Feature Structures and Unification Grammars

11-711 Algorithms for NLP

1 November 2018 – Part II

Linguistic features

- (Linguistic "features" vs. ML "features".)
- Human languages usually include *agreement* constraints; in English, e.g., subject/verb
  - I often swim
  - **He** often swim**s**
  - They often swim
- *Could* have a separate category for each minor type: N1s, N1p, …, N3s, N3p, …
  - *Each* with its own set of grammar rules!

A day without features…

- NP1s → Det-s N1s
- NP1p → Det-p N1p

  …
- NP3s → Det-s N3s
- NP3p → Det-p N3p

  …
- S1s → NP1s VP1s
- S1p → NP1p VP1p
- S3s → NP3s VP3s
- S3p → NP3p VP3p

Linguistic features

- *Could* have a separate category for each minor type: N1s, N1p, … , N3s, N3p, …
  – *Each* with its own set of grammar rules!
- Much better: represent these regularities using independent ***features****:* number, gender, person, …
- Features are typically introduced by lexicon; checked and propagated by constraint equations attached to grammar rules

Feature Structures (FSs)

Having multiple orthogonal features with values leads naturally to ***Feature Structures***:

[Det
[root: *a*]
[number: sg]]

A feature structure’s values can in turn be FSs:

[NP
[agreement: [[number: sg]
[person: 3rd]]]]

Feature Path: <NP agreement person>

Adding constraints to CFG rules

- S → NP VP

  <NP number> = <VP number>

- NP → Det Nominal

  <NP head> = <Nominal head>

  <Det head agree> = <Nominal head agree>

FSs from lexicon, constrs. from rules

Lexicon entry:

[Det
[root: *a*]
[number: sg]]

Rule with constraints:

NP → Det Nominal

<NP number> = <Det number>

<NP number> = <Nominal number>

- Combine to get result:

[NP [Det
[root: *a*]
[number: sg]]
[Nominal [number: sg] …]
[number: sg]]

Similar issue with VP types

Another place where grammar rules could explode:

Jack laughed

VP → Verb *for many specific verbs*

Jack found a key

VP → Verb NP *for many specific verbs*

Jack gave Sue the paper

VP → Verb NP NP *for many specific verbs*

Verb Subcategorization

Verbs have sets of allowed args. Could have many sets of VP rules.
Instead, have a SUBCAT feature, marking sets of allowed arguments:

- +none -- Jack laughed
- +np -- Jack found a key
- +np+np -- Jack gave Sue the paper
- +vp:inf -- Jack wants to fly
- +np+vp:inf -- Jack told the man to go
- +vp:ing -- Jack keeps hoping for the best
- +np+vp:ing -- Jack caught Sam looking at his desk
- +np+vp:base -- Jack watched Sam look at his desk
- +np+pp:to -- Jack gave the key to the man
- +pp:loc -- Jack is at the store
- +np+pp:loc -- Jack put the box in the corner
- +pp:mot -- Jack went to the store
- +np+pp:mot -- Jack took the hat to the party
- +adjp -- Jack is happy
- +np+adjp -- Jack kept the dinner hot
- +sthat -- Jack believed that the world was flat
- +sfor -- Jack hoped for the man to win a prize

50-100 possible ***frames*** for English; a single verb can have several.
(Notation from James Allen "Natural Language Understanding")

Frames for "ask"

(in J+M notation)

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

Adding transitivity constraint

- S → NP VP

  <NP number> = <VP number>

- NP → Det Nominal

  <NP head> = <Nominal head>

  <Det head agree> = <Nominal head agree>

- VP → Verb NP

  <VP head> = <Verb head>

  <VP head subcat> = +np *(which means transitive)*

Applying a verb subcat feature

Lexicon entry:

[Verb
[root: *found*]
[head: find]
[subcat: +np]]

Rule with constraints:

VP → Verb NP

<VP head> = <Verb head>

<VP head subcat> = +np

- Combine to get result:

[VP [Verb
[root: *found*]
[head: find]
[subcat: +np]]
[NP …]
[head: find [subcat: +np]]]]

Relation to LFG constraint notation

- VP → Verb NP

  <VP head> = <Verb head>

  <VP head subcat> = +np

  from JM book is the same as the LFG expression

- VP → Verb NP

  (↑ head) = (↓ head)

  (↑ head subcat) = +np

Unification

- Merging FSs (and failing if not possible) is called ***Unification***
- Simple FS examples:

[number sg] $\sqcup$ [number sg] = [number sg]

[number sg] $\sqcup$ [number pl] FAILS

[number sg] $\sqcup$ [number []] = [number sg]

[number sg] $\sqcup$ [person 3rd] = [number sg,
person 3rd]

New kind of “=” sign

- Already had two meanings in programming:
  - “:=“ means “make the left be equal to the right”
  - “==” means “the left and right happen to be equal”

- Now, a third meaning:
  - ⊔ “=” means “make the left and the right be the same thing (from now on)”

Recap: applying constraints

Lexicon entry:

[Det

[root: *a*]

[number: sg]]

Rule with constraints:

NP → Det Nominal

<NP number> = <Det number>

<NP number> = <Nominal number>

- Combine to get result:

[NP [Det

[root: *a*]

[number: sg]]

[Nominal [number: sg] …]

[number: sg]]

Turning constraint eqns. into FS

Lexicon entry:

[Det
[root: *a*]
[number: sg]]

- Combine to get result:

[NP [Det
[root: *a*]
[number: sg]]
[Nominal [number: sg]
...]
[number: sg]]

Rule with constraints:

NP → Det Nominal

<NP number> = <Det number>

<NP number> = <Nominal number>

becomes:

[NP [Det [number: (1)]]
[Nominal
[number: (1)]
...]
[number: (1)]]

Another example

This (oversimplified) rule:

S → NP VP

<S subject> = NP

<S agreement> = <S subject agreement>

turns into this DAG:

[S [subject (1)

[agreement (2)]]

[agreement (2)]

[NP (1)]

[VP]

Unification example without “EQ“

[agreement [number sg],
subject [agreement [number sg]]]
⊔[subject [agreement [person 3rd,
number sg]]]
= [agreement [number sg],
subject [agreement [person 3rd,
number sg]]]

- <agreement> is (initially) equal to <subject agreement>, but ***not*** EQ
- So not equal anymore *after* operation

Unification example with “EQ“

[agreement (1), subject [agreement (1)]]

$\sqcup$[subject [agreement [person 3rd, number sg]

= [agreement (1),

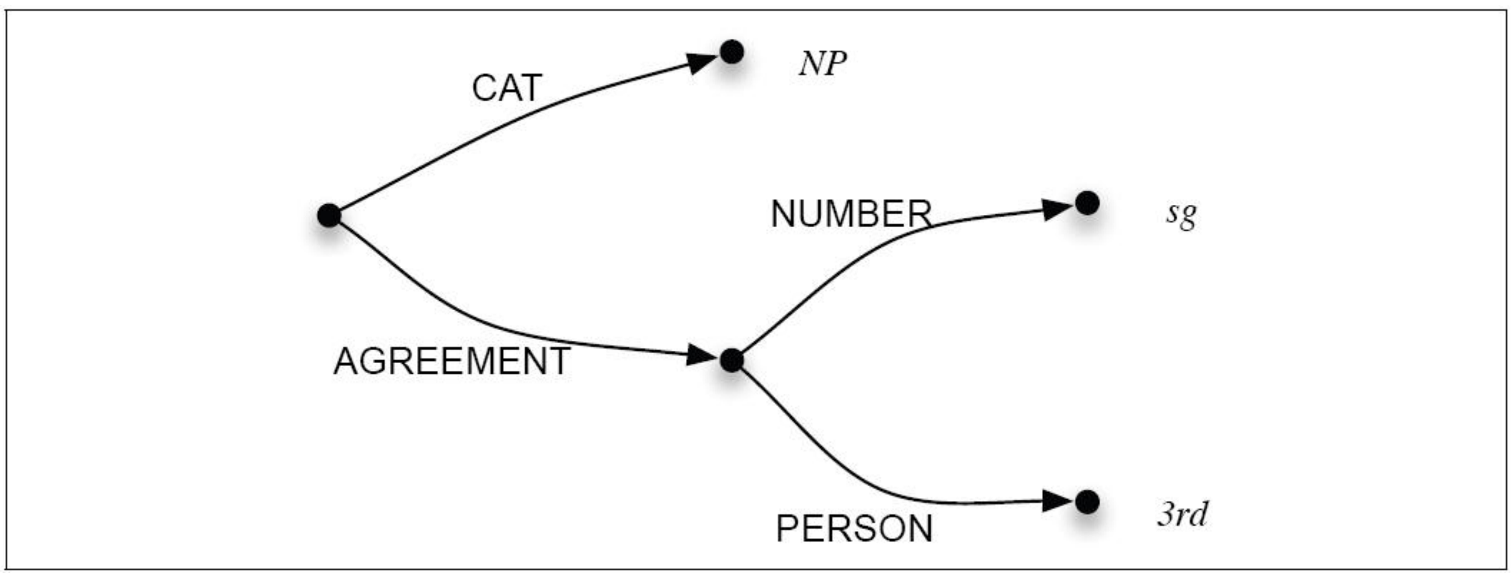
subject [agreement (1) [person 3rd,

number sg]]]

- <agreement> ***is*** <subject agreement> (EQ), so they are equal
- and *stay* equal, always, in the future

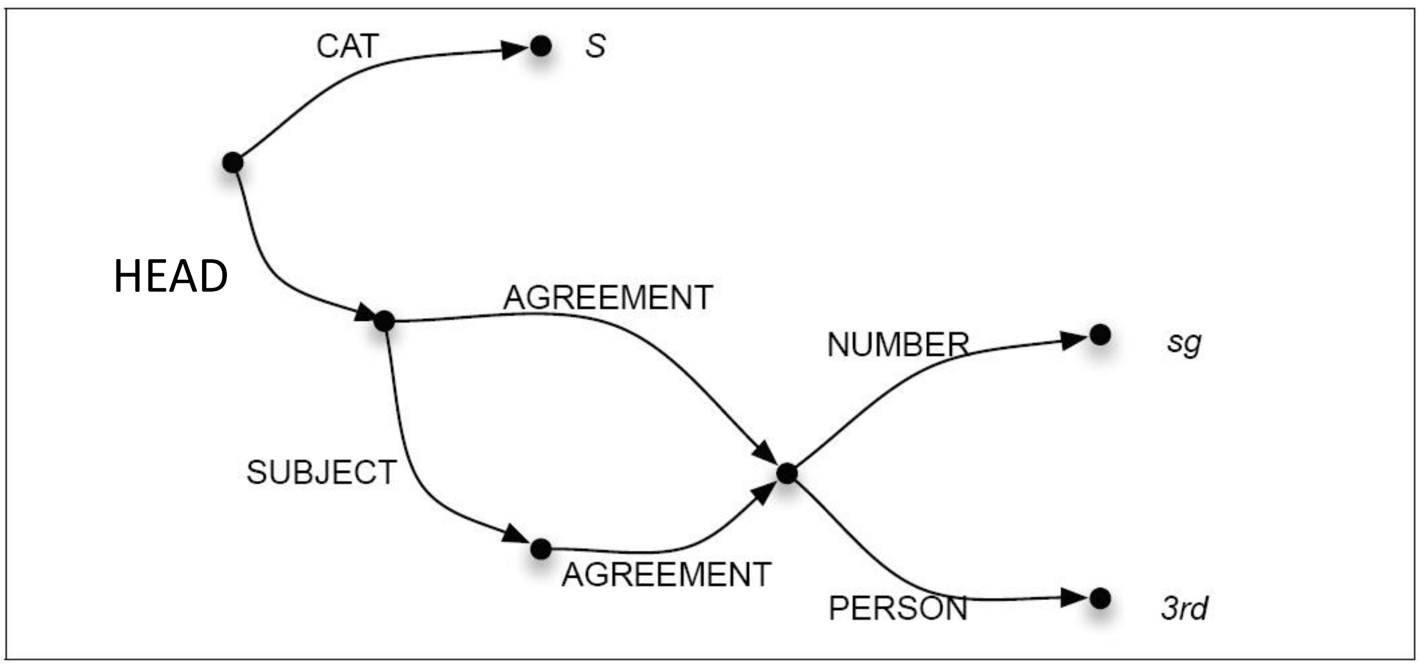
Representing FSs as DAGs

- Taking feature paths seriously
- May be easier to think about than numbered cross-references in text
- [cat NP, agreement [number sg, person 3rd]]



Re-entrant FS as DAGs

- [cat S, head [agreement (1) [number sg,
  person 3rd],
  subject [agreement (1)]]]



Seems tricky. Why bother?

- Unification allows the systems that use it to handle many complex phenomena in "simple" elegant ways:
  - There seems to be a dog in the yard.
  - There seem to be dogs in the yard
- Unification makes this work smoothly.
  - Make the Subjects of the clauses EQ:

    <VP subj> = <VP COMP subj>

    [VP [subj: (1)] [COMP [subj: (1)]]]
  - (Ask Lori Levin for LFG details.)

Real Unification-Based Parsing

- X0 → X1 X2

  <X0 cat> = S, <X1 cat> = NP, <X2 cat> = VP

  <X1 head agree> = <X2 head agree>

  <X0 head> = <X2 head>

- X0 → X1 *and* X2

  <X1 cat> = <X2 cat>, <X0 cat> = <X1 cat>

- X0 → X1 X2

  <X1 orth> = *how*, <X2 sem> = <SCALAR>

Complexity

- Earley modification: "search the chart for states whose DAGs ***unify*** with the DAG of the completed state". Plus a lot of copying.
- Unification parsing is "quite expensive".
  - NP-Complete in some versions.
  - Early AWB paper on Turing Equivalence(!)
- So maybe *too* powerful?

  (like GoTo or Call-by-Name?)
  - Add restrictions to make it tractable:
    - Tomita's Pseudo-unification (Tomabechi too)
    - Gerald Penn work on tractable HPSG: ALE

Formalities: subsumption

- Less specific FS1 ***subsumes*** more specific FS2

  FS1 $\sqsubseteq$ FS2 (Inverse is FS2 ***extends*** FS1)
- Subsumption relation forms a ***semilattice***,

  at the top: []

[number sg] [person 3] [number pl]

[number sg, person 3]

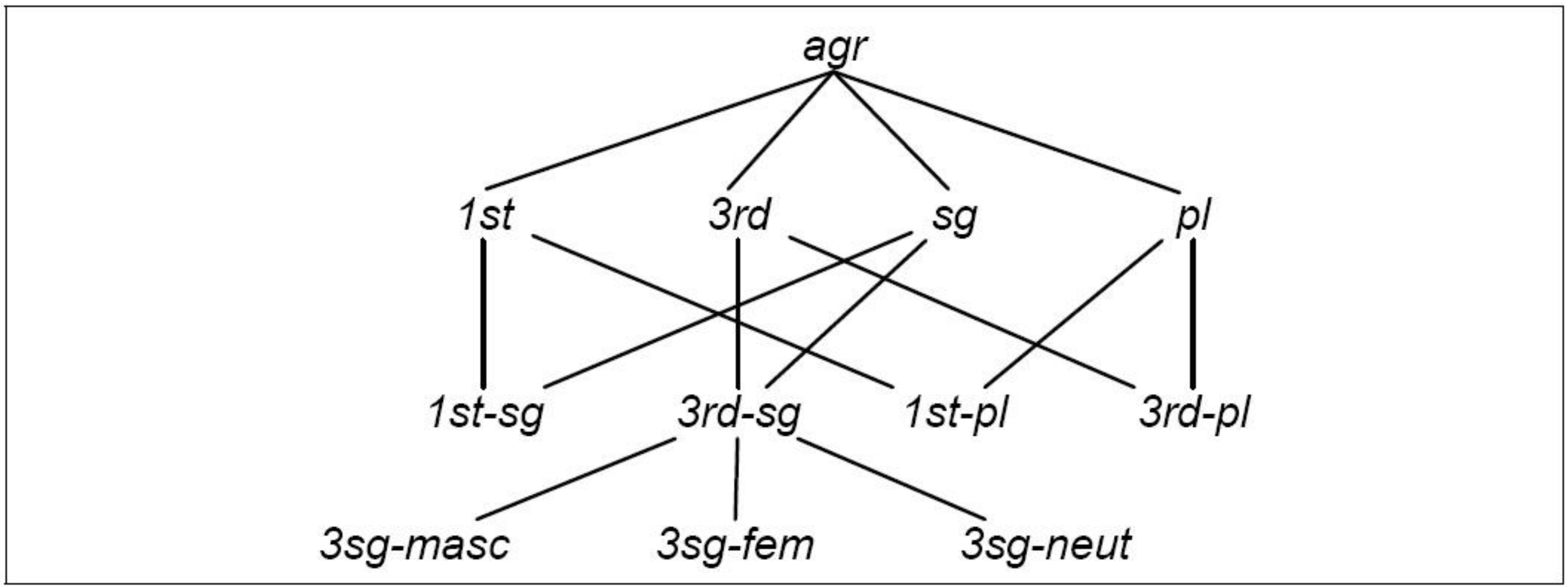
- Unification defined wrt semilattice:

  F $\sqcup$ G = H s.t. F $\sqsubseteq$ H and G $\sqsubseteq$ H

  H is the Most General Unifier (MGU)

Hierarchical Types

Hierarchical types allow *values* to unify too (or not):



Hierarchical subcat frames

Many verbs share *subcat* frames, some with more arguments specified than others: