



Features and Unification

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Overview

- Feature Structures
- Unification of Feature Structures
- Features Structures in the Grammar

Feature – Introduction

- ♦ View grammatical categories like *3sgNP*, *Non3sgAux*, and grammatical rules like $S \rightarrow NP VP$ as **objects** that have complex sets of **properties** associated with them
- ♦ The information in these properties is represented by *constraints*, and models are called **constraint-based formalisms**
- ♦ Grammatical phenomena such as agreement and subcategorization lead to over generation
Non3sgVPto, *NPmass*, *3sgNP*, *Non3sgAux*
- ♦ These new categories led to an explosion in the number of grammar rules

Refer noun-phrase / verb-phrase from previous slides

Feature – Introduction

- ♦ A constraint-based representation scheme will allow to represent information about:
 - number and person,
 - Agreement,
 - subcategorization, as well as
 - semantic categories like mass / count
- ♦ Property NUMBER is used to distinguish singular or plural
 - NP like *this flight* and *those flights* can be distinguished

Det [NUMBER = SG] → this

Det [NUMBER = PL] → those

N [NUMBER = SG] → flight

N [NUMBER = PL] → flights

Feature Structures

- ♦ Feature structure – the representation used to capture the kind of grammatical properties
- ♦ A Feature structure is a set of *feature-value* pairs where
 - Features are unanalyzable atomic symbols drawn from finite set
 - Values are atomic symbols or feature structures
- ♦ Feature structures are illustrated with matrix-like diagram called *attribute-value matrix* or *AVM*

$$\begin{bmatrix} Feature_1 & Value_1 \\ Feature_2 & Value_2 \\ \vdots & \vdots \\ Feature_n & Value_n \end{bmatrix}$$

An Example



$\left[\begin{array}{l} \textit{NUMBER} \\ \textit{SG} \end{array} \right]$

$\left[\begin{array}{l} \textit{NUMBER} \\ \textit{PERSON} \end{array} \right] \begin{array}{l} \textit{SG} \\ 3 \end{array}$

$\left[\begin{array}{l} \textit{CAT} \\ \textit{NUMBER} \\ \textit{PERSON} \end{array} \right] \begin{array}{l} \textit{NP} \\ \textit{SG} \\ 3 \end{array}$

*Feature structure
associated with
3sgNP*

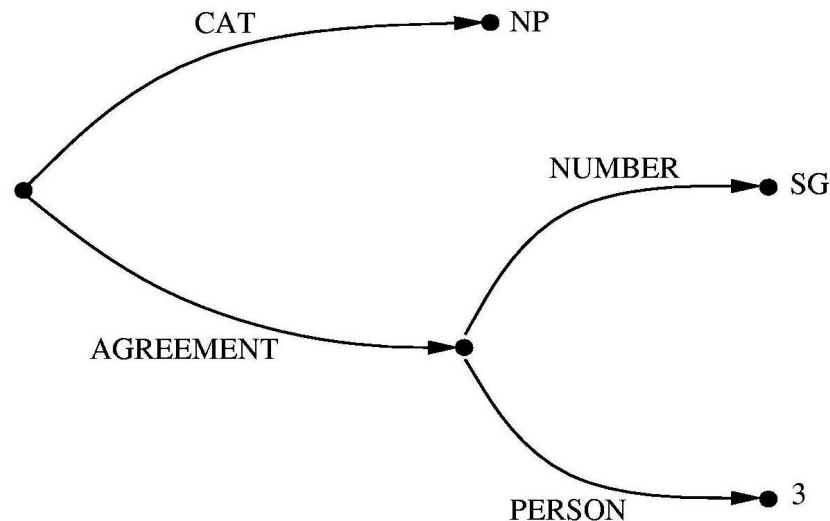
Feature Bundles

- ◆ Features can also have other feature structures as their values
- ◆ Useful to bundle a set of feature-value pairs together
- ◆ For example: AGREEMENT feature consists of NUMBER and PERSON feature-value pairs as its value

$$\left[\begin{array}{l} CAT \\ AGREEMENT \end{array} \left[\begin{array}{l} NP \\ \left[\begin{array}{ll} NUMBER & SG \\ PERSON & 3 \end{array} \right] \end{array} \right] \right]$$

Feature Path [DAG]

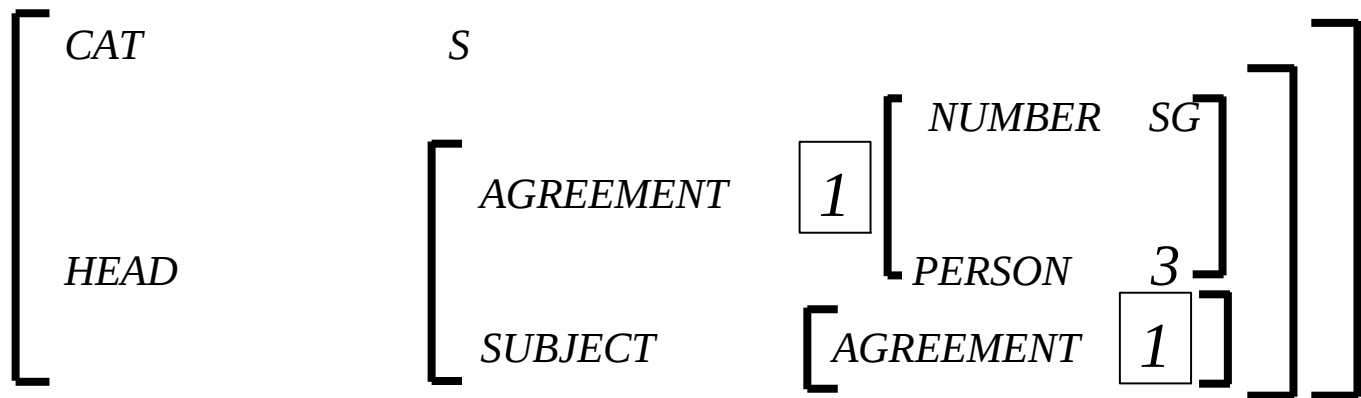
- ♦ A feature path is a list of features through a feature structure leading to a particular value
- ♦ For example <AGREEMENT NUMBER> path leads to the value SG, while <AGREEMENT PERSON> path leads to the value 3



feature – edges
values – nodes

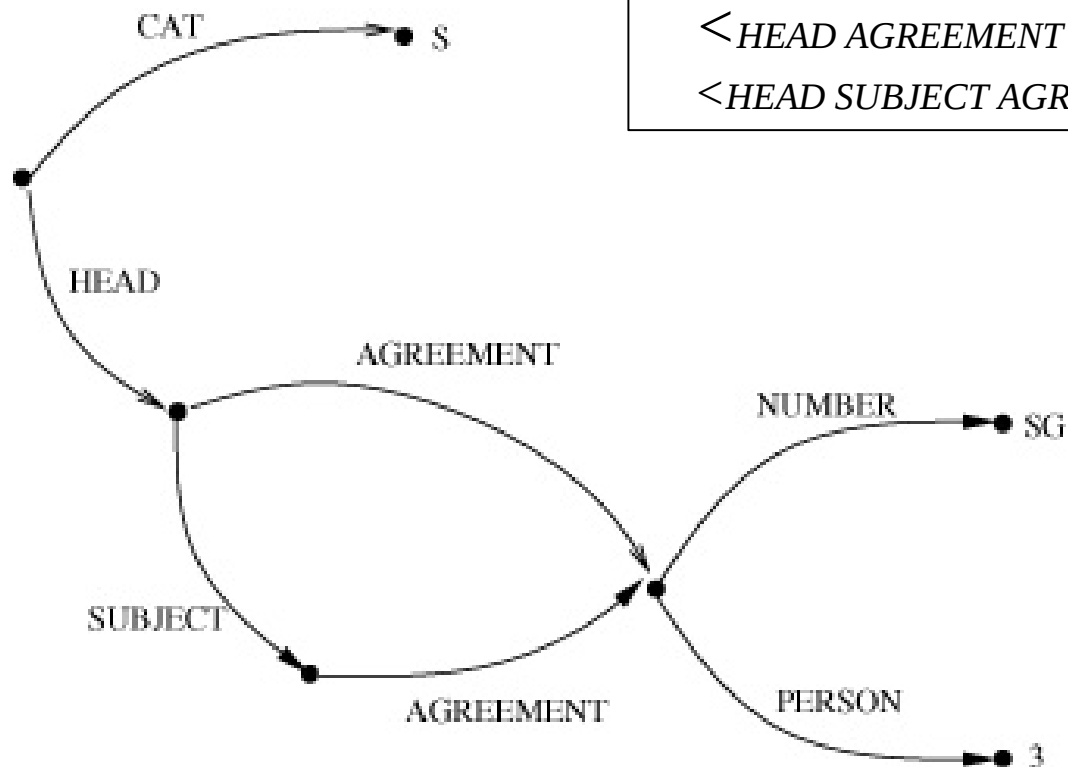
Reentrant structures

- ◆ Features in a feature structures can share some feature structure as a value – **reentrant** structures
- ◆ They share precisely the same feature structure (or node in graph)
- ◆ Shared structures will be denoted in matrix by adding *numerical indexes* that signal the values to be shared



Reentrant DAG

Two feature paths lead to the same node in the structure



Unification of Feature Structures

- ♦ *So what do we want to do with these things...?*
- ♦ Two key operations on feature structures
 - check the compatibility of two structures
 - merge the information in two structures
- ♦ We can do both with a single operation called *Unification*
- ♦ Unifying two feature structures produces a new feature structure that is more specific (has more information) than, or is identical to, each of the input feature structures

Unification of Feature Structures

$[\text{NUMBER SG}] \sqcup [\text{NUMBER SG}] = [\text{NUMBER SG}]$

$[\text{NUMBER SG}] \sqcup [\text{NUMBER PL}]$ *Fails!*

$[\text{NUMBER SG}] \sqcup [\text{NUMBER []}] = [\text{NUMBER SG}]$

$[\text{NUMBER SG}] \sqcup [\text{PERSON 3}] = \begin{bmatrix} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{bmatrix}$

Unification of Reentrant

$$\left[\begin{array}{ll} \text{AGREEMENT} & \langle 1 \rangle \left[\begin{array}{ll} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{array} \right] \\ \text{SUBJECT} & \left[\text{AGREEMENT} \quad \langle 1 \rangle \right] \end{array} \right]$$

II

$$\left[\text{SUBJECT} \quad \left[\text{AGREEMENT} \quad \left[\begin{array}{ll} \text{PERSON} & 3 \\ \text{NUMBER} & \text{SG} \end{array} \right] \right] \right]$$

$$= \left[\begin{array}{ll} \text{AGREEMENT} & \langle 1 \rangle \left[\begin{array}{ll} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{array} \right] \\ \text{SUBJECT} & \left[\text{AGREEMENT} \quad \langle 1 \rangle \right] \end{array} \right]$$

Values following [1] index in first argument matches with second argument

Value of the AGREEMENT feature is *shared* with the SUBJECT feature

Unification of Reentrant

$$\begin{aligned}
 & \left[\begin{array}{cc} \text{AGREEMENT} & [1] \\ \text{SUBJECT} & [\text{AGREEMENT} \ [1]] \end{array} \right] \\
 & \quad \quad \quad \sqcup \\
 & \left[\text{SUBJECT} \left[\text{AGREEMENT} \left[\begin{array}{cc} \text{PERSON} & 3 \\ \text{NUMBER} & \text{SG} \end{array} \right] \right] \right] \\
 & = \left[\begin{array}{cc} \text{AGREEMENT} & [1] \\ \text{SUBJECT} & \left[\text{AGREEMENT} \ [1] \left[\begin{array}{cc} \text{PERSON} & 3 \\ \text{NUMBER} & \text{SG} \end{array} \right] \right] \end{array} \right]
 \end{aligned}$$

Value found in <SUBJECT AGREEMENT> is copied over to first argument

The AGREEMENT feature of 1st argument receives a value because of index [1]

Unification

$$\left[\begin{array}{l} \text{AGREEMENT} \quad [\text{NUMBER} \quad \text{SG}] \\ \text{SUBJECT} \quad [\text{AGREEMENT} \quad [\text{NUMBER} \quad \text{SG}]] \end{array} \right]$$

\sqcup

$$\left[\begin{array}{l} \text{SUBJECT} \quad \left[\text{AGREEMENT} \quad \left[\begin{array}{l} \text{PERSON} \quad 3 \\ \text{NUMBER} \quad \text{SG} \end{array} \right] \right] \end{array} \right]$$

$$= \left[\begin{array}{l} \text{AGREEMENT} \quad \left[\begin{array}{l} \text{NUMBER} \quad \text{SG} \end{array} \right] \\ \text{SUBJECT} \quad \left[\text{AGREEMENT} \quad \left[\begin{array}{l} \text{NUMBER} \quad \text{SG} \\ \text{PERSON} \quad 3 \end{array} \right] \right] \end{array} \right]$$

No index, linking the <AGREEMENT> to the <SUBJECT AGREEMENT> feature, hence the information is not added to the value of the AGREEMENT feature

Unification

$$\left[\begin{array}{ll} \text{AGREEMENT} & \langle 1 \rangle \left[\begin{array}{ll} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{array} \right] \\ \text{SUBJECT} & \left[\text{AGREEMENT} \quad \langle 1 \rangle \right] \end{array} \right]$$

II

$$\left[\begin{array}{ll} \text{AGREEMENT} & \left[\begin{array}{ll} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{array} \right] \\ \text{SUBJECT} & \left[\text{AGREEMENT} \quad \left[\begin{array}{ll} \text{NUMBER} & \text{PL} \\ \text{PERSON} & 3 \end{array} \right] \right] \end{array} \right]$$

= ?

Unification

$$\left[\begin{array}{cc} \text{AGREEMENT} & \langle 1 \rangle \left[\begin{array}{cc} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{array} \right] \\ \text{SUBJECT} & \left[\text{AGREEMENT} \quad \langle 1 \rangle \right] \end{array} \right]$$

II

$$\left[\begin{array}{cc} \text{AGREEMENT} & \left[\begin{array}{cc} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{array} \right] \\ \text{SUBJECT} & \left[\text{AGREEMENT} \quad \left[\begin{array}{cc} \text{NUMBER} & \textcolor{red}{PL} \\ \text{PERSON} & 3 \end{array} \right] \right] \end{array} \right]$$

= FAILS !

Values found at the respective *<SUBJECT AGREEMENT NUMBER>* paths differ

Subsumption

- ♦ A less specific (more abstract) feature structure **subsumes** an equal or more specific one
- ♦ Subsumption is represented by \subseteq .

[NUMBER SG] - 11.1

[PERSON 3] - 11.2

$\begin{bmatrix} \text{NUMBER} & \text{SG} \\ \text{PERSON} & 3 \end{bmatrix}$ - 11.3

$11.1 \subseteq 11.3$ [11.1 subsumes 11.3]

$11.2 \subseteq 11.3$

11.1 does not subsume 11.2 or vice versa

Feature Structures in Grammar

- Number agreement:

$S \rightarrow \text{NP} \quad \text{VP} \quad * \text{Ram walk}$
[NP NUMBER] [VP NUMBER]

$\text{NP} \rightarrow \text{det} \quad \text{N} \quad * \text{those flight}$
[DET NUMBER] [N NUMBER]

Without this check, we'd have more ambiguity:

Flying planes is dangerous.

Flying planes are dangerous.

Feature Structures in Grammar

- ♦ Feature structures and unification operations are integrated with the grammar specification
- ♦ Context-free grammars are augmented with attachments that specify:
 - feature structures for the constituents
 - appropriate unification operation that express constraints on those constituents
- ♦ To denote the grammar augmentations:

$\beta_0 \rightarrow \beta_1 \dots \beta_n$ } grammar rule

{ set of constraints } where the constraints have one of following forms:

$\langle \beta_0 \text{ feature path} \rangle = \text{Atomic value}$

$\langle \beta_i \text{ feature path} \rangle = \langle \beta_j \text{ feature path} \rangle$

Feature Structures in Grammar

- ◆ Number agreement : the number of the NP is equal to the number of the VP
- ◆ The rule can be expressed as follows:
 $S \rightarrow NP VP$
 $\langle NP \text{ NUMBER} \rangle = \langle VP \text{ NUMBER} \rangle$
- ◆ In CFG – concatenate an NP to a VP
- ◆ By augmenting with feature, this concatenation must be accompanied by a successful unification operation
- ◆ Elements of CFG rules will have feature-based constraints associated with them

Feature Structures in Grammar

- ◆ Application of unification constraints to four linguistic phenomena:
 - Agreement
 - Grammatical heads
 - Subcategorization
 - Long-distance dependencies

Agreement

- ♦ The two main types of English agreement phenomena:
 - subject-verb agreement
 - determiner-nominal agreement

- ♦ This flight serves breakfast.
- ♦ Does this flight serve breakfast ?
- ♦ Do these flights serve breakfast ?

- ♦ AGREEMENT feature takes care of PERSON and NUMBER feature
- ♦ $S \rightarrow NP VP$

$\langle NP \text{ AGREEMENT} \rangle = \langle VP \text{ AGREEMENT} \rangle$

Agreement

- ◆ In yes-no questions, the subject NP must agree with aux.verb rather than the main verb:

$S \rightarrow \text{Aux NP VP}$

$\langle \text{Aux AGREEMENT} \rangle = \langle \text{NP AGREEMENT} \rangle$

Does this flight
Do these flights

- ◆ Agreement between determiners and nominals in *NP*:

$\text{NP} \rightarrow \text{Det Nominal}$

$\langle \text{Det AGREEMENT} \rangle = \langle \text{Nominal AGREEMENT} \rangle$

$\langle \text{NP AGREEMENT} \rangle = \langle \text{Nominal AGREEMENT} \rangle$

this flight
those flights

Agreement

- ♦ The lexical constituents receive values for their agreement features directly from the lexicon:
- ♦ Aux → do
 - ⟨Aux AGREEMENT NUMBER⟩ = PL
 - ⟨Aux AGREEMENT PERSON⟩ = 3
- ♦ Aux → does
 - ⟨Aux AGREEMENT NUMBER⟩ = SG
 - ⟨Aux AGREEMENT PERSON⟩ = 3
- ♦ Determiner → this
 - ⟨Determiner AGREEMENT NUMBER⟩ = SG
- ♦ Determiner → these
 - ⟨Determiner AGREEMENT NUMBER⟩ = PL

Agreement

- ♦ Non-lexical constituents can acquire values for at least some of their features from their component constituents:

Grammar: $VP \rightarrow \textit{Verb NP}$

- ♦ $\textit{Verb} \rightarrow \textit{serve}$
 $\langle \textit{Verb AGREEMENT NUMBER} \rangle = \text{PL}$
- ♦ $\textit{Verb} \rightarrow \textit{serves}$
 $\langle \textit{Verb AGREEMENT NUMBER} \rangle = \text{SG}$
 $\langle \textit{Verb AGREEMENT PERSON} \rangle = 3$
- ♦ $VP \rightarrow \textit{Verb NP}$
 $\langle \textit{VP AGREEMENT} \rangle = \langle \textit{Verb AGREEMENT} \rangle$
- ♦ $\textit{Nominal} \rightarrow \textit{Noun}$
 $\langle \textit{Nominal AGREEMENT} \rangle = \langle \textit{Noun AGREEMENT} \rangle$

Head Features

- ◆ Features for grammatical categories are copied from one of the children to the parent
- ◆ The child that provides the features is called the **head of the phrase** and the features copied are referred to as **head features**
- ◆ Consider the following three rules:

◆ $VP \rightarrow Verb\ NP$ head of the phrase
 $\langle VP\ AGREEMENT \rangle = \langle Verb\ AGREEMENT \rangle$

$NP \rightarrow Det\ Nominal$
 $\langle Det\ AGREEMENT \rangle = \langle Nominal\ AGREEMENT \rangle$
 $\langle NP\ AGREEMENT \rangle = \langle Nominal\ AGREEMENT \rangle$

$Nominal \rightarrow Noun$
 $\langle Nominal\ AGREEMENT \rangle = \langle Noun\ AGREEMENT \rangle$

Head Features

- ♦ Rewrite the rules by placing agreement feature structure under HEAD feature:

- ♦ $VP \rightarrow \textit{Verb NP}$

head of the phrase

$$\langle \text{VP HEAD} \rangle = \langle \text{Verb HEAD} \rangle$$

- ♦ $NP \rightarrow \textit{Det Nominal}$

$$\langle \text{NP HEAD} \rangle = \langle \text{Nominal HEAD} \rangle$$

$$\langle \text{Det HEAD AGREEMENT} \rangle = \langle \text{Nominal HEAD AGREEMENT} \rangle$$

- ♦ $\textit{Nominal} \rightarrow \textit{Noun}$

$$\langle \text{Nominal HEAD} \rangle = \langle \text{Noun HEAD} \rangle$$

Head Features

Similarly, the lexical rules must reflect HEAD notion:

Noun → *flights*

⟨Noun HEAD AGREEMENT NUMBER⟩ = PL

Verb → *serve*

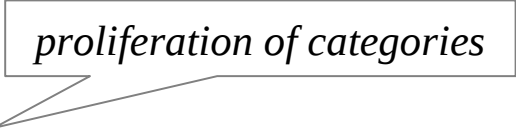
⟨Verb HEAD AGREEMENT NUMBER⟩ = PL

Verb → *serves*

⟨Verb HEAD AGREEMENT NUMBER⟩ = SG

⟨Verb HEAD AGREEMENT NUMBER⟩ = 3

Subcategorization

- ♦ Verbs can be picky about the patterns of arguments that can appear along with
- ♦ *Verb-with-S-comp* → *think*
VP → *Verb-with-S-comp S* 
- ♦ Introduce feature structures to distinguish among various members of verb category
- ♦ Associate the feature SUBCAT with an appropriate value

Subcategorization

- ♦ Example: Verb expects only one argument:

- ♦ Verb → *serves*

⟨Verb HEAD AGREEMENT NUMBER⟩ = SG

⟨Verb HEAD SUBCAT FIRST CAT⟩ = NP

⟨Verb HEAD SUBCAT SECOND⟩ = END

serves dinner

- ♦ Verb with two arguments:

Verb → *leaves*

⟨Verb HEAD AGREEMENT NUMBER⟩ = SG

⟨Verb HEAD SUBCAT FIRST CAT⟩ = NP

⟨Verb HEAD SUBCAT SECOND CAT⟩ = PP

⟨Verb HEAD SUBCAT THIRD⟩ = END

leave Boston in the morning

Subcategorization

- ♦ Example: Verb phrase expects only one argument:

- ♦ $VP \rightarrow \text{Verb NP}$

$\langle VP \text{ HEAD} \rangle = \langle \text{Verb HEAD} \rangle$

$\langle VP \text{ HEAD SUBCAT FIRST CAT} \rangle = \langle NP \text{ CAT} \rangle$

$\langle VP \text{ HEAD SUBCAT SECOND} \rangle = \text{END}$

- ♦ Verb's SUBCAT must match the category of constituent immediately following the verb

- ♦ The form VPto subcategorized for *want*:

- ♦ $\text{Verb} \rightarrow \text{want}$

$\langle \text{Verb HEAD SUBCAT FIRST CAT} \rangle = VP$

$\langle \text{Verb HEAD SUBCAT FIRST FORM} \rangle = \text{INFINITIVE}$

Subcategorization frames for verbs

Noun Phrase Types		
There	nonreferential there	There <i>is still much to learn</i>
It	nonreferential it	It <i>was evident that my ideas</i>
NP	noun phrase	<i>As he was relating</i> his story
Preposition Phrase Types		
PP	preposition phrase	<i>couch their message</i> in terms
PPing	gerundive PP	<i>censured him</i> for not having intervened
PPpart	particle	<i>turn it off</i>
Verb Phrase Types		
VPbrst	bare stem VP	<i>she could</i> discuss it
VPto	to-marked infin. VP	<i>Why do you want</i> to know?
VPwh	wh-VP	<i>it is worth considering</i> how to write
VPing	gerundive VP	<i>I would consider</i> using it
Complement Clause types		
Finite Clause		
Sfin	finite clause	<i>maintain</i> that the situation was unsatisfactory
Swh	wh-clause	<i>it tells us</i> where we are
Sif	whether/if clause	<i>ask</i> whether Aristophanes is depicting a
Nonfinite Clause		
Sing	gerundive clause	<i>see</i> some attention being given
Sto	to-marked clause	<i>know</i> themselves to be relatively unhealthy
Sforto	for-to clause	<i>She was waiting</i> for him to make some reply
Sbrst	bare stem clause	<i>commanded</i> that his sermons be published
Other Types		
AjP	adjective phrase	<i>thought it</i> possible
Quo	quotes	<i>asked</i> “What was it like?”

Potential phrase types to create a set of potential subcategorization frames for verbs

Subcategorization

Subcategorization pattern for the verb *ask* from BNC

<u>Subcat</u>	<u>Example</u>
Quo	<i>asked</i> [_{Quo} “What was it like?”]
NP	<i>asking</i> [_{NP} a question]
Swh	<i>asked</i> [_{Swh} what trades you’re interested in]
Sto	<i>ask</i> [_{Sto} him to tell you]
PP	that means <i>asking</i> [_{PP} at home]
Vto	<i>asked</i> [_{Vto} to see a girl called Evelyn]
NP Sif	<i>asked</i> [_{NP} him] [_{Sif} whether he could make]
NP NP	<i>asked</i> [_{NP} myself] [_{NP} a question]
NP Swh	<i>asked</i> [_{NP} him] [_{Swh} why he took time off]

Subcategorization in other POS

Subcategorization in adjectives *apparent*, *unimportant* and the noun *question*

Example

It was **apparent**_[pp] from the way she rested her hand ...]

It was **apparent**_[sfin] that the kitchen was the only room ...]

It is **unimportant**_[Swheth] whether only a little bit is accepted]

the **question**_[Swheth] whether the authorities might have decided]

Long-Distance Dependencies

- ♦ The constituent which are subcategorized for by a verb may be realized apart from the verb, as a **long-distance dependency**
- ♦ $S \rightarrow Wh-NP Aux NP VP$
*Which flight do you want me to have the travel agent **book**?*
- ♦ The wh-phrase **which flight** must fill the subcategorization requirements of the verb *book* despite two other (*want, have*) in between
- ♦ Feature GAP is used, which is passed up from phrase to phrase in the parse tree
- ♦ The filler (**which flight**) is put on the gap list and must be unified with subcat frame of some verb

References

- ◆ Speech and Language Processing, *Jurafsky and H.Martin*
[Chapter 11. Features and Unification]



Thank You