Feature Structures and Unification Grammars

11-711 Algorithms for NLP

October 2020 – Part II

Review: Inflectional Morphology and syntactic agreement

- Morphology is the study of the internal structure of words.
  - **Derivational morphology.** How new words are created from existing words.
    - *[grace]*
    - *[[grace]ful]*
    - *[un[grace]ful]]*
  - **Inflectional morphology.** How features relevant to the **syntactic context** of a word are marked on that word.
    - This example illustrates number (singular and plural) and tense (present and past).
    - Green indicates irregular. Blue indicates zero marking of inflection. Red indicates regular inflection.
    - This student walks.
    - These students walk.
    - These students walked.
  - ***Compounding.*** Creating new words by combining existing words
    - With or without spaces: surfboard, golf ball, blackboard

Review: Features, morphology, FSTs:

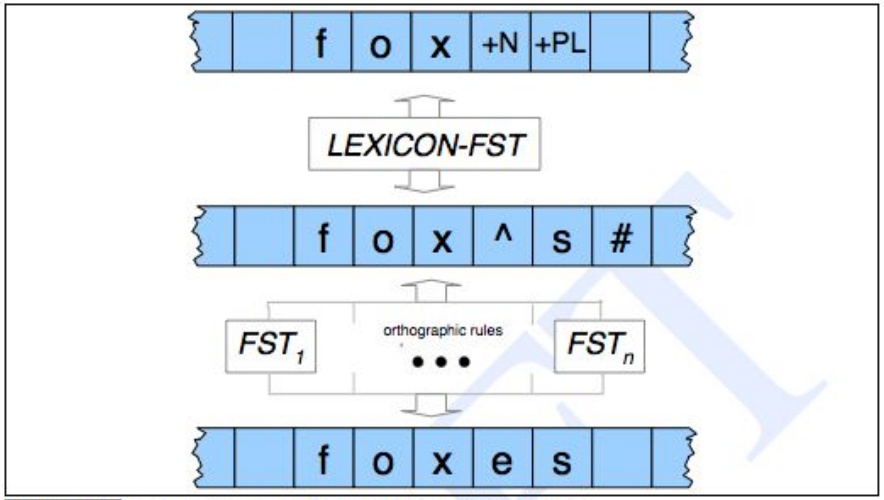


Figure 3.19 Generating or parsing with FST lexicon and rules

parse

generate

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…

- $NP1s \longrightarrow$ Det-s N1s
- $NP1p \longrightarrow$ Det-p N1p

  …
- $NP3s \longrightarrow$ Det-s N3s
- $NP3p \longrightarrow$ Det-p N3p

  …
- $S1s \longrightarrow$ NP1s VP1s
- $S1p \longrightarrow$ NP1p VP1p
- $S3s \longrightarrow$ NP3s VP3s
- $S3p \longrightarrow$ 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 $\longrightarrow$ NP VP

  <NP number> = <VP number>

- NP $\longrightarrow$ 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

$VP \longrightarrow Verb$ *for many* ***specific*** *verbs*

Jack found a key

$VP \longrightarrow Verb\ NP$ *for many* ***specific*** *verbs*

Jack gave Sue the paper

$VP \longrightarrow Verb\ NP\ NP$ *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")

Verb frames are ***not*** totally semantic

- It does seem to be partly lexical:

  John wants to fly

  John likes to fly

  John likes flying

  *John wants flying

- Can vary with dialect:

  *??*The car needs washed *(only in Pittsburghese?)*

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 $\longrightarrow$ NP VP

  <NP number> = <VP number>

- NP $\longrightarrow$ Det Nominal

  <NP head> = <Nominal head>

  <Det head agree> = <Nominal head agree>

- VP $\longrightarrow$ 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]]

- Combine to get result:

[VP [Verb

[root: *found*]

[head: find]

[subcat: +np]]

[NP …]

[head: find [subcat: +np]]]]

Rule with constraints:

VP → Verb NP

<VP head> = <Verb head>

<VP head subcat> = +np

Relation to LFG constraint notation

- VP $\longrightarrow$ Verb NP

  <VP head> = <Verb head>

  <VP head subcat> = +np

  from JM book is the same as the LFG expression

- VP $\longrightarrow$ Verb NP

  ($\uparrow$ head) = ($\downarrow$ head)

  ($\uparrow$ 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 $\longrightarrow$ 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]]

Unifying constraints (1)

Lexicon entries:

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

[Nominal
[root: *dog*]
[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
[root: *dog*]
[number: sg] . . .]
[number: sg]]

Unifying constraints (2)

Lexicon entries:

[Det

[root: *a*]

[number: sg]]

[Nominal

[root: *dogs*]

[number: pl]]

- Rule with constraints:

NP $\longrightarrow$ Det Nominal

<NP number> = <Det number>

<NP number> = <Nominal number>

- Combine to get result:

FAIL

Unifying constraints (3)

Lexicon entries:

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

[Nominal
 [root: *deer*]
 [number: {sg pl}]]

- 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
 [root: *deer*]
 [number: sg] …]
 [number: sg]]

Turning constraint eqns. into FS

FS1: Lexicon entry:

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

- Combine FS1 and FS2 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 FS2:

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

Another example

This (oversimplified) rule:

S $\longrightarrow$ 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*** the operation:
  <agreement person> is still null

Unification example with “EQ“

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

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

= [agreement (1),

subject [agreement (1) [person 3rd,

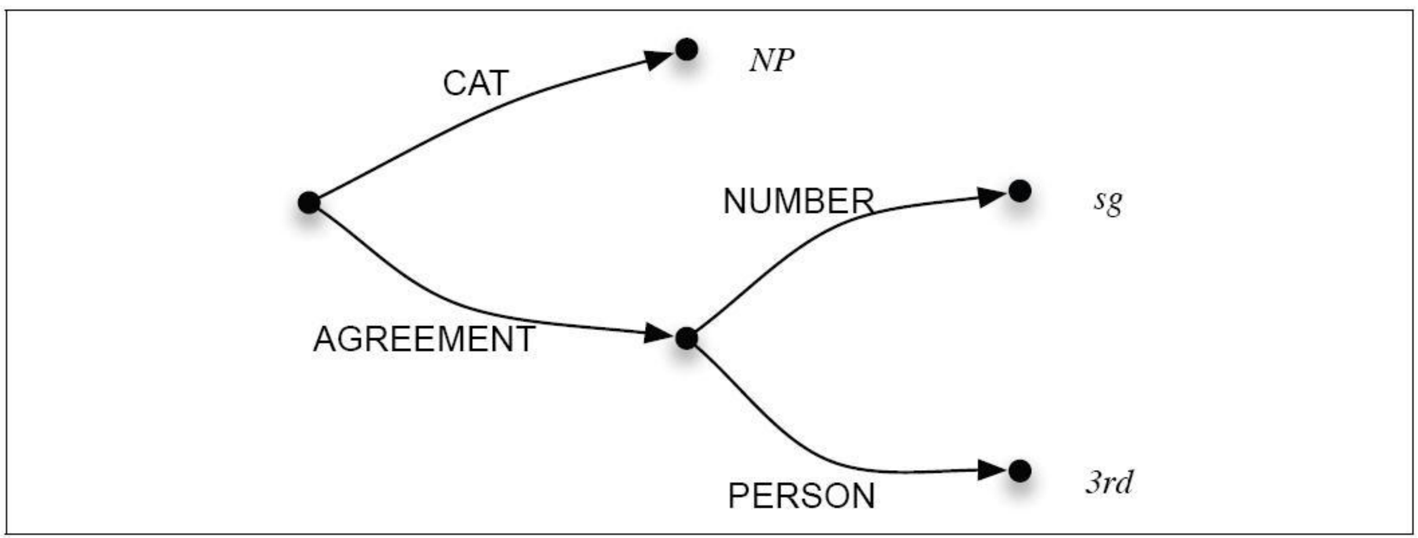
number sg]]]

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

  <agreement person> is 3rd afterwards!

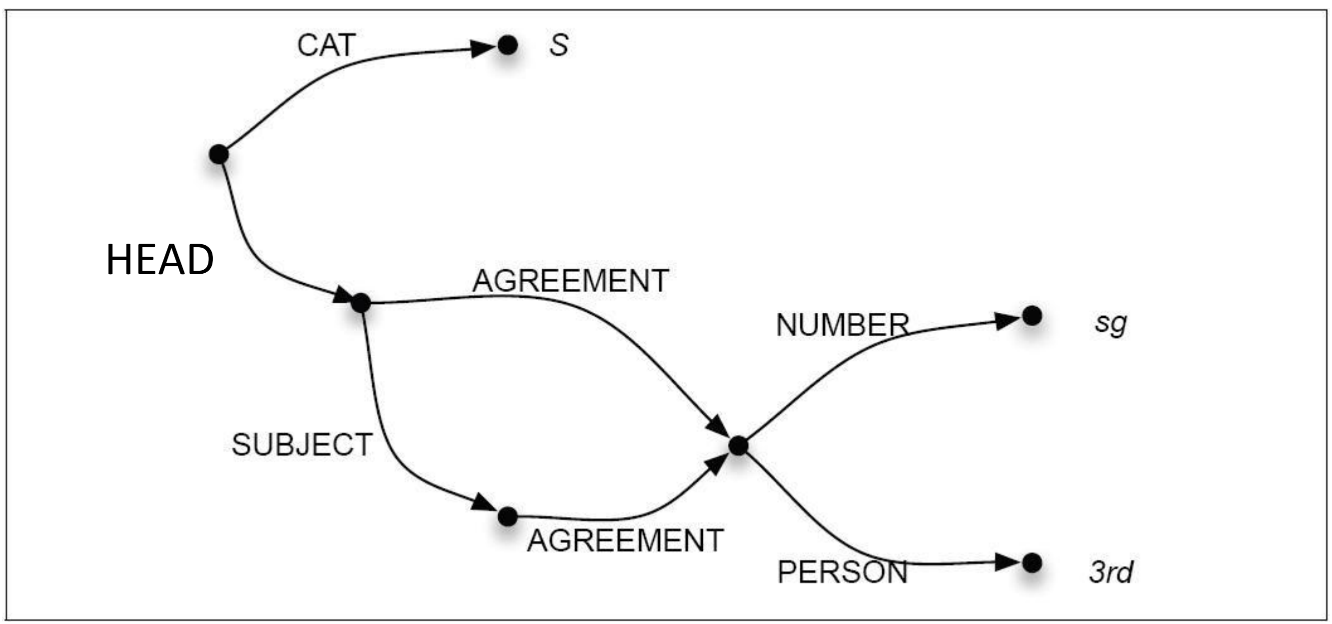
Ordinary FSs as DAGs

- 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 <u>seems</u> to be <u>a dog</u> in the yard.
  - There <u>seem</u> to be <u>dogs</u> 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 $\longrightarrow$ X1 X2

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

  <X1 head agree> = <X2 head agree>

  <X0 head> = <X2 head>

- X0 $\longrightarrow$ X1 *and* X2

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

- X0 $\longrightarrow$ X1 X2

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

Complexity

- J&M II: “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 ⊑ FS2 (Inverse is FS2 ***extends*** FS1)
- Subsumption relation forms a ***semilattice***,

  at the top: []

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

[number sg, person 3]

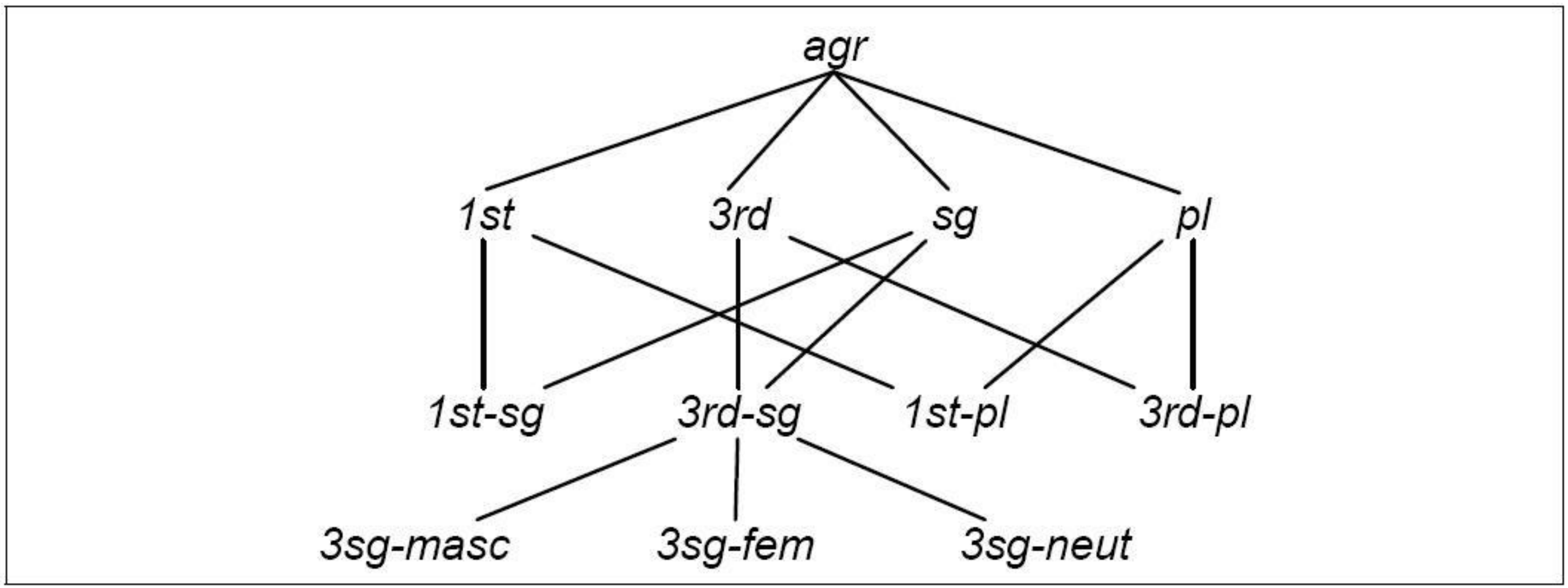
- Unification defined wrt semilattice:

  F ⊔ G = H s.t. F ⊑ H and G ⊑ H

  H is the Most General Unifier (MGU)

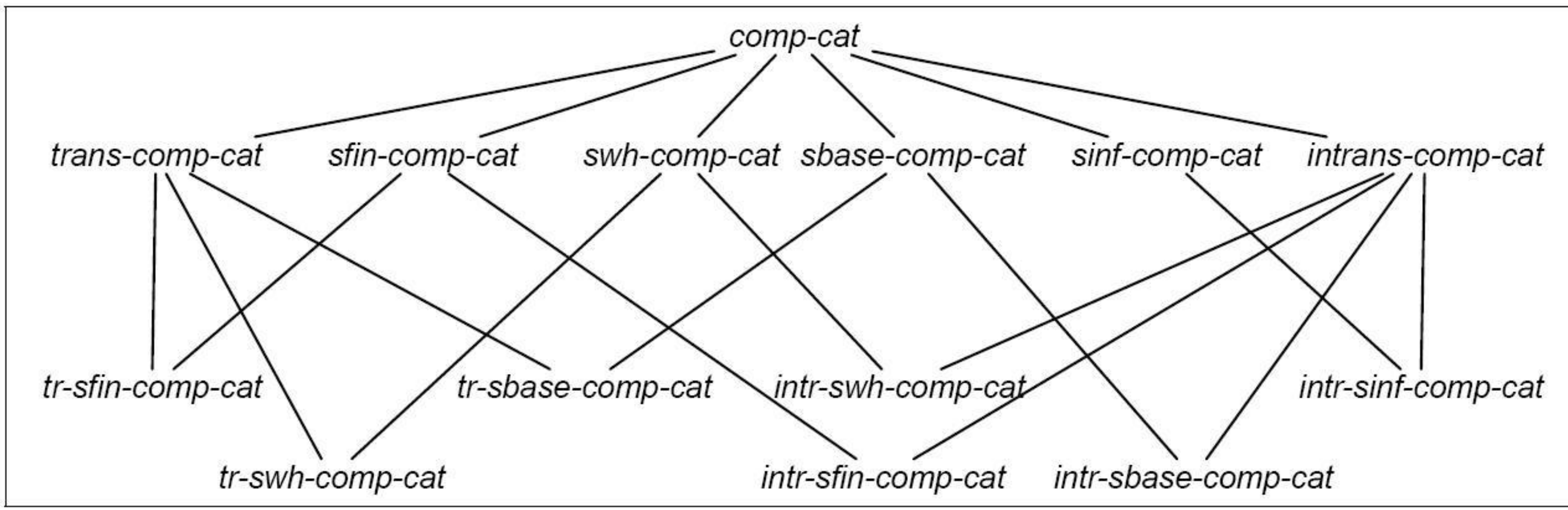
Hierarchical Types

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



Hierarchical subcat frames

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



Questions?

Subcategorization

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