• Introduction
Introduction

Theory of Features
Outline

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- Metarules
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- Metarules
- Theory of Feature Instantiation Principles

Generalized Phrase Structure Grammar
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## Motivation

Attempt to capture the generalizations made by transformations (in transformational grammar) within context-free grammar.

- We could avoid overgeneration resulting from unrestricted transformations.
- We could use parsing algorithms for CFG.
- (Gazdar et al., 1985)
Generalized Phrase Structure Grammar

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Means

Mechanisms to recreate the effects of transformations within context-free formalism.

- Complex features
  - Capture long-distance dependencies without using movement rules.
- Metarules
  - Allow generalizations.
A phrase structure grammar (PSG) $G$ is a quadruple $G = (N, T, P, S)$, where

- $N$ is a finite set of nonterminals,
- $T$ is a finite set of terminals, $N \cap T = \emptyset$
- $P \subseteq (N \cup T)^* N (N \cup T)^* \times (N \cup T)^*$ is a finite relation – we call each $(x, y) \in P$ a rule (or production) and usually write it as

  \[ x \rightarrow y, \]

- $S \in N$ is the start symbol.
Phrase Structure Grammar

Derivation in PSG

Let $G$ be a PSG. Let $u, v \in (N \cup T)^*$ and $p = x \rightarrow y \in P$. Then, we say that $uxv$ directly derives $uyv$ according to $p$ in $G$, written as $uxv \Rightarrow_G uyv [p]$ or simply

$$uxv \Rightarrow uyv$$

We further define $\Rightarrow^+$ as the transitive closure of $\Rightarrow$ and $\Rightarrow^*$ as the transitive and reflexive closure of $\Rightarrow$.

Generated Language

Let $G$ be a PSG. The language generated by $G$ is defined as

$$L(G) = \{ w : w \in T^*, S \Rightarrow^* w \}$$
A context-free grammar is a PSG $G = (N, T, P, S)$ such that every rule in $P$ is of the form:

$$A \rightarrow x$$

where $A \in N$ and $x \in (N \cup T)^*$. 
Components of GPSG

1. Grammatical rule format
2. Theory of features
3. Properties of metarules
4. Theory of feature instantiation principles
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Grammatical rule format

- We assume the standard interpretation of context-free phrase structure rules

\[ A \rightarrow BC \]

(Chomsky normal form)
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## Components of GPSG

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## Features

- Two types of features:
  1. Atom-valued
  2. Category-valued
Atom-valued Features

Types of Features

1. Atom-valued
2. Category-valued

Atom-valued Features

- **Boolean** values
- Symbols such as:
  - $[-INF]$ finite, an inflected verb *eats*
  - $[-INV]$ inverted subject-auxiliary inversion, as in *Is John sick?*
  - $[+INF]$ infinitival *to eat*
## Category-valued Features

### Types of Features

1. **Atom-valued**
2. **Category-valued**

### Category-valued Features

- The value is something like a nonterminal symbol (which is itself a feature specification).
- **SUBCAT** – feature that identifies the complement of the verb
- **SLASH**
SLASH Feature

- Represents missing constituent.
- Consider a normal transitive verb phrase VP.
- Then, VP[SLASH = NP], or VP/NP for short, represents this VP when it has an NP missing.
  - “VP with an NP gap”
- S/NP – sentence with a missing NP, etc.
SLASH Feature

- Represents **missing constituent**.

- Consider a normal transitive verb phrase VP.

- Then, VP \[ \text{SLASH} = NP \], or VP/NP for short, represents this VP when it has an **NP missing**.
  - “VP with an NP gap”

- S/NP – sentence with a missing NP, etc.

**Example**

<table>
<thead>
<tr>
<th>VP</th>
<th>VP/NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>hit the floor</td>
<td>hit [e]</td>
</tr>
<tr>
<td></td>
<td>(as in <em>Who did John hit?</em>)</td>
</tr>
</tbody>
</table>
• To handle *wh*-questions (*Who did John hit?*), we need another feature besides *SLASH*.
  • Encode the “questionlike” nature of these sentences.
• + *WH*
To handle *wh*-questions (*Who did John hit?*), we need another feature besides *SLASH*.

- Encode the “questionlike” nature of these sentences.

- \(+WH\)

**Example**

Now we can differentiate the following NPs:

1. \(-WH[the\ man]\)
2. \(+WH[which\ man]\)
3. \(-WH[John]\)
4. \(+WH[who]\)
• **Extension** of feature specification = larger feature specification containing it
Feature Extension

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**Example**

- Feature specification: 
  \{[+N], [+V]\}
  - The category $A$ - adjective
• **Extension** of feature specification = larger feature specification containing it

**Example**

• Feature specification: 
  \{[+N], [+V]\}
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• Possible extension:
Feature Extension

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**Example**

- Feature specification:
  \{[+N], [+V]\}
  - The category A - adjective

- Possible extension:
  \{[+N], [+V],
• **Extension** of feature specification = larger feature specification containing it

**Example**

- Feature specification:
  \{[+N], [+V]\}
  - The category A - adjective

- Possible extension:
  \{[+N], [+V], [+PRED]\}
Feature Extension

- **Extension** of feature specification = larger feature specification containing it

**Example**

- Feature specification: 
  \{ [+N], [+V] \}
  - The category A - adjective

- Possible extension: 
  \{ [+N], [+V], [+PRED] \}
  - Adjective in a predicative position

  *Mary is \{ [+N], [+V], [+PRED] \} intelligent*
Feature Unification

- Similar to the set union operation.
Feature Unification

- Similar to the set union operation.

Example

- Feature specifications:
  \[
  \{[+V], [+PRED]\}
  \{[-N], [+V]\}
  \]
• Similar to the set union operation.

Example

• Feature specifications:
  \{[+V], [+PRED]\}
  \{[−N], [+V]\}

• Unification:
Feature Unification

- Similar to the *set union* operation.

**Example**

- Feature specifications:
  
  \[
  \{[+V], [+PRED]\} \\
  \{[−N], [+V]\} \\
  \]

- Unification:
  
  \[
  \{[+V]\}, \\
  \]
• Similar to the set union operation.

Example

• Feature specifications:
  \{ [+V], [+PRED] \}
  \{ [−N], [+V] \}

• Unification:
  \{ [+V], [+PRED] \}
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Example

• Feature specifications:
  \{[+V], [+PRED]\}
  \{[−N], [+V]\}

• Unification:
  \{[+V], [+PRED], [−N]\}
Feature Unification

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Example

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Feature Unification

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Example

- Feature specifications:
  \{ [+V], [+PRED] \}
  \{ [−N], [+V] \}

- Unification:
  \{ [+V], [+PRED], [−N] \}

- Note: If features contradict each other, unification is undefined.
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- **Metarules**

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Metarules

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Metarules

- **Metarule** – function from lexical rules to lexical rules.
- Metarules generate related phrase structure rules.
- Similar function to transformations in transformational grammar.
Passive Metarule

Example

John washes the car.
⇒ The car is washed by John.

• We could write rules to generate the second sentence directly.
• Problem with such approach: no generalization
Passive Metarule

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Passive Metarule

\[ VP \to W \text{ NP} \Rightarrow VP[\text{PASSIVE}] \to W(PP[+by]) \]

- For every context-free rule introducing VP as an NP and some variable number of constituents (including the verb) indicated by W, another context-free rule is introduced, such that:
  1. VP is marked with \([+\text{PASSIVE}]\) feature (atom-valued)
  2. NP present in the active form is missing
  3. optimal PP is introduced, marked with \([by]\) feature (atom-valued)
     - “selects preposition by”
- W – varying parameter – standard rewrite rules produced when W is instantiated
Passive Metarule

\[ VP \rightarrow W\ NP \Rightarrow VP[\text{PASSIVE}] \rightarrow W(PP[+by]) \]

Example

\[ [VP \text{ washes the car}] \quad [VP \text{ washed (by NP)}] \]

- Notice that the passive metarule makes no reference to the subject of the sentence – this is because the semantics for the verb will be different for different instantiations.
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Theory of Feature Instantiation Principles

- Metarules capture generalizations made by *local* transformations in a transformational grammar.
- This will allow us to handle *long-distance dependencies*.
Phrase structure rules specify that one category is the head of the phrase.

- **Head** – the category-defining element of the phrase
- **Foot** – the complement of the phrase

**Example**

\[ NP \rightarrow N \text{ Comp} \]

- **Head**: N
- **Foot**: Comp
**HEAD and FOOT Features**

- Phrase structure rules specify that one category is the **head** of the phrase.
- **Head** – the category-defining element of the phrase
- **Foot** – the complement of the phrase

**Example**

NP → N Comp

- Head: N
- Foot: Comp

**Sets of Features**

1. **HEAD features** = \(\{N, V, PLURAL, PERSON, PAST, BAR, \ldots\}\)
2. **FOOT features** = \(\{SLASH, WH\}\)
• Properties of the head elements of rules

• Values: + or –

**HEAD Feature Principle**

The *HEAD* features of a child node must be identical to the *HEAD* features of the parent.
FOOT Features

- Encode more complex information about the movement of *wh*-phrases and NPs
- Values: categories

**FOOT Feature Principle**

The FOOT features instantiated on a parent category in a tree must be identical to the unification of the instantiated FOOT feature specifications in all its children.
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In transformational grammar, we introduce a transformational rule to move the *wh*-phrase *who* or *what* from the deep structure position (marked with a “trace” *e*) to the front of the sentence.

In GPSG, we can generate the sentence without using transformations.
Example: *wh*-questions

**Example**

*Who drives a Honda?*

*What does John drive e?*

- In transformational grammar, we introduce a transformational rule to move the *wh*-phrase *who* or *what* from the deep structure position (marked with a “trace” *e*) to the front of the sentence.

- In GPSG, we can generate the sentence without using transformations.

**Idea**

- Encode the “movement” information on the node of the tree directly.

- Pass this information up and down the tree using features.
First, consider a simple sentence such as the following

Example

John drives a Honda.
Example: *wh*-questions

- First, consider a simple sentence such as the following
  
  Example
  
  *John drives a Honda.*
  
- The rules necessary to build such sentence are:
  
  \[
  S \rightarrow NP \text{ VP} \\
  VP \rightarrow TV \text{ NP} \\
  \]

- TV – transitive verb, which takes NP as its subject

  \[
  TV = \{ [+V], [-N], [\text{SUBCAT} = NP]\} 
  \]
Example: *wh*-questions

- First, consider a simple sentence such as the following

  Example:  
  
  *John drives a Honda.*

  - The rules necessary to build such sentence are:

    \[
    S \rightarrow NP \ VP \\
    VP \rightarrow TV \ NP \\
    \]

  - TV – transitive verb, which takes NP as its subject

    \[
    TV = \{ [+V], [−N], [SUBCAT = NP] \} \\
    \]

  - In order to generate *wh*-movement sentence, we assign the value *NP* to the feature *SLASH* on the VP node.
    - This indicates that there is a constituent missing.
Example: *wh*-questions

- In GPSG, according to the *FOOT* feature principle, rule of the form $VP \rightarrow NP\ SP$ implies rule of the form $VP/\ NP \rightarrow NP/\ NP$

- Similarly, the rule $S \rightarrow NP\ VP$ allows two other rules:
  
  $S/\ NP \rightarrow NP\ VP/\ NP$
  $S/\ NP \rightarrow NP/\ NP\ VP$

- Note: *WH* cannot cooccur with *SLASH*
Example: \textit{wh}-questions

- In GPSG, according to the \textit{FOOT} feature principle, rule of the form $\text{VP} \rightarrow \text{NP SP}$ implies rule of the form $\text{VP} / \text{NP} \rightarrow \text{NP} / \text{NP}$

- Similarly, the rule $\text{S} \rightarrow \text{NP VP}$ allows two other rules:
  \[
  \begin{align*}
  \text{S} / \text{NP} & \rightarrow \text{NP VP} / \text{NP} \\
  \text{S} / \text{NP} & \rightarrow \text{NP} / \text{NP} \text{ VP}
  \end{align*}
  \]

- Using the two features \textit{WH} and \textit{SLASH}, we can account for the \textit{wh}-questions.
- Assume that the rules for expanding the sentence are given as follows
  \[
  \begin{align*}
  \text{S} & \rightarrow \text{NP VP} \\
  \text{S} & \rightarrow \text{NP S} / \text{NP}
  \end{align*}
  \]

- We can add the $[+ \textit{WH}]$ feature to $\text{S}$ – applying the \textit{FOOT} feature principle, the information will be transmitted down the tree.
- Note: \textit{WH} cannot cooccur with \textit{SLASH}
Example: *wh*-questions

*Who drives a Honda?*
*What does John drive?*

\[
S \rightarrow \text{NP VP} \\
S \rightarrow \text{NP S/NP}
\]
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Thank you for your attention!
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