Feature Structures and How to Represent Multiple Phenomena Simultaneously

Adam Meyers

New York University

Outline

- Definitions and Examples
- Parsing with Feature Structures
- The Earley Algorithm
- Other Issues
- GLARF: a Feature Structure Project at NYU

Why Feature Structures?

- A Feature Structure is a good data structure for representing complex objects
  - Can include many linguistic features in one structure: Tense, Agreement, Semantics, Parsed Structure, Coreference, ...
- Represents objects in terms of features value pairs, where the values of features can be complex
- The mathematics of Feature Structures were worked out in great detail in the 1980s and 1990s
- Several linguistic theories are formalized in terms of Feature Structures and operations thereon

Defining Feature Structures

- A Feature Structure is either atomic or a set of feature value pairs
  - FS $\rightarrow$ NIL
  - FS $\rightarrow$ Atom
  - FS $\rightarrow$ {FV_1, FV_2, … FV_N}
  - FV $\rightarrow$ Feature = FS
    - **A values of a feature must be a FS**
- Each Feature and Value Represents a Piece of Information
- More information defines more specific objects

A Simple Example

- FS_1 = **[Color = Green]**
  - Describes a green thing
- FS_2 = [**Height = Tall**]
  - Describes a tall thing
- FS_3 = [**Color = Green**, **Height = Tall**]
  - Describes a tall green thing
- More feature value pairs describe a more specific thing

Typed Feature Structures

- Typed feature structures:
  - Every feature structure has a type
    - The type limits what are the possible features that can be included in it
  - Every feature has a type
    - The type limits its possible values
- Examples
  - A Feature Structure of type **Lego** allows features: color, height, width, depth and material.
  - The value of the feature **Color** allows atomic TFS as values from the set {**red**, **yellow**, **blue**, **green**, ...}

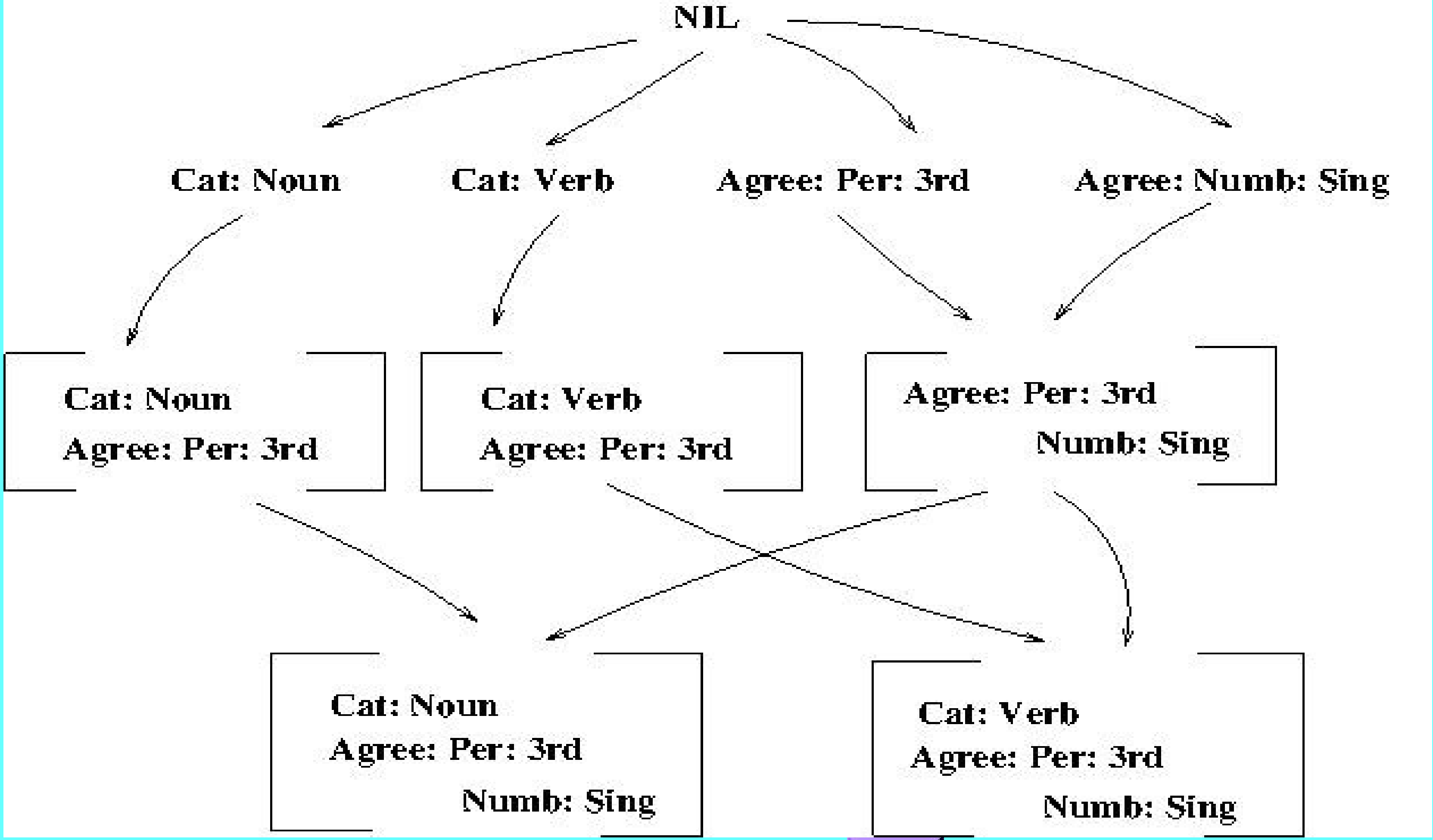
Subsumption

- The operator $\sqsubseteq$ represents "subsumes"
- $FS_1 \sqsubseteq FS_2$, if FS_1
  - describes same or larger set of entities than FS_2 (instances of FS_1 are instances of FS_2, but reverse may not be true).
  - For example, if FS_1 represents something green and FS_2 represents a tall green thing, than $FS_1 \sqsubseteq FS_2$
  - **[Color = Green] $\sqsubseteq$ [Color = Green, Height = Tall]**
- Notice that if $FS_1 \sqsubseteq FS_2$, than FS_2 includes all of the Feature Value pairs in FS_1, but the reverse may not be true.
- For typed feature structures, one must add information about type subsumption and this is essentially based on the definitions of types (similar to type inheritance in OOP)

Properties of Subsumption

- NIL is the most general feature structure
  - Subsumes every other feature structure
    - The set of zero feature value pairs
    - Also subsumes atomic feature structure
    - Possible value for all features (for typed feature structures)
- Subsumption is transitive
- If $FS_1 \sqsubseteq FS_2$ and $FS_2 \sqsubseteq FS_3$, then $FS_1 \sqsubseteq FS_3$
- Subsumption partially orders the set of all FS
  - NIL is the root of a DAG which includes all FSs
  - Edges in paths from the root represent subsumption

Part of the Subsumption Graph for a FS-based Grammar of English



Unification

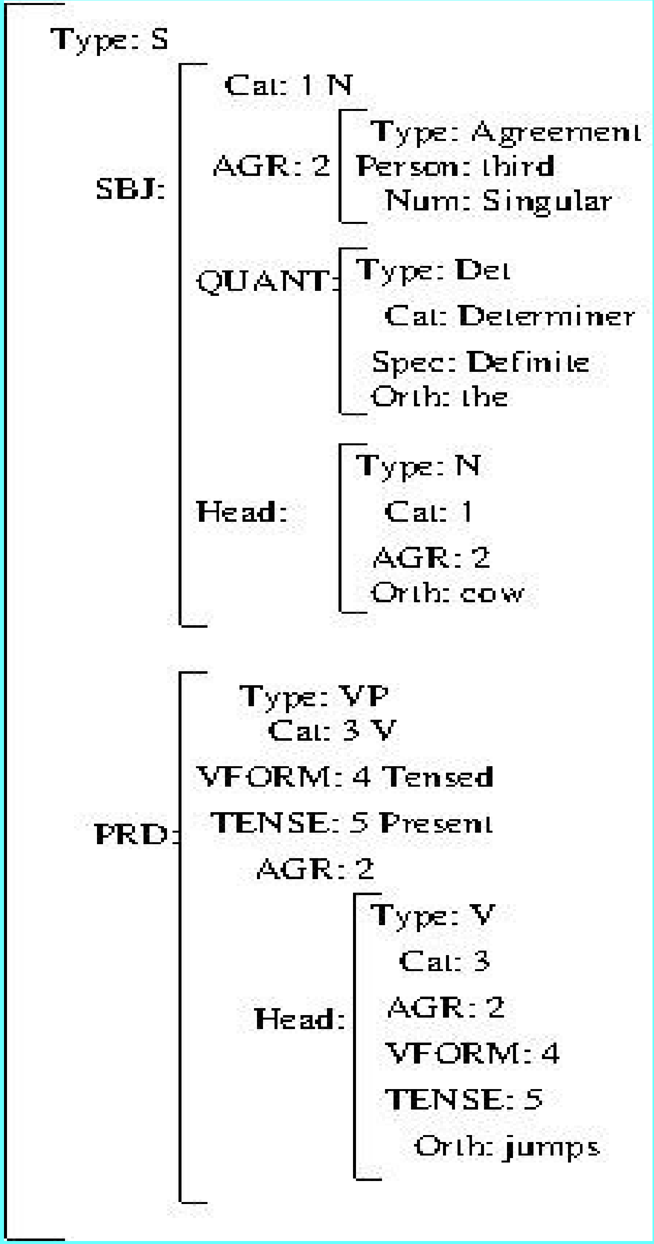
- Unifying (operator = $\sqcup$) two FSs combines the information in both feature structures to produce a FS that instantiates the intersection of entities that the two input FSs instantiate
- $FS_1 \sqcup FS_2 = FS_3$ iff FS_3 is the most general Feature structure (the one with the fewest Feature Value pairs) such that:
  - $FS_1 \sqsubseteq FS_3$ and $FS_2 \sqsubseteq FS_3$
- Properties:
  - Unification is Commutative
    - $FS_1 \sqcup FS_2 = FS_2 \sqcup FS_1$
  - Unification is Associative
    - $(FS_1 \sqcup FS_2) \sqcup FS_3 = FS_1 \sqcup (FS_2 \sqcup FS_3)$

How to Unify (not worrying about efficiency)

- $FS_X \sqcup FS_X \rightarrow FS_X$
- $FS_X \sqcup NIL \rightarrow FS_X$
- $NIL \sqcup FS_X \rightarrow FS_X$
- $Atom_1 \sqcup Atom_2$ Fails if ***$Atom_1 \neq Atom_2$***
- To Unify Complex FSs FS_1 and FS_2, producing FS_3, start with an empty FS_3 and add FVs as follows:
  - For each Feature Value Pair FV_1 in FS_1, try to find a matching FV_2 in FS_2 such that Feature F_1 in FV_1 is the same as F_2 in FV_2
    - If no matching feature exists, then add FV_1 into FS_3
    - Otherwise, try to unify V_1 in FV_1 with V_2 in FV_2
      - If the recursive call to unification Fails, then the larger unification fails as well
      - Otherwise, add F with a value of $V_1 \sqcup V_2$ to FS3
  - For each FV_x in FS_2 that did not match any Feature in FS_1:
    - Add FV_x to FS_3

FS in Bracket Notation representing *The cow jumps*

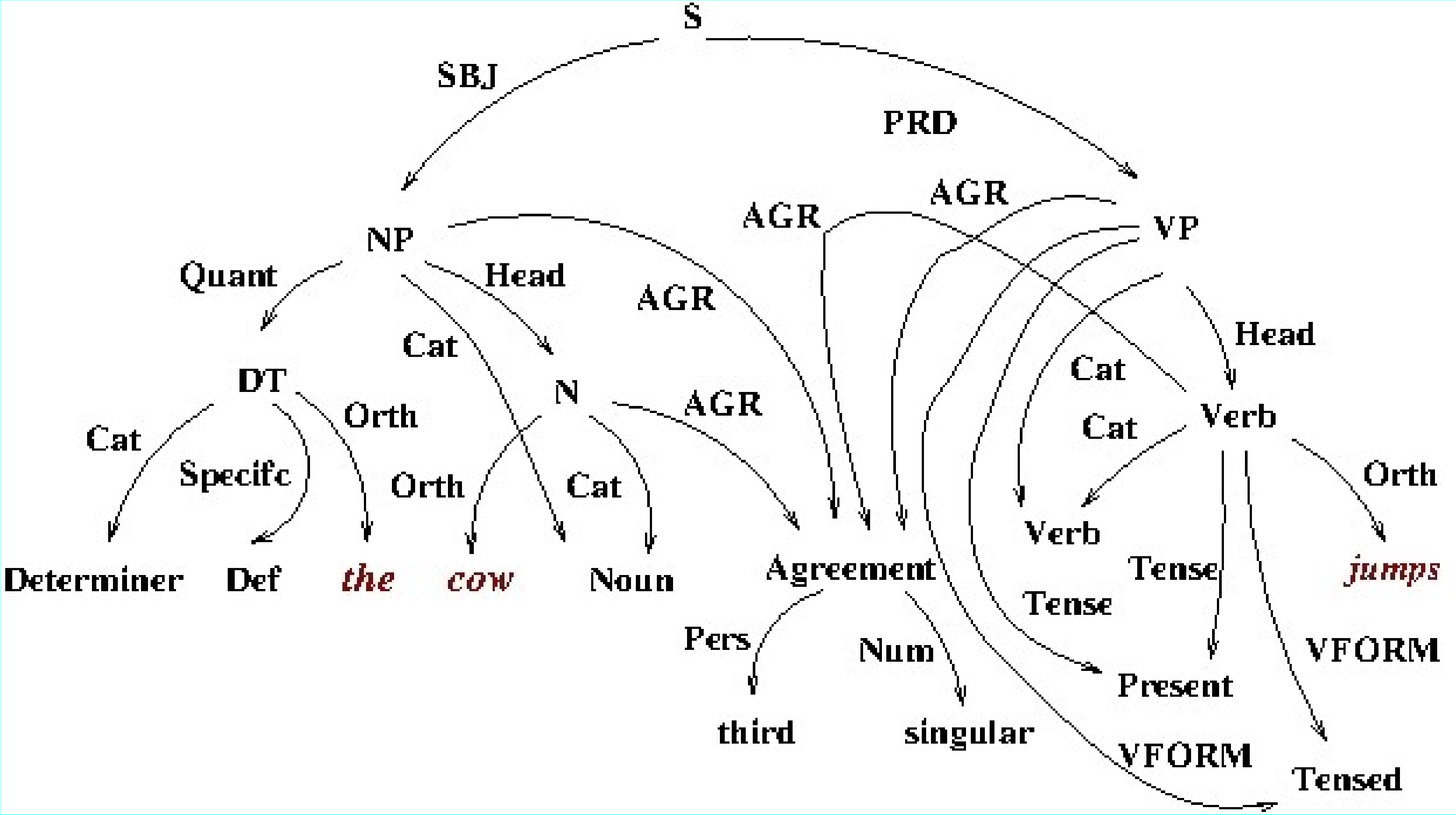
- Indices represent shared structure
- The first feature taking a shared structure as a value is followed by a numbered index and the structure
- Other features sharing that structure are followed by that index



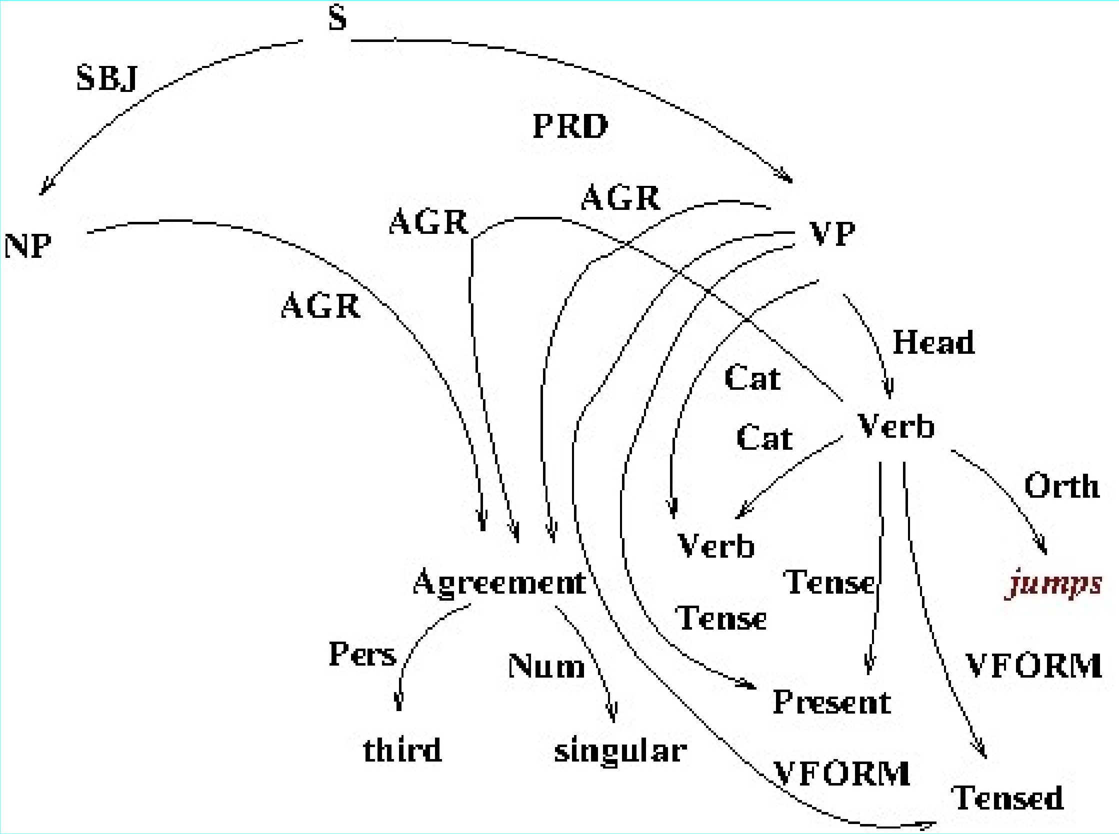
Feature Structures as Edge-Labled DAGs

- Types = Internal Nodes = Non Terminals = Phrasal Categories and Parts of Speech
- Atomic FSs = leaves
- Features = Edge Labels
- Shared Structure is determined by grammar
  - It means that some features values are exactly the same
  - Common Instances
    - Shared between a phrase and its head
    - Agreement between a subject and a verb

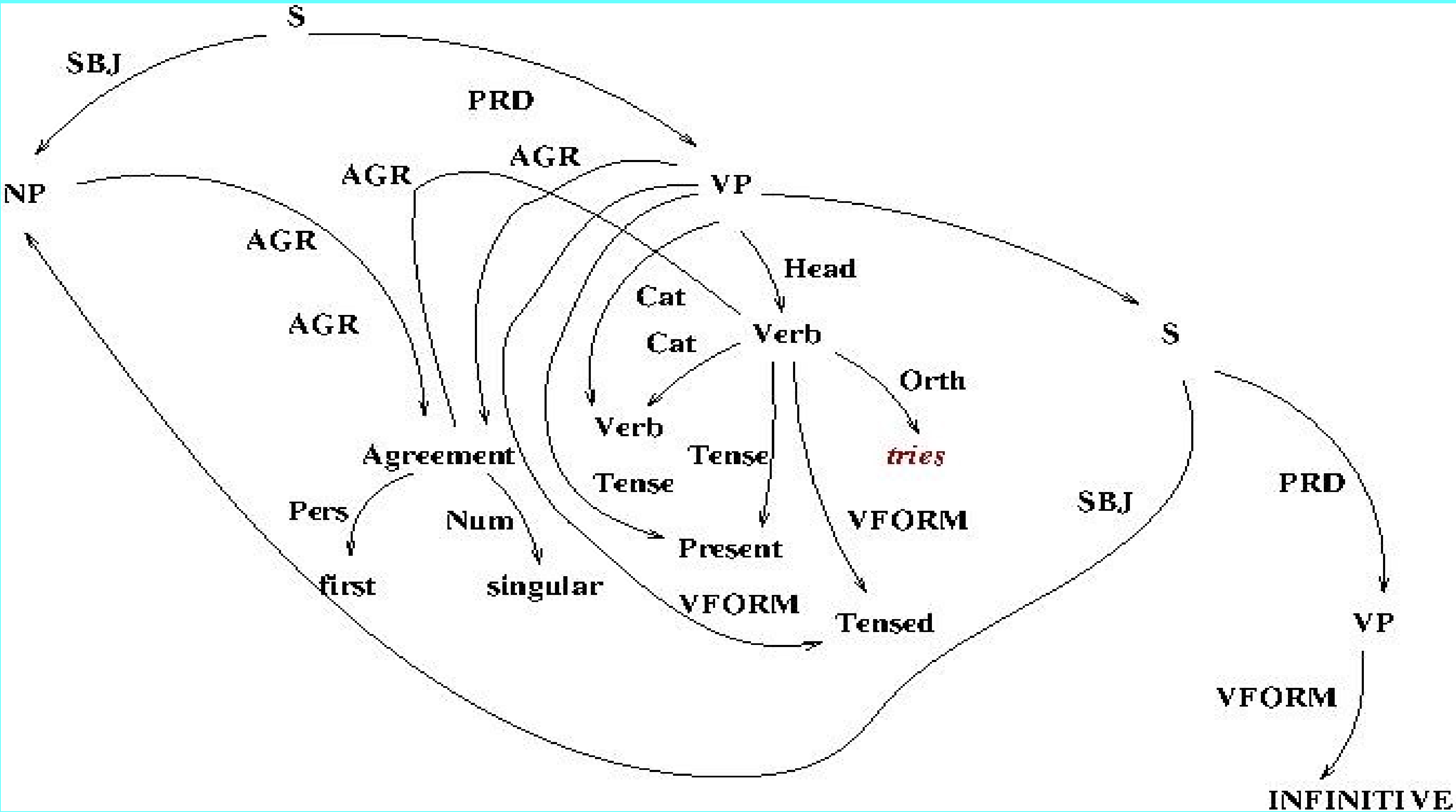
DAG representing ***The cow jumps***



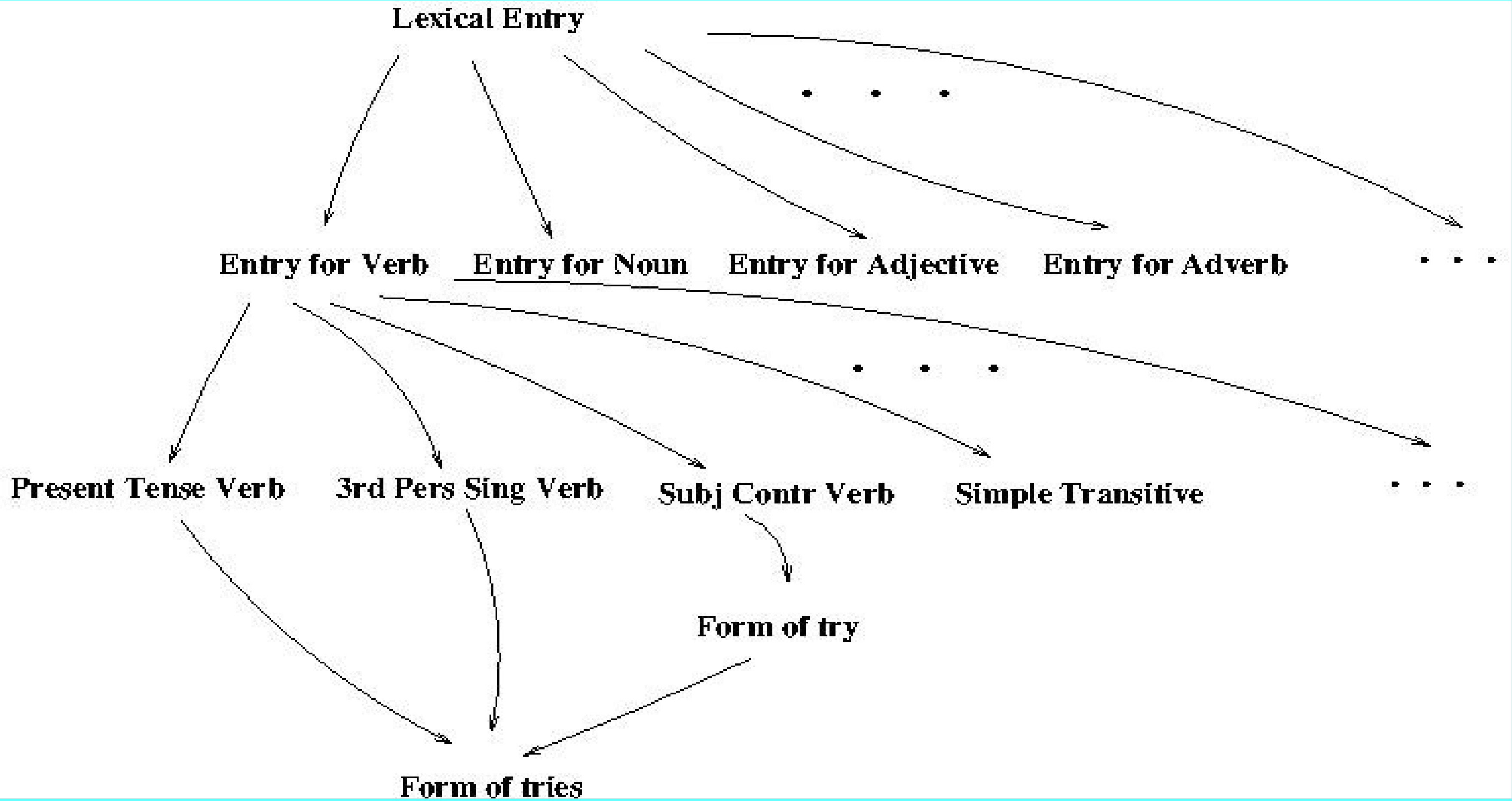
FS for lexical entry for ***jumps***



FS Lexical Entry for the Verb *tries*



Lexicon Can Be Arranged Hierarchically, based on Subsumption



How Can We Use FSs for Parsing?

- For each word, we look up all its feature structure entries (instead of looking up its possible parts of speech)
  - These FSs or generalizations of these feature structures can correspond to either:
    - Initial Terminal Symbols, e.g., FS representing a noun
    - Initial NonTerminal Symbols, e.g., FS representing an S licensed by a verb
- Do we Need Context Free Grammars?
  - Using the second type of entries, it is possible to (in a way) fold the entire grammar into the lexicon
  - Alternatively, a context free grammar can be used to guide the combination of FSs, as in standard parsing
    - FSs constrain possible combinations

The Earley Algorithm

- Shortcoming of Top Down Parsing
  - Left Recursive rules like **NP → NP PP**
  - If NP is recognized, productions starting with **NP** are added to chart including this rule which starts with **NP** (hence infinite recursion)
- The Earley Algorithm solves this problem:
  - it avoids adding duplicate productions to the chart
- Productions $\boldsymbol{XP \rightarrow X_1 \,.\, X_2\, X_3[i,j]}$ in the chart include:
  - A phrase structure rule ($\boldsymbol{XP \rightarrow X_1 .X_2\, X_3}$)
  - A dot (between $\boldsymbol{X_1}$ and $\boldsymbol{X_2}$) such that complete constituents to the left of the dot have been matched
  - The span of text that this rule applies to between i and j
- The Earley algorithm would not add ***NP → NP . PP [0,1]***
  - If there was already an instance in the chart

FS version of the Earley Algorithm

- We assume the model in which phrase structure rules guide combination of FSs
  - A parsing step combines 1 complete and 1 incomplete states
    - A state is complete if the dot is all the way to the right
      - $\boldsymbol{XP \rightarrow X_1\, X_2\, X_3\, .}$
    - An incomplete state has the dot somewhere else
      - $\boldsymbol{YP \rightarrow W_1\ .\, XP\ Z_3}$
  - The result combines the two by matching the complete state with the symbol following the dot and then advancing the dot
      - $\boldsymbol{YP \rightarrow W_1\ XP\ .\, Z_3}$
- For the FS version, matching is based on subsumption
  - Match for purposes of a parsing step (above)
  - Match to check if a production is already in the chart (previous slide)

Efficiency Issues for FS Parsing

- Efficient unification changes input FSs
  - Combining them destructively keeping parts of each
- For chart parsing, original FSs are needed
  - So FS parsing involves lots of copying (this can be inefficient)
- Solutions
  - Use general FSs in productions that subsume "real ones"
    - Generate final FS after final parse is found
  - Lazy copying (Godden 1990)
    - Use instruction like "copy FS_1" to delay copying
    - Then copy only when FS is actually needed

Linguistic Theories Using Feature Structures as Models

- Generalized Phrase Structure Grammar
  - http://www.amazon.com/Generalized-Phrase-Structure-Grammar-Gerald/dp/0674344561
- Head Driven Phrase Structure Grammar
  - http://www.ling.ohio-state.edu/research/hpsg/
- Lexical Function Grammar
  - http://www2.parc.com/isl/groups/nltt/papers/kb82-95.pdf
- Categorial Unification Grammar
  - http://acl-arc.comp.nus.edu.sg/archives/acl-arc-090501d3/data/pdf/anthology-PDF/C/C86/C86-1045.pdf

Other Books about Feature Structures and Related Issues

- The Logic of Typed Feature Structures (B. Carpenter)
  - http://www.amazon.com/The-Logic-Typed-Feature-Structures/dp/0521022541
- Mathematical Methods in Linguistics (Partee, Meulen and Wall)
  - http://books.google.com/books/about/Mathematical_Methods_in_Linguistics.html?id=qV7TUuaYcUIC

GLARF

- See CUNY talk

Readings

- J & M Chapters 13.4.2 and 15