Introduction to Head-Driven Phrase Structure Grammar [Sag and Wasow, 1999]

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Basic Design Choices of HPSG

- Emphasis on the lexicon: The lexical entries are very complex
- Few grammar rules: Grammar rules apply to all phrase types
- The constructed parse trees nodes are feature structures

Outline

- Lexical Entries: How are words represented in the lexicon?
- Lexical hierarchy and inheritance: How can we limit the complexity of the lexical entries?
- Lexical Rules: How do we obtain derived word forms?
- Grammar Rules: How do we combine nodes in a parse tree?
- Principles: What principles guide the parse tree construction?
- Sample Parse: *Ann likes the boy.*

The HPSG lexicon

- Complexity of lexical entries can pose a substantial development bottleneck.
- Creating complex lexical entries for all words fails to capture linguistic generalizations, such as morphological inflections and derivations.
- Words naturally fall into categories (e.g. parts of speech, proper vs. common nouns, etc.)

The lexical hierarchy

- Lexicon is organized in an inheritance hierarchy
- Each type in the hierarchy is associated with a number of features and constraints
- Types inherit features and constraints from types higher in the hierarchy

Default inheritance and defeasibility

The basic idea of the lexical hierarchy are subtypes:

‘If T_2 *is a subtype of* T_1 *then*

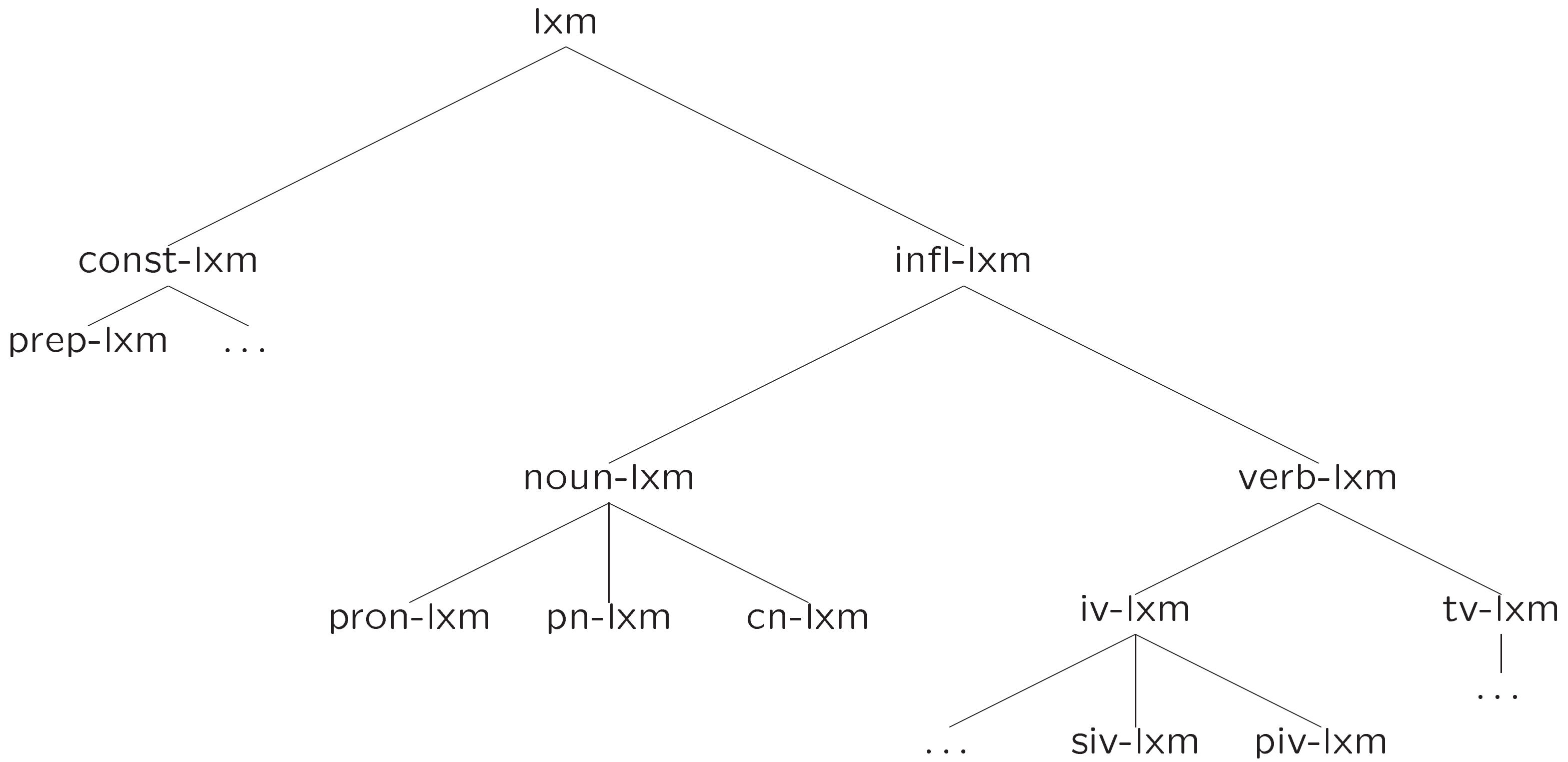
a. every feature specified as appropriate for T_1 *is also appropriate for* T_2*, and*

b. every constraint associated with T_1 *affects all instances and subtypes of* T_2*.’*

Weakened by **default inheritance:**

Some features/constraints marked as default, i.e. they are inherited but can be overridden (**defeasible**)

Lexical Hierarchy



Note: For full lexical hierarchy see pg. 203.

Features, Constraints (example: nouns)

- *pron-lxm:*

$$\left[\ldots\right]$$

- *pn-lxm:*

$$\left[SYN\ [HEAD\ [AGR\ [NUM\ /sg]]]\right]$$

- *cn-lxm:*

$$\begin{bmatrix} SYN & \begin{bmatrix} HEAD & \begin{bmatrix} AGR & \boxed{1} \end{bmatrix} \\ SPR & \langle[\,]\rangle \end{bmatrix} \\ ARG-ST & / \left\langle \begin{matrix} DetP \\ \begin{bmatrix} ARG & \boxed{1} \end{bmatrix} \end{matrix} \right\rangle \end{bmatrix}$$

- *noun-lxm:*

$$\begin{bmatrix} SYN & \begin{bmatrix} HEAD & \begin{bmatrix} noun & \\ AGR & [PER\ /3rd] \\ ANA & /- \end{bmatrix} \end{bmatrix} \\ ARG-ST & /\langle\ \rangle \\ SEM & [MODE\ /ref] \end{bmatrix}$$

- *noun:*

$$\begin{bmatrix} ANA & \{+,-\} \\ CASE & \{nom, acc\} \end{bmatrix}$$

Features, Constraints (example: verbs)

- *iv-lxm (intransitive verb):*

  No constraints.

- *siv-lxm (strict-intransitive verb):*

$$\left[ARG-ST\ \langle[\ ]\rangle\right]$$

- *piv-lxm (prepositional-intransitive verb):*

$$\left[ARG-ST\ \langle[]\ ,PP\rangle\right]$$

- *tv-lxm (transitive verb):*

$$\left[ARG-ST\ \langle[]\ ,NP,\ldots\rangle\right]$$

- *stv-lxm (strict-transitive verb:)*

$$\left[ARG-ST\ \langle[]\ ,[]\rangle\right]$$

- *dtv-lxm (ditransitive verb:)*

$$\left[ARG-ST\ \langle[]\ ,[],NP\rangle\right]$$

- *ptv-lxm (prepositional-transitive verb:)*

$$\begin{bmatrix} ARG-ST\ \langle[]\ ,[],PP\rangle \end{bmatrix}$$

- *verb-lxm:*

$$\begin{bmatrix} SYN & \begin{bmatrix} HEAD & verb \\ SPR & \langle[]\rangle \end{bmatrix} \\ ARG-ST & /\langle NP,\ldots\rangle \\ SEM & [\ MODE \quad prop\ ] \end{bmatrix}$$

- *verb:*

$$[\ldots]$$

Basic Lexical Entries

$$\left\langle Ann, \begin{bmatrix} pn-lxm & \\ SEM & \begin{bmatrix} INDEX & i \\ RESTR & \left\langle \begin{bmatrix} RELN & name \\ SIT & s \\ NAME & Ann \\ NAMED & i \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle$$

$$\left\langle like, \begin{bmatrix} stv-lxm & \\ ARG-ST & \langle [\,]_i [\,]_j \rangle \\ SEM & \begin{bmatrix} INDEX & s \\ RESTR & \left\langle \begin{bmatrix} RELN & like \\ SIT & s \\ LIKER & i \\ LIKED & j \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle$$

$$\left\langle the, \begin{bmatrix} det-lxm & \\ ARG-ST & \langle\rangle \\ SEM & [\ldots] \end{bmatrix} \right\rangle$$

$$\left\langle boy, \begin{bmatrix} cn-lxm & \\ ARG-ST & \langle [COUNT+] \rangle \\ SEM & \begin{bmatrix} INDEX & i \\ RESTR & \left\langle \begin{bmatrix} RELN & boy \\ SIT & s \\ INSTANCE & i \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle$$

Summary of Information Seen So Far

- Lexical entries:
  - Lexical items are of different types.
  - They encode the syntactic and semantic template of the word's usage.
  - The lexicon is organized in a type hierarchy with default inheritance.

Lexical Rules

Singular Noun Lexical Rule:

$$\langle \boxed{1}, [\ noun-lxm\ ] \rangle \Rightarrow$$

$$\left\langle \boxed{1}, \begin{bmatrix} word \\ SYN & [\ HEAD\ [\ AGR\ [\ NUM\ \ sg\ ]\ ]\ ] \end{bmatrix} \right\rangle$$

3rd-Singular Verb Lexical Rule:

$$\left\langle \boxed{3}, \begin{bmatrix} verb-lxm \\ SEM & \begin{bmatrix} RESTR & \boxed{a} \end{bmatrix} \end{bmatrix} \right\rangle \Rightarrow$$

$$\left\langle F_{3SG}(\boxed{3}), \begin{bmatrix} word \\ SYN & [\ HEAD\ [\ FORM\ \ fin\ ]\ ] \\ ARG-ST & \left\langle \begin{bmatrix} CASE & nom \\ AGR & 3sing \end{bmatrix}, \ldots \right\rangle \\ SEM & \begin{bmatrix} INDEX & \boxed{2} \\ RESTR & \boxed{a} \oplus \left\langle \begin{bmatrix} RELN & t-overlap \\ ARG1 & \boxed{2} \\ ARG2 & now \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle$$

Applying Lexical Rules

Notes:

1. Inheritance is applied at the same time as the lexical rules.
2. Features added by lexical rules are in bold face.
3. Inherited features are blue.

Singular Noun Lexical Rule:

$$
\left\langle Ann, \begin{bmatrix} pn-lxm & \\ SEM & \begin{bmatrix} INDEX & i \\ RESTR & \left\langle \begin{bmatrix} RELN & name \\ SIT & s \\ NAME & Ann \\ NAMED & i \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle \Rightarrow
$$

$$
\left\langle Ann, \begin{bmatrix} word & \\ SYN & \begin{bmatrix} HEAD & \begin{bmatrix} noun & \\ ANA & /- \\ CASE & \{nom, acc\} \\ AGR & \begin{bmatrix} \textbf{NUM} & \textbf{sg} \\ PER & /3rd \end{bmatrix} \end{bmatrix} \end{bmatrix} \\ ARG-ST & /\langle\rangle \\ SEM & \begin{bmatrix} INDEX & i \\ MODE & /ref \\ RESTR & \left\langle \begin{bmatrix} RELN & name \\ SIT & s \\ NAME & Ann \\ NAMED & i \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle
$$

Singular Noun Lexical Rule:

$$\left\langle boy, \begin{bmatrix} cn-lxm & \\ ARG-ST & \langle [COUNT+] \rangle \\ SEM & \begin{bmatrix} INDEX & i \\ RESTR & \left\langle \begin{bmatrix} RELN & boy \\ SIT & s \\ INSTANCE & i \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle \Rightarrow$$

$$\left\langle boy, \begin{bmatrix} word & \\ SYN & \begin{bmatrix} HEAD & \begin{bmatrix} noun & \\ AGR & \begin{bmatrix} \textbf{NUM} & \textbf{sg} \\ \boxed{1} & \end{bmatrix} \\ SPR & \langle [\rangle] \\ ANA & /- \\ CASE & \{nom, acc\} \end{bmatrix} \end{bmatrix} \\ ARG-ST & / \left\langle \begin{matrix} DetP & \\ COUNT & + \\ [AGR & \boxed{1}] \end{matrix} \right\rangle \\ SEM & \begin{bmatrix} INDEX & i \\ RESTR & \left\langle \begin{bmatrix} RELN & boy \\ SIT & s \\ INSTANCE & i \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle$$

3rd-Singular Verb Lexical Rule:

$$\left\langle like, \begin{bmatrix} stv-lxm & \\ ARG-ST & \langle [\,]_i [\,]_j \rangle \\ SEM & \begin{bmatrix} INDEX & s \\ RESTR & \left\langle \begin{bmatrix} RELN & like \\ SIT & s \\ LIKER & i \\ LIKED & j \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle \Rightarrow$$

$$\left\langle likes, \begin{bmatrix} word & \\ SYN & \begin{bmatrix} HEAD & \begin{bmatrix} verb & \\ \textbf{FORM} & \textbf{fin} \end{bmatrix} \\ SPR & \langle [\,] \rangle \end{bmatrix} \\ ARG-ST & \langle [NP_i \begin{bmatrix} \textbf{CASE} & \textbf{nom} \\ \textbf{AGR} & \textbf{3sing} \end{bmatrix}][NP_j] \rangle \\ SEM & \begin{bmatrix} MODE & prop \\ INDEX & s \\ RESTR & \left\langle \begin{bmatrix} RELN & like \\ SIT & s \\ LIKER & i \\ LIKED & j \end{bmatrix}, \begin{bmatrix} \textbf{RELN} & \textbf{t-overlap} \\ \textbf{ARG1} & \textbf{s} \\ \textbf{ARG2} & \textbf{now} \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix} \right\rangle$$

Applying Lexical Rules (cont.)

- Similarly, we need a trivial lexical rule for noninflectional lexemes, so that all the lexical FS are of type *word*, on which grammar rules can be applied.

- In particular, the *Constant Lexeme Lexical Rule* is applied:

$$\langle \boxed{1}, [const - lxm] \rangle \Rightarrow \langle \boxed{1}, [word] \rangle$$

- In our example, the *Constant Lexeme Lexical Rule* only applies to 'the'.

Word Level Feature Structures

$$
\left\langle Ann, \begin{bmatrix}
word & \\
SYN & \begin{bmatrix} HEAD & \begin{bmatrix} noun & \\ ANA & /- \\ CASE & \{nom, acc\} \\ AGR & \begin{bmatrix} \textbf{NUM} & \textbf{sg} \\ PER & /3rd \end{bmatrix} \end{bmatrix} \end{bmatrix} \\
ARG-ST & /\langle\rangle \\
SEM & \begin{bmatrix} INDEX & i \\ MODE & /ref \\ RESTR & \left\langle \begin{bmatrix} RELN & name \\ SIT & s \\ NAME & Ann \\ NAMED & i \end{bmatrix} \right\rangle \end{bmatrix}
\end{bmatrix} \right\rangle
$$

$$
\left\langle likes, \left[\begin{array}{ll}
word & \\
SYN & \left[\begin{array}{ll} HEAD & \left[\begin{array}{ll} verb & \\ \textbf{FORM} & \textbf{fin} \end{array}\right] \\ SPR & \langle [\,] \rangle \end{array}\right] \\
ARG-ST & \left\langle [NP_i \left[\begin{array}{ll} \textbf{CASE} & \textbf{nom} \\ \textbf{AGR} & \textbf{3sing} \end{array}\right]][NP_j] \right\rangle \\
SEM & \left[\begin{array}{ll} MODE & prop \\ INDEX & s \\ RESTR & \left\langle \left[\begin{array}{ll} RELN & like \\ SIT & s \\ LIKER & i \\ LIKED & j \end{array}\right], \left[\begin{array}{ll} \textbf{RELN} & \textbf{t-overlap} \\ \textbf{ARG1} & \textbf{s} \\ \textbf{ARG2} & \textbf{now} \end{array}\right] \right\rangle \end{array}\right]
\end{array}\right] \right\rangle
$$

$$
\left\langle the, \left[\begin{array}{ll}
word & \\
ARG-ST & \langle\rangle \\
SYN & \left[\begin{array}{ll} HEAD & \left[\begin{array}{ll} det & \\ COUNT & + \\ NUM & sg, pl \end{array}\right] \end{array}\right] \\
SEM & [\ldots]
\end{array}\right] \right\rangle
$$

$$
\left\langle boy, \begin{bmatrix}
word & & \\
SYN & \begin{bmatrix} HEAD & \begin{bmatrix} noun & \\ AGR & \begin{bmatrix} \mathbf{NUM} & \mathbf{sg} \\ \boxed{1} & \end{bmatrix} \\ SPR & \langle\rangle[\,] \\ ANA & /- \\ CASE & \{nom, acc\} \end{bmatrix} \end{bmatrix} & \\
ARG-ST & / \left\langle \begin{array}{ll} DetP & \\ COUNT & + \\ {[AGR} & \boxed{1}] \end{array} \right\rangle & \\
SEM & \begin{bmatrix} INDEX & i \\ RESTR & \left\langle \begin{bmatrix} RELN & boy \\ SIT & s \\ INSTANCE & i \end{bmatrix} \right\rangle \end{bmatrix} &
\end{bmatrix} \right\rangle
$$

Summary of Information Seen So Far

- Lexical entries:
  - Lexical items are of different types.
  - They encode the syntactic and semantic template of the word's usage.
  - The lexicon is organized in a type hierarchy with default inheritance.
- Lexical rules:
  - Lexical rules turns lexemes (dictionary entries) into words (as observed in the sentence).
  - Lexical rules derive word forms, e.g. plural nouns, past tense verbs.

Grammar Rules

- **Head-Complement Rule**

$$\begin{bmatrix} phrase & \\ COMPS & \langle\rangle \end{bmatrix} \rightarrow H \begin{bmatrix} word & \\ COMPS & \langle \boxed{1}, \ldots, \boxed{n} \rangle \end{bmatrix} \boxed{1}, \ldots, \boxed{n}$$

- **Head-Specifier Rule**

$$\begin{bmatrix} phrase & \\ SPR & \langle\rangle \end{bmatrix} \rightarrow \boxed{1} \quad H \begin{bmatrix} phrase & \\ SPR & \langle \boxed{1} \rangle \end{bmatrix}$$

- **Head-PreModifier Rule**

$$[phrase] \rightarrow \begin{bmatrix} phrase & \\ MOD & \langle \boxed{1} \rangle \end{bmatrix} H \boxed{1} [phrase]$$

- **Head-PostModifier Rule**

$$[phrase] \rightarrow H \boxed{1} [phrase] \quad \begin{bmatrix} phrase & \\ MOD & \langle \boxed{1} \rangle \end{bmatrix}$$

Grammar Rules cont.

- **Coordination Rule**

$$\begin{bmatrix} SYN & \boxed{0} \\ IND & s_0 \end{bmatrix} \rightarrow \begin{bmatrix} SYN & \boxed{0} \\ IND & s_0 \end{bmatrix} \ldots$$

$$\begin{bmatrix} SYN & \boxed{0} \\ IND & s_{n-1} \end{bmatrix} \begin{bmatrix} HEAD & conj \\ IND & s_0 \\ RESTR & \langle [\ ARGS \quad \langle s_1 \ldots s_n \rangle\ ] \rangle \end{bmatrix} \begin{bmatrix} SYN & \boxed{0} \\ IND & s_n \end{bmatrix}$$

- **Imperative Rule**

$$\begin{bmatrix} phrase & \\ HEAD & \begin{bmatrix} verb & \\ FORM & fin \end{bmatrix} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \\ SEM & \begin{bmatrix} MODE & dir \\ INDEX & s \end{bmatrix} \end{bmatrix} \rightarrow \begin{bmatrix} phrase & \\ HEAD & \begin{bmatrix} verb & \\ FORM & inf \end{bmatrix} \\ SPR & \langle NP[\ PER \quad 2nd\ ] \rangle \\ SEM & [\ INDEX \quad s\ ] \end{bmatrix}$$

Only a few Grammar Rules, but...

- Grammar rules are very general (they don't depend on the POS of the head nor the complements and specifier), except for the linear ordering of the constraints.

- For attributive adjectives (*'the tall boy'*), we already would need to introduce a new rule, the Head-PreModifier Rule above.

Parsing ‘Ann likes the boy’
Applying the Head-Complement Rule to ‘Ann’

$$\begin{bmatrix} phrase & \\ COMPS & \langle\rangle \end{bmatrix} \rightarrow H \begin{bmatrix} word & \\ COMPS & \langle \boxed{1}, \ldots, \boxed{n} \rangle \end{bmatrix} \boxed{1}, \ldots, \boxed{n}$$

$$NP \begin{bmatrix} phrase & \\ SYN & \begin{bmatrix} HEAD & \boxed{1} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ ARG-ST & \langle\rangle \\ SEM & \begin{bmatrix} INDEX & i \\ MODE & ref \\ RESTR & \boxed{a} \end{bmatrix} \end{bmatrix} \rightarrow \begin{bmatrix} word & \\ SYN & \begin{bmatrix} HEAD & \boxed{1} \begin{bmatrix} noun & \\ ANA & - \\ CASE & \{nom, acc\} \\ AGR & \begin{bmatrix} NUM & sg \\ PER & 3rd \end{bmatrix} \end{bmatrix} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ ARG-ST & \langle\rangle \\ SEM & \begin{bmatrix} INDEX & i \\ MODE & ref \\ RESTR & \left\langle \boxed{a} \begin{bmatrix} RELN & name \\ SIT & s \\ NAME & Ann \\ NAMED & i \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix}$$

Principles applied to guarantee well-formedness

Head Feature Principle (HFP)

$$
\begin{array}{ccccc}
 & & [HEAD\,\boxed{1}] & & \\
 & / & | & \backslash & \\
\ldots & & \delta_h & & \ldots \\
 & & [HEAD\,\boxed{1}] & &
\end{array}
$$

Semantic Inheritance Principle (SIP)

$$
\begin{array}{ccccc}
 & & \begin{bmatrix} MODE & \boxed{4} \\ INDEX & \boxed{5} \end{bmatrix} & & \\
 & / & | & \backslash & \\
\ldots & & \delta_h & & \ldots \\
 & & \begin{bmatrix} MODE & \boxed{4} \\ INDEX & \boxed{5} \end{bmatrix} & &
\end{array}
$$

Effects of Head Feature Principle and Semantic Inheritance Principle application

$$NP\begin{bmatrix} phrase & & \\ SYN & \begin{bmatrix} HEAD & \boxed{1} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ ARG-ST & \langle\rangle \\ SEM & \begin{bmatrix} INDEX & i \\ MODE & ref \\ RESTR & \boxed{a} \end{bmatrix} \end{bmatrix} \rightarrow \begin{bmatrix} word & \\ SYN & \begin{bmatrix} HEAD & \boxed{1}\begin{bmatrix} noun & \\ ANA & - \\ CASE & \{nom, acc\} \\ AGR & \begin{bmatrix} NUM & sg \\ PER & 3rd \end{bmatrix} \end{bmatrix} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ ARG-ST & \langle\rangle \\ SEM & \begin{bmatrix} INDEX & i \\ MODE & ref \\ RESTR & \left\langle \boxed{a}\begin{bmatrix} RELN & name \\ SIT & s \\ NAME & Ann \\ NAMED & i \end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix}$$

Valence Principle (VP)

- **A**

$$[COMPS\ \boxed{b}]$$

$$/ \qquad | \qquad \backslash$$

$$\ldots \qquad \delta_h \qquad \ldots$$

$$[COMPS\ \boxed{b}]$$

- **B**

$$[SPR\ \boxed{c}]$$

$$/ \qquad | \qquad \backslash$$

$$\ldots \qquad \delta_h \qquad \ldots$$

$$[SPR\ \boxed{c}]$$

+ Valence Principle (B) application

$$
NP \begin{bmatrix} \mathit{phrase} & \\ SYN & \begin{bmatrix} HEAD & \boxed{1} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ ARG-ST & \langle\rangle \\ SEM & \begin{bmatrix} INDEX & i \\ MODE & ref \\ RESTR & \boxed{a} \end{bmatrix} \end{bmatrix} \rightarrow \begin{bmatrix} \mathit{word} & \\ SYN & \begin{bmatrix} HEAD & \boxed{1} \begin{bmatrix} \mathit{noun} & \\ ANA & - \\ CASE & \{nom, acc\} \\ AGR & \begin{bmatrix} NUM & sg \\ PER & 3rd \end{bmatrix} \end{bmatrix} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ ARG-ST & \langle\rangle \\ SEM & \begin{bmatrix} INDEX & i \\ MODE & ref \\ RESTR & \langle \boxed{a} \begin{bmatrix} RELN & name \\ SIT & s \\ NAME & Ann \\ NAMED & i \end{bmatrix} \rangle \end{bmatrix} \end{bmatrix}
$$

Result of applying the Head-Complement Rule to ‘the’

$$DetP \begin{bmatrix} phrase & \\ PHON & the \\ ARG-ST & \langle\rangle \\ SYN & \begin{bmatrix} HEAD & \begin{bmatrix} det & \\ COUNT & + \\ AGR & \begin{bmatrix} NUM & sg, pl \end{bmatrix} \end{bmatrix} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ SEM & \begin{bmatrix} RESTR & \boxed{a} \\ \ldots & \end{bmatrix} \end{bmatrix}$$

Result of applying the Head-Complement Rule to 'boy'

$$
NOM \left[\begin{array}{ll}
\textit{phrase} & \\
SYN & \left[\begin{array}{ll}
HEAD & \left[\begin{array}{ll}
\textit{noun} & \\
AGR & \boxed{1} \left[\begin{array}{ll} PERS & 3rd \\ NUM & sg \end{array} \right] \\
ANA & - \\
CASE & \{nom, acc\}
\end{array} \right] \\
SPR & \left\langle \left[\begin{array}{ll} DetP & \\ COUNT & + \\ [AGR & \boxed{1}] \end{array} \right] \right\rangle \\
COMPS & \langle\rangle
\end{array} \right] \\
SEM & \left[\begin{array}{ll}
MODE & ref \\
INDEX & i \\
RESTR & \langle \boxed{b} \left[\begin{array}{ll} RELN & boy \\ SIT & s \\ INSTANCE & i \end{array} \right] \rangle
\end{array} \right]
\end{array} \right]
$$

Applying the Head-Specifier Rule to ‘the’ and ’boy’

$$
NP \begin{bmatrix} phrase & \\ SYN & \begin{bmatrix} HEAD & \boxed{0} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ SEM & \begin{bmatrix} MODE & ref \\ INDEX & i \\ RESTR & \langle \boxed{a} \oplus \boxed{b} \rangle \end{bmatrix} \end{bmatrix} \rightarrow DetP\boxed{1} \begin{bmatrix} phrase & \\ PHON & the \\ ARG-ST & \langle\rangle \\ SYN & \begin{bmatrix} HEAD & \begin{bmatrix} det & \\ COUNT & + \\ AGR & \boxed{2} \end{bmatrix} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ SEM & \begin{bmatrix} RESTR & \boxed{a} \\ \ldots & \end{bmatrix} \end{bmatrix}
$$

$$
NOM \left[\begin{array}{ll}
\textit{phrase} & \\
SYN & \left[\begin{array}{ll}
HEAD & \boxed{0}\left[\begin{array}{ll}
\textit{noun} & \\
COUNT & + \\
AGR & \boxed{2}\left[\begin{array}{ll} PERS & 3rd \\ NUM & sg \end{array}\right] \\
ANA & - \\
CASE & \{nom, acc\}
\end{array}\right] \\
SPR & \left\langle \boxed{1}\left[\begin{array}{ll}
DetP & \\
COUNT & + \\
[AGR & \boxed{2}]
\end{array}\right] \right\rangle \\
COMPS & \langle\rangle
\end{array}\right] \\
SEM & \left[\begin{array}{ll}
MODE & ref \\
INDEX & i \\
RESTR & \left\langle \boxed{b}\left[\begin{array}{ll}
RELN & boy \\
SIT & s \\
INSTANCE & i
\end{array}\right] \right\rangle
\end{array}\right]
\end{array}\right]
$$

Already seen the effects of Head Feature Principle, Valence Principle Part A and Semantic Inheritance Principle in blue.

Other principles applied to guarantee well-formedness

Semantic Compositionality Principle (SCP)

$$[RESTR \quad \boxed{a} \oplus \cdots \oplus \boxed{n}]$$

$$/ \qquad | \qquad \backslash$$

$$[RESTR \quad \boxed{a}] \qquad \ldots \qquad [RESTR \quad \boxed{n}]$$

Note: the **Nominal SPR Agreement (NSA)** says that nouns must be specified as:

$$\begin{bmatrix} HEAD & \begin{bmatrix} AGR & \boxed{1} \end{bmatrix} \\ SPR & \langle ([\ AGR \quad \boxed{1}\ ]) \rangle \end{bmatrix}$$

Effects of having applied the Semantic Compositionality Principle during the rule application

$$
NP\begin{bmatrix} \textit{phrase} & \\ SYN & \begin{bmatrix} HEAD & \boxed{10} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ SEM & \begin{bmatrix} MODE & ref \\ INDEX & i \\ RESTR & \langle \boxed{a} \bigoplus \boxed{b} \rangle \end{bmatrix} \end{bmatrix} \rightarrow DetP\boxed{1}\begin{bmatrix} \textit{phrase} & \\ PHON & the \\ ARG-ST & \langle\rangle \\ SYN & \begin{bmatrix} HEAD & \begin{bmatrix} det & \\ COUNT & + \\ AGR & \boxed{2} \end{bmatrix} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ SEM & \begin{bmatrix} RESTR & \boxed{a} \\ \ldots & \end{bmatrix} \end{bmatrix}
$$

$$
NOM \begin{bmatrix}
\mathit{phrase} & \\
SYN & \begin{bmatrix}
HEAD & \boxed{10} \begin{bmatrix} \mathit{noun} & \\ COUNT & + \\ AGR & \boxed{2} \begin{bmatrix} PERS & 3rd \\ NUM & sg \end{bmatrix} \\ ANA & - \\ CASE & \{nom, acc\} \end{bmatrix} \\
SPR & \left\langle \boxed{1} \begin{bmatrix} DetP & \\ COUNT & + \\ [AGR & \boxed{2}] \end{bmatrix} \right\rangle \\
COMPS & \langle \rangle
\end{bmatrix} \\
SEM & \begin{bmatrix}
MODE & ref \\
INDEX & i \\
RESTR & \left\langle \boxed{b} \begin{bmatrix} RELN & boy \\ SIT & s \\ INSTANCE & i \end{bmatrix} \right\rangle
\end{bmatrix}
\end{bmatrix}
$$

Applying the Head-Complement Rule to 'likes NP[the boy]'

$$
VP \begin{bmatrix} \textit{phrase} & \\ SYN & \begin{bmatrix} HEAD & \boxed{0} \begin{bmatrix} \textit{verb} & \\ FORM & \textit{fin} \end{bmatrix} \\ SPR & \langle [NP_i \boxed{1} \begin{bmatrix} CASE & \textit{nom} \\ AGR & \textit{3sing} \end{bmatrix}] \rangle \\ COMPS & \langle \rangle \end{bmatrix} \\ SEM & \begin{bmatrix} MODE & \textit{prop} \\ INDEX & s \\ RESTR & \langle \boxed{e} \oplus \boxed{f} \rangle \end{bmatrix} \end{bmatrix} \rightarrow
$$

$$V\begin{bmatrix} word & \\ SYN & \begin{bmatrix} HEAD & \boxed{0}\begin{bmatrix} verb & \\ FORM & fin \end{bmatrix} \\ SPR & \langle [NP_i \boxed{1}\begin{bmatrix} CASE & nom \\ AGR & 3sing \end{bmatrix}\rangle \\ COMPS & \langle NP_j \boxed{2}[\ CASE \quad acc\ ]\rangle \end{bmatrix} \\ ARG-ST & \langle [NP_i \begin{bmatrix} CASE & nom \\ AGR & 3sing \end{bmatrix}][NP_j [\ CASE \quad acc\ ]\rangle \\ SEM & \begin{bmatrix} MODE & prop \\ INDEX & s \\ RESTR & \boxed{e}\langle \begin{bmatrix} RELN & like \\ SIT & s \\ LIKER & i \\ LIKED & j \end{bmatrix}, \\ & \begin{bmatrix} RELN & t-overlap \\ ARG1 & s \\ ARG2 & now \end{bmatrix}\rangle \end{bmatrix} \end{bmatrix}$$

$$NP\boxed{2}\begin{bmatrix} phrase & \\ SYN & \begin{bmatrix} HEAD & \boxed{10}[\ CASE \quad acc\ ] \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ SEM & \begin{bmatrix} MODE & ref \\ INDEX & i \\ RESTR & \boxed{f}\langle \boxed{a} \oplus \boxed{b} \rangle \end{bmatrix} \end{bmatrix}$$

Other Well-Formedness conditions that were applied in the rule application above

Lexical Satisfaction

A word structure:

$$F \rightarrow w$$

satisfies a lexical entry

$$\langle w, d \rangle$$

just in case:
1. F is of type word and F satisfies *d*,
2. **Argument Realization Principle**
F satisfies the following FSD:

$$\begin{bmatrix} SYN & \begin{bmatrix} SPR & \boxed{a} \\ COMPS & \boxed{b} \end{bmatrix} \\ ARG-ST & \boxed{a} \oplus \boxed{b} \end{bmatrix}$$

and
3. **Case Constraint**
Any NP in a noninitial position of F's ARG-ST list is

$$[\ CASE \quad acc\ ]$$

Applying the Head-Specifier Rule to 'NP[Ann] VP[likes the boy]'

$$S \begin{bmatrix} \textit{phrase} & \\ SYN & \begin{bmatrix} HEAD & \boxed{0} \begin{bmatrix} \textit{verb} & \\ FORM & \textit{fin} \end{bmatrix} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\ SEM & \begin{bmatrix} MODE & \textit{prop} \\ INDEX & s \\ RESTR & \langle \boxed{g} \oplus \boxed{h} \rangle \end{bmatrix} \end{bmatrix} \rightarrow$$

$$
NP\,\boxed{1}\begin{bmatrix}
phrase & \\
SYN & \begin{bmatrix} HEAD & \begin{bmatrix} CASE & nom \\ AGR & 3sing \end{bmatrix} \\ SPR & \langle\rangle \\ COMPS & \langle\rangle \end{bmatrix} \\
ARG-ST & \langle\rangle \\
SEM & \begin{bmatrix} INDEX & i \\ MODE & ref \\ RESTR & \boxed{g} \end{bmatrix}
\end{bmatrix}
$$

$$
VP\begin{bmatrix}
phrase & \\
SYN & \begin{bmatrix} HEAD & \boxed{0}\begin{bmatrix} verb & \\ FORM & fin \end{bmatrix} \\ SPR & \langle [NP_i\,\boxed{1}\begin{bmatrix} CASE & nom \\ AGR & 3sing \end{bmatrix}] \rangle \\ COMPS & \langle\rangle \end{bmatrix} \\
SEM & \begin{bmatrix} MODE & prop \\ INDEX & s \\ RESTR & \boxed{h}\langle \boxed{e} \oplus \boxed{f} \rangle \end{bmatrix}
\end{bmatrix}
$$

One last Well-Formedness condition

Initial Symbol Definition

A CFG must include a statement of which category (or categories) can start a tree derivation. The analogue of this 'initial symbol' definition in this grammar is a constraint guaranteeing that for a phrase to stand alone, its synsem-struct must satisfy the following description:

$$\begin{bmatrix} \mathit{phrase} & \\ \mathit{SYN} & \begin{bmatrix} \mathit{HEAD} & \begin{bmatrix} \mathit{verb} & \\ \mathit{FORM} & \mathit{fin} \end{bmatrix} \\ \mathit{SPR} & \langle\rangle \\ \mathit{COMPS} & \langle\rangle \end{bmatrix} \end{bmatrix}$$

Applying the Head-PreModifier Rule to ‘tall’ and ‘boy’

$$[phrase] \rightarrow \begin{bmatrix} phrase & \\ MOD & \langle \boxed{1} \rangle \end{bmatrix} \mathbf{H}\boxed{1}[phrase]$$

$$NP \begin{bmatrix} phrase & \\ SYN & \begin{bmatrix} HEAD & \boxed{0} \\ SPR & \langle \boxed{2} \rangle \\ COMPS & \langle \rangle \end{bmatrix} \\ SEM & \begin{bmatrix} MODE & ref \\ INDEX & i \\ RESTR & \langle \boxed{a} \oplus \boxed{b} \end{bmatrix} \end{bmatrix} \rightarrow AdjP \begin{bmatrix} phrase & \\ MOD & \boxed{1} \\ SYN & \begin{bmatrix} HEAD & [\ adj\ ] \\ SPR & \langle ([\,]) \rangle \end{bmatrix} \\ SEM & \begin{bmatrix} RESTR & \langle \boxed{a} \begin{bmatrix} RELN & tall \\ SIT & r \\ INSTANCE & i \end{bmatrix} \rangle \end{bmatrix} \end{bmatrix}$$

$$
NOM\ \boxed{1}\ \begin{bmatrix}
\textit{phrase} & \\
SYN & \begin{bmatrix}
HEAD & \boxed{0}\begin{bmatrix} \textit{noun} & \\ AGR & \boxed{3}\begin{bmatrix} PERS & 3rd \\ NUM & sg \end{bmatrix} \end{bmatrix} \\
SPR & \left\langle \boxed{2}\begin{bmatrix} DetP & \\ COUNT & + \\ [AGR & \boxed{3}] \end{bmatrix} \right\rangle \\
COMPS & \langle\rangle
\end{bmatrix} \\
SEM & \begin{bmatrix}
MODE & ref \\
INDEX & i \\
RESTR & \left\langle \boxed{b}\begin{bmatrix} RELN & boy \\ SIT & s \\ INSTANCE & i \end{bmatrix} \right\rangle
\end{bmatrix}
\end{bmatrix}
$$

Final Summary

- Lexical entries:
  - Lexical items are of different types.
  - They encode the syntactic and semantic template of the word's usage.
  - The lexicon is organized in a type hierarchy with default inheritance.
- Lexical rules:
  - Lexical rules turns lexemes (dictionary entries) into words (as observed in the sentence).
  - Lexical rules derive word forms, e.g. plural nouns, past tense verbs.
- Grammar rules:
  - Lexical SDs can be combined into larger SDs in the ways permitted by the grammar rules, filtering in features as required by 4 principles: the Semantic Compositionality Principle, the Head Feature Principle, the Valence Principle and the Semantic Inheritance Principle.

- Grammar rules are generally phrase-independent, but they have linear ordering of the constraints.

- Principles:
  - The principles ensure that the parse tree is constructed correctly and that all the well-formedness conditions are satisfied.
  - E.g. the Head-Feature Principle enforces that, in any headed phrase, the HEAD value of the head daughter must be unified with the HEAD value of the mother.

Psycholinguistic Plausibility

- Available psycholinguistic evidence fits rather well with the HPSG conception of the grammar (more in [Pollard and Sag] than in [Sag and Wasow]).

- Constraint-Based Lexicalism
  - incremental
  - process-neutral, i.e. order independent [Pollard and Sag]. The grammar is a declarative system of constraints.
  - strong lexicalization
  - learnability