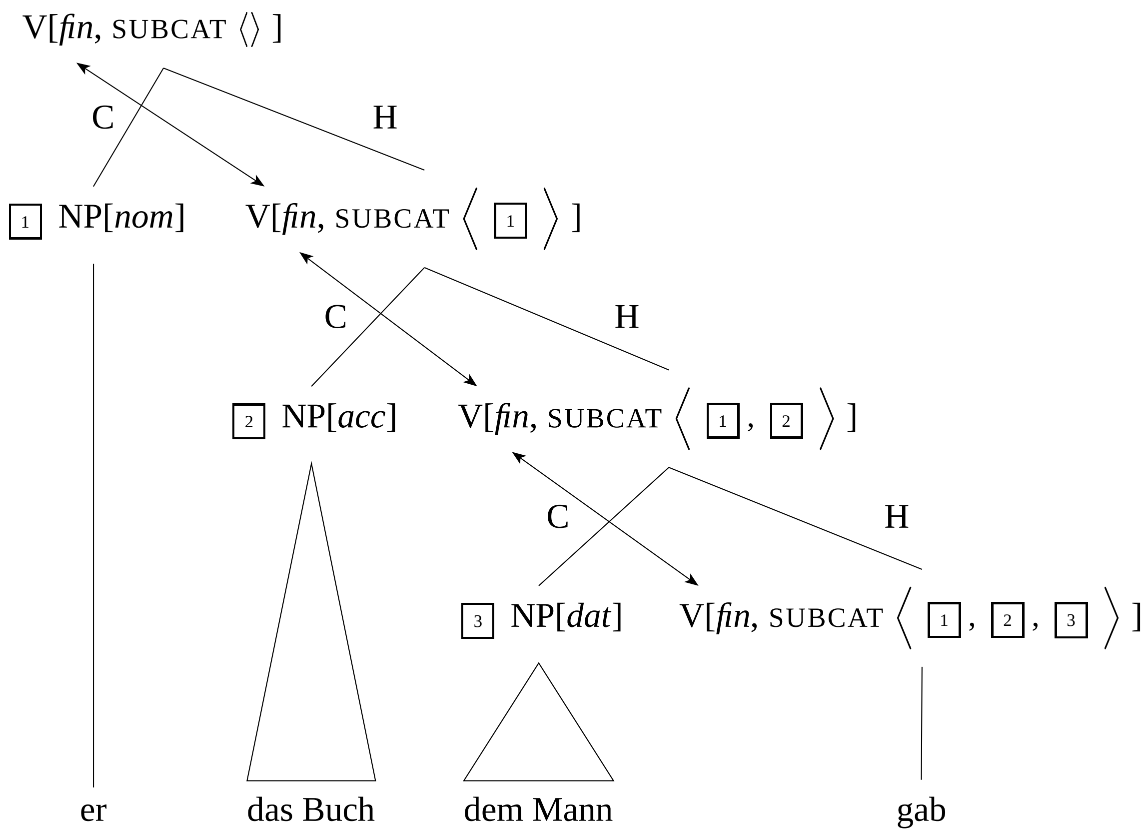
Representation in Feature Structures (Part)

$$\begin{bmatrix} \text{PHON} & \langle \textit{dem Mann, gab} \rangle \\ \text{SUBCAT} & \boxed{1} \\ \text{HEAD-DTR} & \begin{bmatrix} \text{PHON} & \langle \textit{gab} \rangle \\ \text{SUBCAT} & \boxed{1} \left\langle \text{NP}[\textit{nom}], \text{NP}[\textit{acc}] \right\rangle \oplus \left\langle \boxed{2} \right\rangle \end{bmatrix} \\ \text{NON-HEAD-DTRS} & \left\langle \boxed{2} \begin{bmatrix} \text{PHON} & \langle \textit{dem Mann} \rangle \\ \text{P-O-S} & \textit{noun} \\ \text{SUBCAT} & \langle\rangle \\ \text{HEAD-DTR} & \ldots \\ \text{NON-HEAD-DTRS} & \ldots \\ \textit{head-complement-structure} & \end{bmatrix} \right\rangle \\ \textit{head-complement-structure} & \end{bmatrix}$$

Representation in Feature Structures (Part)

$$
\begin{bmatrix}
\text{PHON } \langle \textit{ er, das Buch, dem Mann, gab } \rangle \\
\text{SUBCAT } \boxed{1} \\
\text{HEAD-DTR } \begin{bmatrix} \text{PHON } \langle \textit{ das Buch, dem Mann, gab } \rangle \\ \text{SUBCAT } \boxed{1} \langle\rangle \oplus \left\langle \boxed{2} \right\rangle \\ \textit{head-complement-structure} \end{bmatrix} \\
\text{NON-HEAD-DTRS } \left\langle \boxed{2} \begin{bmatrix} \text{PHON } \langle \textit{ er } \rangle \\ \text{P-O-S } \textit{noun} \\ \text{SUBCAT } \langle\rangle \\ \text{HEAD-DTR} \ldots \\ \text{NON-HEAD-DTRS} \ldots \\ \textit{head-complement-structure} \end{bmatrix} \right\rangle \\
\textit{head-complement-structure}
\end{bmatrix}
$$

Projection of Head Properties



- head is the finite verb
- finiteness of the verb is marked morphologically (*gab* = *gave*)
- information about finiteness and part of speech is needed at the top node → projection

Representation in Feature Descriptions: the HEAD Value

- possible feature geometry:

$$\begin{bmatrix} \text{PHON} & \textit{list of phonemes} \\ \text{P-O-S} & \textit{p-o-s} \\ \text{VFORM} & \textit{vform} \\ \text{SUBCAT} & \textit{list} \end{bmatrix}$$

Representation in Feature Descriptions: the HEAD Value

- possible feature geometry:

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- more structure, grouping information together for projection:

$$\begin{bmatrix} \text{PHON} & \textit{list of phonemes} \\ \text{HEAD} & \begin{bmatrix} \text{P-O-S} & \textit{p-o-s} \\ \text{VFORM} & \textit{vform} \end{bmatrix} \\ \text{SUBCAT} & \textit{list} \end{bmatrix}$$

Different Heads Project Different Features

- VFORM is appropriate only for verbs
- adjectives and nouns project case
- possability: one structure with all features:

$$\begin{bmatrix} \text{P-O-S} & \textit{p-o-s} \\ \text{VFORM} & \textit{vform} \\ \text{CASE} & \textit{case} \end{bmatrix}$$

  for verbs *case* is not filled in

  for nouns *vform* is not filled in

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  for verbs *case* is not filled in

  for nouns *vform* is not filled in

- better solution: different types of feature structures
  - for verbs

$$\begin{bmatrix} \text{VFORM} & \textit{vform} \\ \textit{verb} & \end{bmatrix}$$

  - for nouns

$$\begin{bmatrix} \text{CASE} & \textit{case} \\ \textit{noun} & \end{bmatrix}$$

A Lexical Entry with Head Features

- a lexical entry consists of:

  gibt ('gives' finite form):

  [ ]

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  $$\begin{bmatrix} \text{PHON} & \langle \textit{gibt} \rangle \\ & \\ & \\ & \end{bmatrix}$$

  - phonological information

A Lexical Entry with Head Features

- a lexical entry consists of:

  gibt ('gives' finite form):

$$\begin{bmatrix} \text{PHON} & \langle \textit{gibt} \rangle \\ \text{HEAD} & \begin{bmatrix} \text{VFORM} & \textit{fin} \\ \textit{verb} & \end{bmatrix} \end{bmatrix}$$

  - phonological information
  - head information (part of speech, finiteness, . . .)

A Lexical Entry with Head Features

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  gibt ('gives' finite form):

$$\begin{bmatrix} \textsc{phon} & \langle\, \textit{gibt} \,\rangle \\ \textsc{head} & \begin{bmatrix} \textsc{vform} & \textit{fin} \\ \textit{verb} & \end{bmatrix} \\ \textsc{subcat} & \left\langle \text{NP}[\textit{nom}], \text{NP}[\textit{acc}], \text{NP}[\textit{dat}] \right\rangle \end{bmatrix}$$

  – phonological information

  – head information (part of speech, finiteness, . . .)

  – valence information: a list of feature descriptions

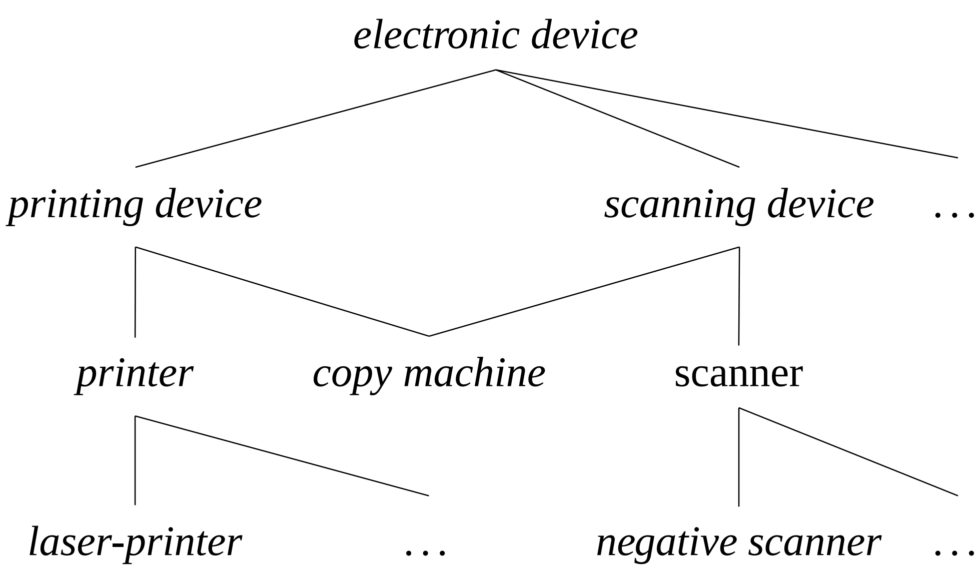
Head Feature Principle (HFP)

- In a headed structure the head features of the mother are token-identical to the head features of the head daughter.

$$\begin{bmatrix} \text{HEAD } \boxed{1} \\ \text{HEAD-DTR}|\text{HEAD } \boxed{1} \\ \textit{headed-structure} \end{bmatrix}$$

- encoding of principles in the type hierarchy:
  Krieger (1994) and Sag (1997)
- *head-complement-structure* inherits constraints of *headed-structure*

Types: A Non-Linguistic Example for Multiple Inheritance



properties of and constraints on types are inherited from supertypes

possible to capture generalizations: general constraints are stated at high types

more special types inherit this information from their supertypes

nonredundant representation of information

Linguistic Generalizations in the Type Hierarchy

- types are arranged in a hierarchy
- the most general type is at the top
- information about properties of an object of a certain type are specified in the definition of the type
- subtypes inherit these properties

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Linguistic Generalizations in the Type Hierarchy

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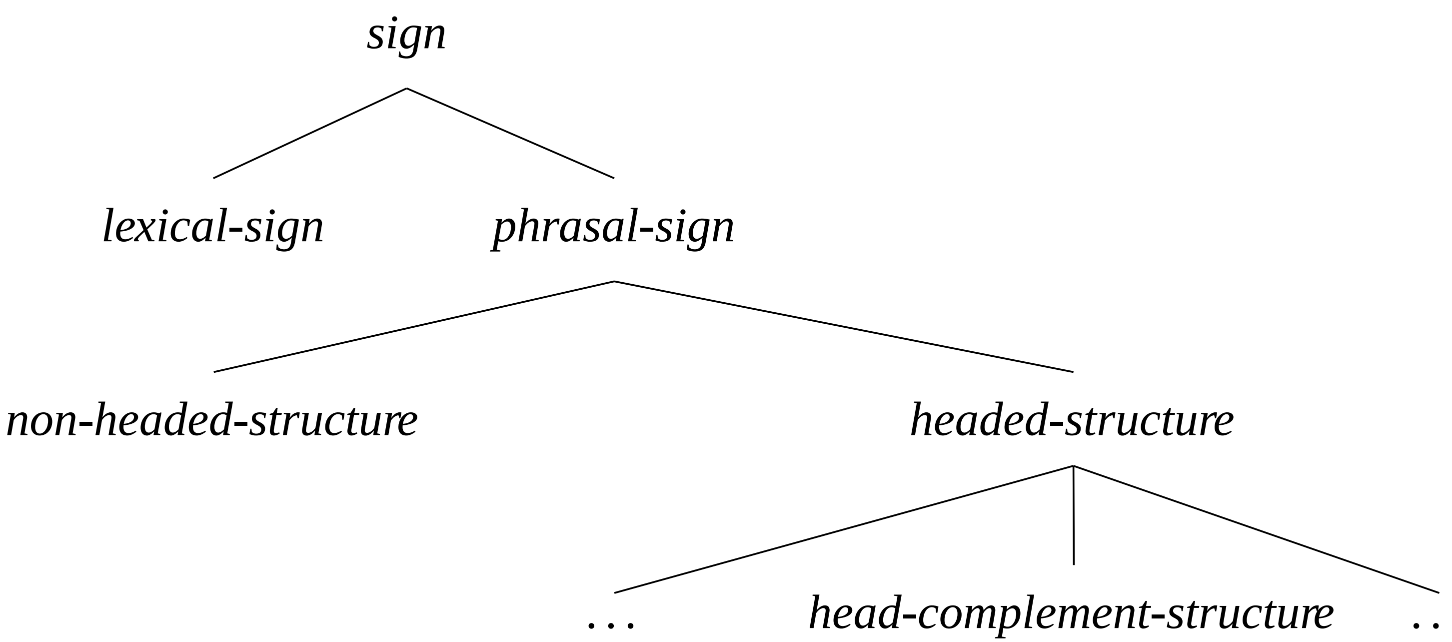
- subtypes inherit these properties
- example: entry in an encyclopedia. references to superconcepts, no repetition of the information that is stated at the superconcept already
- the upper part of a type hierarchy is relevant for all languages (Universal Grammar)
- more specific types may be specific for classes of languages or for one particular language

Type Hierarchy for *sign*



all subtypes of *headed-structure* inherit the constraints

Head Complement Schema + Head Feature Principle

$$
\left[\begin{array}{ll}
\text{HEAD} & \boxed{1} \\
\text{SUBCAT} & \boxed{2} \\
\text{HEAD-DTR} & \left[\begin{array}{ll} \text{HEAD} & \boxed{1} \\ \text{SUBCAT} & \boxed{2} \oplus \left\langle \boxed{3} \right\rangle \end{array}\right] \\
\text{NON-HEAD-DTRS} & \left\langle \boxed{3} \right\rangle \\
\multicolumn{2}{l}{\textit{head-complement-structure}}
\end{array}\right]
$$

Type *head-complement-structure* with information inherited from *headed-structure*

Head Complement Structure with Head Information Shared

$$
\begin{bmatrix}
\text{PHON} \ \langle \textit{dem Mann, gab} \rangle \\
\text{HEAD} \ \boxed{1} \\
\text{SUBCAT} \ \boxed{2} \\
\text{HEAD-DTR} \ \begin{bmatrix}
\text{PHON} \ \langle \textit{gab} \rangle \\
\text{HEAD} \ \boxed{1} \begin{bmatrix} \text{VFORM} \ \textit{fin} \\ \textit{verb} \end{bmatrix} \\
\text{SUBCAT} \ \boxed{2} \left\langle \text{NP}[\textit{nom}], \text{NP}[\textit{acc}] \right\rangle \oplus \left\langle \boxed{3} \right\rangle \\
\textit{lexical-sign}
\end{bmatrix} \\
\text{NON-HEAD-DTRS} \left\langle \boxed{3} \begin{bmatrix}
\text{PHON} \ \langle \textit{dem Mann} \rangle \\
\text{HEAD} \begin{bmatrix} \text{CAS} \ \textit{dat} \\ \textit{noun} \end{bmatrix} \\
\text{SUBCAT} \ \langle\rangle \\
\text{HEAD-DTR} \ \ldots \\
\text{NON-HEAD-DTRS} \ \ldots \\
\textit{head-complement-structure}
\end{bmatrix} \right\rangle \\
\textit{head-complement-structure}
\end{bmatrix}
$$

Outline

- Phrase Structure Grammars
- The Formalism
- Valence and Grammar Rules
- Complementation
- **Semantics**
- Adjunction
- The Lexicon

Semantics

- Pollard and Sag (1987) and Ginzburg and Sag (2001) assume Situation Semantics (Barwise and Perry, 1983; Cooper, Mukai and Perry, 1990; Devlin, 1992)

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- some recent publications use Minimal Recursion Semantics (Copestake, Flickinger and Sag, 1997)
- I will use Situation Semantics.

Individuals, Circumstances and Situations

- persistent things that belong to the causal order of the world, objects that we can track perceptually and affect by acting upon them: individuals (*Karl*, *the woman*, *the fear*, *the promise*)

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- known facts: relations and properties (properties = relations with arity one)
  - zero: *rain*
  - one: *die*
  - two: *love*
  - three: *give*
  - four: *buy*

Individuals, Circumstances and Situations

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- known facts: relations and properties (properties = relations with arity one)
  - zero: *rain*
  - one: *die*
  - two: *love*
  - three: *give*
  - four: *buy*
- semantic roles: Fillmore (1968, 1977), Kunze (1991)
  AGENT, PATIENT, EXPERIENCER, SOURCE, GOAL, THEME, LOCATION, TRANS-OBJ, INSTRUMENT, MEANS, and PROPOSITION
- roles are needed in order to capture generalizations: linking

Parameterized State of Affairs

- State of Affairs: *state of affairs* (*soa*)
- Verb: $\ll beat, agent : X, patient : Y; 1 \gg$
- Adjective: $\ll red, theme : X; 1 \gg$
- Noun: $\ll man, instance : X; 1 \gg$

- parameterized state of affairs (*psoa*)
- Verb

(7) The man beats the dog.

$\ll beat, agent : X, patient : Y; 1 \gg$
$X | \ll man, instance : X; 1 \gg,$
$Y | \ll dog, instance : Y; 1 \gg$

- Adjective

(8) The girl is smart.

$\ll smart, theme : X; 1 \gg$
$X | \ll girl, instance : X; 1 \gg$

Circumstances and Feature Structure Representations

$$\ll beat, agent : X, patient : Y ; 1 \gg$$

$$\begin{bmatrix} \textsc{agent} & X \\ \textsc{patient} & Y \\ \textit{beat} & \end{bmatrix}$$

$$\ll man, instance : X ; 1 \gg$$

$$\begin{bmatrix} \textsc{inst} & X \\ \textit{man} & \end{bmatrix}$$

$$\ll woman, instance : X ; 0 \gg$$

$$\begin{bmatrix} \textsc{arg} & \begin{bmatrix} \textsc{inst} & X \\ \textit{woman} & \end{bmatrix} \\ \textit{neg} & \end{bmatrix}$$

Representation in Feature Descriptions: the CONT value

- possible feature geometry (CONT = CONTENT):

$$\begin{bmatrix} \text{PHON} & \textit{list of phonemes} \\ \text{HEAD} & \textit{head} \\ \text{SUBCAT} & \textit{list} \\ \text{CONT} & \textit{cont} \end{bmatrix}$$

- more structure, separation of syntactic and semantic information (CAT = CATEGORY)

$$\begin{bmatrix} \text{PHON} & \textit{list of phonemes} \\ \text{CAT} & \begin{bmatrix} \text{HEAD} & \textit{head} \\ \text{SUBCAT} & \textit{list} \\ \textit{cat} & \end{bmatrix} \\ \text{CONT} & \textit{cont} \end{bmatrix}$$

Representation in Feature Descriptions: the CONT value

- possible feature geometry (CONT = CONTENT):

$$\begin{bmatrix} \textsc{phon} & \textit{list of phonemes} \\ \textsc{head} & \textit{head} \\ \textsc{subcat} & \textit{list} \\ \textsc{cont} & \textit{cont} \end{bmatrix}$$

- more structure, separation of syntactic and semantic information (CAT = CATEGORY)

$$\begin{bmatrix} \textsc{phon} & \textit{list of phonemes} \\ \textsc{cat} & \begin{bmatrix} \textsc{head} & \textit{head} \\ \textsc{subcat} & \textit{list} \\ \textit{cat} & \end{bmatrix} \\ \textsc{cont} & \textit{cont} \end{bmatrix}$$

- → sharing of syntactic information can be expressed easily
- example: symmetric coordination: the CAT values of conjuncts are identical

(9) a. the man and the woman
    b. He knows and loves this record.
    c. He is stupid and arrogant.

The Semantic Contribution of Nominal Objects

- Index (like discourse referents in DRT (Kamp and Reyle, 1993))
- Restrictions

$$
\begin{bmatrix}
\text{PHON} & \langle \textit{book} \rangle \\
\text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix}\textit{noun}\end{bmatrix} \\ \text{SUBCAT} & \left\langle \text{DET} \right\rangle \end{bmatrix} \\
\text{CONT} & \begin{bmatrix} \text{IND} & \boxed{1} \begin{bmatrix} \text{PER} & \textit{3} \\ \text{NUM} & \textit{sg} \\ \text{GEN} & \textit{neu} \end{bmatrix} \\ \text{RESTR} & \left\{ \begin{bmatrix} \text{INST} & \boxed{1} \\ \textit{book} & \end{bmatrix} \right\} \end{bmatrix}
\end{bmatrix}
$$

- person, number, and gender are important for resolving references:

(10) a. The woman$_i$ bought a table$_j$. She$_i$ likes it$_j$.

b. Die Frau$_i$ hat einen Tisch$_j$ gekauft. Sie$_i$ mag ihn$_j$.

Abbreviations

$$\mathrm{NP}_{[3, sg, fem]} \quad \begin{bmatrix} \textsc{cat} & \begin{bmatrix} \textsc{head} & \begin{bmatrix} \textit{noun} \end{bmatrix} \\ \textsc{subcat} & \langle\rangle \end{bmatrix} \\ \textsc{cont}|\textsc{ind} & \begin{bmatrix} \textsc{per} & \textit{3} \\ \textsc{num} & \textit{sg} \\ \textsc{gen} & \textit{fem} \end{bmatrix} \end{bmatrix}$$

Abbreviations

$$\mathrm{NP}_{[3,sg,fem]} \quad \begin{bmatrix} \textsc{cat} & \begin{bmatrix} \textsc{head} & \begin{bmatrix} noun \end{bmatrix} \\ \textsc{subcat} & \langle\rangle \end{bmatrix} \\ \textsc{cont}|\textsc{ind} & \begin{bmatrix} \textsc{per} & 3 \\ \textsc{num} & sg \\ \textsc{gen} & fem \end{bmatrix} \end{bmatrix}$$

$$\mathrm{NP}_{\boxed{1}} \quad \begin{bmatrix} \textsc{cat} & \begin{bmatrix} \textsc{head} & \begin{bmatrix} noun \end{bmatrix} \\ \textsc{subcat} & \langle\rangle \end{bmatrix} \\ \textsc{cont} & \begin{bmatrix} \textsc{ind} & \boxed{1} \end{bmatrix} \end{bmatrix}$$

Abbreviations

$$\text{NP}_{[3,sg,fem]} \quad \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \textit{noun} \end{bmatrix} \\ \text{SUBCAT} & \langle\rangle \end{bmatrix} \\ \text{CONT}|\text{IND} & \begin{bmatrix} \text{PER} & \textit{3} \\ \text{NUM} & \textit{sg} \\ \text{GEN} & \textit{fem} \end{bmatrix} \end{bmatrix}$$

$$\text{NP}_{\boxed{1}} \quad \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \textit{noun} \end{bmatrix} \\ \text{SUBCAT} & \langle\rangle \end{bmatrix} \\ \text{CONT} & \begin{bmatrix} \text{IND} & \boxed{1} \end{bmatrix} \end{bmatrix}$$

$$\overline{\text{N}}\text{: } \boxed{1} \quad \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \textit{noun} \end{bmatrix} \\ \text{SUBCAT} & \left\langle \text{DET} \right\rangle \end{bmatrix} \\ \text{CONT} & \boxed{1} \end{bmatrix}$$

The Feature Structure Representation of Circumstances

$$\ll beat, agent: X, patient: Y; 1 \gg$$
$$X | \ll man, instance: X; 1 \gg,$$
$$Y | \ll dog, instance: Y; 1 \gg$$

$$\begin{bmatrix} \text{AGENT} & \boxed{1} \\ \text{PATIENT} & \boxed{2} \\ \textit{beat} & \end{bmatrix}$$

$$\begin{bmatrix} \text{IND} & \boxed{1} \begin{bmatrix} \text{PER} & \textit{3} \\ \text{NUM} & \textit{sg} \\ \text{GEN} & \textit{mas} \end{bmatrix} \\ \text{RESTR} & \left\{ \begin{bmatrix} \text{INST} & \boxed{1} \\ \textit{man} & \end{bmatrix} \right\} \end{bmatrix} \qquad \begin{bmatrix} \text{IND} & \boxed{2} \begin{bmatrix} \text{PER} & \textit{3} \\ \text{NUM} & \textit{sg} \\ \text{GEN} & \textit{neu} \end{bmatrix} \\ \text{RESTR} & \left\{ \begin{bmatrix} \text{INST} & \boxed{2} \\ \textit{dog} & \end{bmatrix} \right\} \end{bmatrix}$$

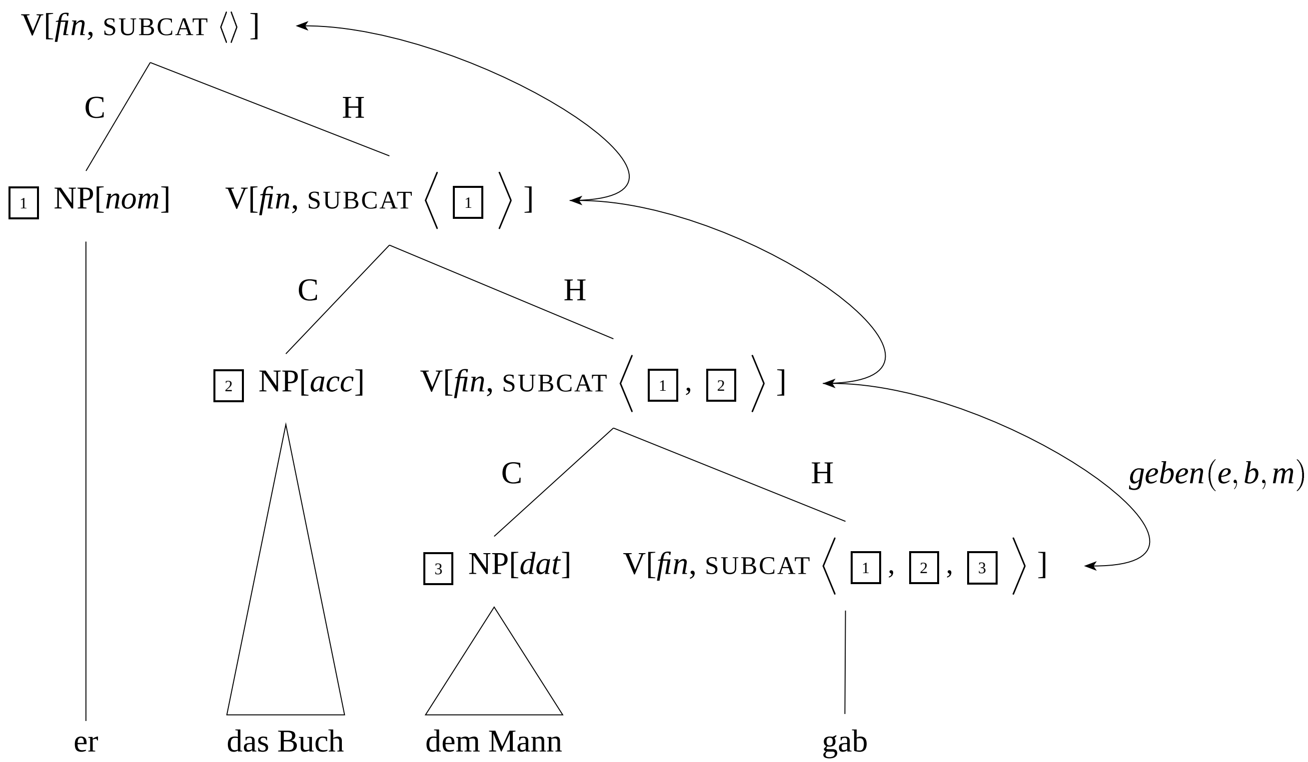
Representation in Feature Descriptions and Linking

- linking between valence and semantic contribution
- type-based
- various valance/linking patterns

gibt (finite Form):

$$\begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{VFORM} & \textit{fin} \\ \textit{verb} & \end{bmatrix} \\ \text{SUBCAT} & \left\langle \text{NP}[\textit{nom}]_{\boxed{1}}, \text{NP}[\textit{acc}]_{\boxed{2}}, \text{NP}[\textit{dat}]_{\boxed{3}} \right\rangle \end{bmatrix} \\ \text{CONT} & \begin{bmatrix} \text{AGENT} & \boxed{1} \\ \text{THEME} & \boxed{2} \\ \text{GOAL} & \boxed{3} \\ \textit{geben} & \end{bmatrix} \end{bmatrix}$$

Projection of the Semantic Contribution of the Head



Semantics Principle (preliminary version)

In headed structures the content of the mother is identical to the content of the head daughter.

$$\begin{bmatrix} \text{CONT} & \boxed{1} \\ \text{HEAD-DTR}|\text{CONT} & \boxed{1} \end{bmatrix}$$

Head Complement Schema + HFP + SemP

$$
\left[\begin{array}{ll}
\text{CAT} & \left[\begin{array}{ll} \text{HEAD} & \boxed{1} \\ \text{SUBCAT} & \boxed{2} \end{array}\right] \\
\text{CONT} & \boxed{3} \\
\text{HEAD-DTR} & \left[\begin{array}{ll} \text{CAT} & \left[\begin{array}{ll} \text{HEAD} & \boxed{1} \\ \text{SUBCAT} & \boxed{2} \oplus \left\langle \boxed{4} \right\rangle \end{array}\right] \\ \text{CONT} & \boxed{3} \end{array}\right] \\
\text{NON-HEAD-DTRS} & \left\langle \boxed{4} \right\rangle \\
\textit{head-complement-structure} &
\end{array}\right]
$$

type *head-complement-structure* with information that is inherited from *headed-structure* and Semantics Principle

Outline

- Phrase Structure Grammars
- The Formalism
- Valence and Grammar Rules
- Complementation
- Semantics
- **Adjunction**
- The Lexicon

Complements vs. Adjuncts

Examples for adjuncts:

adjectives	a *smart* woman
relative clauses	the man, *who Kim loves*,
	the man, *who loves Kim*,
Adverbs	Karl snores *loudly*.

- adjuncts do not fill a semantic role

Complements vs. Adjuncts

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- adjuncts do not fill a semantic role
- adjuncts are optional

Complements vs. Adjuncts

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	the man, *who loves Kim*,
Adverbs	Karl snores *loudly*.

- adjuncts do not fill a semantic role
- adjuncts are optional
- adjuncts can be iterated (11a), complements cannot (11b)

(11) a. a smart beautiful woman

b. * The man the man sleeps.

Adjunction

- adjunct selects head via MODIFIED

(12) the red book

$$\begin{bmatrix} \text{PHON} & \langle \textit{red} \rangle \\ \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{MOD} & \overline{\text{N}} \\ \textit{adj} & \end{bmatrix} \\ \text{SUBCAT} & \langle \rangle \end{bmatrix} \end{bmatrix}$$

- adjectives select an almost saturated nominal projection
- elements that do not modify other elements have the MOD value *none*

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- adjunct selects head via MODIFIED

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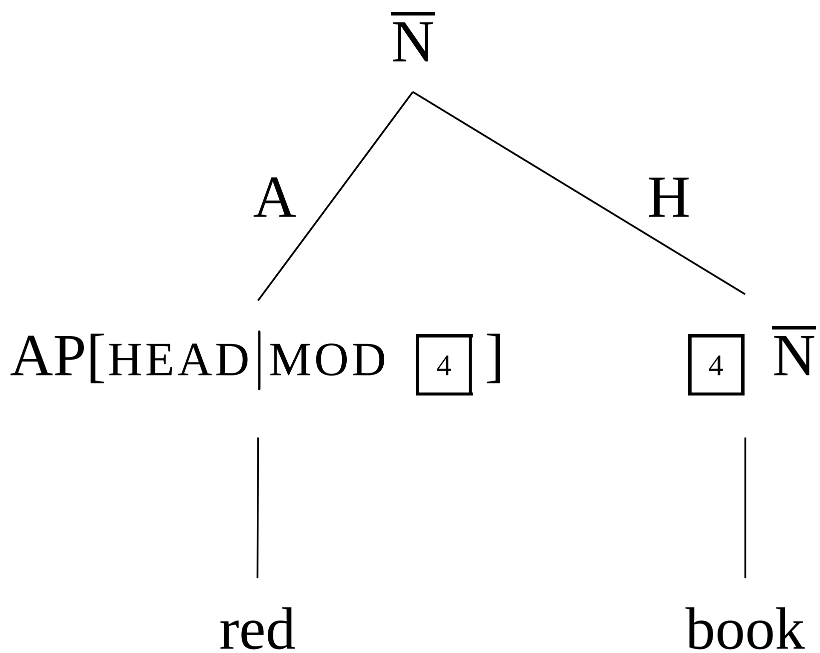
$$\begin{bmatrix} \text{PHON} & \langle \textit{red} \rangle \\ \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{MOD} & \overline{\mathrm{N}} \\ \textit{adj} & \end{bmatrix} \\ \text{SUBCAT} & \langle\rangle \end{bmatrix} \end{bmatrix}$$

- adjectives select an almost saturated nominal projection
- elements that do not modify other elements have the MOD value *none*
- alternative:
  head contains description of all possible adjuncts (Pollard and Sag, 1987)
  problematic because of iteratability (Pollard and Sag, 1994)

Head Adjunct Structure (Selection)



H = Head, A = Adjunct (= Non-Head)

Schema 2 (Head Adjunct Schema (preliminary version))

$$\left[\begin{array}{ll} \text{HEAD-DTR} & \boxed{1} \\ \text{NON-HEAD-DTRS} & \left\langle \left[\text{CAT} \left[\begin{array}{ll} \text{HEAD}|\text{MOD} & \boxed{1} \\ \text{SUBCAT} & \langle\rangle \end{array}\right] \right] \right\rangle \\ \textit{head-adjunct-structure} & \end{array}\right]$$

- the value of the selection feature of the adjunct ($\boxed{1}$) gets identified with the head daughter

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- the value of the selection feature of the adjunct ($\boxed{1}$) gets identified with the head daughter
- the adjunct must be saturated (SUBCAT $\langle\rangle$):

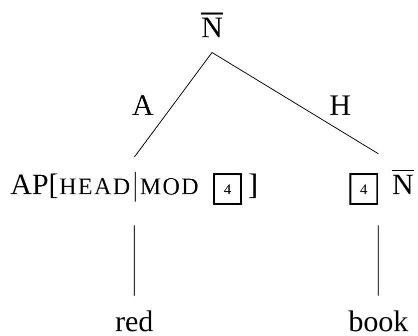
(13) a. the sausage in the cupboard

b. * the sausage in

Why is MOD a Head Feature?

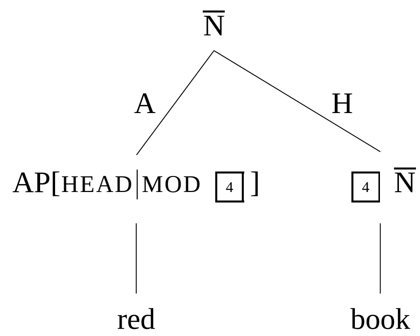
- like adjectives, prepositional phrases can modify
- adjuncts must be saturated in order to be able to modify
- the feature that selects the head to be modified has to be present at the maximal projection of the adjunct
- P + NP = PP
  PP modifies $\overline{\mathrm{N}}$
- MOD has to be present in the lexicon (P) and at a phrasal level (PP)
  project it explicitely or put it in a place that is projected anyway
  $\rightarrow$ head feature

The Semantic Contribution in Head Adjunct Structures



- From where does the semantic representation at the mother node come?
- the meaning of *book* is fixed: book(X)
- possibility: projection of meaning representation of both daughters
- *red* (red(X)) + *book* (book(Y)) = red(X) & book(X)

The Semantic Contribution in Head Adjunct Structures



- From where does the semantic representation at the mother node come?
- the meaning of *book* is fixed: book(X)
- possibility: projection of meaning representation of both daughters
- *red* (red(X)) + *book* (book(Y)) = red(X) & book(X)
- but:

  (14) the alleged murderer

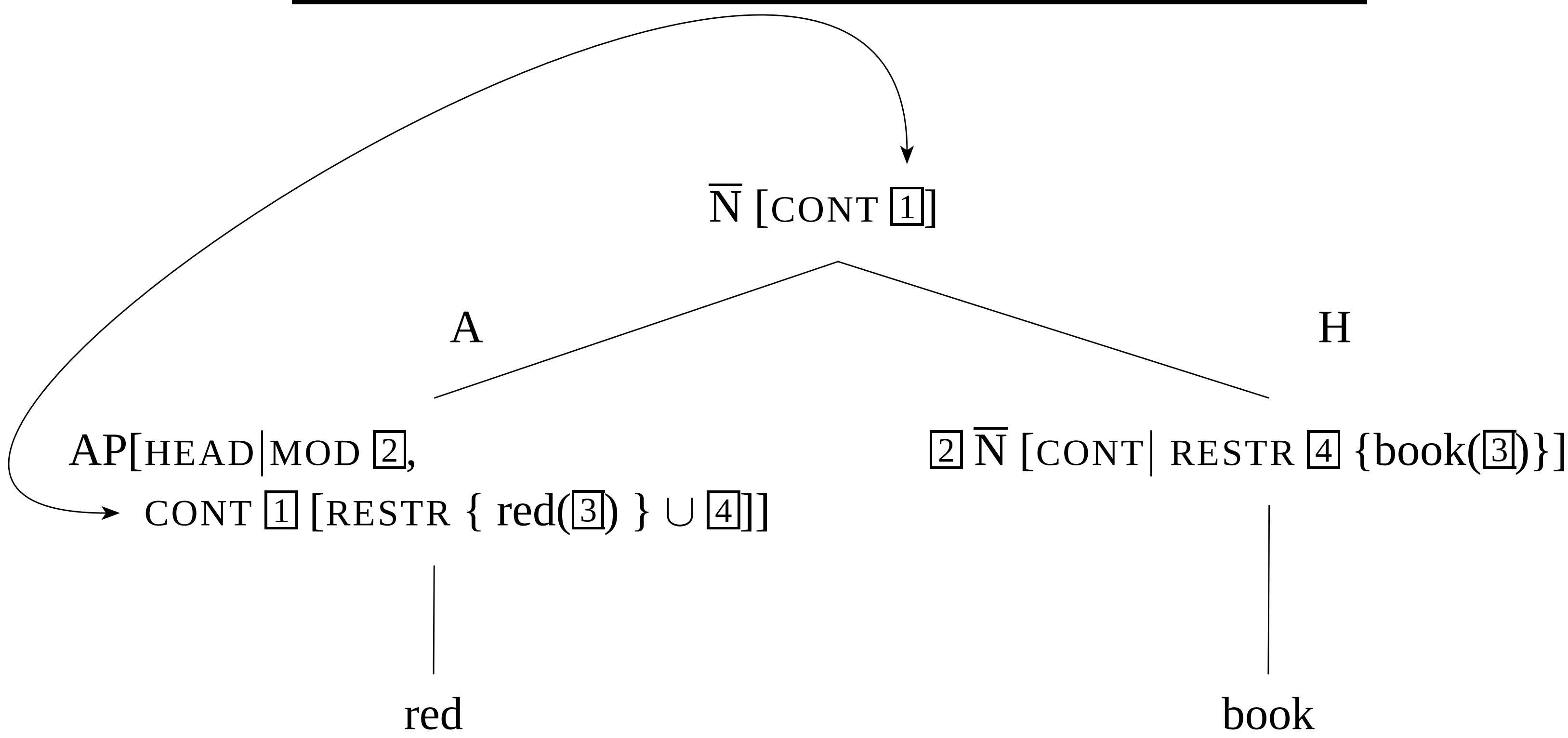
  alleged (alleged(X)) + *murderer* (murderer(Y)) $\neq$ alleged(X) & murderer(X)

- alternative: representation of the meaning at the adjunct:

  The meaning of the mother node is encoded in the lexical entry for *red* and *alleged*.

  The meaning of the modified head is integrated into the meaning of the modifier.

Head Adjunct Structures (Selection and Semantics)



- the head adjunct schema identifies the head with the MOD value of the adjunct daughter ($\boxed{2}$)
- modifier has the meaning of the complete expression under CONT: { red($\boxed{3}$) } ∪ $\boxed{4}$
- semantic contribution of the phrase is projected from the modifier ($\boxed{1}$)

Entry of the Adjective with Semantic Contribution

$$\begin{bmatrix} \text{PHON} & \langle \textit{red} \rangle \\ \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{MOD} & \overline{\text{N}}: \begin{bmatrix} \text{IND} & \boxed{1} \\ \text{RESTR} & \boxed{2} \end{bmatrix} \\ \textit{adj} & \end{bmatrix} \\ \text{SUBCAT} & \langle\rangle \end{bmatrix} \\ \text{CONT} & \begin{bmatrix} \text{IND} & \boxed{1} \begin{bmatrix} \text{PER} & \textit{3} \\ \text{NUM} & \textit{sg} \end{bmatrix} \\ \text{RESTR} & \left\{ \begin{bmatrix} \text{THEME} & \boxed{1} \\ \textit{red} & \end{bmatrix} \right\} \cup \boxed{2} \end{bmatrix} \end{bmatrix}$$

- adjective selects noun to be modified via MOD →
  adjective can access CONT value of the noun (index and restrictions) →
  adjective may include restrictions ($\boxed{2}$) into its own semantic contribution
  identification of indices ($\boxed{1}$) ensures that adjective and noun refer to the same discourse referent
- semantic contribution of the complete structure is projected from the adjunct

The Result of the Combination

$$
\left[\begin{array}{ll}
\text{PHON} & \langle \textit{red book} \rangle \\
\text{CAT} & \left[\begin{array}{ll}
\text{HEAD} & \left[\textit{noun}\right] \\
\text{SUBCAT} & \left\langle \text{DET} \right\rangle
\end{array}\right] \\
\text{CONT} & \left[\begin{array}{ll}
\text{IND} & \boxed{1} \left[\begin{array}{ll}
\text{PER} & \textit{3} \\
\text{NUM} & \textit{sg} \\
\text{GEN} & \textit{neu}
\end{array}\right] \\
\text{RESTR} & \left\{ \left[\begin{array}{ll}
\text{THEME} & \boxed{1} \\
\textit{red} &
\end{array}\right], \left[\begin{array}{ll}
\text{INST} & \boxed{1} \\
\textit{book} &
\end{array}\right] \right\}
\end{array}\right]
\end{array}\right]
$$

meaning of *red book* is not represented in *book* but in the adjective → projection of the semantic contribution form the adjunct

Projection of the Meaning in Head Adjunct Structures

$$\begin{bmatrix} \text{CONT} & \boxed{1} \\ \text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix} \text{CONT} & \boxed{1} \end{bmatrix} \right\rangle \\ \textit{head-adjunct-structure} & \end{bmatrix}$$

The Complete Head Adjunct Schema

Schema 3 (Head Adjunct Schema)

$$\begin{bmatrix} \text{CONT} & \boxed{1} \\ \text{HEAD-DTR} & \boxed{2} \\ \text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD}|\text{MOD} & \boxed{2} \\ \text{SUBCAT} & \langle\rangle \end{bmatrix} \\ \text{CONT} & \boxed{1} \end{bmatrix} \right\rangle \\ \textit{head-adjunct-structure} & \end{bmatrix}$$

The Semantics Principle

In headed structures which are not head adjunct structures, the semantic contribution of the mother is identical to the semantic contribution of the head daughter.

$$\begin{bmatrix} \text{CONT} & \boxed{1} \\ \text{HEAD-DTR}|\text{CONT} & \boxed{1} \\ \textit{head-non-adjunct-structure} & \end{bmatrix}$$

In head adjunct structures, the semantic contribution of the mother is identical to the semantic contribution of the adjunct daughter.

$$\begin{bmatrix} \text{CONT} & \boxed{1} \\ \text{NON-HEAD-DTRS} & \left\langle \begin{bmatrix} \text{CONT} & \boxed{1} \end{bmatrix} \right\rangle \\ \textit{head-adjunct-structure} & \end{bmatrix}$$

Headed structures (*headed-structure*) are subtypes of either *head-non-adjunct-structure* or *head-adjunct-structure*.

Valence in Head Adjunct Structures

book has the same valence like *red book*: a determiner is missing

adjunction does not change valence

valence information at the mother node is identical to the valence information of the head daughter

formal:

$$\begin{bmatrix} \text{CAT}|\text{SUBCAT}\ \boxed{1} \\ \text{HEAD-DTR}|\text{CAT}|\text{SUBCAT}\ \boxed{1} \\ \textit{head-non-complement-structure} \end{bmatrix}$$

In structures of type *head-non-complement-structure*, no argument gets saturated. The subcat value of the mother is identical to the subcat value of the head daughter.

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In structures of type *head-non-complement-structure*, no argument gets saturated. The subcat value of the mother is identical to the subcat value of the head daughter.

Remark:
head-non-complement-structure and *head-complement-structure* have a complementary distribution in the type hierarchy.

I. e., all structures of type *headed-structure* that are not of type *head-complement-structure* are of type *head-non-complement-structure*.

Subcat Principle

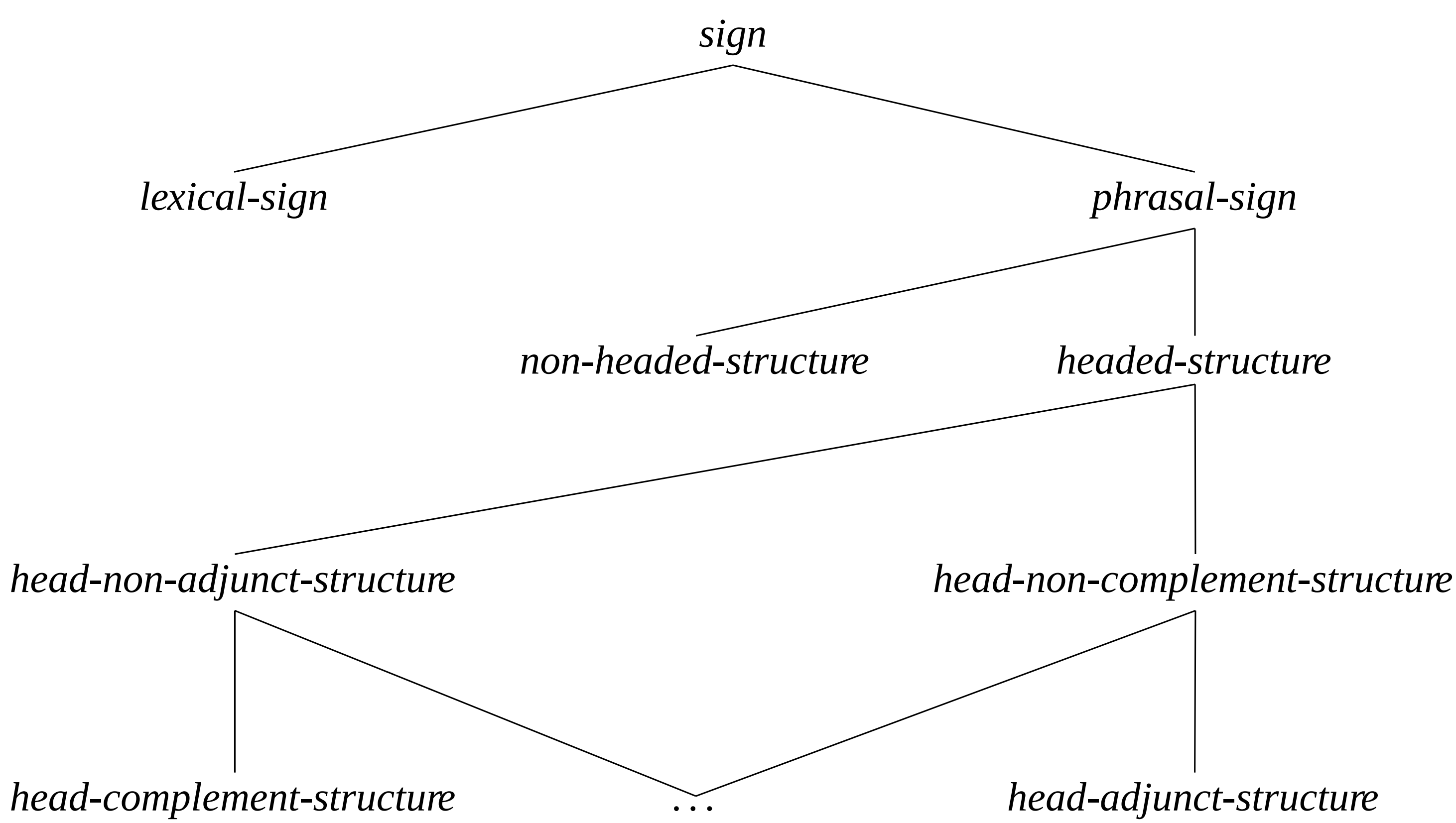
In headed structures the subcat list of the mother is the subcat list of the head daughter minus the complements that were realized as complement daughters.

$$\begin{bmatrix} \text{CAT}|\text{SUBCAT } \boxed{1} \\ \text{HEAD-DTR}|\text{CAT}|\text{SUBCAT } \boxed{1} \oplus \boxed{2} \\ \text{NON-HEAD-DTRS } \boxed{2} \textit{ ne-list} \\ \textit{head-complement-structure} \end{bmatrix}$$

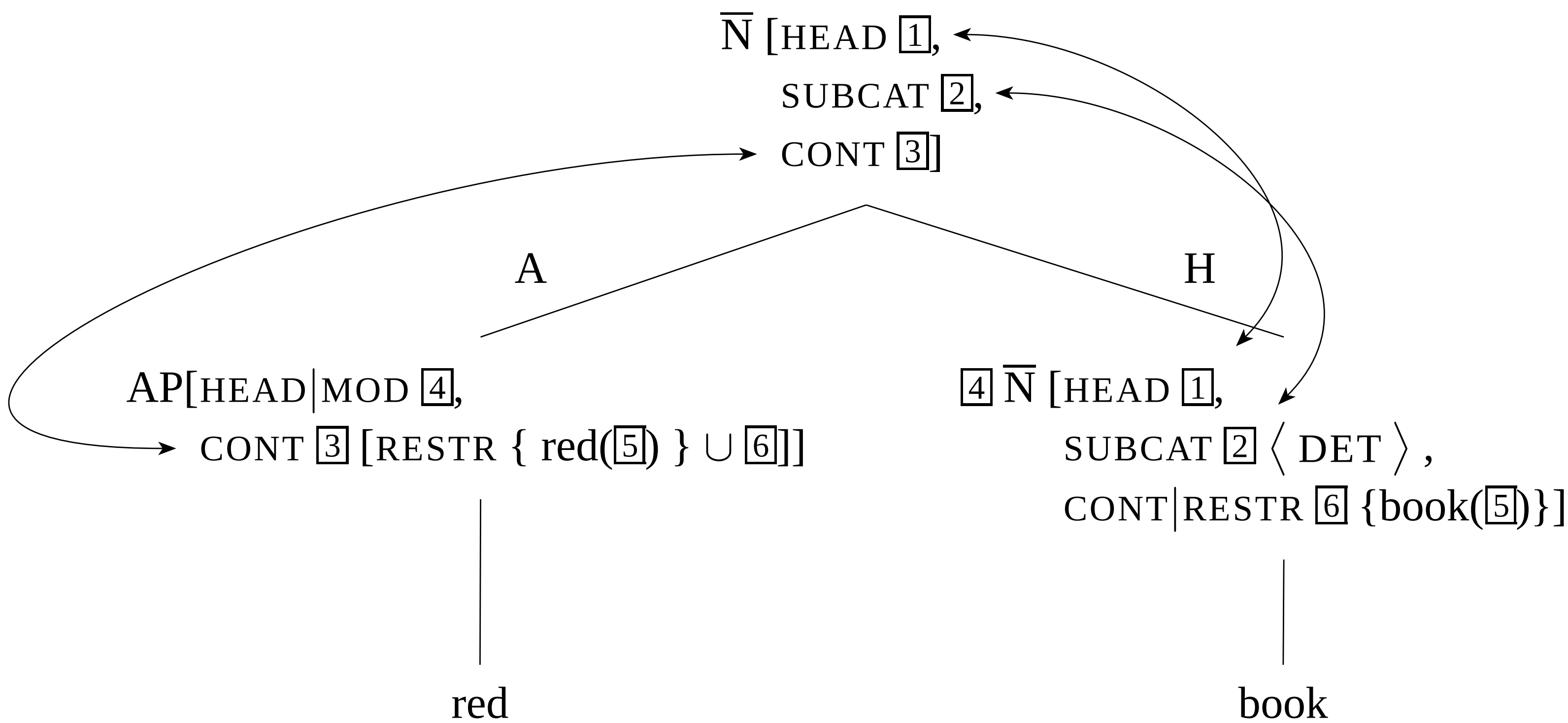
$$\begin{bmatrix} \text{CAT}|\text{SUBCAT } \boxed{1} \\ \text{HEAD-DTR}|\text{CAT}|\text{SUBCAT } \boxed{1} \\ \textit{head-non-complement-structure} \end{bmatrix}$$

Structures with head (*headed-structure*) are subtypes of either *head-complement-structure* or *head-non-complement-structure*.

Type Hierarchy for *sign*



Head Adjunct Structure (Selection, Semantics, HFP, . . .)



Outline

- Why Syntax? / Phrase Structure Grammars
- The Formalism
- Valence and Grammar Rules
- Complementation
- Semantics
- Adjunction
- **The Lexicon**

The Lexicon

- lexicalization → enormous reduction of the number of immediate dominance rules
- lexical entries are very complex
- necessary to structure and crossclassify information → capturing of generalizations & avoiding redundancy
- type hierarchies and lexical rules

The Complexity of a Lexical Entry for a Count Noun

a lexical entry for the root of the count noun *Frau* (‘woman’):

$$\begin{bmatrix} \text{PHON} & \left\langle \textit{frau} \right\rangle \\ \text{SYNSEM} & \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \textit{noun} \end{bmatrix} \\ \text{SUBCAT} & \left\langle \text{DET} \right\rangle \end{bmatrix} \\ \text{CONT} & \begin{bmatrix} \text{IND} & \boxed{1} \begin{bmatrix} \text{PER} & \mathit{3} \\ \text{GEN} & \textit{fem} \end{bmatrix} \\ \text{RESTR} & \left\{ \begin{bmatrix} \text{INST} & \boxed{1} \\ \textit{frau} & \end{bmatrix} \right\} \\ \textit{nom-obj} & \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

just very few information is idiosyncratic

Factoring Out Common Information

a. all nouns

$$\left[\text{SYNSEM} \left[\begin{array}{l} \text{CAT}|\text{HEAD} \left[\textit{noun}\right] \\ \text{CONT } \textit{nom-obj} \end{array}\right]\right]$$

Factoring Out Common Information

a. all nouns

$$\begin{bmatrix} \text{SYNSEM} & \begin{bmatrix} \text{CAT}|\text{HEAD} & \begin{bmatrix} \textit{noun} \end{bmatrix} \\ \text{CONT} & \textit{nom-obj} \end{bmatrix} \end{bmatrix}$$

b. all referential non-pronominal nouns that take a determiner (in addition to a)

$$\begin{bmatrix} \text{SYNSEM} & \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{SUBCAT} & \left\langle \text{DET} \right\rangle \end{bmatrix} \\ \text{CONT} & \begin{bmatrix} \text{IND} & \boxed{1} \begin{bmatrix} \text{PER} & \textit{3} \end{bmatrix} \\ \text{RESTR} & \left\{ \begin{bmatrix} \text{INST} & \boxed{1} \\ \textit{psoa} & \end{bmatrix}, \ldots \right\} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

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c. all feminine nouns (in addition to a und b)

$$\begin{bmatrix} \text{SYNSEM}|\text{CONT}|\text{IND}|\text{GEN} & \textit{fem} \end{bmatrix}$$

Factoring Out Common Information

a lexical entry for a verb with dative complement:

helf- (‘help’, lexical entry (root)):

$$\begin{bmatrix} \text{PHON} & \langle \textit{helf} \rangle \\ \text{SYNSEM} & \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{SUBJ} & \langle \text{NP}[\textit{nom}]_{\boxed{1}} \rangle \\ \textit{verb} & \end{bmatrix} \\ \text{SUBCAT} & \langle \text{NP}[\textit{dat}]_{\boxed{2}} \rangle \end{bmatrix} \\ \text{CONT} & \begin{bmatrix} \text{AGENT} & \boxed{1} \\ \text{EXPERIENCER} & \boxed{2} \\ \textit{help} & \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

a. all verbs

$$\left[\text{SYNSEM}\left[\begin{array}{ll}\text{CAT}|\text{HEAD} & \left[\textit{verb}\right]\\ \text{CONT} & \left[\textit{psoa}\right]\end{array}\right]\right]$$

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$$\begin{bmatrix} \text{SYNSEM} & \begin{bmatrix} \text{CAT}|\text{HEAD} & \begin{bmatrix}\textit{verb}\end{bmatrix} \\ \text{CONT} & \begin{bmatrix}\textit{psoa}\end{bmatrix} \end{bmatrix} \end{bmatrix}$$

b. transitive verbs with a dative object (in addition to a)

$$\begin{bmatrix} \text{SYNSEM} & \begin{bmatrix} \text{CAT} & \begin{bmatrix} \text{HEAD}|\text{SUBJ} & \left\langle \text{NP}[\textit{nom}] \right\rangle \\ \text{SUBCAT} & \left\langle \text{NP}[\textit{dat}] \right\rangle \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

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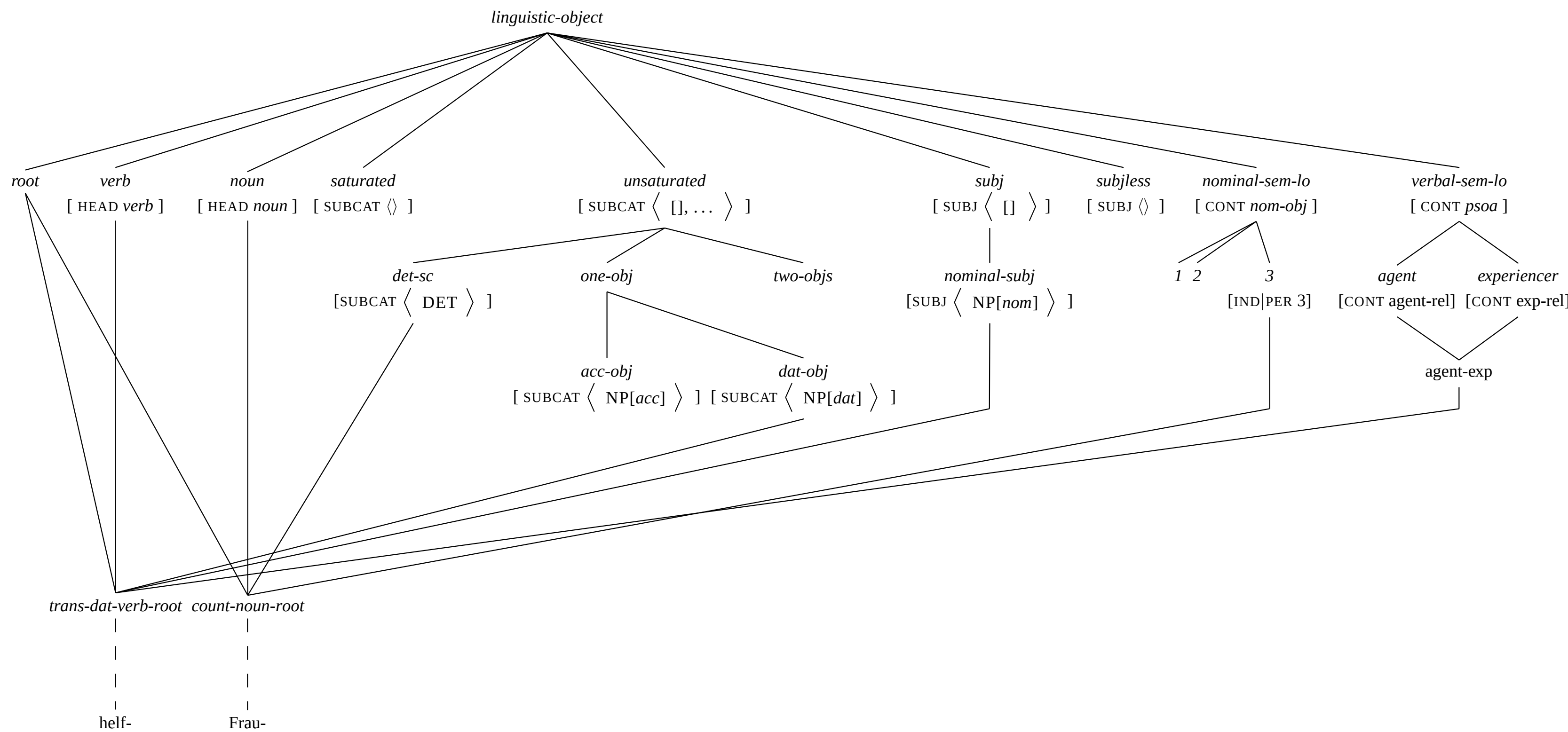
c. all transitive verbs with AGENT and EXPERIENCER (in addition to a)

$$\left[\text{SYNSEM}\ \left[\begin{array}{ll}\text{CAT} & \left[\begin{array}{ll}\text{HEAD}|\text{SUBJ} & \left\langle \left[\text{CONT}|\text{IND}\ \boxed{1}\right] \right\rangle\\ \text{SUBCAT} & \left\langle \left[\text{CONT}|\text{IND}\ \boxed{2}\right] \right\rangle\end{array}\right]\\ \text{CONT} & \left[\begin{array}{ll}\text{AGENT} & \boxed{1}\\ \text{EXPERIENCER} & \boxed{2}\\ \textit{agent-exp} & \end{array}\right]\end{array}\right]\right]$$

Part of an Example Type Hierarchy



- add appropriate paths:
  [SUBCAT ⟨⟩] stands for [SYNSEM|CAT|SUBCAT ⟨⟩]
- constraints will be inherited top down from the supertypes
- instances connected via dotted line

Examples for Lexical Entries

$$\begin{bmatrix} \text{PHON}\ \langle\ \textit{frau} \rangle \\ \text{CONT}|\text{RESTR}\ \left\{ \begin{bmatrix} \textit{frau} \end{bmatrix} \right\} \\ \textit{count-noun-root} \end{bmatrix}$$

$$\begin{bmatrix} \text{PHON}\ \langle\ \textit{helf}\ \rangle \\ \text{CONT}\ \begin{bmatrix} \textit{help} \end{bmatrix} \\ \textit{trans-dat-verb-root} \end{bmatrix}$$

Horizontal and Vertical Generalizations

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  - *woman* and *man*
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- But there are other regularities:
  - *kick* and *kicked* as used in *was kicked*
  - *love* and *loved* as used in *was loved*
- Words in the pairs could be put in the type hierarchy (as subtypes of intransitive and transitive), but than it would not be obvious that the valence change is due to the same process.

Lexical Rules

- Instead: Lexical Rules
  Jackendoff (1975), Williams (1981), Bresnan (1982), Shieber, Uszkoreit, Pereira, Robinson and Tyson (1983),
  Flickinger, Pollard and Wasow (1985), Flickinger (1987),Copestake and Briscoe (1992), Meurers (2000)

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  Flickinger, Pollard and Wasow (1985), Flickinger (1987),Copestake and Briscoe (1992), Meurers (2000)
- A lexical rule relates a description of the stem to an description of the passive form.

Lexical Rule for Passive

$$\begin{bmatrix} \text{SYNSEM|CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{VFORM} & \textit{passive-part} \\ \text{SUBJ} & \left\langle \text{NP}[\textit{nom}]_{\boxed{1}} \right\rangle \end{bmatrix} \\ \text{SUBCAT} & \boxed{2} \end{bmatrix} \\ \text{LEX-DTR} & \begin{bmatrix} \text{SYNSEM|CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{SUBJ} & \left\langle \text{NP}[\textit{nom}] \right\rangle \end{bmatrix} \\ \text{SUBCAT} & \left\langle \text{NP}[\textit{acc}]_{\boxed{1}} \right\rangle \oplus \boxed{2} \end{bmatrix} \\ \textit{stem} & \end{bmatrix} \\ \textit{passive-lexical-rule} & \end{bmatrix}$$

(15) a. The man kicks the dog.

b. The dog is kicked.

Lexical Rule for Passive with Morphology

$$\begin{bmatrix} \text{PHON} & f(\boxed{1}, ed) \\ \text{SYNSEM}|\text{CAT} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix}\text{VFORM} & \textit{passive-part} \\ \text{SUBJ} & \langle \text{NP}[\textit{nom}]_{\boxed{2}} \rangle\end{bmatrix} \\ \text{SUBCAT} & \boxed{3}\end{bmatrix} \\ \text{LEX-DTR} & \begin{bmatrix} \text{PHON} & \boxed{1} \\ \text{SYNSEM}|\text{CAT} & \begin{bmatrix}\text{HEAD} & \begin{bmatrix}\text{SUBJ} & \langle \text{NP}[\textit{nom}]\rangle\end{bmatrix} \\ \text{SUBCAT} & \langle \text{NP}[\textit{acc}]_{\boxed{2}}\rangle \oplus \boxed{3}\end{bmatrix} \\ \textit{stem} & \end{bmatrix} \\ \textit{passive-lexical-rule} & \end{bmatrix}$$

- f is a relation that relates the PHON value of the LEX-DAUGHTER to its participle form (*walk* → *walked*)
- *lexical-sign* $\succ$ *passive-lexical-rule*
- such LRs are equivalent to unary projections
- since LRs are typed, generalizations over lexical rules are possible
- alternative to lexical rules: head affix structures that are similar to binary syntactic structures

General Information about HPSG

- HPSG framework: http://hpsg.stanford.edu/
- Literature: http://www.dfki.de/lt/HPSG/
- systems
  - Development Systems
    - ALE, CMU & Tübingen, Carpenter and Penn (1996); Penn and Carpenter (1999)
      http://www.sfs.nphil.uni-tuebingen.de/~gpenn/ale.html
    - LKB, CSLI Stanford (Copestake, 1999)
      http://hpsg.stanford.edu
    - PAGE, DFKI Saarbrücken (Uszkoreit et. al., 1994)
      http://www.dfki.de/pas/f2w.cgi?lts/page-e
    - (Babel), DFKI Saarbrücken (Müller, 1996)
      http://www.dfki.de/~stefan/Babel/e_index.html
  - Runtime Systems
    - LIGHT, DFKI Saarbrücken (Ciortuz, 2000)
    - PET, DFKI Saarbrücken (Callmeier, In Press)
  - Others
    - http://registry.dfki.de/

Applications

- General source of knowledge about language
  - extraction of subgrammars
  - extraction of CF-PSGs (Kiefer and Krieger, 2000)
  - explanation based learning (Neumann, 1997; Neumann and Flickinger, 1999)
- Speech/Translation
  - Verb*mobil* (Wahlster, 2000) http://verbmobil.dfki.de/
    - German (Müller and Kasper, 2000)
    - English (Flickinger, Copestake and Sag, 2000)
    - Japanese (Siegel, 2000)
- Translation
  - German/Turkish (Kopru, 1999) using Babel
- Information Extraction
  - Whiteboard, DFKI Saarbrücken
- E-Mail Systems / Customer Interaction
  - YY: http://www.yy.com (English, Japanese, . . .)

Final Remarks

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Feature Structures

- feature structure
- attribute-value matrix
- feature matrix
- Shieber (1986), Pollard and Sag (1987), Johnson (1988), Carpenter (1992), King (1994)

Def. 2 (Feature Structure—Preliminary Version)
*A feature structure is a set of pairs of the form [*ATTRIBUTE *value].*

ATTRIBUTE *is an element of the set of feature names ATTR.*

The component value *is*

- *atomic (a string)*
- *or again a feature structure.*

Feature Structures – Examples

$$\begin{bmatrix} \text{A1} & \mathit{W1} \\ \text{A2} & \mathit{W2} \\ \text{A3} & \mathit{W3} \end{bmatrix}$$

$$\begin{bmatrix} \text{A1} & \mathit{W1} \\ \text{A2} & \begin{bmatrix} \text{A21} & \mathit{W21} \\ \text{A22} & \begin{bmatrix} \text{A221} & \mathit{W221} \\ \text{A222} & \mathit{W222} \end{bmatrix} \end{bmatrix} \\ \text{A3} & \mathit{W3} \end{bmatrix}$$

the empty feature strucutre:

$$[\;]$$

Path

Def. 3 *A* **path** *in a feature structure is a continuous sequence of attributes in the feature structure. The* **value of a path** *is the feature structure at the end of the path.*

Structure Sharing

(16) a. Hans sleeps.

b. * Hans sleep.

Def. 4 *If two features in a feature structure have identical values, they are said to share a structure. This identity remains when the feature structure is used in operations. The value of the features is represented only once in the feature structure. The identity is marked by coindexation (little boxed numbers, e.g. $\boxed{1}$).*

other terms: coreference, reentrancy

Structure Sharing

A1 and A2 are token-identical:

$$\begin{bmatrix} \text{A1} & \boxed{1} \begin{bmatrix} \text{A3} & \textit{W3} \end{bmatrix} \\ \text{A2} & \boxed{1} \end{bmatrix}$$

A1 and A2 are equal:

$$\begin{bmatrix} \text{A1} & \begin{bmatrix} \text{A3} & \textit{W3} \end{bmatrix} \\ \text{A2} & \begin{bmatrix} \text{A3} & \textit{W3} \end{bmatrix} \end{bmatrix}$$

difference for structure manipulations

Subject Verb Agreement and Structure Sharing

(17) a. Hans sleeps.

b. * Hans sleep.

$$\begin{bmatrix} \text{SUBJ} & \begin{bmatrix} \text{PHON} & \textit{hans} \\ \text{AGR} & \boxed{1} \begin{bmatrix} \text{NUM} & \textit{sg} \\ \text{PER} & \textit{3} \end{bmatrix} \end{bmatrix} \\ \text{PRED} & \begin{bmatrix} \text{PHON} & \textit{sleeps} \\ \text{AGR} & \boxed{1} \end{bmatrix} \end{bmatrix}$$

Subsumption

Def. 5 *A feature structure F1* **subsumes** *a feature structure F2 (F1 $\succeq$ F2), iff:*

- *Every complete path in F1 is contained in F2 as a complete path and has the same value as in F1.*
- *Every pair of paths in F1 that is structure shared is also structure shared in F2.*

Examples

M1 $\succeq$ M2 $\succeq$ M7 $\succeq$ M8 $\succeq$ M9

M1 $\succeq$ M4 $\succeq$ M6 $\succeq$ M7 $\succeq$ M8 $\succeq$ M9

M1 $\succeq$ M3

M1 $\succeq$ M4 $\succeq$ M5

M1: $[\,]$

M2: $\begin{bmatrix} \text{CAT} & \textit{np} \end{bmatrix}$

M3: $\begin{bmatrix} \text{CAT} & \textit{vp} \end{bmatrix}$

M4: $\begin{bmatrix} \text{AGR}|\text{PER} & \textit{3} \end{bmatrix}$

M5: $\begin{bmatrix} \text{AGR} & \begin{bmatrix} \text{NUM} & \textit{pl} \\ \text{PER} & \textit{3} \end{bmatrix} \end{bmatrix}$

M6: $\begin{bmatrix} \text{AGR} & \begin{bmatrix} \text{NUM} & \textit{sg} \\ \text{PER} & \textit{3} \end{bmatrix} \end{bmatrix}$

M7: $\begin{bmatrix} \text{CAT} & \textit{np} \\ \text{AGR} & \begin{bmatrix} \text{NUM} & \textit{sg} \\ \text{PER} & \textit{3} \end{bmatrix} \end{bmatrix}$

M8: $\begin{bmatrix} \text{CAT} & \textit{np} \\ \text{AGR} & \begin{bmatrix} \text{NUM} & \textit{sg} \\ \text{PER} & \textit{3} \end{bmatrix} \\ \text{SUBJ} & \begin{bmatrix} \text{NUM} & \textit{sg} \\ \text{PER} & \textit{3} \end{bmatrix} \end{bmatrix}$

M9: $\begin{bmatrix} \text{CAT} & \textit{np} \\ \text{AGR} & \boxed{1} \begin{bmatrix} \text{NUM} & \textit{sg} \\ \text{PER} & \textit{3} \end{bmatrix} \\ \text{SUBJ} & \boxed{1} \end{bmatrix}$

Unification

Def. 6 *Let F1, F2 and F3 be feature structures.*
F3 is the **unification** *of F1 and F2 (F3 = F1 $\wedge$ F2), iff*

- *F1 and F2 subsume F3 and*
- *F3 subsumes all other feature structures that are also subsumed by F1 and F2*

Examples

$$\begin{bmatrix}\text{CAT} & np\end{bmatrix} \wedge \begin{bmatrix}\text{CAT} & np\end{bmatrix} = \begin{bmatrix}\text{CAT} & np\end{bmatrix}$$

$$\begin{bmatrix}\text{CAT} & np\end{bmatrix} \wedge \begin{bmatrix}\text{AGR} & \begin{bmatrix}\text{PER} & 3\\ \text{NUM} & sg\end{bmatrix}\end{bmatrix} = \begin{bmatrix}\text{CAT} & np\\ \text{AGR} & \begin{bmatrix}\text{PER} & 3\\ \text{NUM} & sg\end{bmatrix}\end{bmatrix}$$

$$\begin{bmatrix}\text{CAT} & np\end{bmatrix} \wedge \begin{bmatrix}\text{AGR} & \begin{bmatrix}\text{PER} & 3\\ \text{NUM} & sg\end{bmatrix}\end{bmatrix} \neq \begin{bmatrix}\text{CAT} & np\\ \text{AGR} & \begin{bmatrix}\text{PER} & 3\\ \text{NUM} & sg\end{bmatrix}\\ \text{SUBJ} & \begin{bmatrix}\text{NUM} & sg\end{bmatrix}\end{bmatrix}$$

Unification and Structure Sharing

$$\begin{bmatrix} \text{AGR} & \boxed{1} \begin{bmatrix} \text{NUM} & sg \end{bmatrix} \\ \text{SUBJ} & \boxed{1} \end{bmatrix} \wedge \begin{bmatrix} \text{SUBJ} & \begin{bmatrix} \text{PER} & 3 \end{bmatrix} \end{bmatrix} = \begin{bmatrix} \text{AGR} & \boxed{1} \begin{bmatrix} \text{NUM} & sg \\ \text{PER} & 3 \end{bmatrix} \\ \text{SUBJ} & \boxed{1} \end{bmatrix}$$

$$\begin{bmatrix} \text{AGR} & \begin{bmatrix} \text{NUM} & sg \end{bmatrix} \\ \text{SUBJ} & \begin{bmatrix} \text{NUM} & sg \end{bmatrix} \end{bmatrix} \wedge \begin{bmatrix} \text{SUBJ} & \begin{bmatrix} \text{PER} & 3 \end{bmatrix} \end{bmatrix} = \begin{bmatrix} \text{AGR} & \begin{bmatrix} \text{NUM} & sg \end{bmatrix} \\ \text{SUBJ} & \begin{bmatrix} \text{NUM} & sg \\ \text{PER} & 3 \end{bmatrix} \end{bmatrix}$$

Lists

Lists of feature structures are introduced as a shorthand.

A list $\left\langle \mathrm{A}_1, \mathrm{A}_2, \mathrm{A}_3 \right\rangle$ can be written as:

$$\begin{bmatrix} \text{FIRST} & A_1 \\ \text{REST} & \begin{bmatrix} \text{FIRST} & A_2 \\ \text{REST} & \begin{bmatrix} \text{FIRST} & A_3 \\ \text{REST} & \textit{nil} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

$\langle\rangle$ stands for the empty list, i.e., a list with no elements

Functions and Relations

$$append(\left\langle X_1, X_2, \ldots, X_n \right\rangle, \left\langle Y_1, Y_2, \ldots, Y_m \right\rangle) = \left\langle X_1, X_2, \ldots, X_n, Y_1, Y_2, \ldots, Y_m \right\rangle$$

symbol for *append*: $\oplus$

A is the concatenation of the value of B with the value of C:

$$\begin{bmatrix} \text{A} & \boxed{1} \oplus \boxed{2} \\ \text{B} & \boxed{1} \\ \text{C} & \boxed{2} \end{bmatrix}$$

Typed Feature Structures

no restrictions on possible features and their values in a feature structure

$$\begin{bmatrix} \textsc{agr} & \begin{bmatrix} \textsc{per} & \mathit{3} \\ \textsc{num} & \mathit{sg} \end{bmatrix} \end{bmatrix}$$

$$\begin{bmatrix} \textsc{color} & \mathit{blue} \end{bmatrix}$$

compatible, although totally different objects are described

negation and disjunction

$\neg[\textsc{num}\ \mathit{pl}] \stackrel{?}{=} [\textsc{num}\ \mathit{sg}] \vee [\textsc{num}\ \mathit{17}] \vee [\textsc{color}\ \mathit{blue}]$

information unknown or irrelevant or inappropriate

Types and Appropriateness

What features belong to a structure of a given type?

What kind of values do they have?

Example:

$$\begin{bmatrix} \text{PHON} & \textit{hans} \\ \text{AGR} & \begin{bmatrix} \text{PER} & \textit{3} \\ \text{NUM} & \textit{sg} \\ \textit{agr} & \end{bmatrix} \\ \textit{construction} & \end{bmatrix} \qquad \begin{bmatrix} \text{PHON} & \textit{string} \\ \text{AGR} & \textit{agr} \\ \textit{construction} & \end{bmatrix} \qquad \begin{bmatrix} \text{PER} & \textit{per} \\ \text{NUM} & \textit{num} \\ \textit{agr} & \end{bmatrix}$$

type definition: feature structures of the type *constr* always have the features PHON and AGR

feature structures of the type *agr* always have the features PER and NUM

complex types:

$$\begin{bmatrix} \text{PHON} & \textit{string} \\ \text{AGR} & \begin{bmatrix} \text{PER} & \textit{3} \\ \text{NUM} & \textit{sg} \\ \textit{agr} & \end{bmatrix} \\ \textit{3rd-sg-construction} & \end{bmatrix}$$

Typed Feature Structures

$$
\begin{bmatrix}
\text{SUBJ} & \begin{bmatrix} \text{PHON} & \begin{bmatrix} \textit{hans} \end{bmatrix} \\ \text{AGR} & \boxed{1} \begin{bmatrix} \text{NUM} & \begin{bmatrix} \textit{sg} \end{bmatrix} \\ \text{PER} & \begin{bmatrix} \textit{3} \end{bmatrix} \\ \textit{agr} & \end{bmatrix} \\ \textit{constr} & \end{bmatrix} \\
\text{PRED} & \begin{bmatrix} \text{PHON} & \begin{bmatrix} \textit{sleeps} \end{bmatrix} \\ \text{AGR} & \boxed{1} \\ \textit{constr} & \end{bmatrix} \\
\textit{sentence} &
\end{bmatrix}
$$

Subsumption and Unification with Types

definition analogous to definition for untyped feature structures

Def. 7 *A type t1* **subsumes** *a type t2 (t1 $\succeq$ t2) iff*

- *If t1 and t2 do not have structure then t1 must be at least as specific as t2.*
- *If t1 and t2 have structure then t1 must be at least as specific as t2 and Every feature* ATTR *in feature structures of type t1 must be present in feature strucutres of type t2 and for the types $t1_{ATTR}$ and $t2_{ATTR}$ that belong to* ATTR *the following holds: $t1_{ATTR} \succeq t2_{ATTR}$.*

t1 is a **supertype** of *t2* and *t2* is a **subtype** of *t1*.

Def. 8 *Let t1, t2 and t3 be types. t3 is the* **unification** *of t1 and t2, iff*

- *t1 and t2 subsume t3 and*
- *t3 subsumes all types t that are also subsumed by t1 and t2*

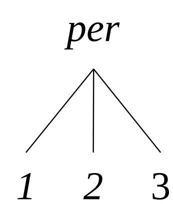
An Example

$$A = \begin{bmatrix} \text{A1} & a \\ \text{A2} & \begin{bmatrix} \text{A21} & c \\ b & \end{bmatrix} \\ aa & \end{bmatrix} \qquad B = \begin{bmatrix} \text{A1} & a \\ \text{A2} & \begin{bmatrix} \text{A21} & c \\ d & \end{bmatrix} \\ \text{A3} & e \\ bb & \end{bmatrix}$$

A $\succeq$ B, if aa $\succeq$ bb and b $\succeq$ d

Atomic and Complex Types in Inheritance Hierarchies

atomic:



similar hierarchies with complex types

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