Features and Unification
Chapter 15

Lecture #10

October 2012

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Context Free Grammars

- We have been introduced to the notion of a context free grammar for capturing English constructions.
  - Context Free rules, have a single non-terminal on the left hand side, and a list of terminals and/or non-terminals on the right hand side.
- We have seen a very simple example of a context free grammar for English
- We have seen that we can parse using context free grammars fairly easily.

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English Constituent Problems for Context Free Grammars

- Agreement
- Subcategorization
- Movement (for want of a better term)

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Agreement

Determiner/Noun Agreement	Our grammar also generates
• This dog	• *This dogs
• Those dogs	• *Those dog

Subject/Verb Agreement	Our grammar also generates
• This dog eats	• *This dog eat
• Those dogs eat	• *Those dogs eats

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Handing Number Agreement in CFGs

To handle, would need to expand the grammar with multiple sets of rules. We must have a different word class for each kind of determiner and noun.

- NP_sg → Det_sg N_sg
- NP_pl → Det_pl N_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

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Subcategorization

• Sneeze:	John sneezed
	*John sneezed [the book]$_{NP}$
• Find:	Please find [a flight to NY]$_{NP}$
	*Please find
• Give:	Give [me]$_{NP}$[a cheaper fare]$_{NP}$
	*Give [with a flight]$_{PP}$
• Help:	Can you help [me]$_{NP}$[with a flight]$_{PP}$
• Prefer:	I prefer [to leave earlier]$_{TO\text{-}VP}$
	*I prefer [United has a flight]$_{S}$
• Told:	I was told [United has a flight]$_{S}$
• …	

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Subcategorization

- Subcat expresses the constraints that a predicate (verb for now) places on the number and type of the argument it wants to take

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So?

- So the various rules for VPs overgenerate.
  - They permit the presence of strings containing verbs and arguments that don't go together
  - For example
  - VP -> V NP therefore

    Sneezed the book is a VP since "sneeze" is a verb and "the book" is a valid NP

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Possible CFG Solution

- VP -> V
- VP -> V NP
- VP -> V NP PP
- …

- VP -> IntransV
- VP -> TransV NP
- VP -> TransPP NP PP
- …

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Movement

- Core example
  - My travel agent booked the flight

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Movement

- Core example
  - [[My travel agent]$_{NP}$ [booked [the flight]$_{NP}$]$_{VP}$]$_{S}$

- I.e. "book" is a straightforward transitive verb. It expects a single NP arg within the VP as one of its arguments, and a single NP arg as the subject.

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Movement

- What about?
  - Which flight do you want me to have the travel agent book_?

- The direct object argument to "book" isn't appearing in the right place. It is in fact a long way from where its supposed to appear.

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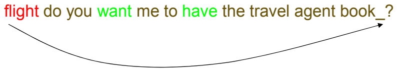
Movement

- What about?
  - Which flight do you want me to have the travel agent book_?



- The direct object argument to “book” isn’t appearing in the right place. It is in fact a long way from where its supposed to appear.
- And note that its separated from its verb by 2 other verbs.

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The Point

- CFGs appear to be just about what we need to account for a lot of basic syntactic structure in English.
- But there are problems
  - That can be dealt with adequately, although not elegantly, by staying within the CFG framework.
- There are simpler, more elegant, solutions that take us out of the CFG framework (beyond its formal power)
- We will use feature structures and the constraint-based unification formalism

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Features

- Go back to subject verb agreement case
- An alternative is to rethink the terminal and non-terminals as complex objects with associated properties (called features) that can be manipulated.
- Features take on different values
- The application of grammar rules is constrained by testing on these features

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Subject-Verb Agreement

- We could use features that allow us to code rules such as the following:

- S → NP VP
- *Only if the number of the NP is equal to the number of the VP (that is, the NP and VP agree in number).*

- This allows us to have the best of both worlds.

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Features and Feature Structures

- We can encode these properties by associating what are called Feature Structures with grammatical constituents.
- Feature structures are sets of feature-value pairs where:
  - The features are atomic symbols and
  - The values are either atomic symbols or feature structures

$$\begin{bmatrix} \mathit{Feature}_1 & \mathit{Value}_1 \\ \mathit{Feature}_2 & \mathit{Value}_2 \\ \vdots & \vdots \\ \mathit{Feature}_n & \mathit{Value}_n \end{bmatrix}$$

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Example Feature Structures

$$\begin{bmatrix} \mathit{Number} & \mathit{SG} \end{bmatrix}$$

$$\begin{bmatrix} \mathit{Number} & \mathit{SG} \\ \mathit{Person} & \mathit{3} \end{bmatrix}$$

$$\begin{bmatrix} \mathit{Cat} & \mathit{NP} \\ \mathit{Number} & \mathit{SG} \\ \mathit{Person} & \mathit{3} \end{bmatrix}$$

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Bundles of Features

- Feature Values can be feature structures themselves.
- This is useful when certain features commonly co-occur, as number and person.

$$\begin{bmatrix} \mathit{Cat} & \mathit{NP} \\ \mathit{Agreement} & \begin{bmatrix} \mathit{Number} & \mathit{SG} \\ \mathit{Person} & 3 \end{bmatrix} \end{bmatrix}$$

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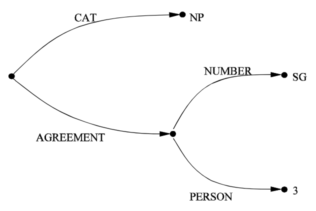
Feature Structures as DAGs



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Reentrant Structure

- We'll allow multiple features in a feature structure to share the same values. By this we mean that they share the same structure, not just that they have the same value.

$$\begin{bmatrix} \mathit{Cat} & S \\ \mathit{Head} & \begin{bmatrix} \mathit{Agreement} & \boxed{1} \begin{bmatrix} \mathit{Number} & \mathit{SG} \\ \mathit{Person} & 3 \end{bmatrix} \\ \mathit{Subject} & \begin{bmatrix} \mathit{Agreement} & \boxed{1} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

- Numerical indices indicate the shared value.

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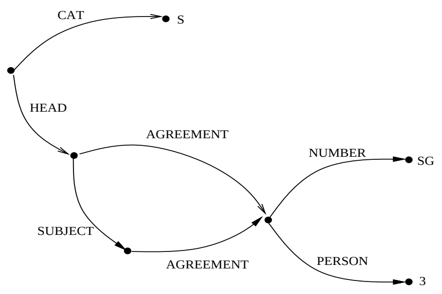
Reentrant DAGs



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Reentrant Structure

- It will also be useful to talk about paths through feature structures. As in the paths
- <HEAD AGREEMENT NUMBER>
- <HEAD SUBJECT AGREEMENT NUMBER>

$$\begin{bmatrix} \mathit{Cat} & S \\ \mathit{Head} & \begin{bmatrix} \mathit{Agreement} & \boxed{1} \begin{bmatrix} \mathit{Number} & \mathit{SG} \\ \mathit{Person} & 3 \end{bmatrix} \\ \mathit{Subject} & \begin{bmatrix} \mathit{Agreement} & \boxed{1} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

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The Unification Operation

So what do we want to do with these things...

- check the compatibility of two structures
- merge the information in two structures

We can do both with an operation called Unification.

Merging 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.

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The Unification Operation

- We say two feature structures can be unified if the component features that make them up are compatible.

- [number sg] U [number sg] = [number sg]
- [number sg] U [number pl] = fails!

- Structures are compatible if they contain no features that are incompatible.
- If so, unification returns the union of all feature/value pairs.

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The Unification Operation

- [number sg] U [number []] =

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The Unification Operation

- [number sg] U [number []] = [number sg]

- [number sg] U [person 3] =

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The Unification Operation

- [number sg] U [number []] = [number sg]

- [number sg] U [person 3] = $\begin{bmatrix} \textit{number} & \textit{sg} \\ \textit{person} & \textit{3} \end{bmatrix}$

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Unification Operation

$$\begin{bmatrix} \textit{Agreement} & \textit{[Number sg]} & \\ \textit{Subject} & \textit{[Agreement} & \textit{[Number sg]]} \end{bmatrix}$$

U

[Subject [Agreement [Person 3]]]

=

$$\begin{bmatrix} \textit{Agreement} & \textit{[Number sg]} \\ \textit{Subject} & \begin{bmatrix} \textit{Agreement} & \begin{bmatrix} \textit{Number} & \textit{sg} \\ \textit{Person} & \textit{3} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

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The Unification Operation

[Head [Subject [Agreement [Number PL]]]]

U

$$\begin{bmatrix} \textit{Cat} & \textit{S} \\ \textit{Head} & \begin{bmatrix} \textit{Agreement} & \boxed{1}\begin{bmatrix} \textit{Number SG} \\ \textit{Person 3} \end{bmatrix} \\ \textit{Subject} & \begin{bmatrix} \textit{Agreement} & \boxed{1} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

= Fail!

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Properties of Unification

- Monotonic: if some description is true of a feature structure, it will still be true after unifying it with another feature structure.
- Order independent: given a set of feature structures to unify, we can unify them in any order and we'll get the same result.

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Features, Unification, and Grammars

We'll incorporate all this into our grammars in two ways:

- We'll assume that constituents are objects which have feature-structures associated with them
- We'll associate sets of unification constraints with grammar rules that must be satisfied for the rule to be satisfied.

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Unification Constraints

$\beta_0 \rightarrow \beta_1 \ldots \beta_n$

{ set of constraints }

< β_i feature path > = atomic value
< β_i feature path > = < β_k feature path >

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Agreement

NP → Det Nominal
< Det AGREEMENT > = < Nominal AGREEMENT >
< NP AGREEMENT > = < Nominal AGREEMENT >

Noun → flight
< Noun AGREEMENT NUMBER > = SG

Noun → flights
< Noun AGREEMENT NUMBER > = PL

Nominal → Noun
< Nominal AGREEMENT > = < Noun AGREEMENT >

Det → this
< Det AGREEMENT NUMBER > = SG

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Unification and Parsing

- OK, let's assume we've augmented our grammar with sets of path-like unification constraints.
- What changes do we need to make to a parser to make use of them?
  - Building feature structures and associating them with a subtree
  - Unifying feature structures as subtrees are created
  - Blocking ill-formed constituents

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Unification and Earley Parsing

With respect to an Earley-style parser…

- Building feature structures (represented as DAGs) and associate them with states in the chart
- Unifying feature structures as states are advanced in the chart
- Block ill-formed states from entering the chart

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Building Feature Structures

- Features of most grammatical categories are copied from head child to parent (e.g., from V to VP, Nom to NP, N to Nom)

VP → V NP
- < VP HEAD > = < V HEAD >

S → NP VP
- < NP HEAD AGREEMENT > = < VP HEAD AGREEMENT>
- < S HEAD > = < VP HEAD >

$$\left[\begin{array}{lll} S & [head\ \boxed{1}\ ] & \\ NP & [head & [agreement\ \boxed{2}\ ]] \\ VP & [head & \boxed{1}\ [agreement\ \boxed{2}\ ]] \end{array}\right]$$

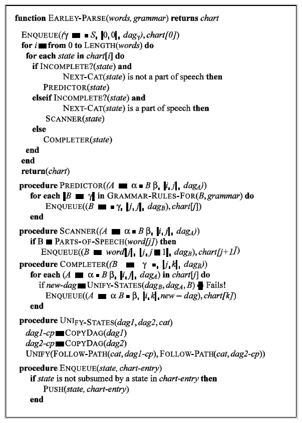
Augmenting States with DAGs

- We just add a new field to the representation of the states

S → . NP VP, [0,0], [], Dag

Unifying States and Blocking

- Keep much of the Earley Algorithm the same.
- We want to unify the DAGs of existing states as they are combined as specified by the grammatical constraints.
- Alter COMPLETER – when a new state is created, first make sure the individual DAGs unify. If so, then add the new DAG (resulting from the unification) to the new state.



```
function EARLEY-PARSE(words, grammar) returns chart

  ENQUEUE((γ ■ ▪ S, |0, 0|, dagγ), chart[0])
  for i ■ from 0 to LENGTH(words) do
   for each state in chart[i] do
     if INCOMPLETE?(state) and
              NEXT-CAT(state) is not a part of speech then
         PREDICTOR(state)
     elseif INCOMPLETE?(state) and
              NEXT-CAT(state) is a part of speech then
          SCANNER(state)
     else
         COMPLETER(state)
   end
  end
  return(chart)

 procedure PREDICTOR((A ■ α ▪ B β, |i, j|, dagA))
    for each |B ■ γ| in GRAMMAR-RULES-FOR(B, grammar) do
         ENQUEUE((B ■ ▪ γ, |j, j|, dagB), chart[j])
    end

 procedure SCANNER((A ■ α ▪ B β, |i, j|, dagA))
    if B ■ PARTS-OF-SPEECH(word[j]) then
        ENQUEUE((B ■ word|j|, |j, j ■ 1|, dagB), chart[j+1])
 procedure COMPLETER((B ■ γ ▪, |j, k|, dagB))
    for each (A ■ α ▪ B β, |i, j|, dagA) in chart[j] do
       if new-dag ■ UNIFY-STATES(dagB, dagA, B) ■ Fails!
         ENQUEUE((A ■ α B ▪ β, |i, k|, new − dag), chart[k])
    end

 procedure UNIFY-STATES(dag1, dag2, cat)
   dag1-cp ■ COPYDAG(dag1)
   dag2-cp ■ COPYDAG(dag2)
   UNIFY(FOLLOW-PATH(cat, dag1-cp), FOLLOW-PATH(cat, dag2-cp))

 procedure ENQUEUE(state, chart-entry)
    if state is not subsumed by a state in chart-entry then
        PUSH(state, chart-entry)
    end
```

Modifying Earley

Completer
- Recall: Completer adds new states to chart by finding states whose dot can be advanced (i.e., category of next constituent matches that of completed constituent)
- Now: Completer will only advance those states if their feature structures unify.

Also, new test for whether to enter a state in the chart
- Now DAGs may differ, so check must be more complex
- Don't add states that have DAGs that are more specific than states in chart; is new state subsumed by existing states?

Example

- NP → Det . Nominal [0,1], [SDet], DAG1

$$\left[\begin{array}{llll} np & [head\ \boxed{1}\ ] & & \\ det & [head & [agreement\ \boxed{2} & [number\ sg]]] \\ nominal & [head & \boxed{1}\ [agreement\ \boxed{2} &]] \end{array}\right]$$

- Nominal → Noun ., [1,2], [SNoun], Dag2

$$\left[\begin{array}{llll} nominal & [head\ \boxed{1}\ ] & & \\ noun & [head & \boxed{1}\ [agreement & [number\ sg]]] \end{array}\right]$$