Outline of today's lecture

Subjects, verbs and objects

subject	verb	object
John	bought	a book

- Subject-verb rule:

  `S -> NP VP`

- Verb-object rule:

  `VP -> V NP`

Expanded CFG (from last time)

- number agreement: subject verb agreement. e.g., *they fish*, *it fishes*, **it fish*, **they fishes*. * means ungrammatical
- case: pronouns (and maybe *who/whom*) e.g., *they like them*, **they like they*

```
S  -> NP-sg-nom VP-sg         NP-sg-nom -> he
S  -> NP-pl-nom VP-pl         NP-sg-acc -> him
VP-sg -> V-sg NP-sg-acc       NP-sg-nom -> fish
VP-sg -> V-sg NP-pl-acc       NP-pl-nom -> fish
VP-pl -> V-pl NP-sg-acc       NP-sg-acc -> fish
VP-pl -> V-pl NP-pl-acc       NP-pl-acc -> fish
```

BUT: very large grammar, misses generalizations, no way of saying when we don't care about agreement.

Constraint-based grammar (feature structures)

Providing a more adequate treatment of syntax than simple CFGs by replacing the atomic categories by more complex data structures.

- allow to encode a set of constraints on the categories
- these constraints will be instantiated when a rule is applied
- e.g. to encode number agreement in the subject-verb rule or case in the verb-object rule

Intuitive solution for case and agreement

- Separate slots, features, for CASE and AGR
- Slot values for CASE may be **nom** (e.g., *they*), **acc** (e.g., *them*) or unspecified (i.e., don't care)
- Slot values for AGR may be **sg**, **pl** or unspecified
- Subjects have the same value for AGR as their verbs
- Subjects have CASE **nom**, objects have CASE **acc**

dog (n) $\begin{bmatrix} \text{CASE} & [\,] \\ \text{AGR} & \textbf{sg} \end{bmatrix}$ fish (n) $\begin{bmatrix} \text{CASE} & [\,] \\ \text{AGR} & [\,] \end{bmatrix}$

she $\begin{bmatrix} \text{CASE} & \textbf{nom} \\ \text{AGR} & \textbf{sg} \end{bmatrix}$ them $\begin{bmatrix} \text{CASE} & \textbf{acc} \\ \text{AGR} & \textbf{pl} \end{bmatrix}$

Feature structures

$$\begin{bmatrix} \text{CASE} & [\,] \\ \text{AGR} & \textbf{sg} \end{bmatrix}$$

1. Features like AGR with simple values: atomic-valued
2. Values for some features themselves have features: complex-valued, e.g. subcategorisation features
3. Unspecified values possible on features: compatible with any value.
4. Unification: combining two feature structures, retaining all information from each, or fail if information is incompatible.
5. In grammars, rules relate FSs — i.e. lexical entries and phrases are represented as FSs
6. Rule application by unification

Simple unification examples

1. $\begin{bmatrix} \text{CASE} & [\,] \\ \text{AGR} & \textbf{sg} \end{bmatrix} \sqcap \begin{bmatrix} \text{CASE} & \textbf{nom} \\ \text{AGR} & [\,] \end{bmatrix} = \begin{bmatrix} \text{CASE} & \textbf{nom} \\ \text{AGR} & \textbf{sg} \end{bmatrix}$

2. $\begin{bmatrix} \text{CASE} & [\,] \\ \text{AGR} & \textbf{sg} \end{bmatrix} \sqcap \begin{bmatrix} \text{CASE} & \textbf{nom} \\ \text{AGR} & \textbf{pl} \end{bmatrix} = \text{fail}$

CFG with agreement

```
S -> NP-sg VP-sg
S -> NP-pl VP-pl
VP-sg -> V-sg NP-sg
VP-sg -> V-sg NP-pl
VP-pl -> V-pl NP-sg
VP-pl -> V-pl NP-pl
V-pl -> like
V-sg -> likes
NP-sg -> it
NP-pl -> they
NP-sg -> fish
NP-pl -> fish
```

FS grammar fragment encoding agreement

subj-verb rule $\begin{bmatrix} \text{CAT} & \textbf{S} \\ \text{AGR} & \boxed{1} \end{bmatrix} \rightarrow \begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & \boxed{1} \end{bmatrix}, \begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \boxed{1} \end{bmatrix}$

verb-obj rule $\begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \boxed{1} \end{bmatrix} \rightarrow \begin{bmatrix} \text{CAT} & \textbf{V} \\ \text{AGR} & \boxed{1} \end{bmatrix}, \begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & [\,] \end{bmatrix}$

Root structure: $\begin{bmatrix} \text{CAT} & \textbf{S} \end{bmatrix}$

they $\begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & \textbf{pl} \end{bmatrix}$ it $\begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & \textbf{sg} \end{bmatrix}$ likes $\begin{bmatrix} \text{CAT} & \textbf{V} \\ \text{AGR} & \textbf{sg} \end{bmatrix}$

fish $\begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & [\,] \end{bmatrix}$ like $\begin{bmatrix} \text{CAT} & \textbf{V} \\ \text{AGR} & \textbf{pl} \end{bmatrix}$

Parsing ‘they like it’

- The lexical structures for *like* and *it* are unified with the corresponding structures on the right hand side of the verb-obj rule (unifications succeed).
- The structure corresponding to the mother of the rule is then:

$$\begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \textbf{pl} \end{bmatrix}$$

- This unifies with the rightmost daughter position of the subj-verb rule.
- The structure for *they* is unified with the leftmost daughter.
- The result unifies with root structure.

Rules as FSs

But what does the coindexation of parts of the rule mean? Treat rule as a FS: e.g., rule features MOTHER, DTR1, DTR2 . . . DTRN.

informally:

$$\begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \boxed{1} \end{bmatrix} \rightarrow \begin{bmatrix} \text{CAT} & \textbf{V} \\ \text{AGR} & \boxed{1} \end{bmatrix}, \begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & [\,] \end{bmatrix}$$

actually:

$$\begin{bmatrix} \text{MOTHER} & \begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \boxed{1} \end{bmatrix} \\ \text{DTR1} & \begin{bmatrix} \text{CAT} & \textbf{V} \\ \text{AGR} & \boxed{1} \end{bmatrix} \\ \text{DTR2} & \begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & [\,] \end{bmatrix} \end{bmatrix}$$

Verb-obj rule application

Feature structure for *like* unified with the value of DTR1:

$$\begin{bmatrix} \text{MOTHER} & \begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \boxed{1}\ \textbf{pl} \end{bmatrix} \\ \text{DTR1} & \begin{bmatrix} \text{CAT} & \textbf{V} \\ \text{AGR} & \boxed{1} \end{bmatrix} \\ \text{DTR2} & \begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & [\,] \end{bmatrix} \end{bmatrix}$$

Feature structure for *it* unified with the value for DTR2:

$$\begin{bmatrix} \text{MOTHER} & \begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \boxed{1}\ \textbf{pl} \end{bmatrix} \\ \text{DTR1} & \begin{bmatrix} \text{CAT} & \textbf{V} \\ \text{AGR} & \boxed{1} \end{bmatrix} \\ \text{DTR2} & \begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & \textbf{sg} \end{bmatrix} \end{bmatrix}$$

Subject-verb rule application 1

MOTHER value from the verb-object rule acts as the DTR2 of the subject-verb rule:

$\begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \textbf{pl} \end{bmatrix}$ unified with the DTR2 of:
$$\begin{bmatrix} \text{MOTHER} & \begin{bmatrix} \text{CAT} & \textbf{S} \\ \text{AGR} & \boxed{1} \end{bmatrix} \\ \text{DTR1} & \begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & \boxed{1} \end{bmatrix} \\ \text{DTR2} & \begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \boxed{1} \end{bmatrix} \end{bmatrix}$$

Gives:

$$\begin{bmatrix} \text{MOTHER} & \begin{bmatrix} \text{CAT} & \textbf{S} \\ \text{AGR} & \boxed{1}\ \textbf{pl} \end{bmatrix} \\ \text{DTR1} & \begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & \boxed{1} \end{bmatrix} \\ \text{DTR2} & \begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \boxed{1} \end{bmatrix} \end{bmatrix}$$

Subject rule application 2

FS for *they*: $\begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & \textbf{pl} \end{bmatrix}$

Unification of this with the value of DTR1 succeeds (but adds no new information):

$$\begin{bmatrix} \text{MOTHER} & \begin{bmatrix} \text{CAT} & \textbf{S} \\ \text{AGR} & \boxed{1}\ \textbf{pl} \end{bmatrix} \\ \text{DTR1} & \begin{bmatrix} \text{CAT} & \textbf{NP} \\ \text{AGR} & \boxed{1} \end{bmatrix} \\ \text{DTR2} & \begin{bmatrix} \text{CAT} & \textbf{VP} \\ \text{AGR} & \boxed{1} \end{bmatrix} \end{bmatrix}$$

Final structure unifies with the root structure: $\begin{bmatrix} \text{CAT} & \textbf{S} \end{bmatrix}$

Subcategorisation

Subcategorisation: constraints that predicates (typically verbs) place onto their arguments

- number of arguments
- types of arguments

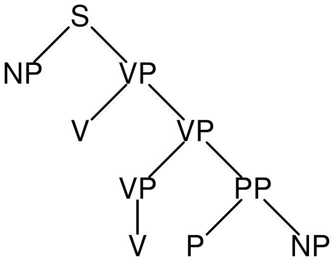
Verbs can be

- intransitive: take only subject NP, e.g. *Kim slept*
- transitive: take a subject and one object, e.g. *Kim adored Sandy*
- ditransitive: take a subject and two objects, e.g. *Kim gave Sandy a book*

Concepts for subcategorisation

$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \\ \text{AGR} & \textbf{pl} \end{bmatrix} \end{bmatrix}$$

- HEAD: information shared between a lexical entry and the dominating phrases of the same category



Concepts for subcategorisation

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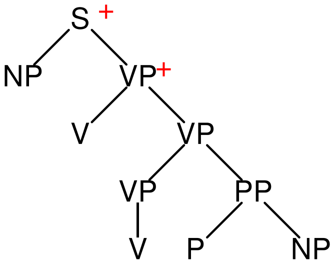

Concepts for subcategorisation

$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \\ \text{AGR} & \textbf{pl} \end{bmatrix} \end{bmatrix}$$

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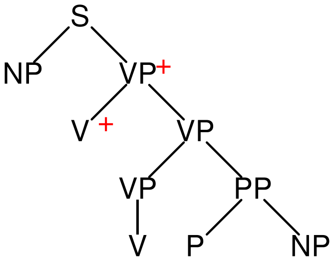
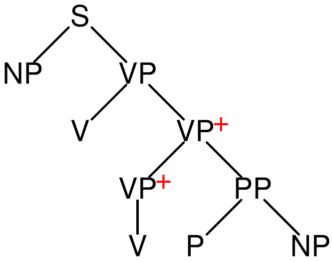


Concepts for subcategorisation

$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \\ \text{AGR} & \textbf{pl} \end{bmatrix} \end{bmatrix}$$

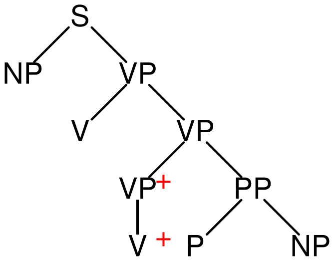
- HEAD: information shared between a lexical entry and the dominating phrases of the same category



Concepts for subcategorisation

$$\left[\text{HEAD} \left[\begin{array}{ll}\text{CAT} & \textbf{noun}\\ \text{AGR} & \textbf{pl}\end{array}\right]\right]$$

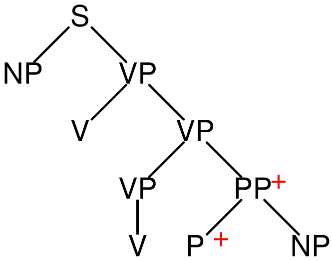
- HEAD: information shared between a lexical entry and the dominating phrases of the same category



Concepts for subcategorisation

$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \\ \text{AGR} & \textbf{pl} \end{bmatrix} \end{bmatrix}$$

- HEAD: information shared between a lexical entry and the dominating phrases of the same category



Concepts for subcategorisation

$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \\ \text{AGR} & \textbf{pl} \end{bmatrix} \end{bmatrix}$$

- HEAD: information shared between a lexical entry and the dominating phrases of the same category
- SUBJ: constraints on the subject

Concepts for subcategorisation

$$\left[\text{HEAD} \begin{bmatrix} \text{CAT} & \textbf{noun} \\ \text{AGR} & \textbf{pl} \end{bmatrix}\right]$$

- HEAD: information shared between a lexical entry and the dominating phrases of the same category
- SUBJ: constraints on the subject
- OBJ: constraints on the object

Lexicon: verbs

fish

$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{verb} \\ \text{AGR} & \textbf{pl} \end{bmatrix} \\ \text{OBJ} & \textbf{filled} \\ \text{SUBJ} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

can (modal)

$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{verb} \\ \text{AGR} & \begin{bmatrix} \; \end{bmatrix} \end{bmatrix} \\ \text{OBJ} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{verb} \end{bmatrix} \end{bmatrix} \\ \text{SUBJ} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

can (transitive)

$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{verb} \\ \text{AGR} & \textbf{pl} \end{bmatrix} \\ \text{OBJ} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \end{bmatrix} \\ \text{OBJ} & \textbf{filled} \end{bmatrix} \\ \text{SUBJ} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

Lexicon: nouns

they
$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \\ \text{AGR} & \textbf{pl} \end{bmatrix} \\ \text{OBJ} & \textbf{filled} \\ \text{SUBJ} & \textbf{filled} \end{bmatrix}$$

fish
$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \\ \text{AGR} & [\,] \end{bmatrix} \\ \text{OBJ} & \textbf{filled} \\ \text{SUBJ} & \textbf{filled} \end{bmatrix}$$

it
$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{noun} \\ \text{AGR} & \textbf{sg} \end{bmatrix} \\ \text{OBJ} & \textbf{filled} \\ \text{SUBJ} & \textbf{filled} \end{bmatrix}$$

Grammar with subcategorisation

Subject-verb rule:

$$\begin{bmatrix} \text{HEAD} & \boxed{1} \\ \text{OBJ} & \textbf{filled} \\ \text{SUBJ} & \textbf{filled} \end{bmatrix} \rightarrow \boxed{2}\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{AGR} & \boxed{3} \end{bmatrix} \\ \text{OBJ} & \textbf{filled} \\ \text{SUBJ} & \textbf{filled} \end{bmatrix}, \begin{bmatrix} \text{HEAD} & \boxed{1}\begin{bmatrix} \text{AGR} & \boxed{3} \end{bmatrix} \\ \text{OBJ} & \textbf{filled} \\ \text{SUBJ} & \boxed{2} \end{bmatrix}$$

Verb-obj rule: $\begin{bmatrix} \text{HEAD} & \boxed{1} \\ \text{OBJ} & \textbf{filled} \\ \text{SUBJ} & \boxed{3} \end{bmatrix} \rightarrow \begin{bmatrix} \text{HEAD} & \boxed{1} \\ \text{OBJ} & \boxed{2} \\ \text{SUBJ} & \boxed{3} \end{bmatrix}, \boxed{2}\begin{bmatrix} \text{OBJ} & \textbf{filled} \end{bmatrix}$

Example rule application: *they fish*

Lexical entry for fish: $\begin{bmatrix} \text{HEAD} & \begin{bmatrix}\text{CAT} & \textbf{v}\\ \text{AGR} & \textbf{pl}\end{bmatrix}\\ \text{OBJ} & \textbf{fld}\\ \text{SUBJ} & \begin{bmatrix}\text{HEAD} & \begin{bmatrix}\text{CAT} & \textbf{n}\end{bmatrix}\end{bmatrix}\end{bmatrix}$

subject-verb rule:

$$\begin{bmatrix} \text{HEAD} & \boxed{1}\\ \text{OBJ} & \textbf{fld}\\ \text{SUBJ} & \textbf{fld}\end{bmatrix} \rightarrow \boxed{2}\begin{bmatrix} \text{HEAD} & \begin{bmatrix}\text{AGR} & \boxed{3}\end{bmatrix}\\ \text{OBJ} & \textbf{fld}\\ \text{SUBJ} & \textbf{fld}\end{bmatrix}, \begin{bmatrix} \text{HEAD} & \boxed{1}\begin{bmatrix}\text{AGR} & \boxed{3}\end{bmatrix}\\ \text{OBJ} & \textbf{fld}\\ \text{SUBJ} & \boxed{2}\end{bmatrix}$$

unification with second dtr position gives:

$$\begin{bmatrix} \text{HEAD} & \boxed{1}\begin{bmatrix}\text{CAT} & \textbf{v}\\ \text{AGR} & \boxed{3}\ \textbf{pl}\end{bmatrix}\\ \text{OBJ} & \textbf{fld}\\ \text{SUBJ} & \textbf{fld}\end{bmatrix} \rightarrow \boxed{2}\begin{bmatrix} \text{HEAD} & \begin{bmatrix}\text{CAT} & \textbf{n}\\ \text{AGR} & \boxed{3}\end{bmatrix}\\ \text{OBJ} & \textbf{fld}\\ \text{SUBJ} & \textbf{fld}\end{bmatrix}, \begin{bmatrix} \text{HEAD} & \boxed{1}\\ \text{OBJ} & \textbf{fld}\\ \text{SUBJ} & \boxed{2}\end{bmatrix}$$

Lexical entry for *they*: $\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{n} \\ \text{AGR} & \textbf{pl} \end{bmatrix} \\ \text{OBJ} & \textbf{fld} \\ \text{SUBJ} & \textbf{fld} \end{bmatrix}$

unify this with first dtr position:

$$\begin{bmatrix} \text{HEAD} & \boxed{1} \begin{bmatrix} \text{CAT} & \textbf{v} \\ \text{AGR} & \boxed{3}\ \textbf{pl} \end{bmatrix} \\ \text{OBJ} & \textbf{fld} \\ \text{SUBJ} & \textbf{fld} \end{bmatrix} \rightarrow \boxed{2} \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{n} \\ \text{AGR} & \boxed{3} \end{bmatrix} \\ \text{OBJ} & \textbf{fld} \\ \text{SUBJ} & \textbf{fld} \end{bmatrix}, \begin{bmatrix} \text{HEAD} & \boxed{1} \\ \text{OBJ} & \textbf{fld} \\ \text{SUBJ} & \boxed{2} \end{bmatrix}$$

Root is: $\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{v} \end{bmatrix} \\ \text{OBJ} & \textbf{fld} \\ \text{SUBJ} & \textbf{fld} \end{bmatrix}$

Mother structure unifies with root, so valid.

Parsing with feature structure grammars

- standard chart parser with modified rule application
- Rule application:
  1. copy rule
  2. copy daughters (lexical entries or FSs associated with edges)
  3. unify rule and daughters
  4. if successful, add new edge to chart with rule FS as category

Templates

Capture generalizations in the lexicon:

fish INTRANS_VERB
sleep INTRANS_VERB
snore INTRANS_VERB

INTRANS_VERB
$$\begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{v} \\ \text{AGR} & \textbf{pl} \end{bmatrix} \\ \text{OBJ} & \textbf{fld} \\ \text{SUBJ} & \begin{bmatrix} \text{HEAD} & \begin{bmatrix} \text{CAT} & \textbf{n} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

Interface to morphology: inflectional affixes as FSs

s PLURAL_NOUN $\left[\begin{array}{ll}\text{HEAD} & \left[\begin{array}{ll}\text{CAT} & \textbf{n} \\ \text{AGR} & \textbf{pl}\end{array}\right]\end{array}\right]$

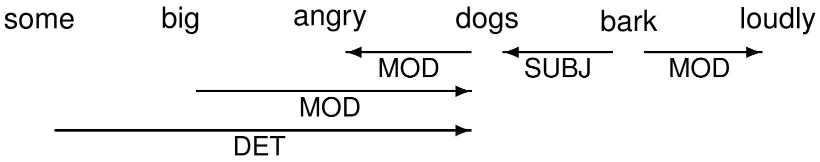
ε SINGULAR_NOUN $\left[\begin{array}{ll}\text{HEAD} & \left[\begin{array}{ll}\text{CAT} & \textbf{n} \\ \text{AGR} & \textbf{sg}\end{array}\right]\end{array}\right]$

BASE_NOUN $\left[\begin{array}{ll}\text{HEAD} & \left[\begin{array}{ll}\text{CAT} & \textbf{n} \\ \text{AGR} & [\;]\end{array}\right] \\ \text{OBJ} & \textbf{filled} \\ \text{SUBJ} & \textbf{filled}\end{array}\right]$

dog BASE_NOUN

Dependency structure

- Alternative to syntax trees for ‘who does what to whom’.
- Relate words to each other via labelled directed arcs – dependencies.
- May be syntactic or semantic.



Why are dependencies important?

Example

John hit the ball.

Dependency parsing

```
(SUBJ head=hit dep=John)
(OBJ head=hit dep=ball)
(DET head=ball dep=the)
```

The cost of parsing errors...

Incorrect dependencies

```
(SUBJ head=hit dep=ball)
(OBJ head=hit dep=John)
(DET head=ball dep=the)
```