Feature Structures, Unification

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Today’s lecture

1. Some grammatical phenomena
   - Linguistic features

2. Feature structures

3. Operations on feature structures
   - Subsumption
   - Unification

4. Features in the NLTK
   - Creating feature structures
   - FeatStruct behavior
Verb types

Consider the phrase structure rules in the PTB for verbs:

- $VP \rightarrow VBZ \ NP$
  
  ...breaks the jar

- $VP \rightarrow VBP \ NP$
  
  ...break the jar

- $VP \rightarrow VBD \ NP$
  
  ...broke the jar

- $VP \rightarrow VBN \ NP$
  
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We could capture the regularity by a rule like this:

\( VP \rightarrow VBx\ NP \)

What exactly is ‘x’ representing?
Noun types

And for nouns:

- $NP \rightarrow DT \ NN$
  
  ...the book

- $NP \rightarrow DT \ NNS$
  
  ...the books
Noun types

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Subject-Verb Agreement

- *The parrot talks.*
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Subject-Verb Agreement

- *The parrot talks.*
- *The parrot talk.*
- *They know Mary.*
Subject-Verb Agreement

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Subject-Verb Agreement

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- *They knows Mary.*
- *We sing.*
Subject-Verb Agreement

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- *We sings.*
Subject-Verb Agreement

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- *The parrot talk.*
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- *We sings.*

Furthermore agreement information is not captured in treebanks such as the PTB:

$S \rightarrow NP \ VP$

The $NNx$ in the $NP$ does not depend on the $VBx$ in the $VP$. 
Features and values

Definition

**linguistic feature**: a property-like element that changes the grammatical behavior of syntactic constituents; the elements into which linguistic units, such as words, can be broken down. For a given sub-domain of grammar, there is a relevant feature:
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- **noun class** (e.g., Chinese)
Features and values

**Definition**

Features are usually modeled as pairs of feature **names** and **feature values**. A **value** refers to the language-specific phenomenon within the sub-domain:

- person: 1st, 2nd, 3rd
- number: singular, plural, paucal, dual, trial, etc.
- case: accusative, ergative, locative, directional
- tense: past, present, future, hodiernal past, hesternal past
- modality: conditional, subjunctive, abilitative
- honorifics: plus honorific, minus honorific
- evidentiality: visual, auditory, hearsay, folklore
- noun class: I, II, III, etc.
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Ontology of features

Whereas NPs, VPs, NNs, etc. are conceived of as categories (first-order “citizens”) in the grammar, features are more property-like.
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- The VP has the feature value ‘past tense’
- The verb is a ‘past tense’ verb
- The noun has a case feature ‘absolutive’.
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Whereas NPs, VPs, NNs, etc. are conceived of as categories (first-order “citizens”) in the grammar, features are more **property-like**.

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- The verb is a ‘past tense’ verb
- The noun has a case feature ‘absolutive’.

Just like, for example, an object like a **car** can have a color property **red**.
Bundles of feature (values)

Sometimes features are conceived of as the atomic units that compose more complex categories.
Bundles of feature (values)

Sometimes features are conceived of as the atomic units that compose more complex categories.

A noun is a **feature bundle** of semantic, morphological and phonological features:

\[
\begin{bmatrix}
\text{form} & \text{‘dog’} \\
\text{number} & \text{singular} \\
\text{animacy} & \text{animate}
\end{bmatrix}
\]
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Feature structures

A feature structure is, informally speaking, a set of feature names and values:

\[
\begin{bmatrix}
\text{feature}_1 & \text{value}_1 \\
\text{feature}_2 & \text{value}_2 \\
\text{feature}_3 & \text{value}_3
\end{bmatrix}
\]

A feature structure is defined according to particular grammatical traditions:

- Functional Unification Grammar
- Lexical Functional Grammar
- Head-Driven Phrase Structure Grammar (Ling566)
Typed feature structures: HPSG formal definition

Definition

A typed feature structure is defined on a finite set of features $\text{Feat}$ and a type hierarchy $\langle \text{Type}, \sqsubseteq \rangle$. It is a tuple $\langle Q, r, \delta, \theta \rangle$ where:

- $Q$ is a finite set of nodes,
- $r \in Q$ ($r$ is the root node)
- $\theta : Q \rightarrow \text{Type}$ is a partial typing function
- $\delta : Q \times \text{Feat} \rightarrow Q$ is a partial feature value function

from Copestake (2000), Appendix.
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subject to the following conditions:

1. $r$ isn’t a $\theta$-descendant.
2. all members of $Q$ except $r$ are $\theta$-descendants of $r$.
3. Some systems add an extra (no cycles) condition: there is no node $n$ or path $\pi$ such that $\delta(n, \pi) = n$.

from Copestake (2000), Appendix.
More about feature values

**atomic value**: an unstructured value, one with only one part

\[
\begin{bmatrix}
\text{tense} & \text{past} \\
\text{person} & 2
\end{bmatrix}
\]
More about feature values

**atomic value**: an unstructured value, one with only one part

\[
\begin{bmatrix}
tense & past \\
person & 2
\end{bmatrix}
\]

**complex value**: a structured value, itself a feature structure

\[
\begin{bmatrix}
tense & past \\agreement & \begin{bmatrix}
person & 2 \\
number & singular
\end{bmatrix}
\end{bmatrix}
\]
Feature structures are a type of attribute-value matrix (AVM), a more generalized data structure used to represent all kinds of information. Feature structures (and AVMs) can be represented as graphs with nodes and arcs (cf. textbook figures).
Graphs or matrices

Feature structures are a type of attribute-value matrix (AVM), a more generalized data structure used to represent all kinds of information. Feature structures (and AVMs) can be represented as graphs with nodes and arcs (cf. text book figures).

- **Nodes** correspond to variable values and the paths to the variable names.
- **Arcs** represent the feature names.
- A **feature path** is a list of features through a feature structure leading to a particular value.
Feature path

\[
\begin{bmatrix}
tense & past \\
agreement & \begin{bmatrix}
person & 2 \\
number & singular
\end{bmatrix}
\end{bmatrix}
\]

Path:
\[
\langle agreement \ number \rangle = \text{singular}
\]
Feature path

```
[ tense  past ]

[ agreement ]

[ person 2 ]

[ number  singular ]
```

Path:

\[
\langle \text{agreement} \ \text{number} \rangle = \text{singular}
\]
Feature path

\[
\begin{bmatrix}
\text{tense} & \text{past} \\
\text{agreement} & \begin{bmatrix}
\text{person} & 2 \\
\text{number} & \text{singular}
\end{bmatrix}
\end{bmatrix}
\]

Path:
\[
\langle\text{agreement number}\rangle = \text{singular}
\]
Feature path

\[
\begin{bmatrix}
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\text{agreement} & \begin{bmatrix}
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\text{number} & \text{singular}
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\]

Path:
\[\langle \text{agreement number} \rangle = \text{singular} \]
Reentrant structures

**Definition**

**Reentrant structure**: one in which the attribute has a value that is another feature structure.

\[
\begin{bmatrix}
  S & [\text{head} \ 1] \\
  \text{NP} & [\text{head} \ [\text{agr} \ 2]] \\
  \text{VP} & [\text{head} \ 1 [\text{agr} \ 2]]
\end{bmatrix}
\]
Reentrant structures

**Definition**

Reentrant structure: one in which the attribute has a value that is another feature structure.

A feature structure can be used to represent partial information.
More linguistic examples

Feature structure for a verb:

\[
\begin{array}{ll}
\text{cat} & \text{VB} \\
\text{lex} & | \text{GO} |
\end{array}
\]

\[
\begin{array}{ll}
\text{tense} & \text{past} \\
\text{aspect} & \text{progressive} \\
\text{form} & \text{"was going"}
\end{array}
\]

Feature structure for a noun:

\[
\begin{array}{ll}
\text{cat} & \text{NN} \\
\text{lex} & | \text{dog} |
\end{array}
\]

\[
\begin{array}{ll}
\text{number} & \text{PL} \\
\text{form} & \text{"dogs"}
\end{array}
\]
Linguistic examples

Feature structure for a noun phrase (e.g., the boy):

```
[cat NP
  [spec 1 [cat DT
          [number SG
              [definite yes
                  [form "the"]
            ]
        ]
    ]
  [head 2 [cat NN
            [number SG
                [lex | boy |
                    [form "boy"]
                ]
            ]
        ]
  [definite yes
      [number SG
    ]
]]
```
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Subsumption

Definition

Subsumption is a relation that holds between feature structures. A less specific (more abstract) feature structure subsumes an equally or more specific one. The subsumption symbol is $\sqsubseteq$.

\[
\begin{bmatrix}
\text{number} & \text{PL}
\end{bmatrix}
\]
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\[
\begin{bmatrix}
\text{number} & \text{PL}
\end{bmatrix} \sqsubseteq \begin{bmatrix}
\text{number} & \text{PL} \\
\text{person} & 3
\end{bmatrix}
\]
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\[
\begin{bmatrix}
\text{number} & \text{PL} \\
\end{bmatrix}
\sqsubseteq
\begin{bmatrix}
\text{number} & \text{PL} \\
\text{person} & 3 \\
\end{bmatrix}
\sqsubseteq
\begin{bmatrix}
\text{number} & \text{PL} \\
\text{person} & 3 \\
\text{lex} & | \text{dog} | \\
\end{bmatrix}
\]
Subsumption

\[
\begin{array}{c}
\text{[number PL]} \\
\text{person 3}
\end{array}
\quad
\begin{array}{c}
\text{[number PL]}
\end{array}
\]

\[
\begin{array}{c}
\text{[number PL]} \\
? \quad \text{[number SG]}
\end{array}
\]

\[
\begin{array}{c}
? \\
\text{[number SG]}
\end{array}
\]
### Subsumption

<table>
<thead>
<tr>
<th>feature structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>number PL</td>
</tr>
<tr>
<td>person 3</td>
</tr>
<tr>
<td>number PL</td>
</tr>
<tr>
<td>number SG</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
\left[ \text{number PL} \right] & \not\subseteq \left[ \text{number PL} \right] \\
\left[ \text{number PL} \right] & \not\subseteq \left[ \text{number SG} \right] \\
\left[ \text{number PL} \right] & \subseteq \left[ \text{number SG} \right]
\end{align*}
\]
Subsumption

\[
\begin{align*}
\text{number} & \quad \text{PL} \\
\text{person} & \quad 3
\end{align*}
\preceq
\begin{align*}
\text{number} & \quad \text{PL}
\end{align*}
\]

\[
\begin{align*}
\text{number} & \quad \text{PL} \\
\text{number} & \quad \text{SG}
\end{align*}
\]

\[
\begin{align*}
\text{number} & \quad \text{SG}
\end{align*}
\]
Subsumption

\[
\begin{align*}
&\left[ \text{number} \quad \text{PL} \right] \quad \neg \quad \subseteq \quad \left[ \text{number} \quad \text{PL} \right] \\
&\left[ \text{number} \quad \text{PL} \right] \quad ? \quad \left[ \text{number} \quad \text{SG} \right] \\
&\left[ \quad ? \quad \right] \quad ? \quad \left[ \text{number} \quad \text{SG} \right]
\end{align*}
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Subsumption

\[
\begin{align*}
\left[ \text{number PL} \right] & \not\sqsubseteq \left[ \text{number PL} \right] \\
\left[ \text{number PL} \right] & \not\sqsubseteq \left[ \text{number SG} \right] \\
\left[ \right] & \not\sqsubseteq \left[ \text{number SG} \right]
\end{align*}
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Subsumption

\[
\begin{align*}
[\text{number PL}] & \not\subseteq [\text{number PL}] \\
[\text{number PL}] & \not\subseteq [\text{number SG}] \\
[ \text{?} ] & \subseteq [\text{number SG}]
\end{align*}
\]
Subsumption

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\begin{array}{c}
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\left[ \text{person} \quad 3 \right] \\
\left[ \text{number} \quad \text{PL} \right] \quad \neg \quad \sqsubseteq \quad \left[ \text{number} \quad \text{SG} \right] \\
\left[ \right] \quad \sqsubseteq \quad \left[ \text{number} \quad \text{SG} \right]
\end{array}
\]
Subsumption

Criteria for $\sqsubseteq$

$F \sqsubseteq G$ iff:

- For every feature $x$ in $F$, $F(x) \sqsubseteq G(x)$, where $F(x)$ means “the value of the feature $x$ of feature structure $F$”.
- For all paths $p$ and $q$ in $F$ such that $F(p) = F(q)$, it is also the case that $G(p) = G(q)$. 
The unification operation

Definition

**Unification** is a binary operation over two feature structures $f_1$ and $f_2$, used for comparing or combining information.
The unification operation

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*Unification* is a binary operation over two feature structures $f_1$ and $f_2$, used for comparing or combining information.

Unification of $f_1$ and $f_2$ either returns a merged feature structure with the information from both $f_1$ and $f_2$, or false if $f_1$ and $f_2$ are incompatible. The unification operator is represented by: $\sqcup$. 
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\[
\begin{bmatrix}
\text{number} & \text{PL} \\
\end{bmatrix} \sqcup \begin{bmatrix}
\text{person} & 2 \\
\end{bmatrix}
\]
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\[ \left[ \text{number PL} \right] \sqcup \left[ \text{person 2} \right] = \left[ \text{number PL} \right. \left. \text{person 2} \right] \]
The unification operation

For comparing information in two feature structures, unification can be used. Are two feature structures the same, or are they incompatible?

\[
\begin{array}{c}
\text{number PL} \sqcup \text{number PL} = \\
\text{number PL} \sqcup \text{number SG} = \text{False}
\end{array}
\]
The unification operation

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\[
\begin{align*}
\left[ \text{number}\ \text{PL} \right] & \sqcup \left[ \text{number}\ \text{PL} \right] = \left[ \text{number}\ \text{PL} \right] \\
\end{align*}
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\[
\begin{align*}
\left[ \text{number \ PL} \right] \sqcap \left[ \text{number \ PL} \right] &= \left[ \text{number \ PL} \right] \\
\left[ \text{number \ PL} \right] \sqcap \left[ \text{number \ SG} \right] &= \text{False}
\end{align*}
\]

Unification preserves and possibly adds information to the resulting feature structure. This property is called: monotonicity.
The unification operation

For comparing information in two feature structures, unification can be used. Are two feature structures the same, or are they incompatible?

\[
[\text{number} \ \text{PL}] \sqcup [\text{number} \ \text{PL}] = [\text{number} \ \text{PL}] \\
[\text{number} \ \text{PL}] \sqcup [\text{number} \ \text{SG}] = \text{False}
\]
The unification operation

For comparing information in two feature structures, unification can be used. Are two feature structures the same, or are they incompatible?

\[
\begin{align*}
\left[ \text{number} \quad \text{PL} \right] & \sqsupseteq \left[ \text{number} \quad \text{PL} \right] = \left[ \text{number} \quad \text{PL} \right] \\
\left[ \text{number} \quad \text{PL} \right] & \sqsupseteq \left[ \text{number} \quad \text{SG} \right] = \text{False}
\end{align*}
\]

Unification preserves and possibly adds information to the resulting feature structure. This property is called:
The unification operation

For comparing information in two feature structures, unification can be used. Are two feature structures the same, or are they incompatible?

\[
\begin{align*}
\left[ \text{number} \quad \text{PL} \right] & \sqcup \left[ \text{number} \quad \text{PL} \right] = \left[ \text{number} \quad \text{PL} \right] \\
\left[ \text{number} \quad \text{PL} \right] & \sqcup \left[ \text{number} \quad \text{SG} \right] = \text{False}
\end{align*}
\]

Unification preserves and possibly adds information to the resulting feature structure. This property is called: \textit{monotonicity}
Unification of dissimilar structures

\[
\left[ \text{agreement} \left[ \text{number} \; \text{PL} \right] \right] \sqcap \left[ \text{number} \; \text{PL} \right] =
\]
Unification of dissimilar structures

\[
\begin{align*}
\text{agreement} & \left[ \begin{array}{c} \text{number} \\ \text{PL} \end{array} \right] & \sqsubset & \left[ \begin{array}{c} \text{number} \\ \text{PL} \end{array} \right] = \\
\text{agreement} & \left[ \begin{array}{c} \text{number} \\ \text{PL} \end{array} \right] \\
\left[ \begin{array}{c} \text{number} \\ \text{PL} \end{array} \right] \\
\end{align*}
\]
Unification: example

**Grammar entry for a sentence**

\[
\begin{array}{c}
\text{cat} & S \\
\text{voice} & \text{active} \\
\text{agent} & 1 \left[ \begin{array}{c}
\text{cat} & \text{NP} \\
\text{number} & 4
\end{array} \right] \\
\text{process} & 2 \left[ \begin{array}{c}
\text{cat} & \text{VB} \\
\text{number} & 4
\end{array} \right] \\
\text{patient} & 3 \left[ \begin{array}{c}
\text{cat} & \text{NP}
\end{array} \right] \\
\text{pattern} & \left[ \begin{array}{c}
\text{subject} & 1 \\
\text{verb} & 2 \\
\text{object} & 3
\end{array} \right]
\end{array}
\]
Unification: example

Grammar entry for a noun phrase

```
<table>
<thead>
<tr>
<th>cat</th>
<th>NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>spec</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>head</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>number</td>
<td>3</td>
</tr>
<tr>
<td>definite</td>
<td>4</td>
</tr>
<tr>
<td>pattern</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>
```

---

**Feature Structures, Unification**

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Some grammatical phenomena
Linguistic features
Feature structures
Operations on feature structures
Subsumption
Unification
Features in the NLTK
Creating feature structures
FeatStruct behavior
Lexical entries in AVM form

\[
\begin{bmatrix}
\text{cat} & \text{DT} \\
\text{definite} & \text{yes} \\
\text{number} & \text{SG} \\
\text{form} & \text{“the”}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\text{cat} & \text{DT} \\
\text{definite} & \text{yes} \\
\text{number} & \text{PL} \\
\text{form} & \text{“these”}
\end{bmatrix}
\]
Unification: example

Unifying a noun phrase with a determiner

\[
\begin{align*}
\text{cat} & \quad \text{NP} \\
\text{spec} & \quad \begin{bmatrix}
\text{cat} & \text{DT} \\
\text{number} & 3 \\
\text{definite} & 4
\end{bmatrix} \\
\text{head} & \quad \begin{bmatrix}
\text{cat} & \text{NN} \\
\text{number} & 3
\end{bmatrix} \\
\text{number} & \quad 3 \\
\text{definite} & \quad 4 \\
\text{pattern} & \quad \begin{bmatrix}
\text{first} & 1 \\
\text{second} & 2
\end{bmatrix}
\end{align*}
\]

\[
\begin{array}{c}
\text{cat} \quad \text{DT} \\
\text{definite} \quad \text{yes} \\
\text{number} \quad \text{PL} \\
\text{form} \quad \text{“these”}
\end{array}
\]

\[
\sqcup
\]

\[
\begin{bmatrix}
\text{cat} & \text{DT} \\
\text{number} & \text{PL} \\
\text{definite} & \text{yes}
\end{bmatrix}
\]
Unification: example

Unifying the right part of a noun phrase with a determiner

\[
\begin{bmatrix}
\text{cat}  \\
\text{number}  \\
\text{definite}
\end{bmatrix}
\begin{bmatrix}
\text{DT}  \\
\text{yes}  \\
\text{“these”}
\end{bmatrix}
\sqcup
\begin{bmatrix}
\text{cat}  \\
\text{definite}  \\
\text{number}  \\
\text{form}
\end{bmatrix}
\begin{bmatrix}
\text{DT}  \\
\text{PL}
\end{bmatrix}
= 
\]
Unifying the right part of a noun phrase with a determiner

\[
\begin{array}{c}
\text{cat DT} \\
\text{number 3} \\
\text{definite 4}
\end{array}
\begin{array}{c}
\text{cat DT} \\
\text{definite yes} \\
\text{number PL} \\
\text{form “these”}
\end{array}
\begin{array}{c}
\text{cat DT} \\
\text{definite yes} \\
\text{number PL} \\
\text{form “these”}
\end{array}
\]
Unification: example

Result of unification

\[
\begin{array}{c}
\text{cat} \quad \text{NP} \\
\text{spec} \quad 1 \\
\text{definite} \quad \text{yes} \\
\text{form} \quad \text{"these"} \\
\text{head} \quad 2 \\
\text{number} \quad \text{PL} \\
\text{pattern} \\
\text{first} \quad 1 \\
\text{second} \quad 2
\end{array}
\]
Today’s lecture

1. Some grammatical phenomena
   - Linguistic features

2. Feature structures

3. Operations on feature structures
   - Subsumption
   - Unification

4. Features in the NLTK
   - Creating feature structures
   - FeatStruct behavior
The main features module

The NLTK has a module for feature structures and accompanying operations: `nltk.featstruct`

The basic feature structure `nltk.featstruct.FeatStruct` is implemented as a mapping (dictionary) from features to values.

```python
>>> from nltk.featstruct import FeatStruct

>>> fs1 = FeatStruct(number='singular', person=3)

>>> print fs1

[ number = 'singular' ]
[ person = 3 ]
```
The main features module

```python
>>> fs2 = FeatStruct(type='NP', agr=fs1)

>>> print fs2

[ agr = [ number = 'singular' ] ]
[ [ person = 3 ] ]
[ ]
[ type = 'NP' ]
```
Unification in the NLTK

The NLTK has an implementation of unification with `nltk.featstruct.FeatStruct.unify()`.

\[ fs1 \]

\[
[ agr = [ \text{number} = '\text{singular}' ] ] \\
[ ] \\
[ person = 3 ] \\
[ ] \\
[ type = 'NP' ]
\]

\[ fs2 \]

\[
[ agr = [ \text{number} = ?n ] ] \\
[ ] \\
[ subj = [ \text{number} = ?n ] ]
\]
>>> print fs2.unify(fs3)

```python
[ agr = [ number = 'singular' ] ]
[ [ person = 3 ] ]
[ ]
[ subj = [ number = 'singular' ] ]
[ ]
[ type = 'NP' ]
```
Creating feature structures: FeatStruct

```python
fs1 = FeatStruct(consentment= \
    FeatStruct(number='singular', person='third'))
```
Creating feature structures: FeatStruct

fs1 = FeatStruct(agendaement=\
    FeatStruct(number='singular', person='third'))

[ agreement = [ number = 'singular' ] ]
[ [ person = 'third' ] ]
Creating feature structures: FeatStruct

fs1 = FeatStruct(aggregate= \\
    FeatStruct(number='singular', person='third'))

[ agreement = [ number = 'singular' ] ]
[ [ person = 'third' ] ]

Use the FeatStruct constructor; note how quotes are used.
Creating feature structures, short-hand

fs1 = FeatStruct("[agreement = \[number='singular',person='third']"]")
Creating feature structures, short-hand

\[
\text{fs1} = \text{FeatStruct}([\text{agreement} = \\
[\text{number} = '\text{singular}', \text{person} = '\text{third}'])]
\]

[ agreement = [ number = 'singular' ] ]
[ ]
[ [ person = 'third' ] ]
Creating feature structures, short-hand

fs1 = FeatStruct("[agreement = \
   [number=‘singular’,person=‘third’]]")

[ agreement = [ number = ‘singular’ ] ]
[ [ person = ‘third’ ] ]

The feature structure is parsed from the string. Values are quoted.
Creating feature structures, short-hand w/o value quotes

fs1 = FeatStruct("[agreement = \\
    [number=singular,person=third]]")
Creating feature structures, short-hand w/o value quotes

fs1 = FeatStruct("[agreement = \n    [number=singular,person=third]]")

    [ agreement = [ number = ‘singular’ ] ]
    [ person = ‘third’ ]

Value quotes aren't necessary.
Creating feature structures, short-hand w/o value quotes

```
fs1 = FeatStruct("[agreement = \\
    [number=singular,person=third]]")
```

```
[ agreement = [ number = ‘singular’ ] ]
[ [ person = ‘third’ ] ]
```

Value quotes aren’t necessary.
Using indices

```python
fs = FeatStruct("[
    NAME=Lee, \
    ADDRESS=(1)[NUMBER=74, STREET='rue Pascal'],\n    SPOUSE=[NAME=Kim, ADDRESS->(1)],\n]")
```
Using indices

fs = FeatStruct("[\n    NAME=Lee, \n    ADDRESS=(1)[NUMBER=74, STREET='rue Pascal'],\n    SPOUSE=[[NAME=Kim, ADDRESS->(1)],]"")

[ ADDRESS = (1) [ NUMBER = 74 ] ]
[ [ STREET = 'rue Pascal' ] ]
[ ]
[ NAME = 'Lee' ]
[ ]
[ SPOUSE = [ ADDRESS -> (1) ] ]
[ [ NAME = 'Kim' ] ]
Using indices

fs = FeatStruct("[\n    NAME=Lee, \n    ADDRESS=(1)[NUMBER=74, STREET=‘rue Pascal’],\n    SPOUSE=[NAME=Kim, ADDRESS->(1)],]"
)

[ ADDRESS = (1) [ NUMBER = 74 ] ]
[     [ STREET = ‘rue Pascal’ ] ]
[   ]
[ NAME = ’Lee’ ]
[ ]
[ SPOUSE = [ ADDRESS -> (1) ] ]
[   [ NAME = ‘Kim’ ] ]

The index is assigned a value, and then referenced.
Using indices: reference before assignment

```python
fs = FeatStruct("[
    NAME=Lee, \
    SPOUSE=[NAME=Kim, ADDRESS->(1)], \
    ADDRESS=(1)[NUMBER=74, STREET='rue Pascal']
]")
```
Using indices: reference before assignment

```python
fs = FeatStruct("[
    NAME=Lee, 
    SPOUSE=[NAME=Kim, ADDRESS->(1)], 
    ADDRESS=(1)[NUMBER=74, STREET='rue Pascal']
]")

ValueError: Error parsing feature structure
    [NAME=Lee,
     SPOUSE=[NAME=Kim, ADDRESS->(1)], ...
     ~ Expected bound identifier
```
from nltk.sem.logic import Variable

fs10=FeatStruct("\
    [NP=[head=[agreement=?n]], \  
    VP=[head=(1)[agreement=?n]]]")
from nltk.sem.logic import Variable

fs10=FeatStruct("\n    [NP=[head=[agreement=?n]], \n    VP=[head=(1)[agreement=?n]]]"")

[ NP = [ head = [ agreement = ?n ] ] ]
[ ]
[ VP = [ head = [ agreement = ?n ] ] ]
What does this feature structure represent?

\[
\begin{align*}
S & \rightarrow [\text{head \ 1}] \\
NP & \rightarrow [\text{head \ agreement \ 2}] \\
VP & \rightarrow [\text{head \ 1 \ agreement \ 2}]
\end{align*}
\]
What does this feature structure represent?

\[
S \rightarrow NPVP
\]
What does this feature structure represent?

\[
\begin{align*}
S & \rightarrow NPVP \\
\langle \text{NP head agreement} \rangle & = \langle \text{VP head agreement} \rangle
\end{align*}
\]
Example from textbook

What does this feature structure represent?

\[
S \quad \text{[head 1]} \\
NP \quad \text{[head agreement 2]} \\
VP \quad \text{[head 1 [agreement 2]]} \\
\]

\[S \rightarrow NPVP\]

\[\langle \text{NP head agreement} \rangle = \langle \text{VP head agreement} \rangle\]

\[\langle \text{S head} \rangle = \langle \text{VP head} \rangle\]
Need to combine variables and indices

fs3=FeatStruct("\n  [NP=[head=[agreement=?n]], \n  VP=[head=(1)[agreement=?n]], \n  S=[head->(1)]]")
fs3=FeatStruct("\n    [NP=[head=[agreement=?n]], \n    VP=[head=(1)[agreement=?n]], \n    S=[head->(1)]\")

[ NP = [ head = [ agreement = ?n ] ] ]
[ ]
[ S = [ head = (1) [ agreement = ?n ] ] ]
[ ]
[ VP = [ head -> (1) ] ]
Unification in NLTK


[ NP = [ head = [ agreement = ?n ] ] ]
[ ]

[ S = [ head = (1) [ agreement = ?n ] ] ]
[ ]

[ VP = [ head -> (1) ] ]
Printed version looks odd, but graph is intact.