6.863J Natural Language Processing
Lecture 12: Featured attraction

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The Menu Bar

- Administrivia:
  - 3a due Friday; Lab 3b out Weds; due after vacation

Agenda:

Parsing strategies: Honey, I shrank the grammar!

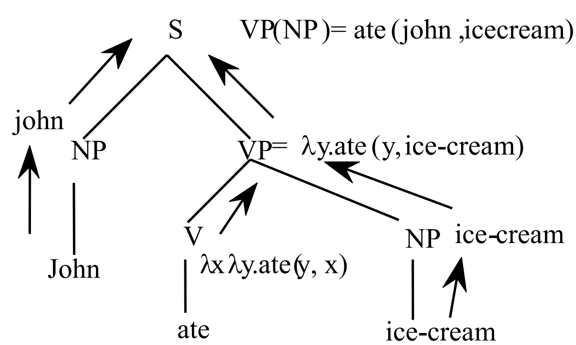
Features

Why: recover meaning from structure

John ate ice-cream → ate(John, ice-cream)

-This must be done from *structure*
-Actually want something like λxλy ate(x,y)
How?

Why: recover meaning from structure



Two parts:

- Syntax: define hierarchical structure
- Semantics: interpret over hierarchical structure

- What are the constraints?

Conclusion we will head to

- If we use too powerful a formalism, it lets us write ‘unnatural’ grammars
- This puts burden on the person writing the grammar – which may be ok.
- However, child doesn’t presumably do this (they don’t get ‘late days’)
- We want to strive for automatic programming – ambitious goal

Key elements – part 1

- Establish basic phrase types: S, VP, NP, PP, …
- Where do these come from???

What *kinds* of phrases are there?

- Noun phrases, verb phrases, adjectival phrases ("green with envy"), adverbial phrases ("quickly up the hill"), prepositional phrases ("off the wall"), etc.
- In general: *grounded* on lexical items
- Shows us the *constraints* on context-free rules for *natural grammars*
- Example:

Phrase types are constrained by lexical projection

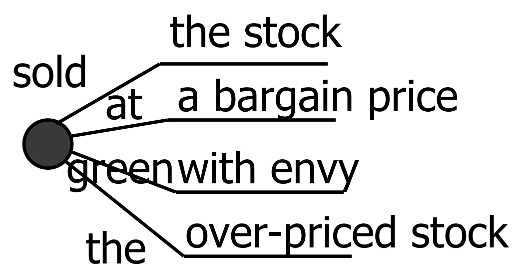
Verb Phrase → Verb Noun Phrase
"is-a" ("kick the ball")
Prepositional Phrase → Preposition Noun Phrase
("on the table")
Adjective Phrase → Adjective Prep. Phrase
("green with envy")
Etc. … what is the pattern?

Function-argument relation

XP →X arguments, where X= Noun, Verb, Preposition, Adjective (all lexical categories in the language)
Like function-argument structure
(so-called "Xbar theory")
Constrains what grammar rules *cannot* be:
Verb Phrase →Noun Noun Phrase
or even
Verb Phrase →Noun Phrase Verb Noun Phrase

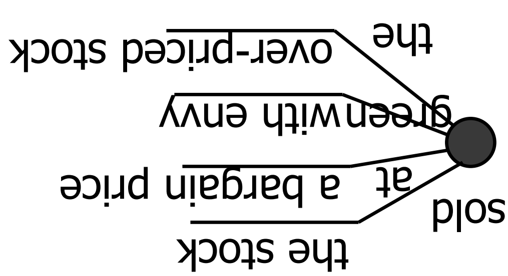
English is function-argument form

function args



Other languages are the mirror-inverse: arg-function

This is like Japanese



Key elements – part 2

- Establish *verb subcategories*
- What are these?
  - Different verbs take different # arguments
  - 0, 1, 2 arguments ('complements')
  - Poirot thought; Poirot thought the gun; Poirot thought the gun was the cause.
  - Some verbs take certain sentence complements:
  - *I know who John saw/? I think who John saw* propositional types:
  - Embedded questions: *I wonder whether…*
  - Embedded proposition: *I think that John saw Mary*

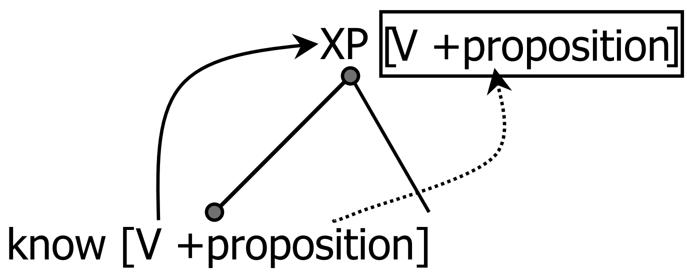
Key elements

- Subtlety to this
- Believe, know, think, wonder,…
  - ? I believe why John likes ice-cream
  - I know why John likes ice-cream
  - I believe that John likes ice-cream
  - I believe (that) John likes ice-cream

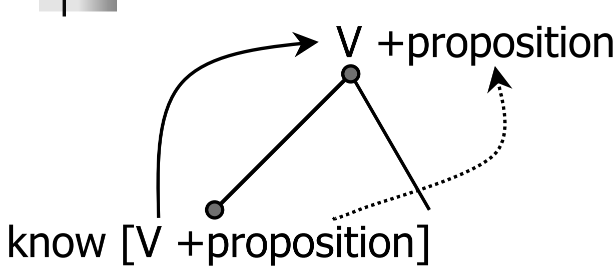
- # args, type: <u>Verb subcategories</u>
- How many subcategories are there?
- What is the structure?

Idea for phrases

- They are based on ‘projections’ of words (lexical items) – imagine features ‘percolating’ up

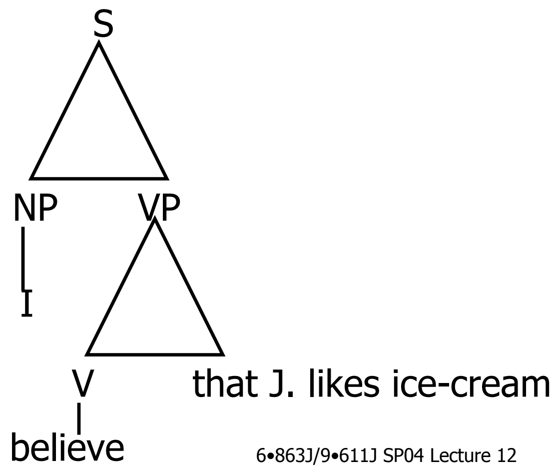


Heads of phrases

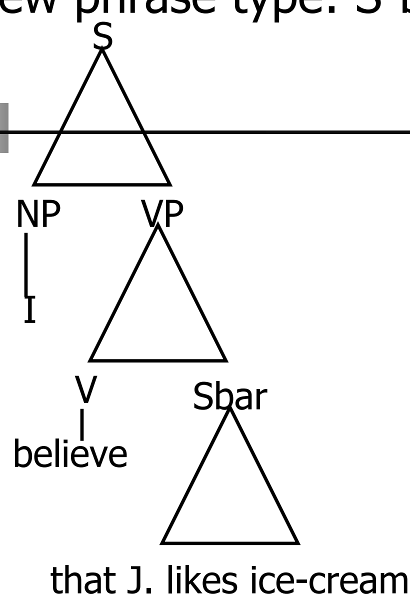


The parse structure for 'embedded' sentences

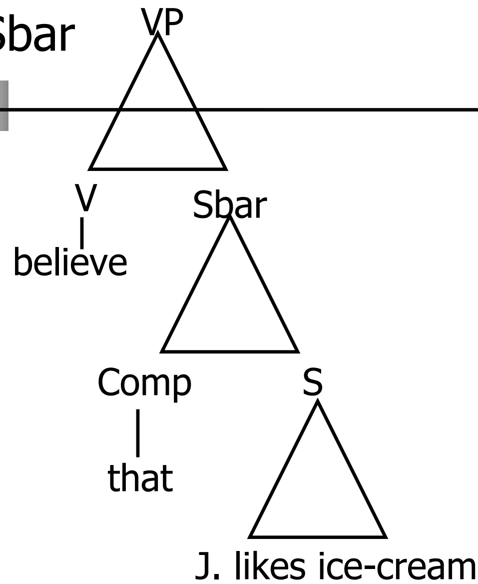
I believe (that) John likes ice-cream



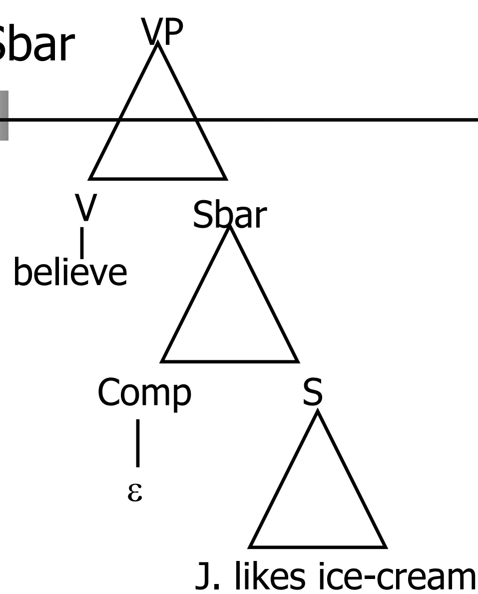
New phrase type: S-bar



Sbar


VP
V
believe
Sbar
Comp
that
S
J. likes ice-cream

Sbar


VP
V
believe
Sbar
Comp
ε
S
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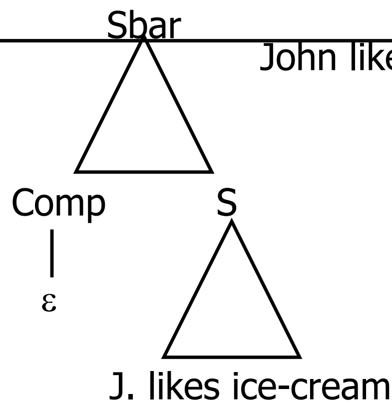
In fact, true for all sentences…



John likes ice-cream

Why?

What rules will we need?

- (U do it..)

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Verb types - continued

- What about:

  Clinton admires honesty/Honesty admires Clinton

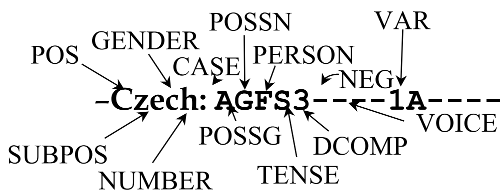
How do we encode these in a CFG?

Should we encode them?

- Colorless green ideas sleep furiously
- Revolutionary new ideas appear infrequently

Problems with this – how much info?

Agreement gets complex…



Other sentence types

- Questions:
  - Will John eat ice-cream?
  - Did John eat ice-cream?
- How do we encode this?

`Empty’ elements or categories

- Where surface phrase is displaced from its canonical syntactic position
- Examples:
  - The ice-cream was eaten vs.
  - John ate the ice-cream
  - What did John eat?
  - What did Bill say that that John thought the cat ate?
  - For What x, did Bill say… the cat ate x
  - Bush is too stubborn to talk to
  - Bush is too stubborn [x to talk to Bush]
  - Bush is too stubborn to talk to the Pope
  - Bush is too stubborn [Bush to talk to the Pope]

More interesting clause types

- Apparently “long distance” effects: ‘displacement’ of phrases from their ‘base’ positions

1. So-called ‘wh-movement’:

   What did John eat   ?

2. Topicalization (actually the same)

   On this day, it snowed two feet.

3. Other cases: so-called ‘passive’:

   The eggplant was eaten by John

- How to handle this?

We can think of this as 'fillers' and 'gaps'

- Filler= the displaced item
- Gap = the place where it belongs, as argument
- Fillers can be NPs, PPs, S's
- Gaps are *invisible*- so hard to parse! (we have to guess)
- Can be complex:

  Which book did you file__ without__ reading__ ?

  Which violins are these sonatas difficult to play__ on ___

Problems with this – how much info?

- Even verb subcategories not obvious

  John gave Mary the book → NP NP

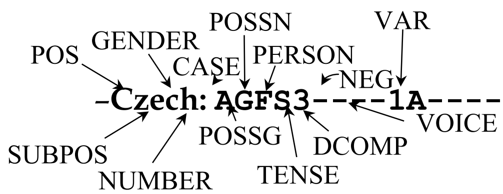
  John gave the book to Mary → NP PP

But:

John donated the book to the library

'Alternation' pattern – semantic? NO!

Agreement gets complex…



More interesting clause types

- Apparently "long distance" effects: 'displacement' of phrases from their 'base' positions

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   The eggplant was eaten by John

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`Empty' elements or categories

- Where surface phrase is displaced from its canonical syntactic position & *nothing* shows on the surface
- Examples:
  - The ice-cream was eaten vs.
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  - What did John eat?
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'missing' or empty categories

- John promised Mary ___ to leave
- John promised Mary [John to leave]
- Known as 'control'

- John persuaded Mary [___ to leave]
- John persuaded Mary [Mary to leave]

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- Can be complex:

  Which book did you file__ without__ reading__ ?

  Which violins are these sonatas difficult to play__ on ___

Gaps

- Pretend “kiss” is a pure transitive verb.
- Is “the president kissed” grammatical?
  - If so, what type of phrase is it?

- the sandwich that
- ~~I wonder what~~
- What else ~~has~~ ________

the president kissed e
Sally said the president kissed e
Sally consumed the pickle with e
Sally consumed e with the pickle

Gaps

- Object gaps:
- the sandwich that
- I wonder what
- What else has

the president kissed e
Sally said the president kissed e
Sally consumed the pickle with e
Sally consumed e with the pickle

[how could you tell the difference?]

- Subject gaps:
- the sandwich that
- I wonder what
- What else has

e kissed the president
Sally said e kissed the president

Gaps

- All gaps are really the same – a missing XP:
- the sandwich that
- I wonder what
- What else has

the president kissed e
Sally said the president kissed e
Sally consumed the pickle with e
Sally consumed e with the pickle
e kissed the president
Sally said e kissed the president

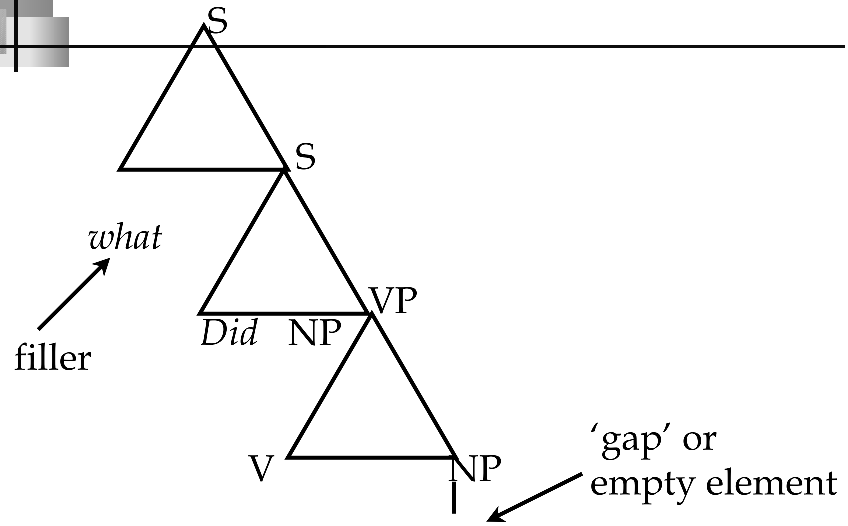
Phrases with missing NP:
X[missing=NP]
or just X/NP for short

Representation & computation questions again

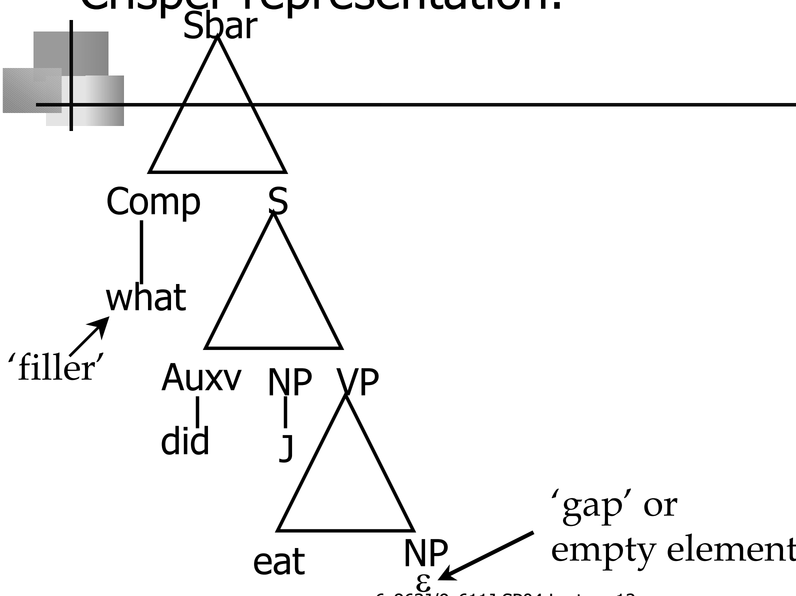
- How do we *represent* this displacement? (difference between underlying & surface forms)
- How do we *compute* it? (I.e., parse sentences that exhibit it)
- We want to recover the *underlying* structural relationship because this tells us what the predicate-argument relations are – *Who did what to whom*
- Example: *What did John eat* → For which x, x a thing, did John eat x?
- Note how the eat-x predicate-argument is established

Representations with gaps

- Let's first look at a tree with gaps:



Crisper representation:



Fillers can be arbitrarily far from gaps they match with…

- What did John say that Mary thought that the cat ate___?

Fillers and gaps

- Since 'gap' is NP going to empty string, we could just add rule, NP$\rightarrow\varepsilon$
- But this will *overgenerate* why?
- We need a way to distinguish between
  - What did John eat
  - Did John eat
- How did this work in the FSA case?

So, what do we need?

- A rule to expand NP as the empty symbol; that's easy enough: NP$\rightarrow\varepsilon$
- A way to make sure that NP is expanded as empty symbol iff there is a gap (in the right place) before/after it
- A way to link the filler and the gap
- We can do all this by futzing with the nonterminal names: *Generalized Phrase Structure Grammar (GPSG)*

Example: relative clauses

- What are they?
- Noun phrase with a sentence embedded in it:
  - The sandwich that the president ate
- What about it? What's the syntactic representation that will make the semantics *transparent?*

The sandwich$_i$ that the president ate e$_i$

OK, that's the output…what are the cfg rules?

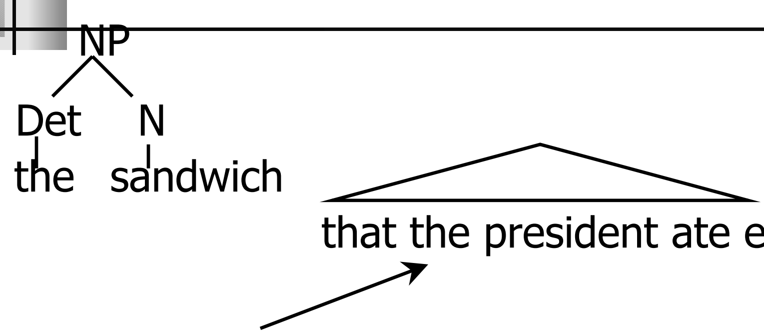
- Need to expand the object of *eat* as an empty string
- So, need rule NP$\rightarrow\varepsilon$
- But more, we need to link the head noun "the sandwich" to this position
- Let's use the fsa trick to 'remember' something – what is that trick???
- Remember?

Memory trick

- Use state of fsa to remember
- What is state in a CFG?
- The nonterminal names
- We need something like vowel harmony – sequence of states = nonterminals

the sandwich that the president ate e

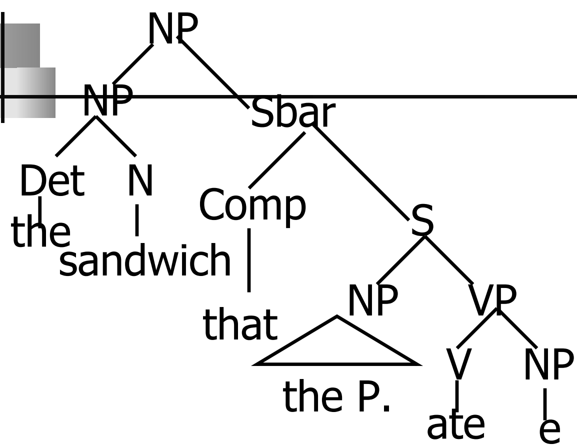
As a parse structure



What's this? We've seen it before…

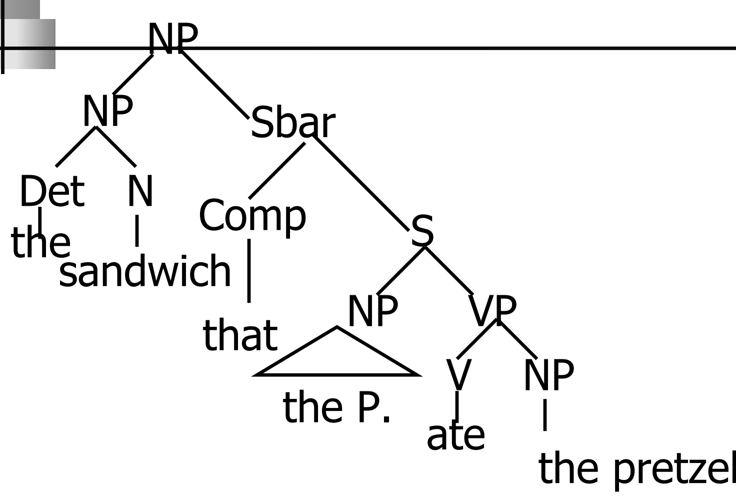
It's an Sbar = Comp+S

Parse structure for relative clause



But how to generate this and block this:

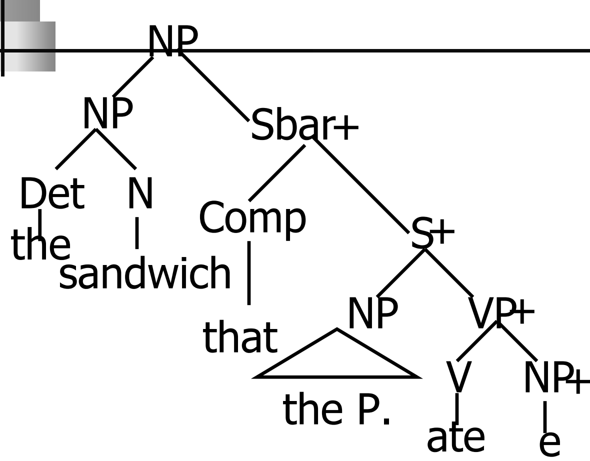
Not OK!



In short..

- We can expand out to e <u>iff</u> there is a prior NP we want to link to
- So, we need some way of 'marking' this in the state – I.e., the nonterminal
- Further, we have to somehow co-index e and 'the sandwich'
- Well: let's use a mark, say, "+"

The mark…



But we can add + except this way:

- Add as part of atomic nonterminal name
  - Before: NP→ NP Sbar
    Sbar → Comp S
    S → NP VP
    VP → VP NP
  - After: NP → NP Sbar+
    Sbar+ → Comp S+
    S+ → NP VP+
    VP+ → V NP+
    NP+ → e

Why does this work?

- Has desired effect of <u>blocking</u> 'the sandwich that the P. ate the pretzel'
- Has desired effect of allowing e exactly when there is no other object
- Has desired effect of 'linking' sandwich to the object (how?)
- Also: desired <u>configuation</u> between filler and gap (what is this?)

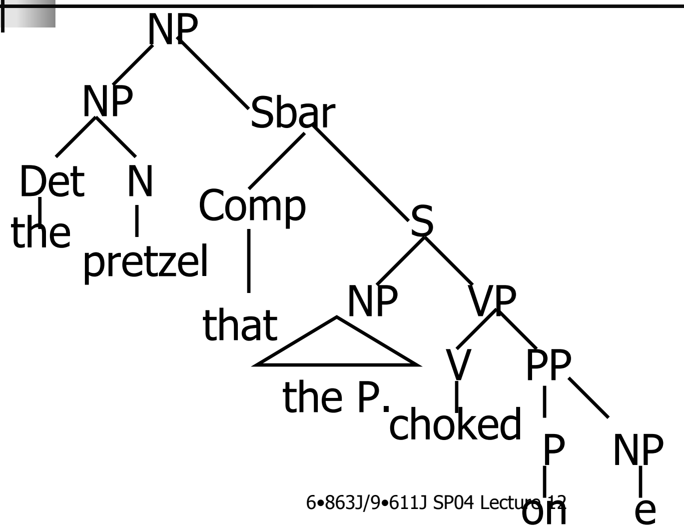
Actual ‘marks’ in the literature

- Called a ‘slash category’
- Ordinary category: Sbar, VP, NP
- Slash category: Sbar/NP, VP/NP, NP/NP
- “X/Y” is ONE atomic nonterminal
- Interpret as: Subtree X is missing a Y (expanded as e) underneath
- Example: Sbar/NP = Sbar missing NP underneath (see our example)

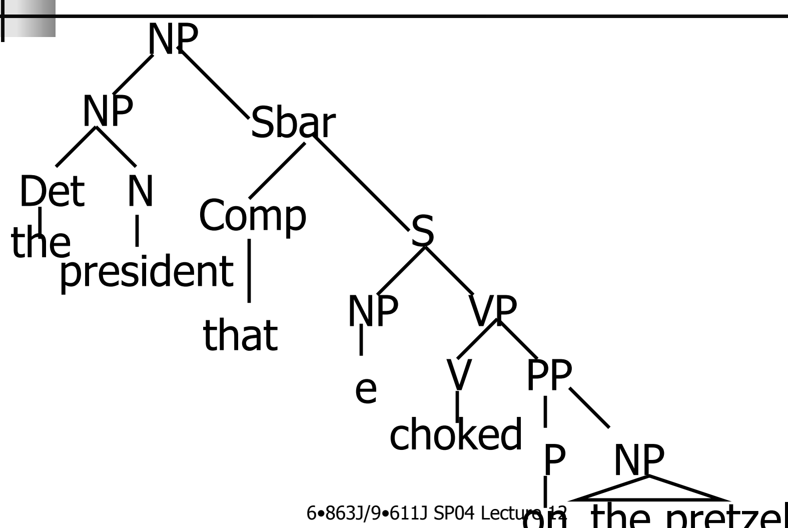
As for slash rules…

- We need slash category introduction rule, e.g., Sbar $\rightarrow$ Comp S/NP
- We need ‘elimination’ rule NP/NP$\rightarrow$e
- These are paired (why?)
- We’ll need other slash categories, e.g.,

Need PP/NP…

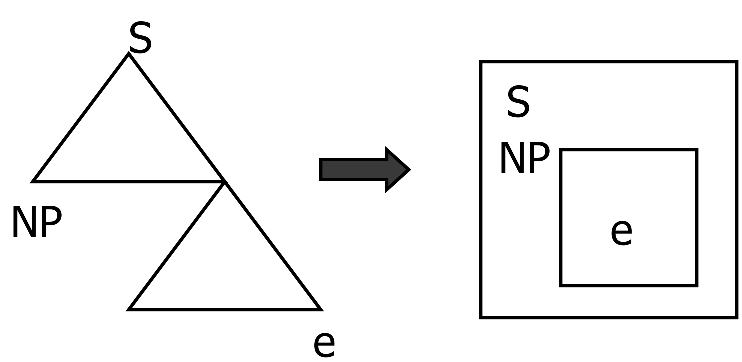


Also have 'subject' gaps



How would we write this?

Filler-gap configuration

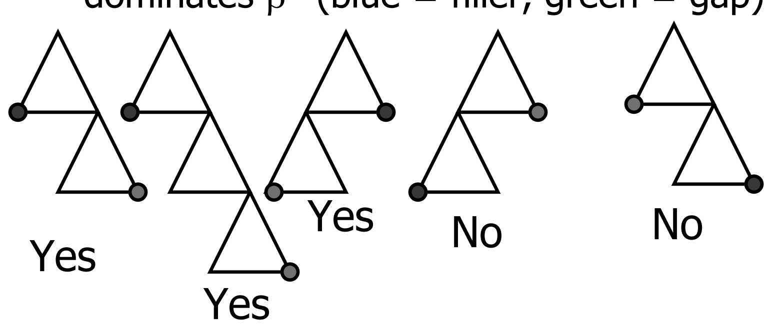


Filler-gap configuration

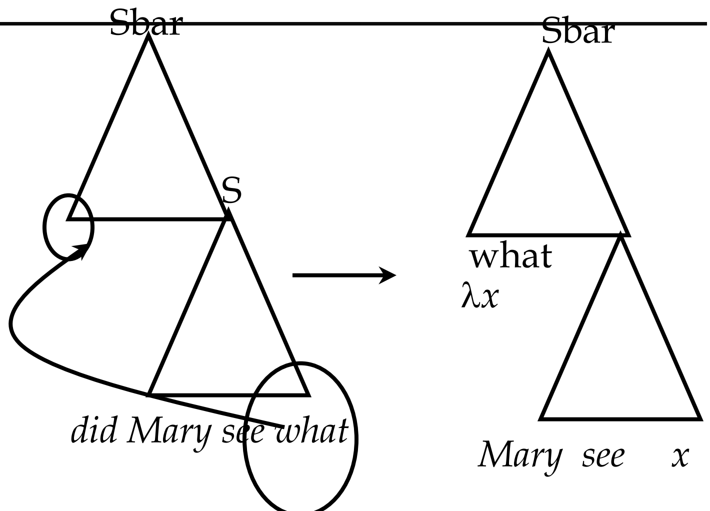
- Equivalent to notion of 'scope' for natural languages (scope of variables) ≈ Environment frame in Scheme/binding environment for 'variables' that are empty categories
- Formally: Fillers c-command gaps (constituent command)
- Definition of c-command:

C-command

- A phrase α c-commands a phrase β iff the first branching node that dominates α also dominates β (blue = filler, green = gap)



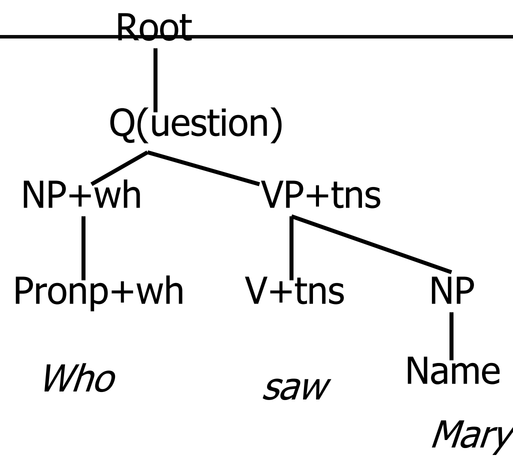
Natural for λ abstraction



Puzzle:

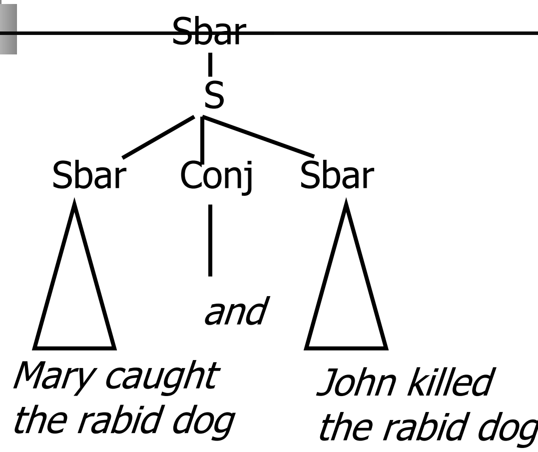
- Who saw Mary?

Idea 1: WYSIG syntax

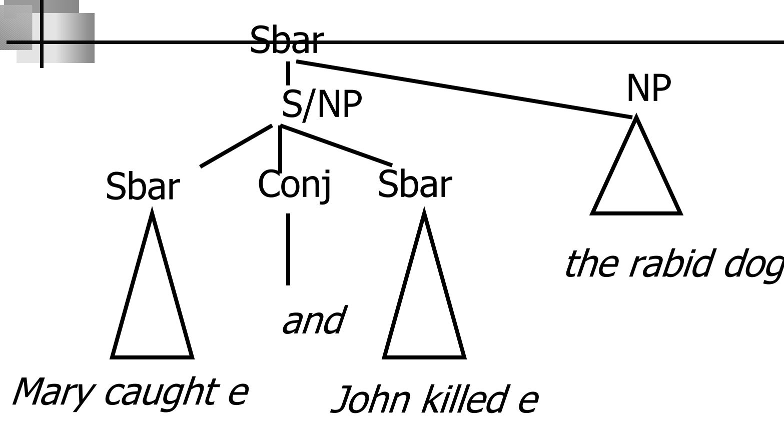


Is this right?

Another example



What if we move the object?



Why not read off the rules?

- Why can't we just build a machine to do this?
- We could induce rules from the structures
- But we have to know the right representations (structures) to begin with
- Penn treebank has structures – so could use learning program for that
- This is, as noted, a *construction based* approach
- We have to account for various *constraints*, as noted

So what?

- What about multiple fillers and gaps?
- Which violins are these sonatas difficult to play ______ on ______ ?

  these sonatas   which violins

How many context-free rules?

- For every displaced phrase, what do we do to the ‘regular’ context-free rules?
- How many kinds of displaced rules are there?

  Which book and Which pencil did Mary buy?

  *Mary asked who and what bought
- Well, how many???
- Add in agreement…

And then..

- John saw more horses than bill saw cows or Mary talked to
- John saw more horses than bill saw cows or mary talked to cats
- The kennel which Mary made and Fido sleeps in has been stolen
- The kennel which Mary made and Fido sleeps has been stolen

CFG Solution

- Encode constraints into the non-terminals
  - Noun/verb agreement

    S→ SgS

    S → PlS

    SgS → SgNP SgVP

    SgNP → SgDet SgNom
  - Verb subcategories:

    IntransVP → IntransV

    TransVP → TransV NP
  - Complex nonterminal names

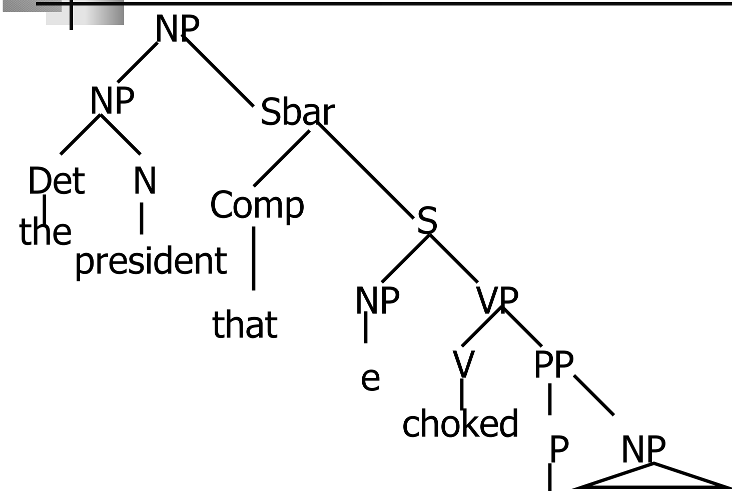
How big can the grammar get???

- But this means huge proliferation of rules…
- An alternative:
  - View terminals and non-terminals as complex objects with associated features, which take on different values
  - Write grammar rules whose application is constrained by tests on these features, e.g.
    - S → NP VP (only if the NP and VP agree in number)

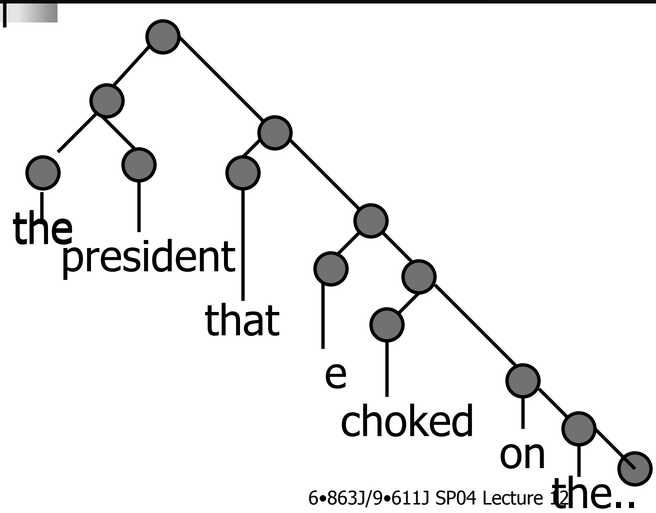
Design advantage

- Decouple skeleton syntactic structure from lexicon
- In fact, the syntactic structure really <u>is</u> a skeleton:

From this…



To this



Features are everywhere

morphology of a single word:

Verb[head=thrill, tense=present, num=sing, person=3,…] $\rightarrow$ thrills

projection of features up to a bigger phrase

VP[head=α, tense=β, num=γ…] $\rightarrow$ V[head=α, tense=β, num=γ…] NP

provided α is in the set TRANSITIVE-VERBS

agreement between sister phrases:

S[head=α, tense=β] $\rightarrow$ NP[num=γ,…] VP[head=α, tense=β, num=γ…]

provided α is in the set TRANSITIVE-VERBS

Better approach to factoring linguistic knowledge

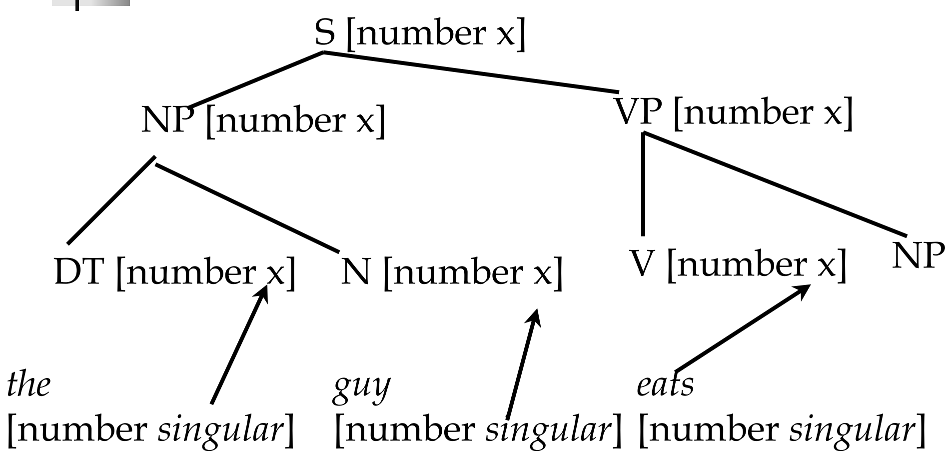
- Use the *superposition* idea: we superimpose one set of constraints on top of another:

1. Basic skeleton tree
2. Plus the added feature constraints

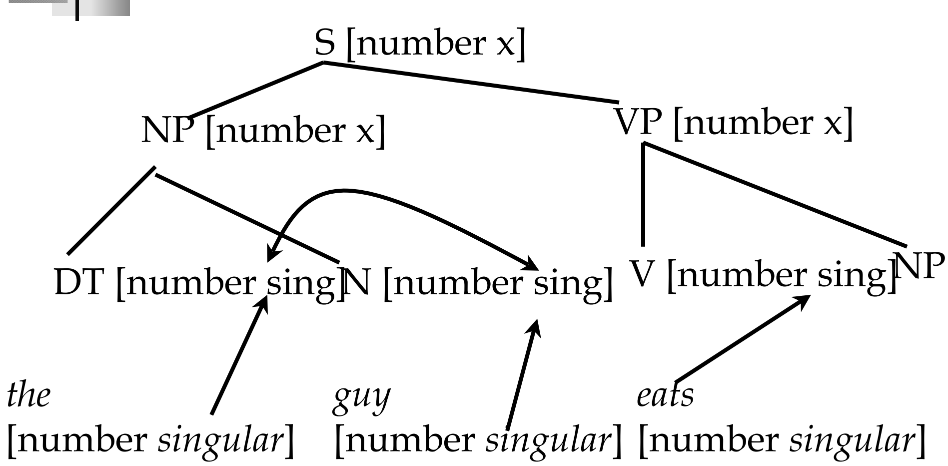
- S $\rightarrow$ NP VP

S	$\rightarrow$	NP	VP
[num x]		[num x]	[num x]
		the guy	*eats*
		[num singular]	[num singular]

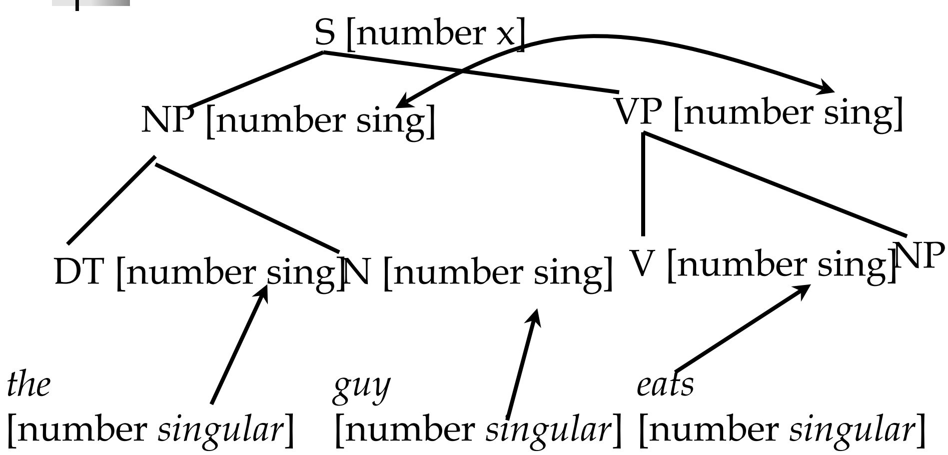
Or in tree form:



Values trickle up



Checking features



What sort of power do we need here?

- We have [*feature value*] combinations so far
- This seems fairly widespread in language
- We call these *atomic feature-value combinations*
- Other examples:

1. In English:

person feature (1st, 2nd, 3rd);

Case feature (degenerate in English: nominative, object/accusative, possessive/genitive): I know *her* vs. I know *she;*

Number feature: plural/sing; definite/indefinite

Degree: comparative/superlative

Other languages; formalizing features

- Two kinds:

1. Syntactic features, purely grammatical function

   Example: Case in German (NOMinative, ACCusative, DATive case) – relative pronoun must agree w/ Case of verb with which it is construed

   Wer micht strak is, muss klug sein

   Who not strong is, must clever be

   NOM NOM

   Who isn't strong must be clever

Continuing this example

Ich nehme, wen du mir empfiehlst

I take whomever you me recommend

ACC ACC ACC

I take whomever you recommend to me

**Ich nehme, wen du vertraust*

I take whomever you trust

ACC ACC DAT

Other class of features

2. Syntactic features w/ meaning – example, number, def/indef., adjective degree

Hungarian

Akart egy könyvet

He-wanted a book

-DEF -DEF

egy könyv amit akart

A book which he-wanted

-DEF -DEF

Feature Structures

- Sets of feature-value pairs where:
  - Features are atomic symbols
  - Values are atomic symbols or feature structures
  - Illustrated by attribute-value matrix

How to formalize?

- Let *F* be a finite set of feature names, let *A* be a set of feature values
- Let *p* be a function from feature names to permissible feature values, that is,

  $p: F \rightarrow 2^A$
- Now we can define a *word category* as a triple <*F, A, p*>
- This is a partial function from feature names to feature values

Example

- *F*= {CAT, PLU, PER}
- *p:*

  p(*CAT*)={*V, N, ADJ*}

  p(*PER*)={*1, 2, 3*}

  p(*PLU*)={*+, -*}

sleep = {[CAT V], [PLU -], [PER 1]}

sleep = {[CAT V], [PLU +], [PER 1]}

sleeps= {[CAT V], [PLU -], [PER 3]}

Checking whether features are compatible is relatively simple here…how bad can it get?

Operations on Feature Structures

- What will we need to do to these structures?
  - Check the compatibility of two structures
  - Merge the information in two structures
- We can do both using unification
- We say that two feature structures can be unified if the component features that make them up are compatible
  - [Num SG] U [Num SG] = [Num SG]
  - [Num SG] U [Num PL] fails!
  - [Num SG] U [Num []] = [Num SG]

- [Num SG] U [Pers 3] =

- Structures are <u>compatible</u> if they contain no features that are incompatible
- Unification of two feature structures:
  - Are the structures compatible?
  - If so, return the union of all feature/value pairs
- A failed unification attempt

Features, Unification and Grammars

- How do we incorporate feature structures into our grammars?
  - Assume that constituents are objects which have feature-structures associated with them
  - Associate sets of unification constraints with grammar rules
  - Constraints must be satisfied for rule to be satisfied
- For a grammar rule $\beta_0 \rightarrow \beta_1 \ldots \beta_n$
  - <β_i feature path> = Atomic value
  - <β_i feature path> = <β_j feature path>
- NB: if <u>simple</u> feat-val pairs, no arbitrary nesting, then no need for paths

Feature unification examples

(1) [agreement: [number: singular
person: first]]

(2) [agreement: [number: singular]
case: nominative]

- (1) and (2) *can* unify, producing (3):

(3) [agreement: [number: singular
person: first]
case: nominative]

(try overlapping the graph structures corresponding to these two)

Feature unification examples

1) [agreement: [number: singular
person: first]]

(2) [agreement: [number: singular]
case: nominative]

(4) [agreement: [number: singular
person: third]]

- (2) & (4) *can* unify, yielding (5):

(5) [agreement: [number: singular
person: third]
case: nominative]

- BUT (1) and (4) *cannot* unify because their values conflict on <agreement person>

- To enforce subject/verb number agreement

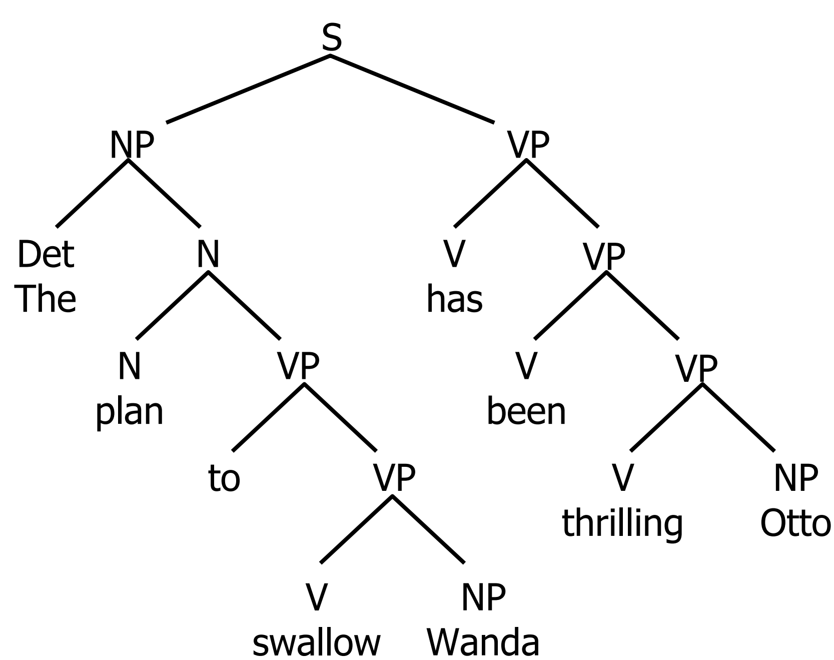
S → NP VP

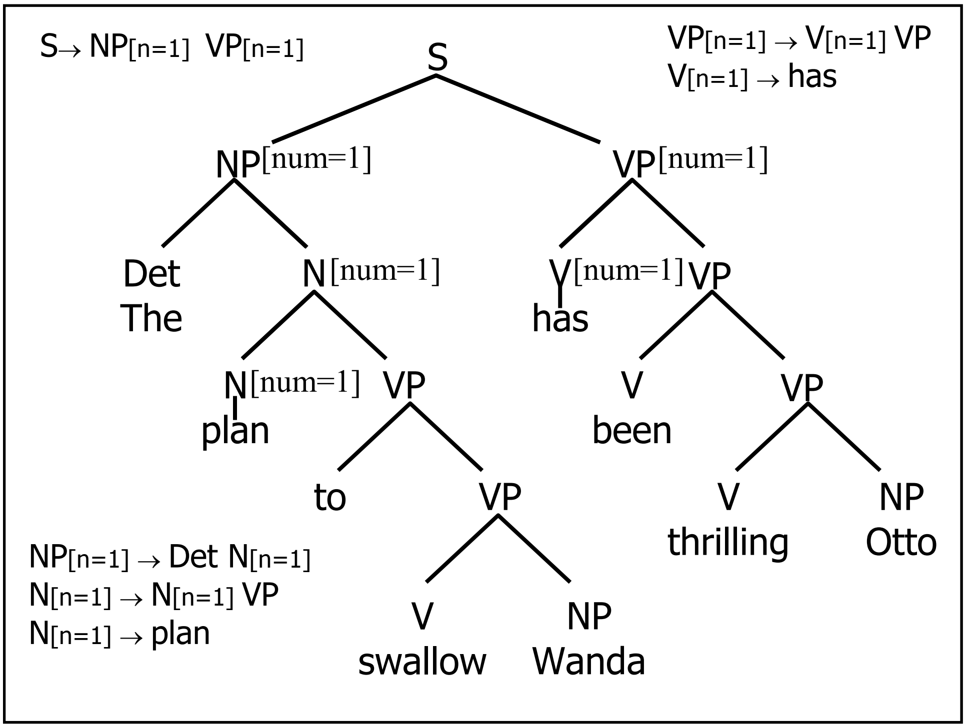
<NP NUM> = <VP NUM>

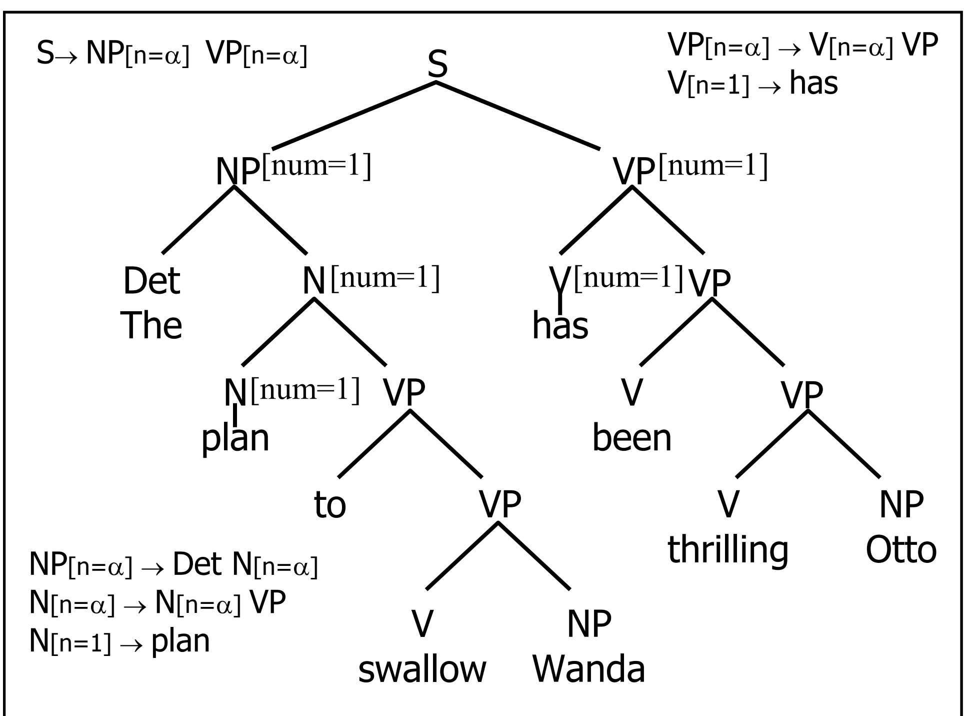
Head Features

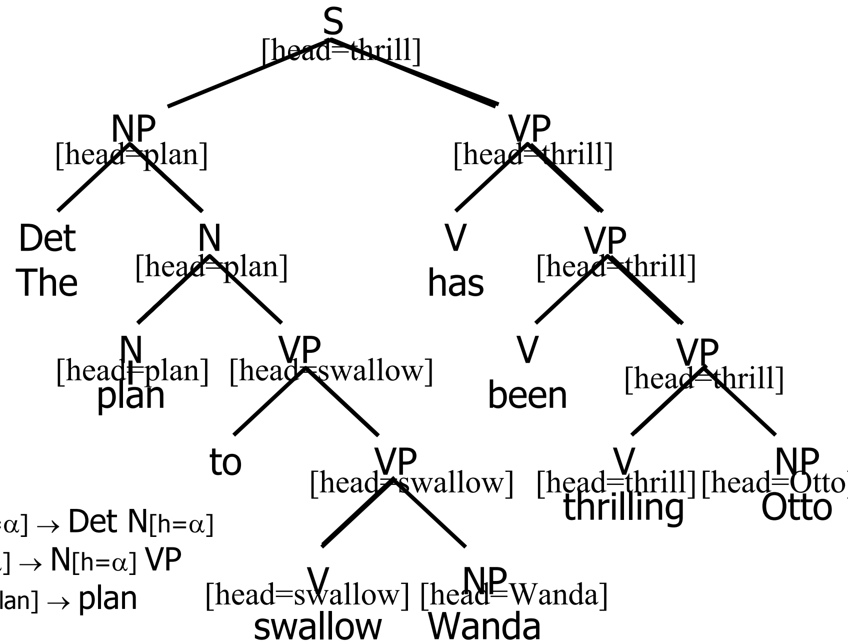
- Features of most grammatical categories are copied from <u>head</u> child to parent (e.g. from V to VP, Nom to NP, N to Nom, …)
- These normally written as 'head' features, e.g.

VP → V NP
<VP HEAD> = <V HEAD>
NP → Det Nom
<NP→ HEAD> = <Nom HEAD>
<Det HEAD AGR> = <Nom HEAD AGR>
Nom → N
<Nom HEAD> = <N HEAD>




S→ NP[n=1] VP[n=1]
VP[n=1] → V[n=1] VP
V[n=1] → has
S
NP[num=1]
VP[num=1]
Det
The
N[num=1]
V[num=1]
has
VP
N[num=1]
plan
VP
V
been
VP
to
VP
V
thrilling
NP
Otto
NP[n=1] → Det N[n=1]
N[n=1] → N[n=1] VP
N[n=1] → plan
V
swallow
NP
Wanda

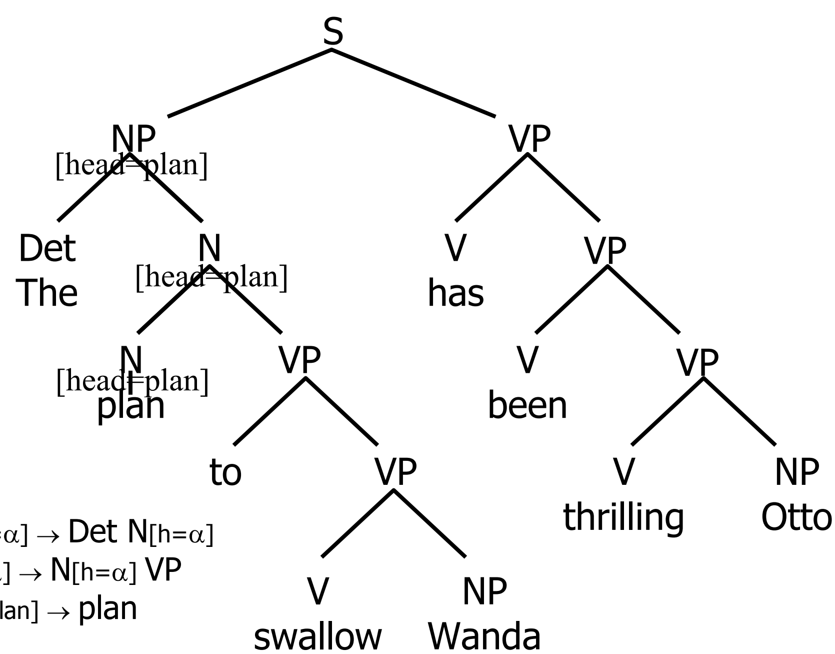

S→ NP[n=α] VP[n=α]
VP[n=α] → V[n=α] VP
V[n=1] → has
S
NP[num=1]
VP[num=1]
Det
The
N[num=1]
V[num=1]
has
VP
N[num=1]
plan
VP
V
been
VP
to
VP
V
thrilling
NP
Otto
NP[n=α] → Det N[n=α]
N[n=α] → N[n=α] VP
N[n=1] → plan
V
swallow
NP
Wanda



$NP_{[h=\alpha]} \rightarrow Det\ N_{[h=\alpha]}$

$N_{[h=\alpha]} \rightarrow N_{[h=\alpha]}\ VP$

$N_{[h=plan]} \rightarrow plan$

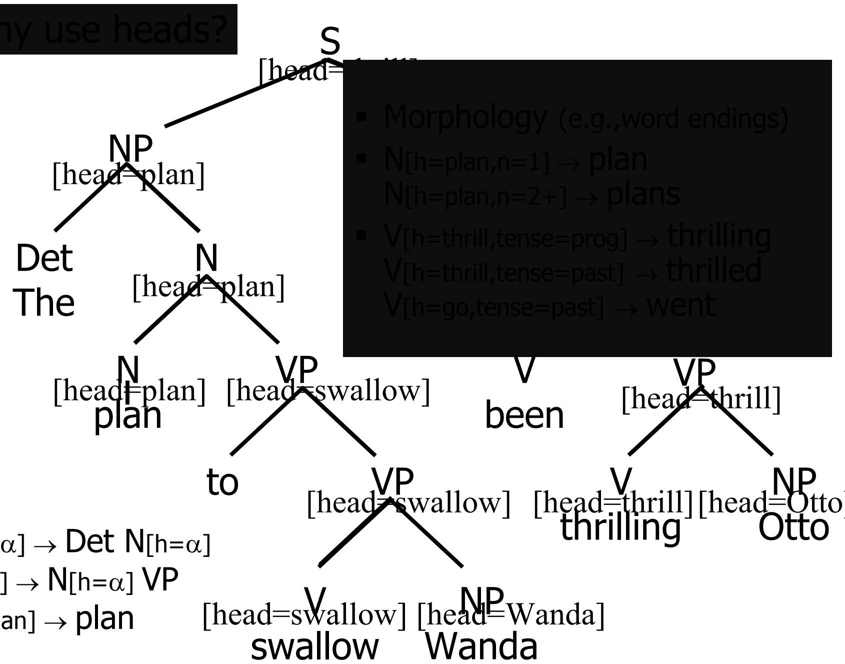


$NP_{[h=\alpha]} \rightarrow Det\ N_{[h=\alpha]}$

$N_{[h=\alpha]} \rightarrow N_{[h=\alpha]}\ VP$

$N_{[h=plan]} \rightarrow plan$

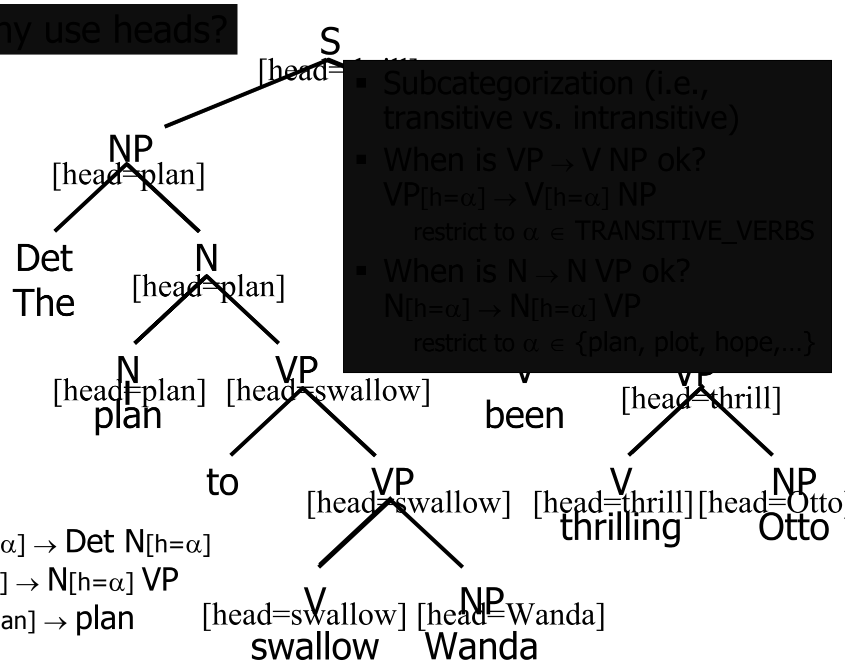
[redacted]



[redacted]

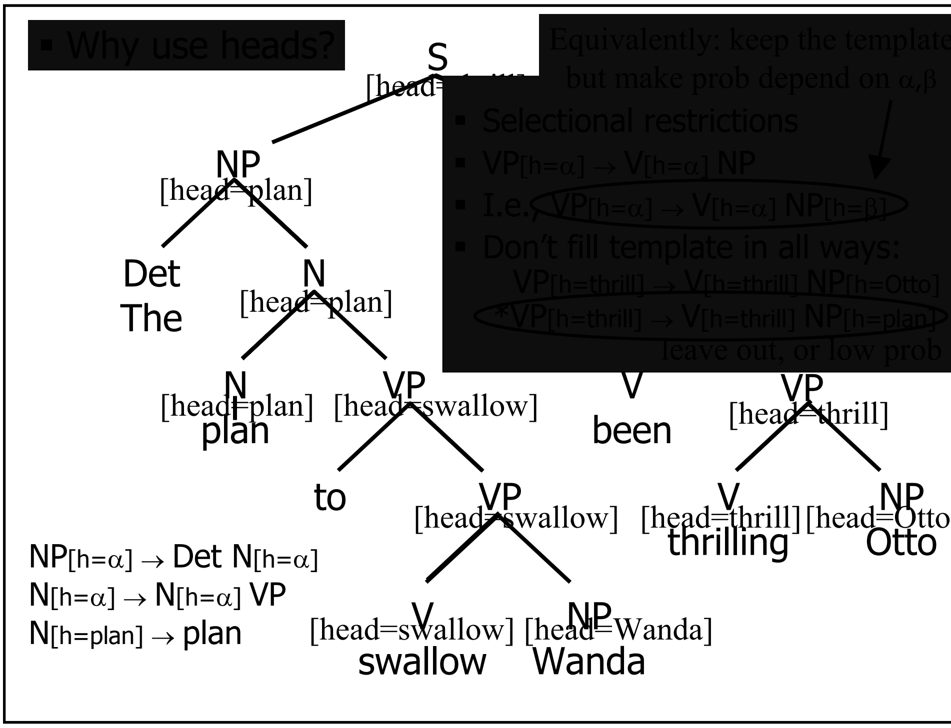
NP[h=α] → Det N[h=α]
N[h=α] → N[h=α] VP
N[h=plan] → plan

[redacted]



[redacted]

NP[h=α] → Det N[h=α]
N[h=α] → N[h=α] VP
N[h=plan] → plan



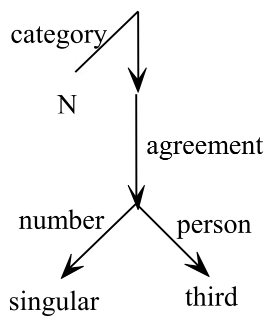
- How do we define 3plNP?
- How does this improve over the CFG solution?
- Feature values can be feature structures themselves
- Useful when certain features commonly co-occur, e.g. number and person

- Feature path: path through structures to value (e.g.

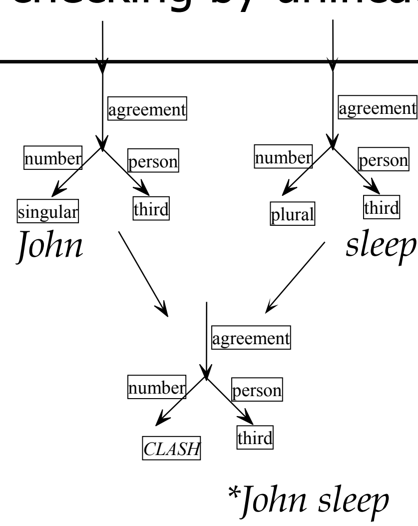
  Agr → Num → SG

Features and grammars

[category: N
agreement: [person: third
number: singular]]



Feature checking by unification



Our feature structures

- **NP[agr ?B] -> DET[agr ?B] N[agr ?B]**
- **VP[fin ?A, agr ?B] -> V2[fin ?A, agr ?B] NP**
- **Maria NAME[agr [person 3, plural -]]**

Kimmo entry for Verb (eg, 'coge' after analysis):

- **+e Suffix "[fin +, agr [tense pres, mode ind, person 3, plural -]]"**

How can we parse with feature structures?

- Unification operator: takes 2 features structures and returns *either* a merged feature structure or *fail*
- Input structures represented as DAGs
  - Features are labels on edges
  - Values are atomic symbols or DAGs
- Unification algorithm goes through features in one input DAG_1 trying to find corresponding features in DAG_2 – if all match, success, else fail
- WE WILL USE MUCH SIMPLER kind of feature structure

Features and Earley Parsing

- Goal:
  - Use feature structures to provide richer representation
  - Block entry into chart of ill-formed constituents
- Changes needed to Earley
  - Add feature structures to grammar rules, & lexical entries
  - Add field to states containing set representing feature structure corresponding to state of parse, e.g.

    S → • NP VP, [0,0], [], Set= [Agr [plural -]]

- Add new test to Completer operation
  - Recall: Completer adds new states to chart by finding states whose • 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
- New test for whether to enter a state in the chart
  - Now feature structures may differ, so check must be more complex
  - Suppose feature structure is <u>more specific</u> than existing one tied to this state? Do we add it?

Evidence that you don't need this much power

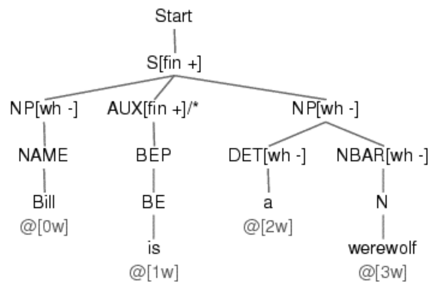
- Linguistic evidence: looks like you just check whether features are *nondistinct*, rather than equal or not – variable *matching,* not variable substitution
- Full unification lets you generate unnatural languages:
  a^i, *s.t. i a power of 2* – e.g., *a, aa, aaaa, aaaaaaaa, …*
  why is this 'unnatural' – another (seeming) property of natural languages:

Natural languages seem to obey a *constant growth* property

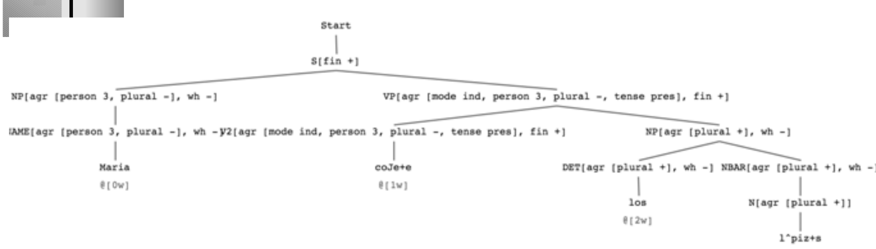
Parsing with features – hook from kimmo to earley

- Features written in this form (in Kimmo)
- **+as Suffix "[fin +, agr [tense pres, mode ind, person 2, plural -]]"**
- In general:
  [feature value, feature [feature val, …, feature val]]

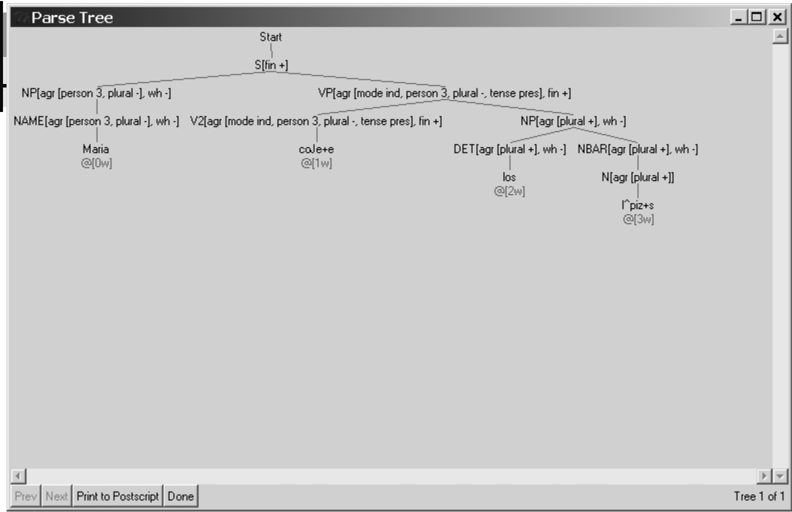
Where wolf

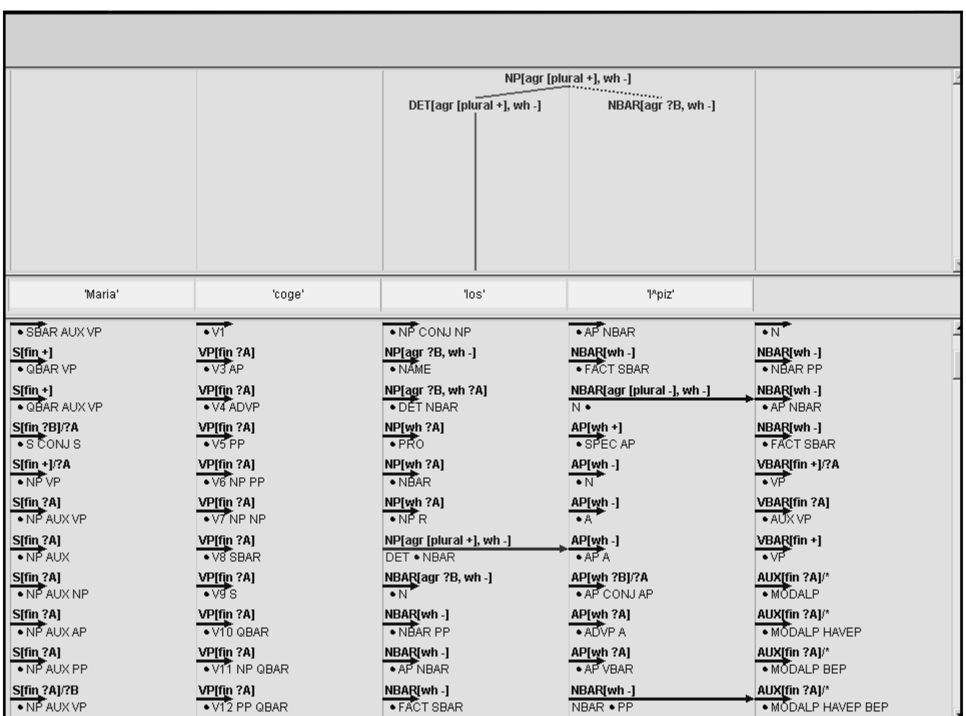


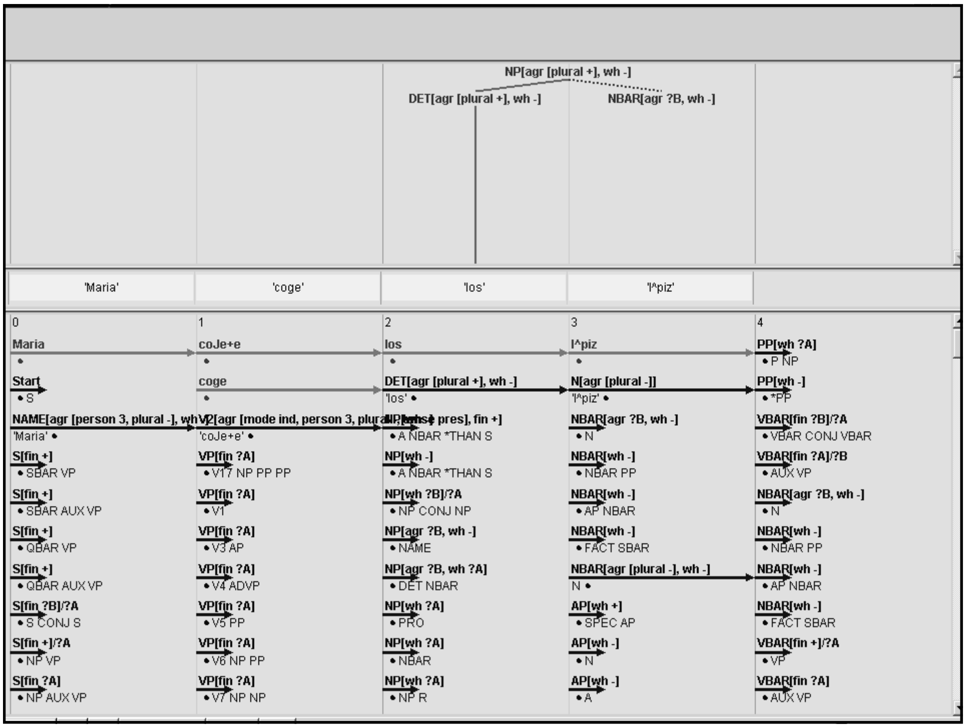
Start
S[fin +]
NP[wh -]
AUX[fin +]/*
NP[wh -]
NAME
BEP
DET[wh -]
NBAR[wh -]
Bill
@[0w]
BE
is
@[1w]
a
@[2w]
N
werewolf
@[3w]

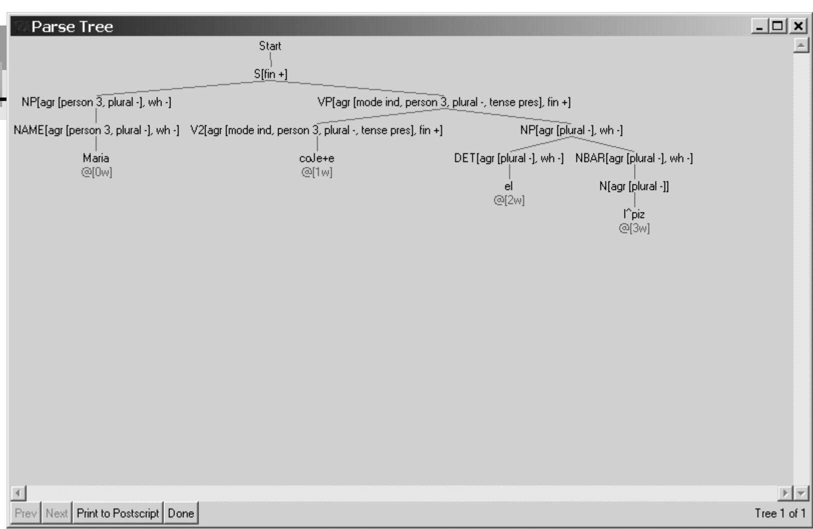


Start
S[fin +]
NP[agr [person 3, plural -], wh -]
VP[agr [mode ind, person 3, plural -, tense pres], fin +]
V2[agr [mode ind, person 3, plural -, tense pres], fin +]
NP[agr [plural +], wh -]
Maria
@[0w]
coJe+e
@[1w]
DET[agr [plural +], wh -]
NBAR[agr [plural +], wh -]
los
@[2w]
N[agr [plural +]]
l^piz+s
@[3w]


Parse Tree
Start
S[fin +]
NP[agr [person 3, plural -], wh -]
VP[agr [mode ind, person 3, plural -, tense pres], fin +]
NAME[agr [person 3, plural -], wh -]
V2[agr [mode ind, person 3, plural -, tense pres], fin +]
NP[agr [plural +], wh -]
Maria
@[0w]
coJe+e
@[1w]
DET[agr [plural +], wh -]
NBAR[agr [plural +], wh -]
los
@[2w]
N[agr [plural +]]
l^piz+s
@[3w]
Prev
Next
Print to Postscript
Done
Tree 1 of 1


NP[agr [plural +], wh -]
DET[agr [plural +], wh -]
NBAR[agr ?B, wh -]
'Maria'
'coge'
'los'
'l^piz'
• SBAR AUX VP
S[fin +]
• QBAR VP
S[fin +]
• QBAR AUX VP
S[fin ?B]/?A
• S CONJ S
S[fin +]/?A
• NP VP
S[fin ?A]
• NP AUX VP
S[fin ?A]
• NP AUX
S[fin ?A]
• NP AUX NP
S[fin ?A]
• NP AUX AP
S[fin ?A]
• NP AUX PP
S[fin ?A]/?B
• NP AUX VP
• V1
VP[fin ?A]
• V3 AP
VP[fin ?A]
• V4 ADVP
VP[fin ?A]
• V5 PP
VP[fin ?A]
• V6 NP PP
VP[fin ?A]
• V7 NP NP
VP[fin ?A]
• V8 SBAR
VP[fin ?A]
• V9 S
VP[fin ?A]
• V10 QBAR
VP[fin ?A]
• V11 NP QBAR
VP[fin ?A]
• V12 PP QBAR
• NP CONJ NP
NP[agr ?B, wh -]
• NAME
NP[agr ?B, wh ?A]
• DET NBAR
NP[wh ?A]
• PRO
NP[wh ?A]
• NBAR
NP[wh ?A]
• NP R
NP[agr [plural +], wh -]
DET • NBAR
NBAR[agr ?B, wh -]
• N
NBAR[wh -]
• NBAR PP
NBAR[wh -]
• AP NBAR
NBAR[wh -]
• FACT SBAR
• AP NBAR
NBAR[wh -]
• FACT SBAR
NBAR[agr [plural -], wh -]
N •
AP[wh +]
• SPEC AP
AP[wh -]
• N
AP[wh -]
• A
AP[wh -]
• AP A
AP[wh ?B]/?A
• AP CONJ AP
AP[wh ?A]
• ADVP A
AP[wh ?A]
• AP VBAR
NBAR[wh -]
NBAR • PP
• N
NBAR[wh -]
• NBAR PP
NBAR[wh -]
• AP NBAR
NBAR[wh -]
• FACT SBAR
VBAR[fin +]/?A
• VP
VBAR[fin ?A]
• AUX VP
VBAR[fin +]
• VP
AUX[fin ?A]/*
• MODALP
AUX[fin ?A]/*
• MODALP HAVEP
AUX[fin ?A]/*
• MODALP BEP
AUX[fin ?A]/*
• MODALP HAVEP BEP


NP[agr [plural +], wh -]
DET[agr [plural +], wh -]
NBAR[agr ?B, wh -]
'Maria'
'coge'
'los'
'l^piz'
0
Maria
Start
• S
NAME[agr [person 3, plural -], wh
'Maria' •
S[fin +]
• SBAR VP
S[fin +]
• SBAR AUX VP
S[fin +]
• QBAR VP
S[fin +]
• QBAR AUX VP
S[fin ?B]/?A
• S CONJ S
S[fin +]/?A
• NP VP
S[fin ?A]
• NP AUX VP
1
coJe+e
coge
V2[agr [mode ind, person 3, plura
'coJe+e' •
VP[fin ?A]
• V17 NP PP PP
VP[fin ?A]
• V1
VP[fin ?A]
• V3 AP
VP[fin ?A]
• V4 ADVP
VP[fin ?A]
• V5 PP
VP[fin ?A]
• V6 NP PP
VP[fin ?A]
• V7 NP NP
2
los
DET[agr [plural +], wh -]
'los' •
• A NBAR *THAN S
NP[wh -]
• A NBAR *THAN S
NP[wh ?B]/?A
• NP CONJ NP
NP[agr ?B, wh -]
• NAME
NP[agr ?B, wh ?A]
• DET NBAR
NP[wh ?A]
• PRO
NP[wh ?A]
• NBAR
NP[wh ?A]
• NP R
3
l^piz
N[agr [plural -]]
'l^piz' •
NBAR[agr ?B, wh -]
• N
NBAR[wh -]
• NBAR PP
NBAR[wh -]
• AP NBAR
NBAR[wh -]
• FACT SBAR
NBAR[agr [plural -], wh -]
N •
AP[wh +]
• SPEC AP
AP[wh -]
• N
AP[wh -]
• A
4
PP[wh ?A]
• P NP
PP[wh -]
• *PP
VBAR[fin ?B]/?A
• VBAR CONJ VBAR
VBAR[fin ?A]/?B
• AUX VP
NBAR[agr ?B, wh -]
• N
NBAR[wh -]
• NBAR PP
NBAR[wh -]
• AP NBAR
NBAR[wh -]
• FACT SBAR
VBAR[fin +]/?A
• VP
VBAR[fin ?A]
• AUX VP


Parse Tree
Start
S[fin +]
NP[agr [person 3, plural -], wh -]
VP[agr [mode ind, person 3, plural -, tense pres], fin +]
NAME[agr [person 3, plural -], wh -]
V2[agr [mode ind, person 3, plural -, tense pres], fin +]
NP[agr [plural -], wh -]
Maria
@[0w]
coJe+e
@[1w]
DET[agr [plural -], wh -]
NBAR[agr [plural -], wh -]
el
@[2w]
N[agr [plural -]]
l^piz
@[3w]
Prev
Next
Print to Postscript
Done
Tree 1 of 1

Constant growth property

Claim: ∃ Bound k on the 'distance gap' between any two consecutive sentences in this list, which can be specified in advance (fixed)

- 'Intervals' between valid sentences cannot get too big – cannot grow w/o bounds
- We can do this a bit more formally

Constant growth

- Dfn. A language L is *semilinear* if the number of occurrences of each symbol in any string of L is a linear combination of the occurrences of these symbols in some fixed, finite set of strings of L.
- Dfn. A language L is *constant growth* if there is a constant c_0 and a finite set of constants C s.t. for all $w \in L$, where $|w| > c_0 \; \exists \; w' \in L$ s.t. $|w| = |w'| + c$, some $c \in C$
- Fact. (Parikh, 1971). Context-free languages are semilinear, and constant-growth
- Fact. (Berwick, 1983). The power of 2 language is non constant-growth

General feature grammars – how violate these properties

- Take example from so-called "lexical-functional grammar" but this applies as well to any general unification grammar
- Lexical functional grammar (LFG): add checking rules to CF rules (also variant HPSG)

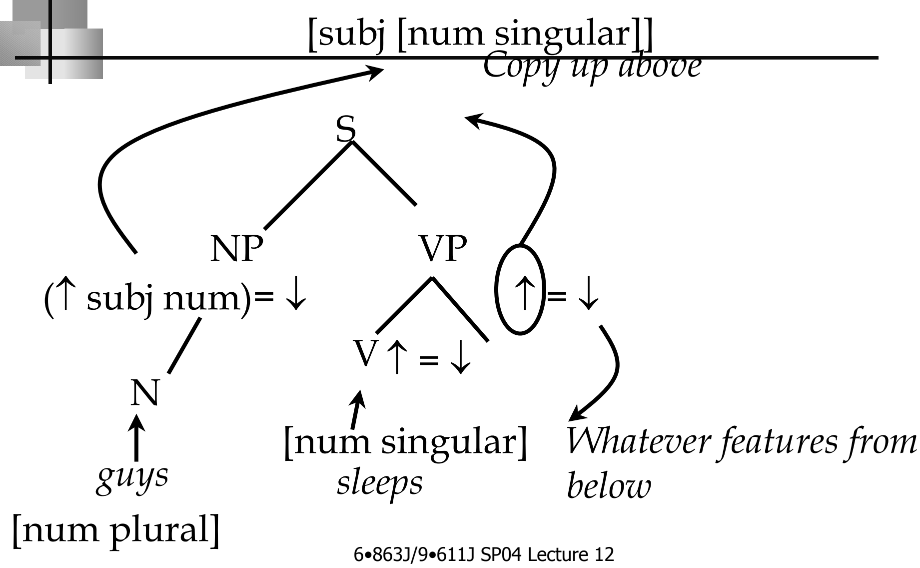
Example LFG

- Basic CF rule:
  $S \rightarrow NP\ VP$
- Add corresponding 'feature checking'

$S \rightarrow$	NP	VP
	$(\uparrow$ subj num$) = \downarrow$	$\uparrow = \downarrow$

- What is the interpretation of this?

Applying feature checking in LFG



Alas, this allows non-constant growth, unnatural languages

- Can use LFG to generate power of 2 language
- Very simple to do
- A→ A A

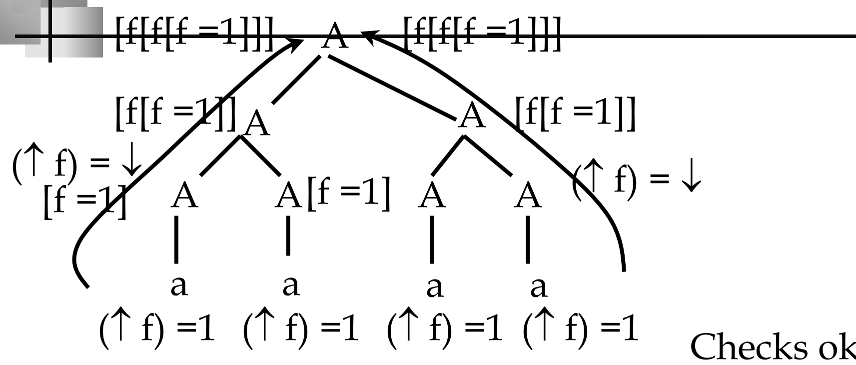
  (↑ f) = ↓ (↑ f) = ↓

  A → a

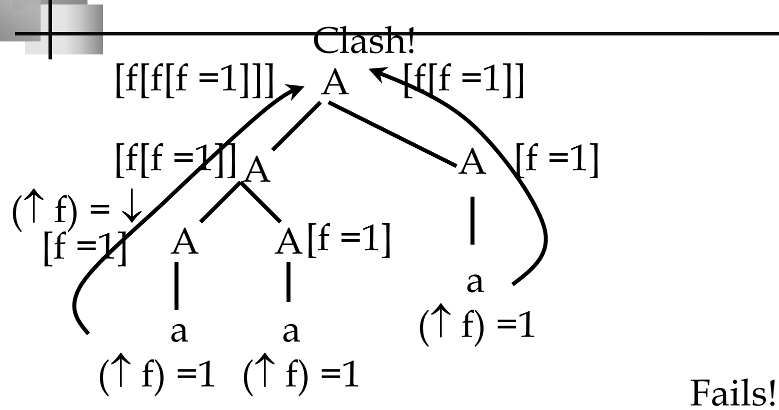
  (↑ f) =1

Lets us `count' the number of embeddings on the right & the left – make sure a power of 2

Example



If mismatch anywhere, get a feature clash…



Conclusion then

- If we use too powerful a formalism, it lets us write ‘unnatural’ grammars
- This puts burden on the person writing the grammar – which may be ok.
- However, child doesn’t presumably do this (they don’t get ‘late days’)
- We want to strive for automatic programming – ambitious goal