CMPT-413 Computational Linguistics

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Writing a grammar for natural language: Grammar Development

- Grammar development is the process of writing a grammar for a particular language
- This can be either for a particular application or concentrating on a particular phenomena in the language under consideration
- Check against text corpora to check the coverage of your grammar – to do this you need a parser
- Also consider generalizations provided by a linguistic analysis

Real Grammars get Messy

- Consider the grammar development using CFGs for the ATIS Corpus
- To capture all the morphological details which affect the syntax, the CFG ends up with rules like:

```
S \rightarrow 3sgAux 3sgNP VP
```

 $S \rightarrow Non3sgAux Non3sgNP VP$

 $3sgAux \rightarrow does \mid has \mid can \mid ...$

Non3sgAux \rightarrow do | have | can | ...

Real Grammars get Messy

- This is to deal with sentences like:
 - 1. Do I get dinner on this flight ? (1sg = 1st person singular)
 - 2. Do you have a flight from Boston to Fort Worth ? (2sg = 2nd person singular)
 - 3. Does he visit Toronto ? (3sg = 3rd person singular)
 - 4. Does Delta fly from Atlanta to San Diego ? (3sg = 3rd person singular)
 - 5. Do they visit Toronto ? (3pl = 3rd person plural)

Real Grammars get Messy

Not just grammatical features but also subcategorization (what kind of arguments does a verb expect?):

```
VP → Verb-with-NP-complement NP "prefer a morning flight"
```

 $/P \rightarrow Verb$ -with-S-complement S "said there were two flights"

VP → Verb-with-Inf-VP-complement VPinf "try to book a flight"

VP → Verb-with-no-complement "disappear"

Solution to non-terminal and rule blowup: Feature Structures

- Feature structures provide a natural way to provide complex information with each non-terminal. In some formalisms, the non-terminal is replaced with feature structures, resulting in a potentially infinite set of non-terminals.
- Feature structures are also known as f-structures, feature bundles, feature matrices, functional structures, terms (as in Prolog), or dags (directed acyclic graphs)

- A feature structure is defined as a partial function from features to their values.
- For instance, we can define a function mapping the feature number onto the value singular and mapping person to third. The common notation for this function is:

[number: singular] person: 3

Feature values can themselves be feature structures:

cat: NP
agreement: number: singular person: 3

► Consider features *f* and *g* with two distinct feature structure values of the same type:

$$\begin{bmatrix} f: [h: a] \\ g: [h: a] \end{bmatrix}$$

► Feature structures can also share values. For instance, *g* shares the same value as *f* in:

$$\begin{bmatrix} f: \ \boxed{} [h: a] \\ g: \ \boxed{} \end{bmatrix}$$

► The shared value is written using a co-indexation – indicating that the value is stored only once, with the index acting as a pointer.

Feature Path Notation

The feature structure:

```
agreement: 1 number: sg person: 3 subject: agreement: 1
```

is represented as:

```
<agreement number>=sg
<agreement person>=3
<subject agreement>=<agreement>
or:
  [ agreement = (1) [ number = 'sg', person = 3 ],
subject = [ agreement->(1) ] ]
or:
  [ agreement = ?n [ number = 'sg', person = 3 ],
subject = [ agreement = ?n ] ]
```

- Feature structures have different amounts of information. Can we find an ordering on feature structures that corresponds to the compatibility and relative specificity of the information contained in them.
- Subsumption is a precise method of defining such an ordering over feature structures.

Consider the feature structure:

$$D_{np} = \begin{bmatrix} cat: NP \end{bmatrix}$$

Compare with the feature structure:

$$D_{np3sg} = \begin{bmatrix} cat: NP \\ agreement: \begin{bmatrix} number: singular \\ person: 3 \end{bmatrix}$$

- ▶ D_{np} makes the claim that a phrase is a noun phrase, but leaves open the question of what the agreement properties of this noun phrase are.
- D_{np3sg} also contains information about a noun phrase, but makes the agreement properties specific.
- ▶ The feature structure D_{np} is said to carry less information than, or to be more general than, or to subsume the feature structure D_{np3sg}

- ▶ $D_{np} = [cat: NP]$
- \triangleright D_{npsa} = cat: NP agreement: number: singular

 $D_{np3saSbi} =$ agreement: number: singular person: 3

subject: number: singular person: 3

- \triangleright $D_{np3sg} =$ cat: NP
- cat: NP
 | agreement: | number: singular | person: 3 | | agreement: 1 | number: singular | person: 3 | subject: 1
 - The following subsumption relations hold: $D_{var} \sqsubseteq D_{np} \sqsubseteq D_{npsq} \sqsubseteq D_{np3sq} \sqsubseteq D_{np3sqSbi} \sqsubseteq D'_{np3sqSbi}$

Two feature structures might have different and incompatible information:

```
cat: NP
agreement: number: singular

cat: NP
agreement: number: plural
```

In this case, there is no feature structure that is subsumed by both feature structures

- Subsumption is only a partial order that is, not every two feature structures are in a subsumption relation with each other.
- Two feature structures might have different but compatible information:

```
cat: NP
agreement: [number: singular]

cat: NP
agreement: [person: 3]
```

If two feature structures have different but compatible information then there always exists a more specific feature structure that is subsumed by both feature structures:

```
cat: NP
agreement: number: singular person: 3
```

But there are many feature structures subsumed by both of the original feature structures:

cat: NP

agreement: number: singular person: 3
gender: masculine

- So instead of considering all such feature structures we only consider the most general FS that is subsumed by the two original FSs
- This definition provides a feature structure that contains information from both input FSs but no additional information.

- Now we can define unification
- The unification of two feature structures D' and D" is defined as the most general feature structure D such that D'

 □ D and D"
 □ D.
- ► This operation of unification is denoted as D = D' \(\subseteq D'' \)

$$[] \sqcup [cat: NP] = [cat: NP]$$

$$[person: sg] \sqcup [number: 3] = [person: sg] \\ number: 3$$

```
agreement: [number: sg]
subject: agreement: [number: sg]
 subject: agreement: person: 3
 agreement: number: sg subject: agreement: number: sg person: 3
```

Algorithms for Unification

- Represent input feature structure as a directed acyclic graph (dag). Unification is equivalent to the union-find algorithm.
- Unification is more efficient if it can be destructive: it destroys the input feature structures to create the result of unification.
- ► The (destructive) unification algorithm in J&M (page 423) does it in two steps: represent feature structures as dags, and then perform graph matching (and merging)
- Note that this algorithm can produce as output a dag (i.e. a feature structure) containing cycles.

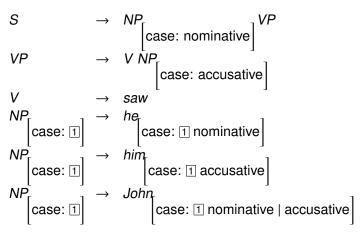
A feature structure can have part of itself as a subpart:

$$\left[f: \, \mathbb{I} \left[g: \left[h: \, \mathbb{I} \right] \right] \right]$$

- ► This can be avoided with an explicit check for each call to the unify algorithm called the **occur check**.
- Computationally expensive since we have to traverse the whole dag at each step

Feature Structures in CFGs

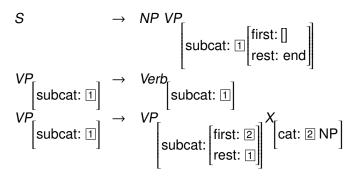
Feature Structures impose constraints on CFG derivations:



- This CFG derives: he saw him but not: *him saw he
- Also derives: John saw him, he saw John.
- Co-indexing in each FS is local to each CFG rule.

Feature Structures in CFGs

A more complex example for encoding subcategorization as feature structures:



Feature Structures in CFGs

- In the above example, the CFG can generate an arbitrary number of NPs in the subcat feature structure for the verb.
- In effect, the above steps of unification in a CFG derivation creates a list containing the subcat elements. The subcat feature structure uses first and rest to construct the list in the recursive rule VP → VP X.
- The lexical terminal Verb can impose a constraint on which subcat frame is required.
- Other categories can be added simply by adding a new cat attribute for X: e.g. [cat: S] for verbs that can have a subcat of NP S.

Unification Algorithm

```
function unify(f1, f2):
 returns f-structure or failure
 if f1.content == null: f1.pointer = f2
 if f2.content == null: f2.pointer = f1
 if f1.content == f2.content: f1.pointer = f2
 if f1.content and f2.content are complex f-structures:
      f2.pointer = f1
      for each f in f2.content:
          other-feature = find or create feature
              corresponding to f in f1.content
          if unify(f, other-feature) == failure:
              return failure
  return f1
```

- ▶ predictor: if $(A \to \alpha \bullet B \beta, [i, j], dag_{A_1})$ then $\forall (B \to \gamma, dag_{B_1})$ enqueue($(B \to \bullet \gamma, [j, j], dag_{B_1})$, chart[j])
- ▶ scanner: if $(A \to \alpha \bullet a \beta, [i, j], dag_{A_1})$ and a = tokens[j] then enqueue $((A \to \alpha a \bullet \beta, [i, j + 1], dag_{A_1}), chart[j + 1])$
- ▶ completer: if $(B \to \gamma \bullet, [j, k], \mathrm{dag}_{B_1})$, for each $(A \to \alpha \bullet B \beta, [i, j], \mathrm{dag}_{A_1})$ enqueue($(A \to \alpha B \bullet \gamma, [i, k], \mathrm{copy-and-unify}(\mathrm{dag}_{A_1}, \mathrm{dag}_{B_1}))$, chart[k]) unless copy-and-unify($\mathrm{dag}_{A_1}, \mathrm{dag}_{B_1}$) fails
- copy-and-unify means that we make copies of the dags before unification because we are using a destructive unification algorithm
- copy-and-unify ensures that dag A₁ in state
 (A → α B β, [i, j], dag_{A₁}) is not destroyed since it can be used in the completer with other states and unify with them.

- ► Consider two different enqueue requests: enqueue($(A \rightarrow \alpha \ B \bullet \gamma, [i, k], dag_{A_1})$, chart[k]) enqueue($(A \rightarrow \alpha \ B \bullet \gamma, [i, k], dag_{A_2})$, chart[k])
- Consider the case where: $\operatorname{dag}_{A_1} = \begin{bmatrix} \operatorname{tense: past} \mid \operatorname{plural} \end{bmatrix}$ and $\operatorname{dag}_{A_2} = \begin{bmatrix} \operatorname{tense: past} \end{bmatrix}$ Clearly, $\operatorname{dag}_{A_1} \sqsubseteq \operatorname{dag}_{A_2}$

- Which feature structure should be selected after the two enqueue commands above?
 - Three options: $dag_{A_1}, dag_{A_2}, dag_{A_1} \sqcup dag_{A_2}$
- In general, the feature inserted should subsume both dag_{A1} and dag_{A2}
- In practice exactly one of the following conditions is always true:
 - ▶ If $dag_{A_1} \sqsubseteq dag_{A_2}$ then enqueue picks dag_{A_1} ,
 - ▶ If $dag_{A_2} \sqsubseteq dag_{A_1}$ then enqueue picks dag_{A_2} .
 - If $\deg_{A_1} \not\sqsubseteq \deg_{A_2}$ and $\deg_{A_2} \not\sqsubseteq \deg_{A_1}$ then enqueue picks $\deg_{A_1} \sqcup \deg_{A_2}$

- During the enqueue of a state, we always pick the most general feature structure possible.
- To see why consider an example:
 - Consider a chart which contains the state:

$$S_1 = (NP \rightarrow \bullet DT NP, [i, i], dag_{S_1} = [])$$

The parser then tries to enqueue a new state:

$$S_2 = (NP \rightarrow \bullet DT NP, [i, i], dag_{S_2} = [DT.num = sing])$$

- Consider two possible situations:
 - 1. a singular DT is scanned, then either dag_{S_1} or dag_{S_2} would unify and parsing would continue.
 - 2. a plural DT is scanned, then if we picked dag_{S_2} we have a unification failure; on the other hand picking the more general feature structure dag_{S_1} allows parsing to continue.
- So, if there are two possible ways to derive a span, then the most general feature structure is the one we must choose.

Summary

- Feature structures generalize the notion of non-terminals in a grammar.
- Complex morphological details can be encoded into a feature structure.
- Feature structures can have shared or co-referential parts.
- Feature structures can implement arbitrary lists (the notation is very computationally powerful).
- Unification provides a means to combine the information in two feature structures.
- Feature structures can be used in a context-free grammar, and
- Unification is done while parsing to ensure that the constraints specified in the features are not violated.