Generalized Phrase Structure Grammar

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Outline

Topic

- **Introduction**
- **Theory of Features**
- **Metarules**
- **Theory of Feature Instantiation Principles**
- **Examples**

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)

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.

Definition

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*.

Derivation in PSG

Let G be a PSG. Let $u, v \in (N \cup T)^*$ and $p = x \to y \in P$. 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

$$L(G) = \{w : w \in T^*, S \Rightarrow^* w\}$$

Definition

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

Grammatical rule format

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

$$A \rightarrow BC$$

(Chomsky normal form)

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Features

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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.

Example

VP	VP/NP
hit the floor	*hit* [*e*]
	(as in *Who did John hit?*)

$+$*WH* Feature

- 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*]

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

$$\textit{Mary is } [_{\{[+N],[+V],[+PRED]\}}\textit{intelligent}]$$

Feature Unification

- Similar to the set union operation.

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

- 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.
$\Rightarrow$ *The car is washed by John.*

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

Passive Metarule

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

- 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 [+*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

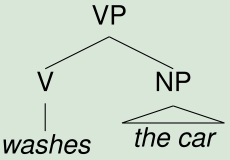
Passive Metarule

Passive Metarule

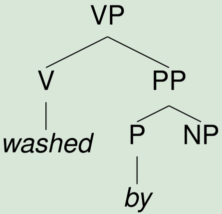
$$VP \rightarrow W\ NP \Rightarrow VP[\textit{PASSIVE}] \rightarrow W(PP[+\textit{by}])$$

Example

[$_{VP}$ *washes the car*]



[$_{VP}$ *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 Instatiation Principles

- Metarules capture generalizations made by local transformations in a transformational grammar.
- This will allow us to handle long-distance dependencies.

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 $\rightarrow$ N Comp

- Head: N
- Foot: Comp

Sets of Features

1. *HEAD* features $= \{N, V, PLURAL, PERSON, PAST, BAR, \ldots\}$
2. *FOOT* features $= \{SLASH, WH\}$

HEAD Features

- 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.

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

FOOT Feature Principle

The *FOOT* features instantied 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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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.

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:

$$\begin{array}{rcl} \text{S} & \rightarrow & \text{NP VP} \\ \text{VP} & \rightarrow & \text{TV NP} \end{array}$$

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

$$\text{TV} = \{[+V], [-N], [SUBCAT = NP]\}$$

- 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

$$\mathrm{VP}/\mathrm{NP} \quad \rightarrow \quad \mathrm{NP}/\mathrm{NP}$$

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

$$\begin{array}{lcl} \mathrm{S}/\mathrm{NP} & \rightarrow & \mathrm{NP}\ \mathrm{VP}/\mathrm{NP} \\ \mathrm{S}/\mathrm{NP} & \rightarrow & \mathrm{NP}/\mathrm{NP}\ \mathrm{VP} \end{array}$$

- Using the two features *WH* and *SLASH*, we can account for the *wh*-questions.
- Assume that the rules for expanding the sentence are given as follows

$$\begin{array}{lcl} \mathrm{S} & \rightarrow & \mathrm{NP}\ \mathrm{VP} \\ \mathrm{S} & \rightarrow & \mathrm{NP}\ \mathrm{S}/\mathrm{NP} \end{array}$$

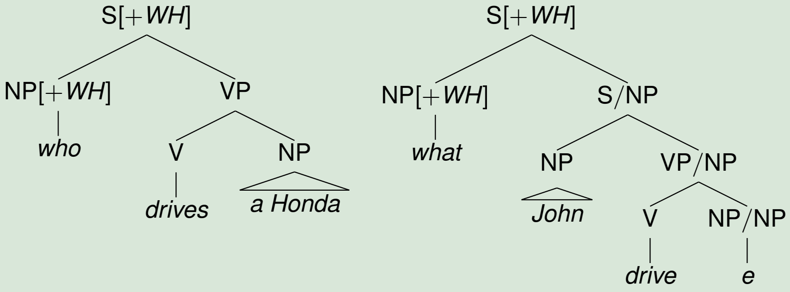
- We can add the [+*WH*] feature to S – applying the *FOOT* feature principle, the information will be transmitted down the tree.
- Note: *WH* cannot cooccur with *SLASH*

Example

Who drives a Honda?
What does John drive?

$$S \rightarrow NP\ VP \qquad\qquad S \rightarrow NP\ S/NP$$

Example



References

James Allen:
Natural Language Understanding,
The Benjamin/Cummings Publishing Company. Inc., 2005

Gerald Gazdar, Ewan H. Klein, Geoffery K. Pullum, Ivan A. Sag:
Generalized Phrase Structure Grammar,
Harvard University Press, 1985

Robert N. Moll, Michael A. Arbib, A. J. Kfoury:
An Introduction to Formal Language Theory,
Springer-Verlag, 1988