Introduction to Syntax and Context-Free Grammars

Slides with contributions from Owen Rambow, Dan Jurafsky and James Martin

Announcements

- Thanks for answering poll (60 voted so far)
- Poll re-opened so please answer if you haven't
  - Majority likes in class interaction
  - Slimmer majority feels Piazza is useful despite flaws
  - Majority would prefer another platform
  - Majority prefer online questions to verbal ones
  - Majority would prefer more lecture to discussion
- Comments
  - Certain kinds of questions are more suitable
  - Some really like the polls (e.g., Video students)

Looking ahead

- Today: grammars, Context Free and Dependency
- Thursday: Context Free Grammars
- Tuesday: Dependency parsing
- Your homework: Learning a dependency parser

What is Syntax?

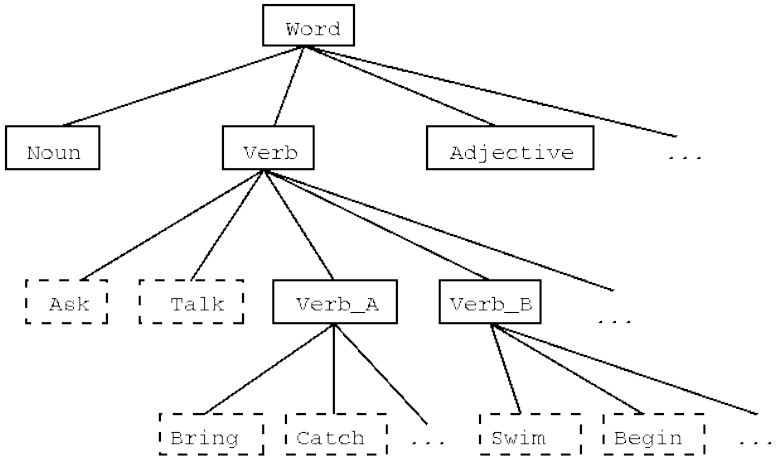
- Study of structure of language
- How words are arranged in a sentence and the relationship between them.
- Goal: relate surface form (perception) to semantics (meaning)

What Syntax is Not

- Phonology: study of sound systems and how sounds combine
- Morphology: study of how words are formed from smaller parts (morphemes)
- Semantics: study of meaning of language

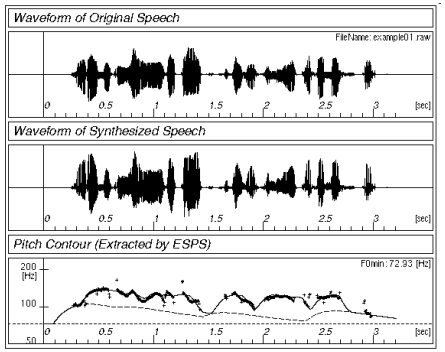
Syntax as an interface

Representational Device



Simplified View of Linguistics

Phonology

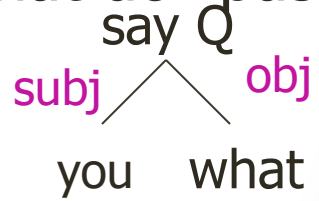


⇔ /waddyasai/

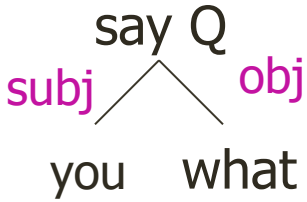
Morphology /waddyasai/ ⇔ what did you say

What did you say ⇔ what do+past2ndP say

Syntax what do you say ⇔



Semantics



⇔ Q[λx. say(you, x)]

The Big Picture

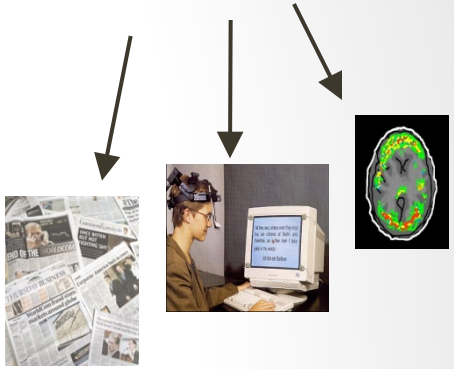
Formalisms

- Data structures
- Formalisms (e.g., CFG)
- Algorithms
- Distributional Models

?

Empirical Matter

?



Maud expects there to be a riot
*Teri promised there to be a riot
Maud expects the shit to hit the fan
*Teri promised the shit to hit the fan

?

?

Linguistic Theory

What About Chomsky?

- At birth of formal language theory (comp sci) and formal linguistics
- Major contribution: syntax is **cognitive** reality
- Humans able to learn languages quickly, but not all languages ⇒ **universal grammar** is biological
- Goal of syntactic study: find universal **principles and** language-specific **parameters**
- Specific Chomskyan theories change regularly
- General ideas adopted by almost all contemporary syntactic theories ("principles-and-parameters-type theories")

Types of Linguistic Theories

- **Prescriptive**: "prescriptive linguistics" is an oxymoron
  - **Prescriptive grammar:** how people ought to talk
- **Descriptive**: provide account of syntax of a language
  - **Descriptive grammar**: how people do talk
  - often appropriate for NLP engineering work
- **Explanatory**: provide principles-and-parameters style account of syntax of (preferably) several languages

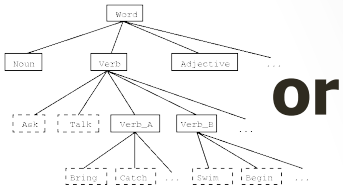
The Big Picture

Empirical Matter

Formalisms

- Data structures
- Formalisms (e.g., CFG)
- Algorithms
- Distributional Models

?



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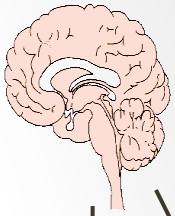

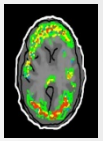

Maud expects there to be a riot
*Teri promised there to be a riot
Maud expects the shit to hit the fan
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?

?

Linguistic Theory

Need for Syntax

- Grammar checkers
- Question answering
- Information extraction
- Machine translation

- Given variability in language, helps to normalize

key ideas of syntax

- Constituency (we'll spend most of our time on this)
- Subcategorization
- Grammatical relations
- Movement/long-distance dependency

Structure in Strings

- Some words: *the a small nice big very boy girl sees likes*
- Some good sentences:
  - *the boy likes a girl*
  - *the small girl likes the big girl*
  - *a very small nice boy sees a very nice boy*
- Some bad sentences:
  - **the boy the girl*
  - **small boy likes nice girl*
- Can we find subsequences of words (**constituents**) which in some way behave alike?

Structure in Strings
Proposal 1

- Some words: *the a small nice big very boy girl sees likes*
- Some good sentences:
  - (the) boy (likes a girl)
  - (the small) girl (likes the big girl)
  - (a very small nice) boy (sees a very nice boy)
- Some bad sentences:
  - *(the) boy (the girl)
  - *(small) boy (likes the nice girl)

Structure in Strings
Proposal 2

- Some words: *the a small nice big very boy girl sees likes*
- Some good sentences:
  - (the boy) likes (a girl)
  - (the small girl) likes (the big girl)
  - (a very small nice boy) sees (a very nice boy)
- Some bad sentences:
  - *(the boy) (the girl)
  - *(small boy) likes (the nice girl)

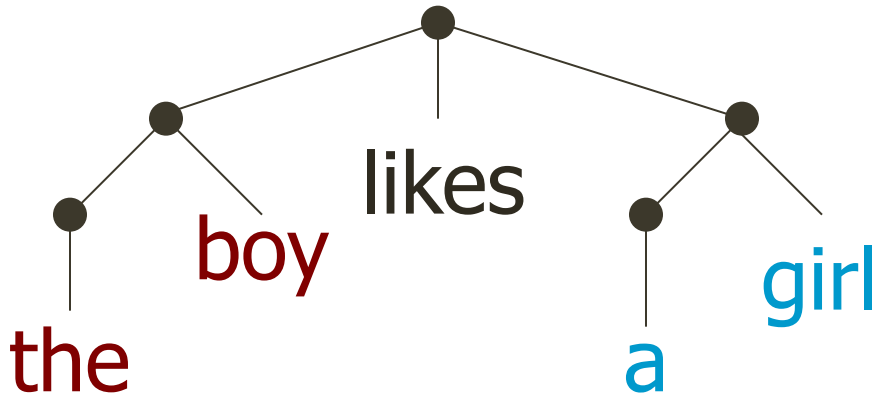
- *Is proposal 1 or proposal 2 better?*
- *Why?*

More Structure in Strings

- Some words: *the a small nice big very boy girl sees likes*
- Some good sentences:
  - ((the) boy) likes ((a) girl)
  - ((the) (small) girl) likes ((the) (big) girl)
  - ((a) ((very) small) (nice) boy) sees ((a) ((very) nice) girl)
- Some bad sentences:
  - *((the) boy) ((the) girl)
  - *((small) boy) likes ((the) (nice) girl)

From Substrings to Trees

- (((the) boy) likes ((a) girl))

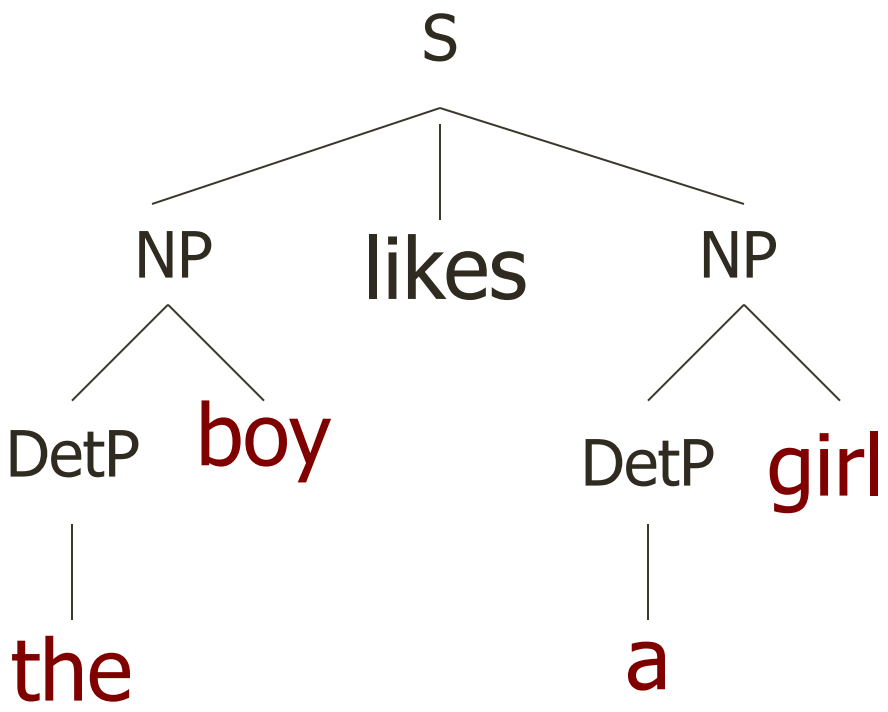


Node Labels?

- (((the) boy) likes ((a) girl))
- Choose constituents so each one has one non-bracketed word: the **head**
- Group words by distribution of constituents they head (part-of-speech, POS):
  - Noun (N), verb (V), adjective (Adj), adverb (Adv), determiner (Det)
- Category of constituent: XP, where X is POS
  - NP, S, AdjP, AdvP, DetP

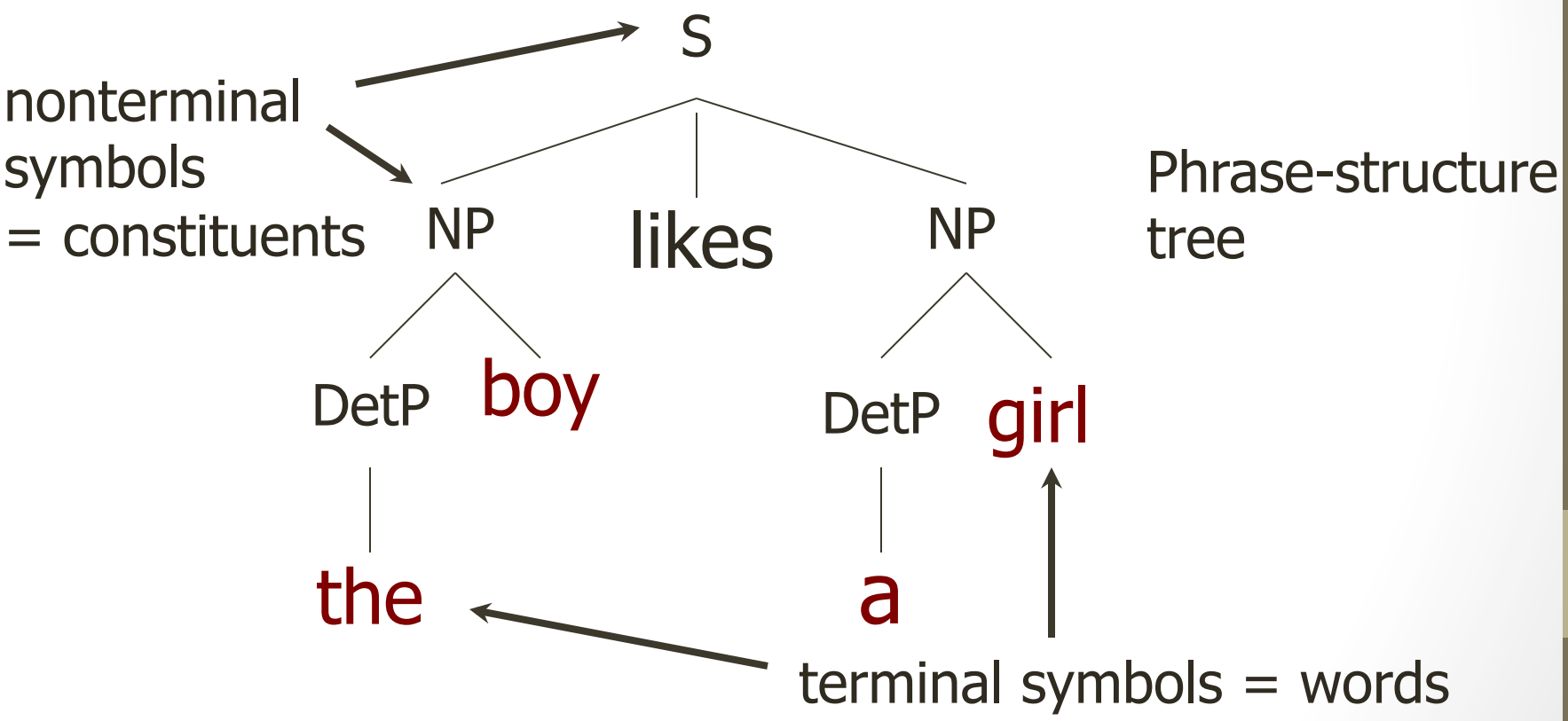
Node Labels

- (((the/Det) boy/N) likes/V ((a/Det) girl/N))



Types of Nodes

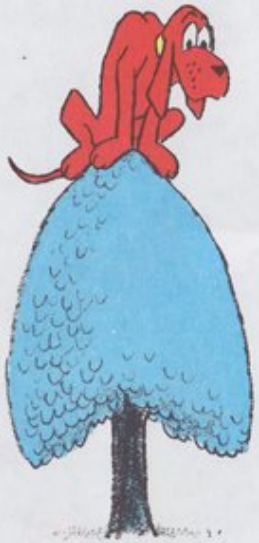
- (((the/Det) boy/N) likes/V ((a/Det) girl/N))



Go, Dog. Go!

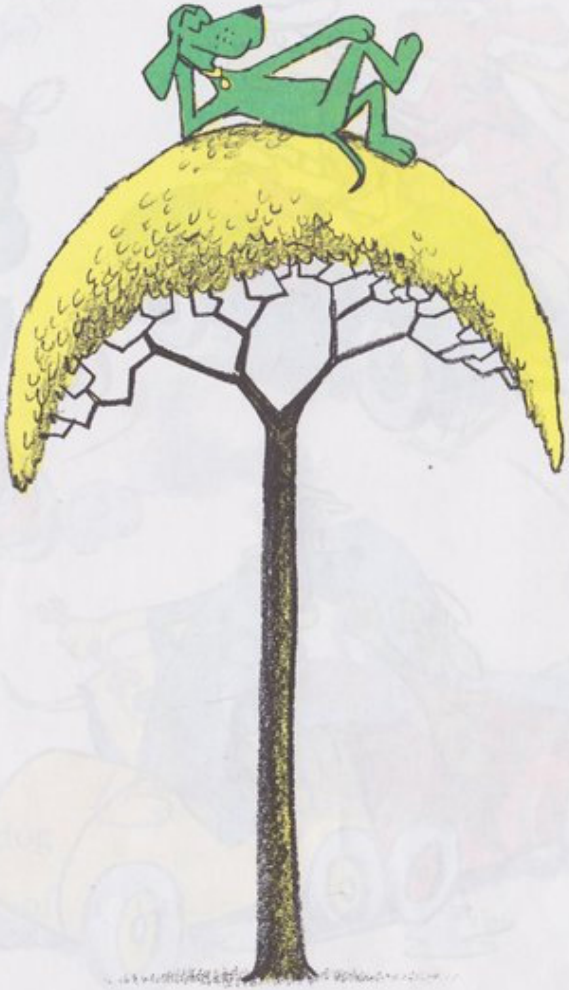
by P.D.Eastman

A red dog
on a blue tree.

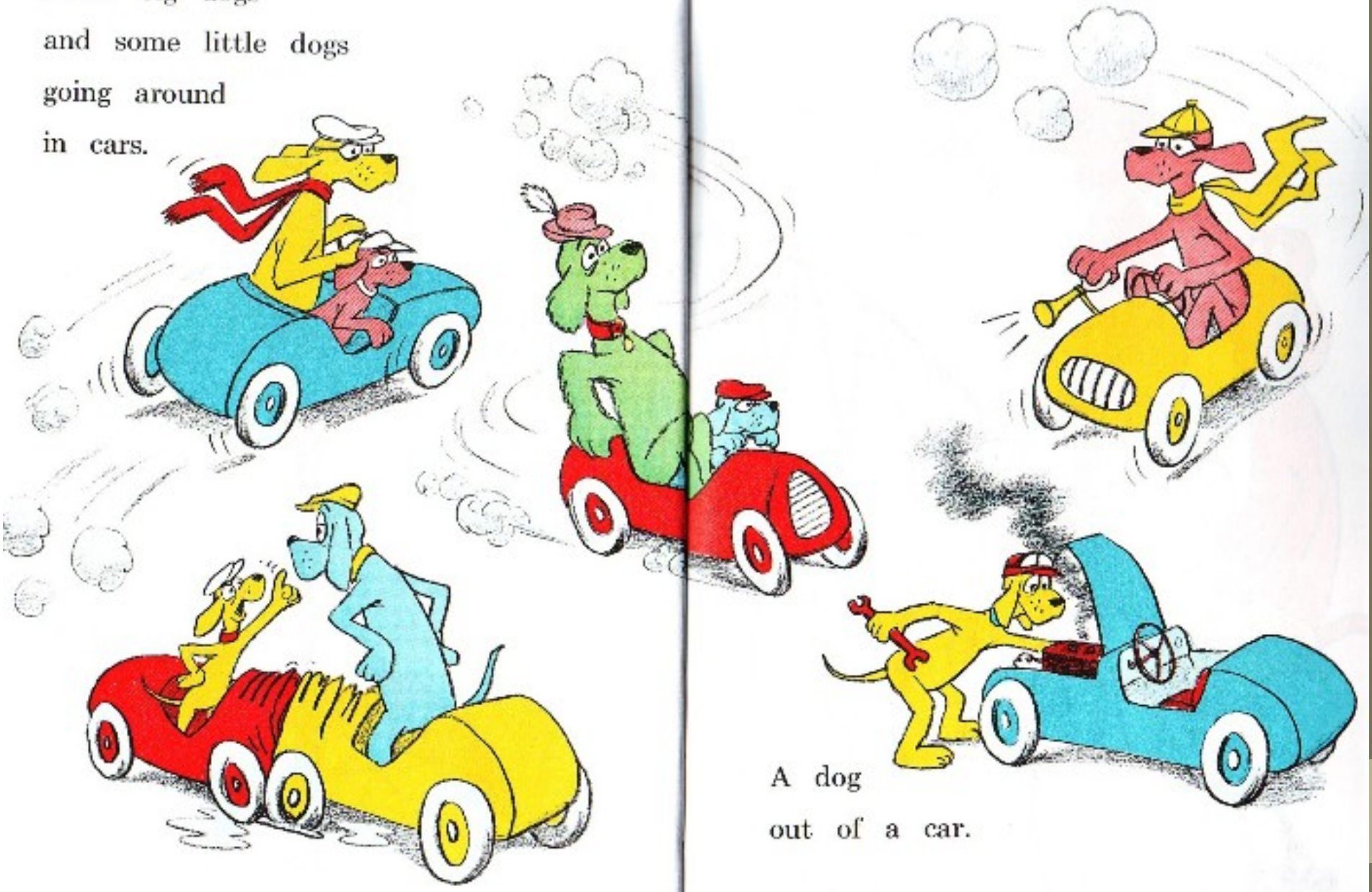


A blue dog
on a red tree.

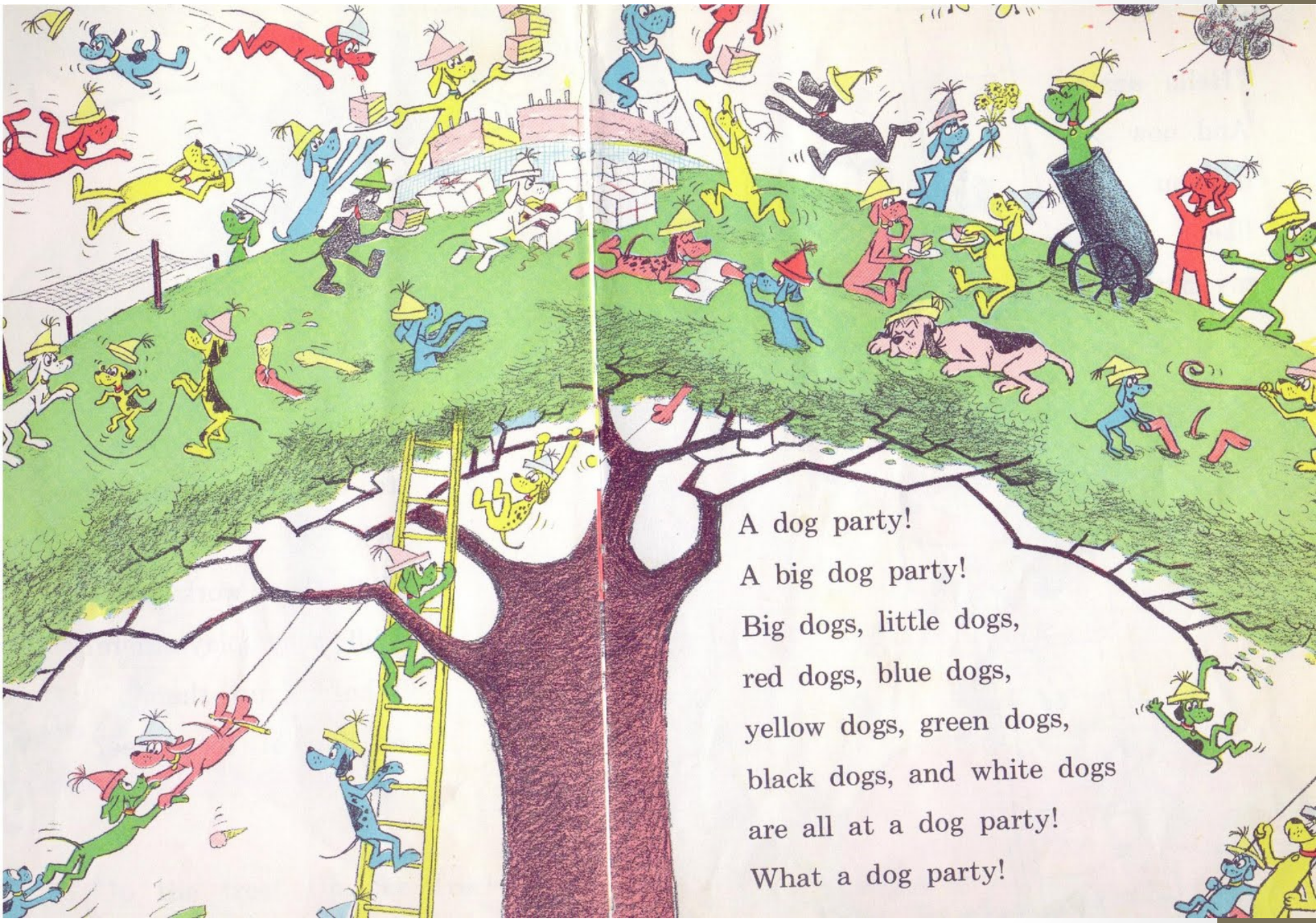
A green dog
on a yellow tree.



Some big dogs
and some little dogs
going around
in cars.



A dog
out of a car.



A dog party!
A big dog party!
Big dogs, little dogs,
red dogs, blue dogs,
yellow dogs, green dogs,
black dogs, and white dogs
are all at a dog party!
What a dog party!

Constituency (Review)

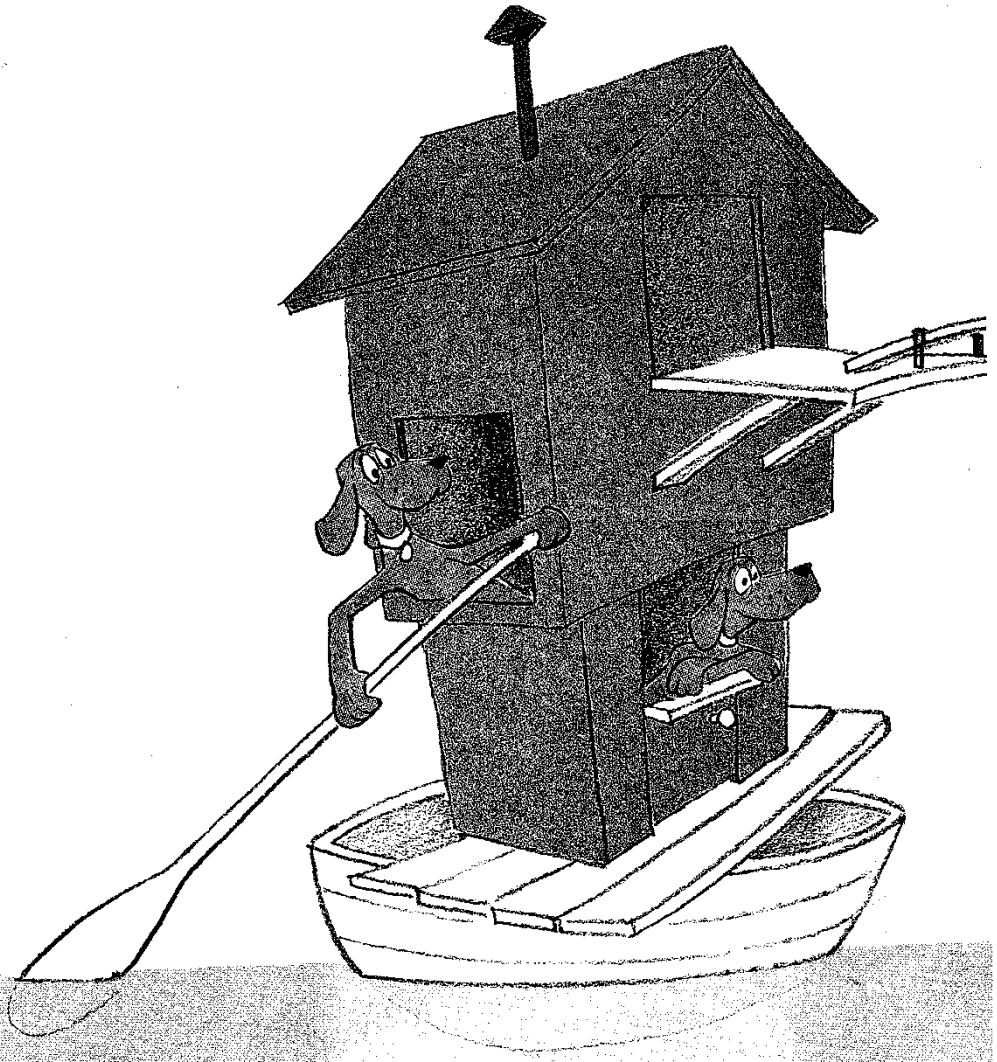
- E.g., Noun phrases (NPs)
  - *A red dog on a blue tree*
  - *A blue dog on a red tree*
  - *Some big dogs and some little dogs*
  - *A dog*
  - *We*
  - *Big dogs, little dogs, red dogs, blue dogs, yellow dogs, green dogs, black dogs, and white dogs*
- How do we know these form a constituent?

Constituency (II)

- They can all appear before a verb:
  - Some big dogs and some little dogs are going around in cars…
  - Big dogs, little dogs, red dogs, blue dogs, yellow dogs, green dogs, black dogs, and white dogs are all at a dog party!
  - I do not
- But individual words can't always appear before verbs:
  - *little are going…
  - *blue are…
  - *and are
- Must be able to state generalizations like:
  - Noun phrases occur before verbs

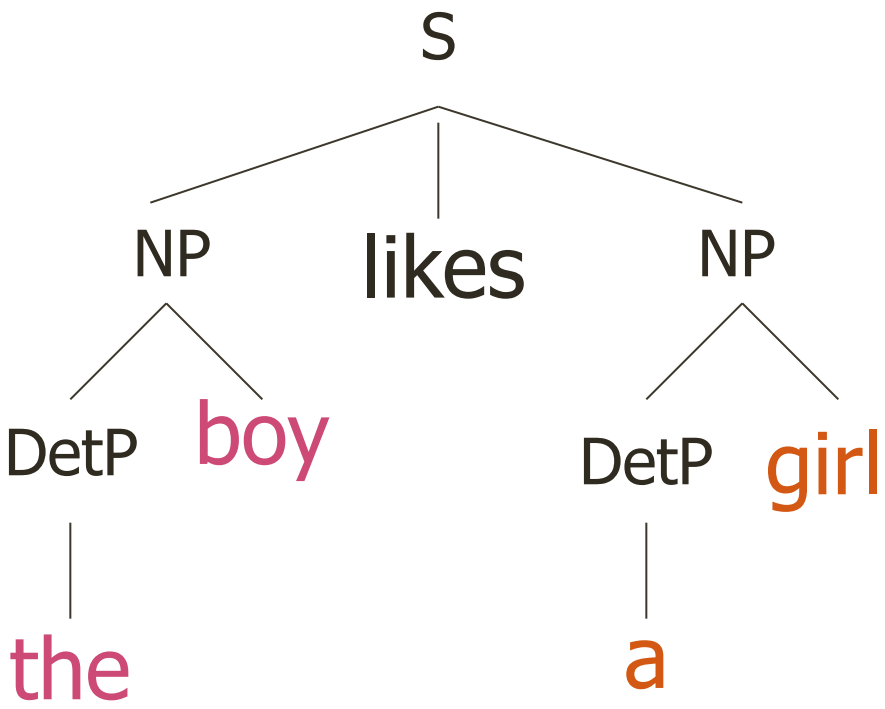
Constituency (III)

- Preposing and postposing:
  - Under a tree is a yellow dog.
  - A yellow dog is under a tree.
- But not:
  - *Under, is a yellow dog a tree.
  - *Under a is a yellow dog tree.
- Prepositional phrases notable for ambiguity in attachment

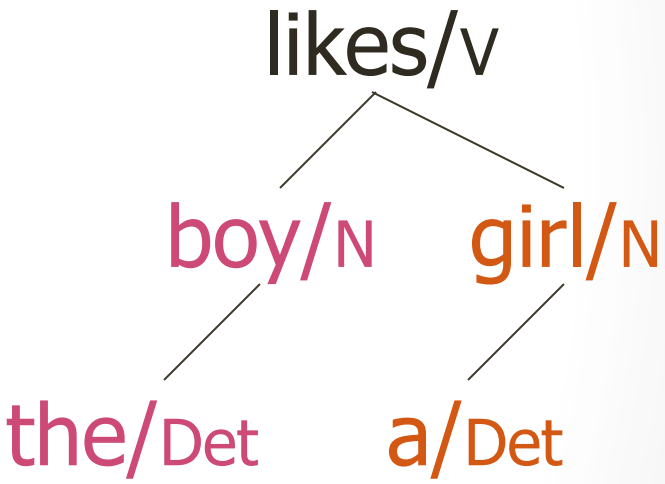


Two dogs
in a house
on a boat
in the water.

Phrase Structure and Dependency Structure

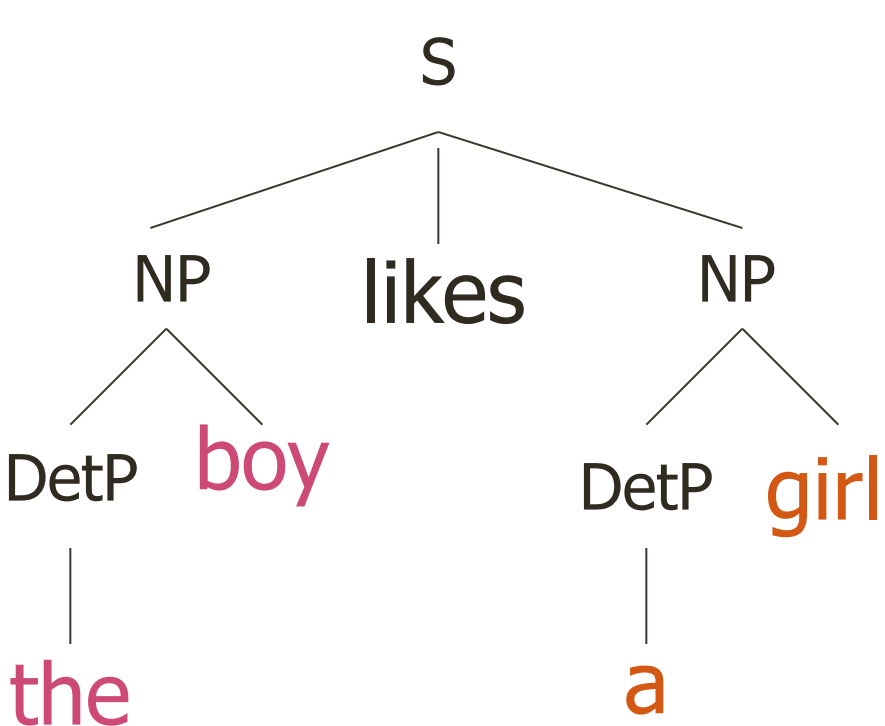


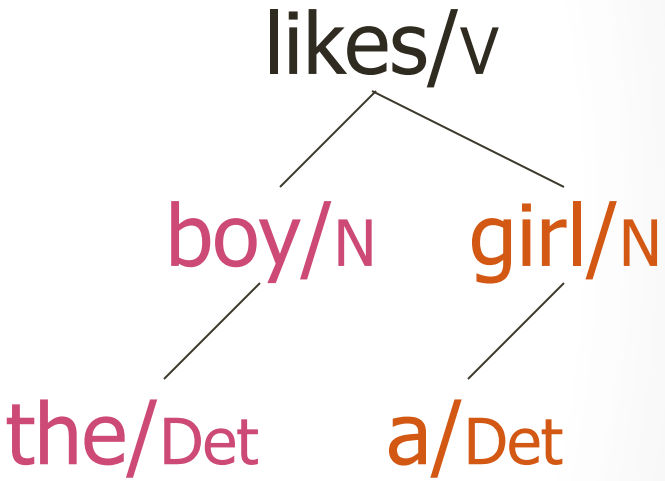
Only leaf nodes labeled with words!



All nodes are labeled with words!

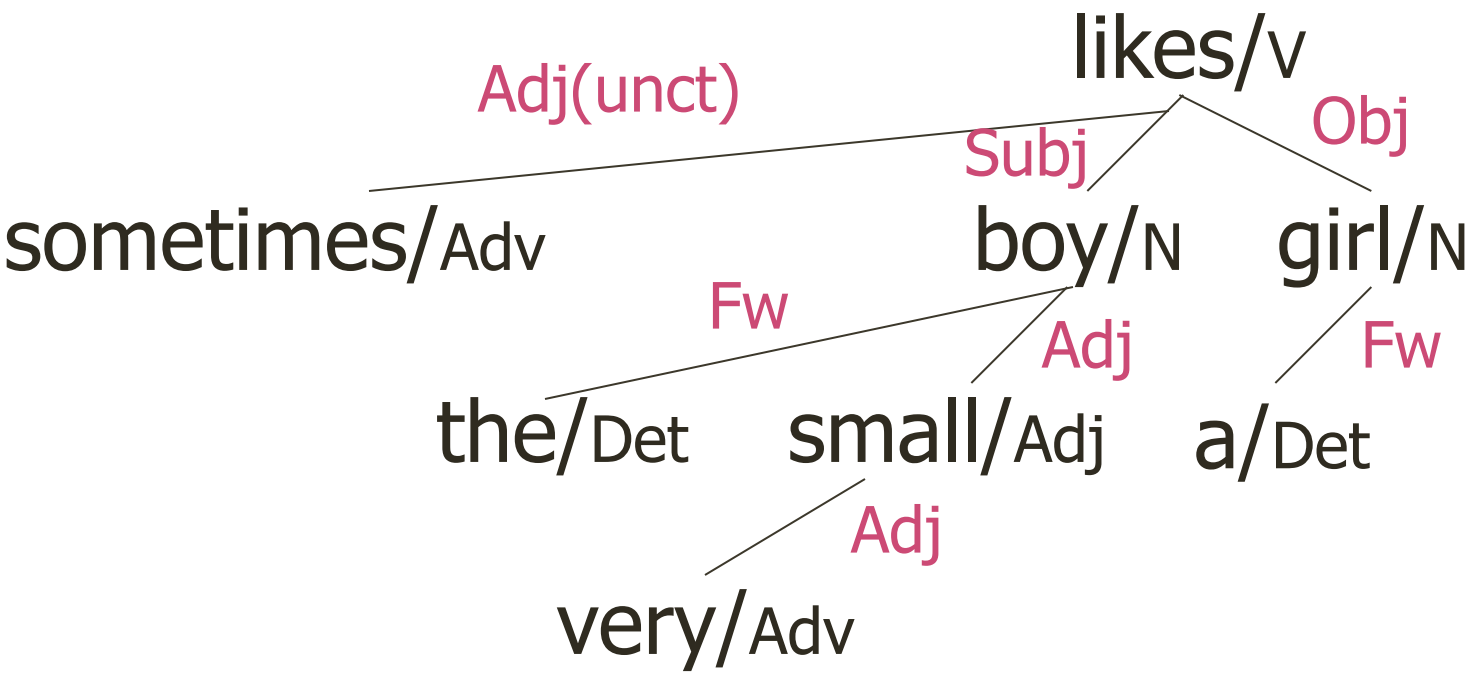
Phrase Structure and Dependency Structure (ctd)





Representationally equivalent if each nonterminal node has one lexical daughter (its head)

Types of Dependency



Grammatical Relations

- Types of relations between words
  - Arguments: subject, object, indirect object, prepositional object
  - Adjuncts: temporal, locative, causal, manner, …
  - Function Words

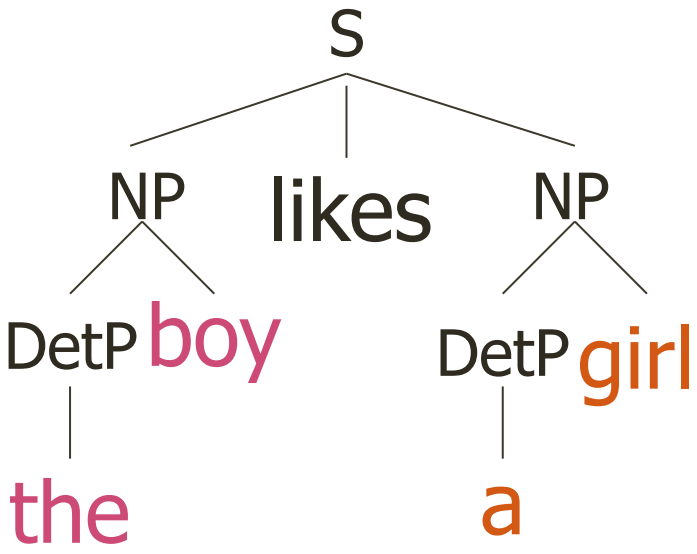
Subcategorization

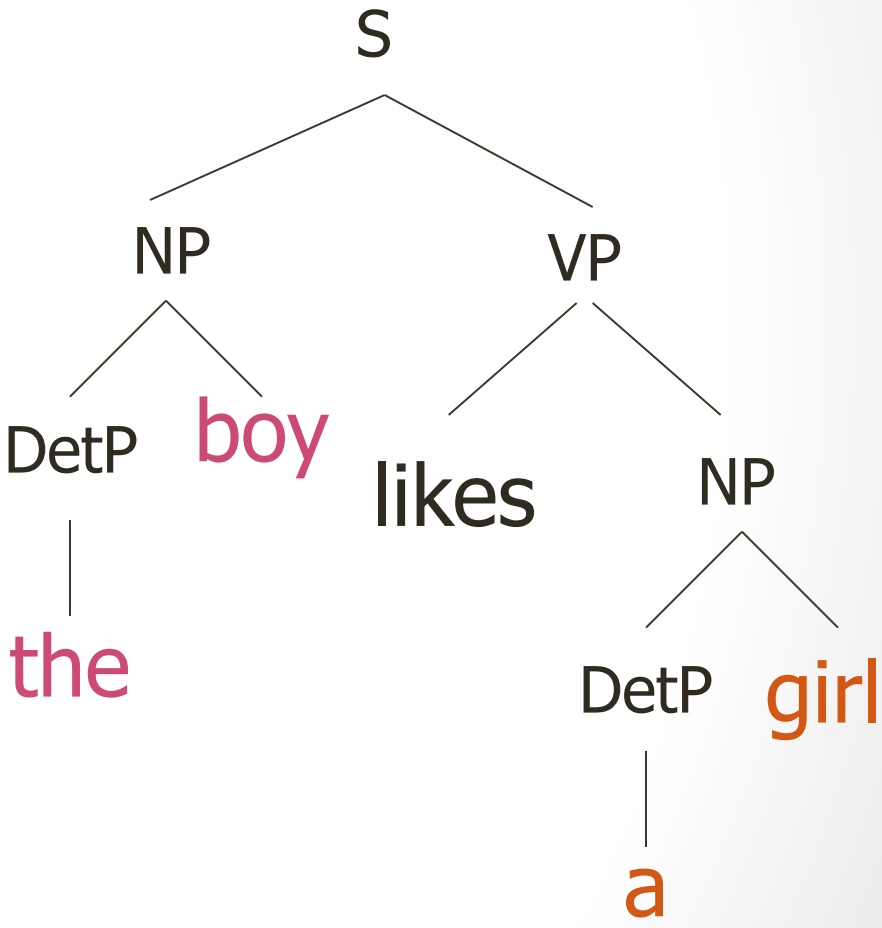
- List of arguments of a word (typically, a verb), with features about realization (POS, perhaps case, verb form etc)
- In canonical order Subject-Object-IndObj
- Example:
  - like: N-N, N-V(to-inf)
  - see: N, N-N, N-N-V(inf)
- Note: J&M talk about subcategorization only within VP

Subcategorization examples

- *Give*
- *Pretend*
- *Tell*
- *Bet*

What About the VP?





What About the VP?

- Existence of VP is a linguistic (i.e., empirical) claim, not a methodological claim
- Semantic evidence???
- Syntactic evidence
  - VP-fronting (*and quickly clean the carpet he did!*)
  - VP-ellipsis (*He cleaned the carpets quickly, and so did she*)
  - Can have adjuncts before and after VP, but not in VP (*He often eats beans, *he eats often beans*)
- Note: VP cannot be represented in a dependency representation

Context-Free Grammars

- Defined in formal language theory (comp sci)
- Terminals, nonterminals, start symbol, rules
- String-rewriting system
- Start with start symbol, rewrite using rules, done when only terminals left
- NOT A LINGUISTIC THEORY, just a formal device

CFG: Example

- Many possible CFGs for English, here is an example (fragment):
  - S → NP VP
  - VP → V NP
  - NP → DetP N | AdjP NP
  - AdjP → Adj | Adv AdjP
  - N → boy | girl
  - V → sees | likes
  - Adj → big | small
  - Adv → very
  - DetP → a | the

the very small boy likes a girl

Derivations in a CFG

S

S → NP VP
VP → V NP
NP → DetP N | AdjP NP
AdjP → Adj | Adv AdjP
N → boy | girl
V → sees | likes
Adj → big | small
Adv → very
DetP → a | the

S

Derivations in a CFG

NP VP

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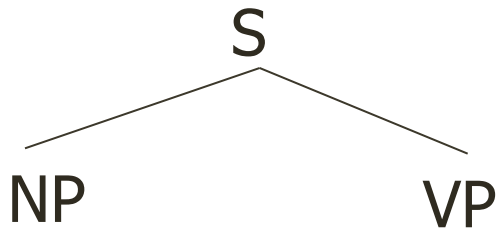


Derivations in a CFG

DetP N VP

S → NP VP

VP → V NP

NP → DetP N | AdjP NP

AdjP → Adj | Adv AdjP

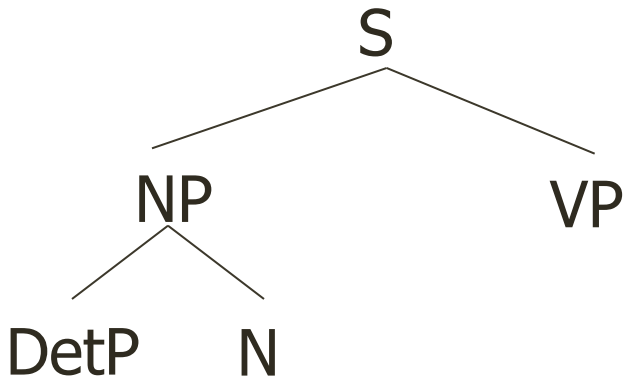
N → boy | girl

V → sees | likes

Adj → big | small

Adv → very

DetP → a | **the**



Derivations in a CFG

the boy VP

S → NP VP

VP → V NP

NP → DetP N | AdjP NP

AdjP → Adj | Adv AdjP

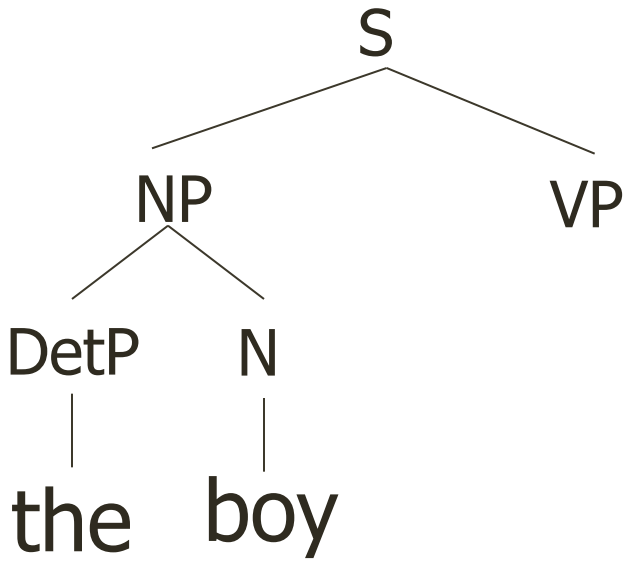
N → boy | girl

V → sees | **likes**

Adj → big | small

Adv → very

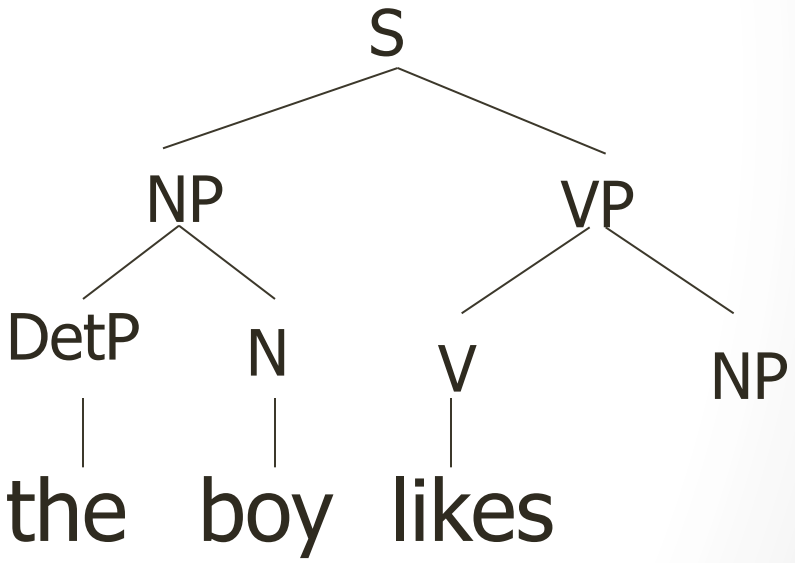
DetP → a | the



Derivations in a CFG

the boy likes NP

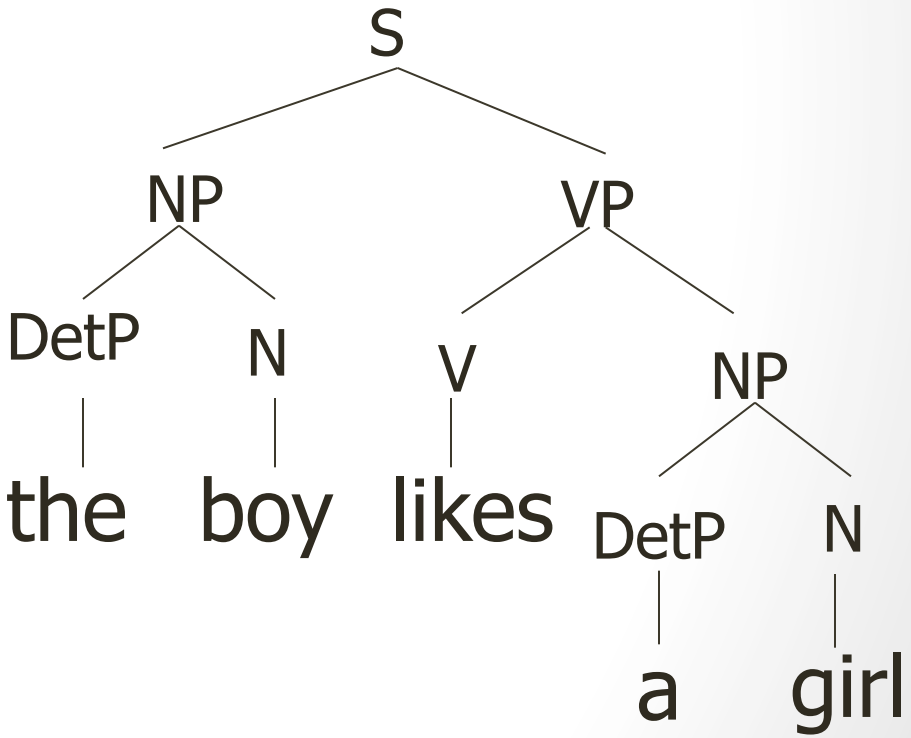
S → NP VP
VP → V NP
NP → DetP N | AdjP NP
AdjP → Adj | Adv AdjP
N → boy | **girl**
V → sees | likes
Adj → big | small
Adv → very
DetP → a | the



Derivations in a CFG

the boy likes a girl

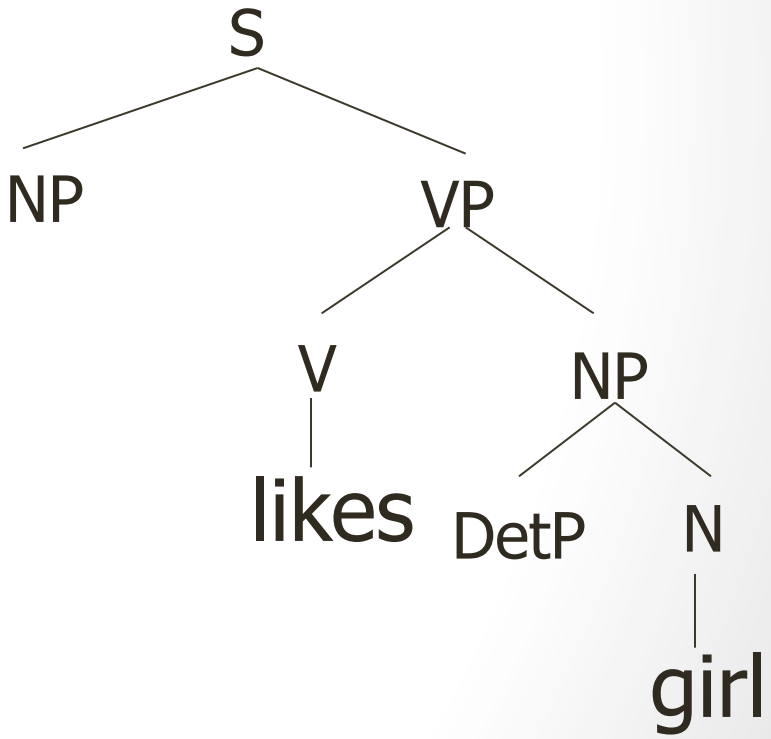
S → NP VP
VP → V NP
NP → DetP N | AdjP NP
AdjP → Adj | Adv AdjP
N → boy | girl
V → sees | likes
Adj → big | small
Adv → very
DetP → a | the



Derivations in a CFG; Order of Derivation Irrelevant

NP likes DetP girl

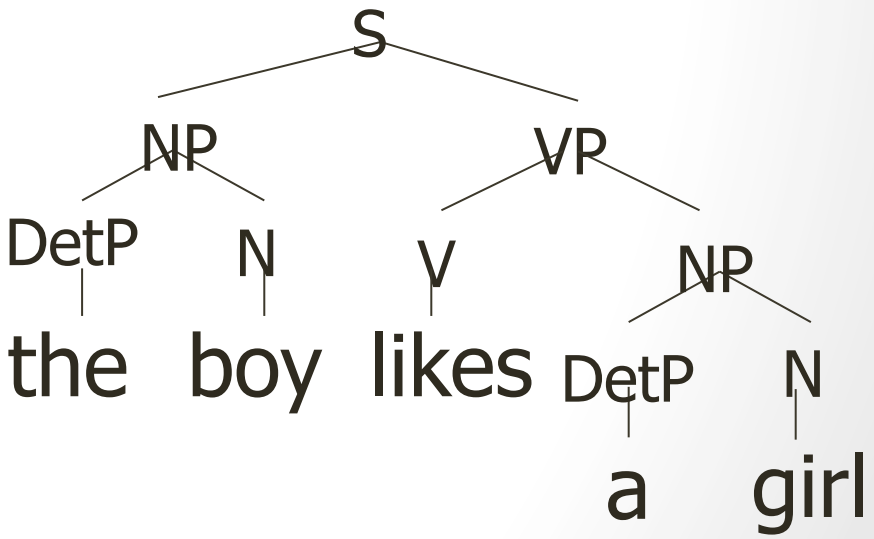
S → NP VP
VP → V NP
NP → DetP N | AdjP NP
AdjP → Adj | Adv AdjP
N → boy | girl
V → sees | likes
Adj → big | small
Adv → very
DetP → a | the



Derivations of CFGs

- String rewriting system: we derive a string (=**derived** structure)
- But derivation history represented by phrase-structure tree (=**derivation** structure)!

the boy likes a girl



Formal Definition of a CFG

G = (V,T,P,S)

- V: finite set of nonterminal symbols
- T: finite set of terminal symbols, V and T are disjoint
- P: finite set of productions of the form
  $A \rightarrow \alpha$, $A \in V$ and $\alpha \in (T \cup V)^*$
- $S \in V$: start symbol

Context?

- The notion of context in CFGs has nothing to do with the ordinary meaning of the word context in language

- All it really means is that the non-terminal on the left-hand side of a rule is out there all by itself (free of context)

  A -> B C

  Means that I can rewrite an A as a B followed by a C regardless of the context in which A is found

Key Constituents (English)

- Sentences
- Noun phrases
- Verb phrases
- Prepositional phrases

"Hello!"

"Hello!"

"Do you like my hat?"

"I do not."

"Good-by!"

"Good-by!"

Why are they going fast
in those cars?
What are they going to do?
Where are those dogs going?

There they go.
Look at those dogs go!

Now it is day.
The sun is up.
Now is the time
for all dogs to get up.

"Get up!"
It is day.
Time to get going.
Go, dogs. Go!

Sentence-Types

- Declaratives: I do not.
  S -> NP VP
- Imperatives: Go dogs! Go!
  S -> VP
- Yes-No Questions: Do you like my hat?
  S -> Aux NP VP
- WH Questions: What are they going to do?
  S -> WH Aux NP VP

NPs

- NP -> Pronoun
  - I came, you saw it, they conquered
- NP -> Proper-Noun
  - New Jersey is west of New York City
  - Lee Bollinger is the president of Columbia
- NP -> Det Noun
  - The president
- NP -> Nominal
- Nominal -> Noun Noun
  - A morning flight to Denver

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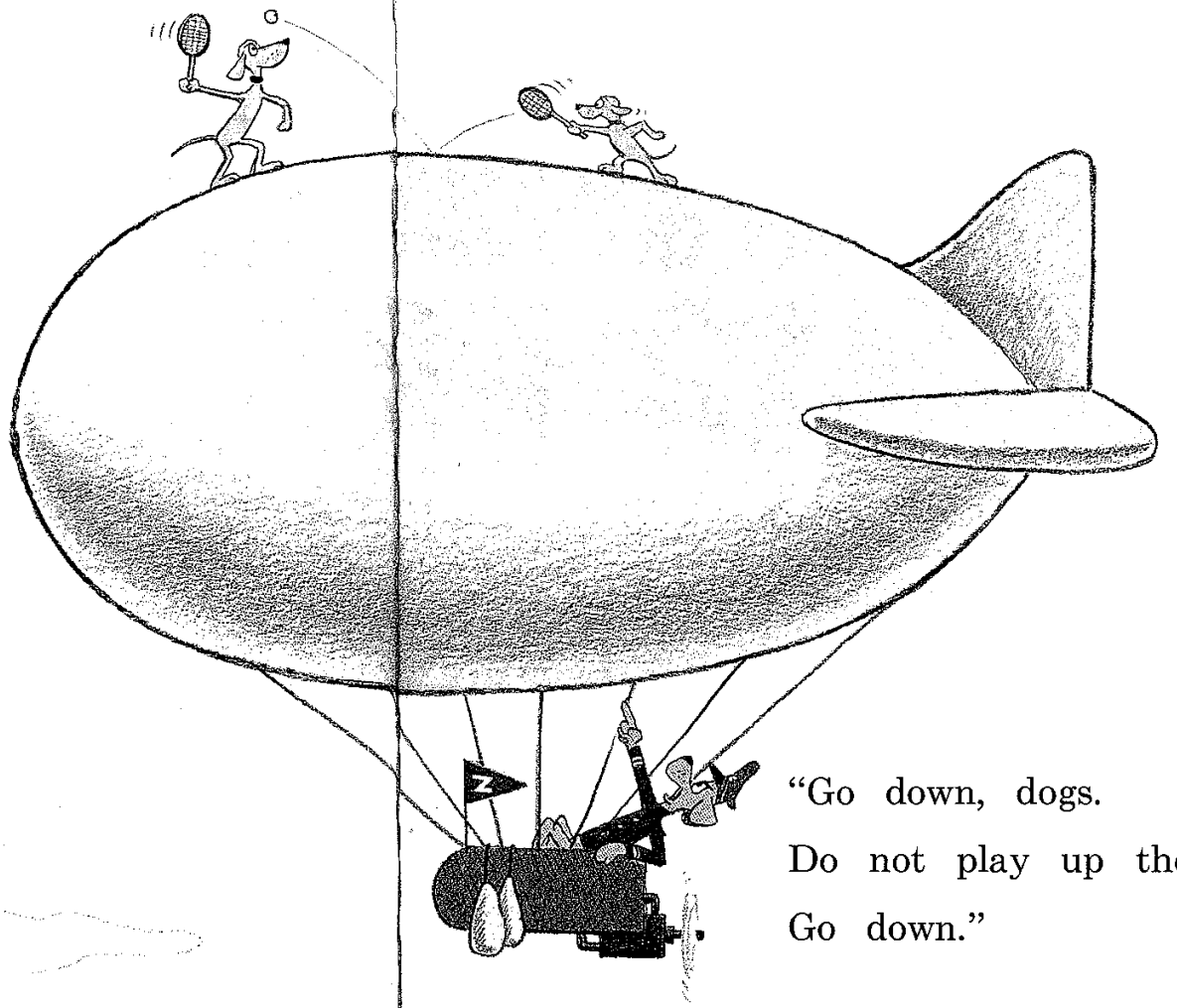
What other types of nominals do you find in English? Give examples.

PPs

- PP -> Preposition NP
  - Over the house
  - Under the house
  - To the tree
  - At play
  - At a party on a boat at night

Two dogs at play.

At play up on top.



"Go down, dogs.

Do not play up there.

Go down."

Three dogs
at a "party"
on a boat
at night.

It is hot out here in the sun.

It is not hot here under the house.

What is “here”?

Recursion

- We'll have to deal with rules such as the following where the non-terminal on the left also appears somewhere on the right (directly)

NP -> NP PP [[The flight] [to Boston]]

VP -> VP PP [[departed Miami] [at noon]]

(indirectly)

NP -> NP Srel

Srel -> NP VP [[the dog] [[the cat] likes]]

Recursion

- Of course, this is what makes syntax interesting

The dog bites

The dog the mouse bit bites

The dog the mouse the cat ate bit bites

Recursion

[[Flights] [from Denver]]

[[[Flights] [from Denver]] [to Miami]]

[[[[Flights] [from Denver]] [to Miami]] [in February]]

[[[[[Flights] [from Denver]] [to Miami]] [in February]] [on a Friday]]

Etc.

NP -> NP PP

Implications of Recursion and Context-Freeness

- VP -> V NP
- (I) hate

  flights from Denver

  flights from Denver to Miami

  flights from Denver to Miami in February

  flights from Denver to Miami in February on a Friday

  flights from Denver to Miami in February on a Friday under $300

  flights from Denver to Miami in February on a Friday under $300 with lunch
- This is why context-free grammars are appealing! If you have a rule like

  VP -> V NP

  - It only cares that the thing after the verb is an NP

    It doesn't have to know about the internal affairs of that NP

Grammar Equivalence

- Can have different grammars that generate same set of strings (weak equivalence)
  - Grammar 1: NP → DetP N and DetP → a | the
  - Grammar 2: NP → a N | NP → the N
- Can have different grammars that have same set of derivation trees (strong equivalence)
  - With CFGs, possible only with useless rules
  - Grammar 2: NP → a N | NP → the N
  - Grammar 3: NP → a N | NP → the N, DetP → many
- Strong equivalence implies weak equivalence

Normal Forms &c

- There are weakly equivalent normal forms (Chomsky Normal Form, Greibach Normal Form)
- There are ways to eliminate useless productions and so on

Chomsky Normal Form

A CFG is in Chomsky Normal Form (CNF) if all productions are of one of two forms:

- $A \rightarrow BC$ with A, B, C nonterminals
- $A \rightarrow a$, with A a nonterminal and a a terminal

Every CFG has a weakly equivalent CFG in CNF

"Generative Grammar"

- Formal languages: formal device to generate a set of strings (such as a CFG)
- Linguistics (Chomskyan linguistics in particular): approach in which a linguistic theory enumerates all possible strings/ structures in a language (=competence)
- Chomskyan theories do not really use formal devices – they use CFG + informally defined transformations

Nobody Uses Simple CFGs (Except Intro NLP Courses)

- All major syntactic theories (Chomsky, LFG, HPSG, TAG-based theories) represent both phrase structure and dependency, in one way or another
- All successful parsers currently use statistics about phrase structure and about dependency
- Derive dependency through "head percolation": for each rule, say which daughter is head

Massive Ambiguity of Syntax

- For a standard sentence, and a grammar with wide coverage, there are 1000s of derivations!

- Example:
  - The large portrait painter told the delegation that he sent money orders in a letter on Wednesday

Penn Treebank (PTB)

- Syntactically annotated corpus of newspaper texts (phrase structure)
- The newspaper texts are naturally occurring data, but the PTB is not!
- PTB annotation represents a particular linguistic theory (but a fairly "vanilla" one)
- Particularities
  - Very indirect representation of grammatical relations (need for head percolation tables)
  - Completely flat structure in NP (*brown bag lunch, pink-and-yellow child seat*)
  - Has flat Ss, flat VPs

Example from PTB

```
( (S (NP-SBJ It)
    (VP 's
      (NP-PRD (NP (NP the latest investment craze)
            (VP sweeping
                (NP Wall Street)))
          :
          (NP (NP a rash)
            (PP of
                (NP (NP new closed-end country funds)
                    ,
                    (NP (NP those
                            (ADJP publicly traded)
                            portfolios)
                        (SBAR (WHNP-37 that)
                            (S (NP-SBJ *T*-37)
                                (VP invest
                                    (PP-CLR in
                                        (NP (NP stocks)
                                            (PP of
                                                (NP a single foreign country)))))))))
```

Types of syntactic constructions

- Is this the same construction?
  - An elf **decided** to clean the kitchen
  - An elf **seemed** to clean the kitchen

  An elf cleaned the kitchen
- Is this the same construction?
  - An elf **decided** to be in the kitchen
  - An elf **seemed** to be in the kitchen

  An elf was in the kitchen

Types of syntactic constructions (ctd)

- Is this the same construction?

  There is an elf in the kitchen

  - There **decided** to be an elf in the kitchen
  - There **seemed** to be an elf in the kitchen

- Is this the same construction?

  It is raining/it rains

  - It **decided** to rain/be raining
  - It **seemed** to rain/be raining

Types of syntactic constructions (ctd)

- Is this the same construction?
  - An elf **decided** that he would clean the kitchen
  - An elf **seemed** that he would clean the kitchen

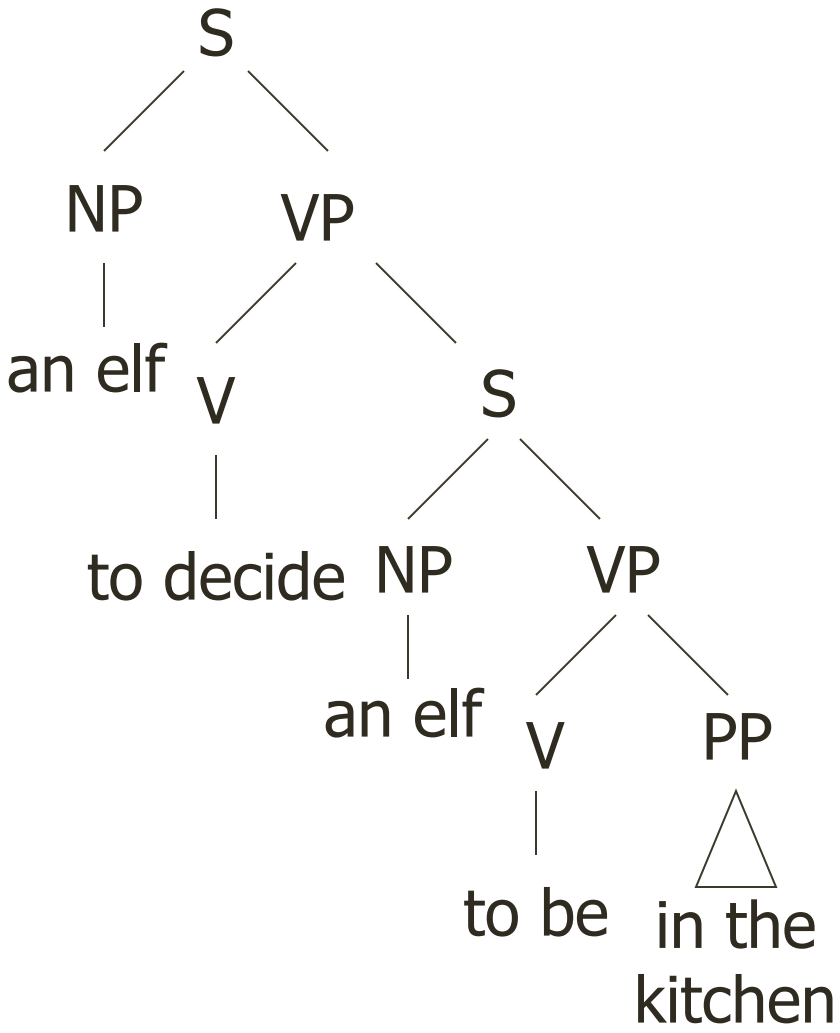
  An elf cleaned the kitchen

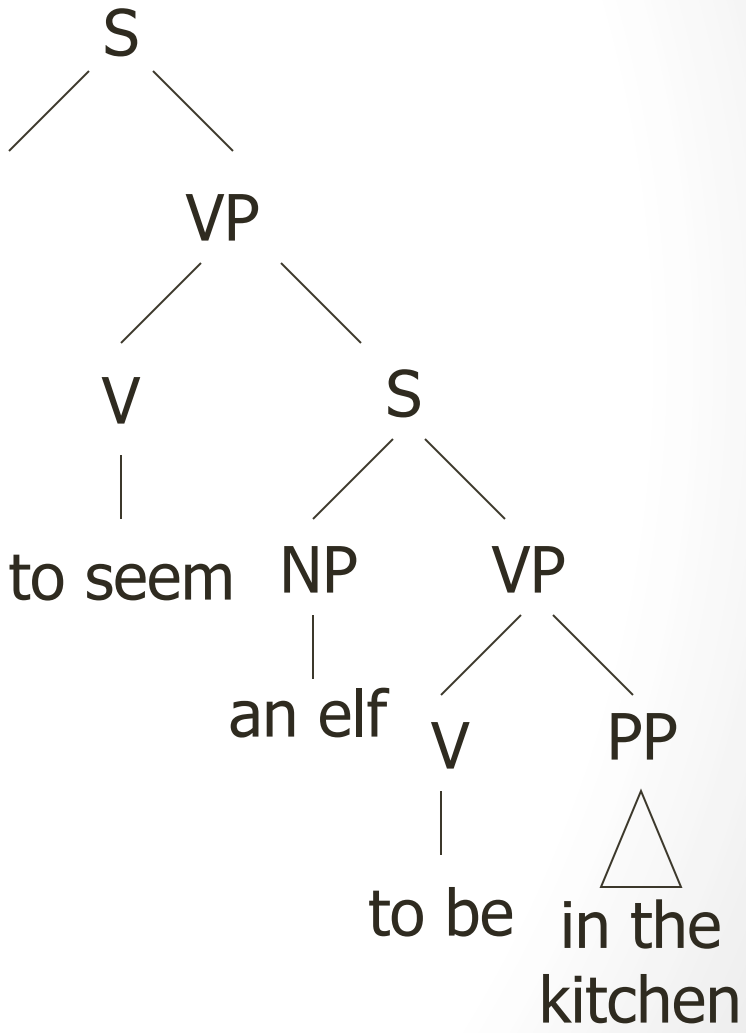
Types of syntactic constructions (ctd)

Conclusion:

- *to seem:* whatever is embedded surface subject can appear in upper clause
- *to decide:* only full nouns that are referential can appear in upper clause
- Two types of verbs

Types of syntactic constructions: Analysis





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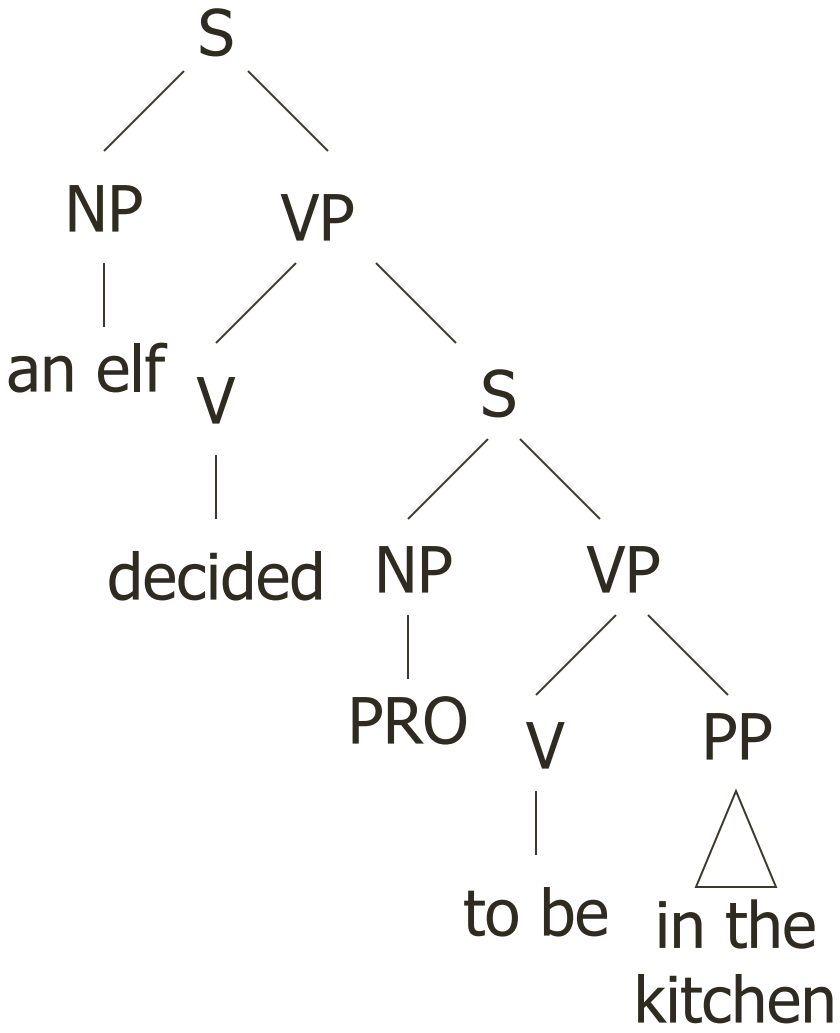

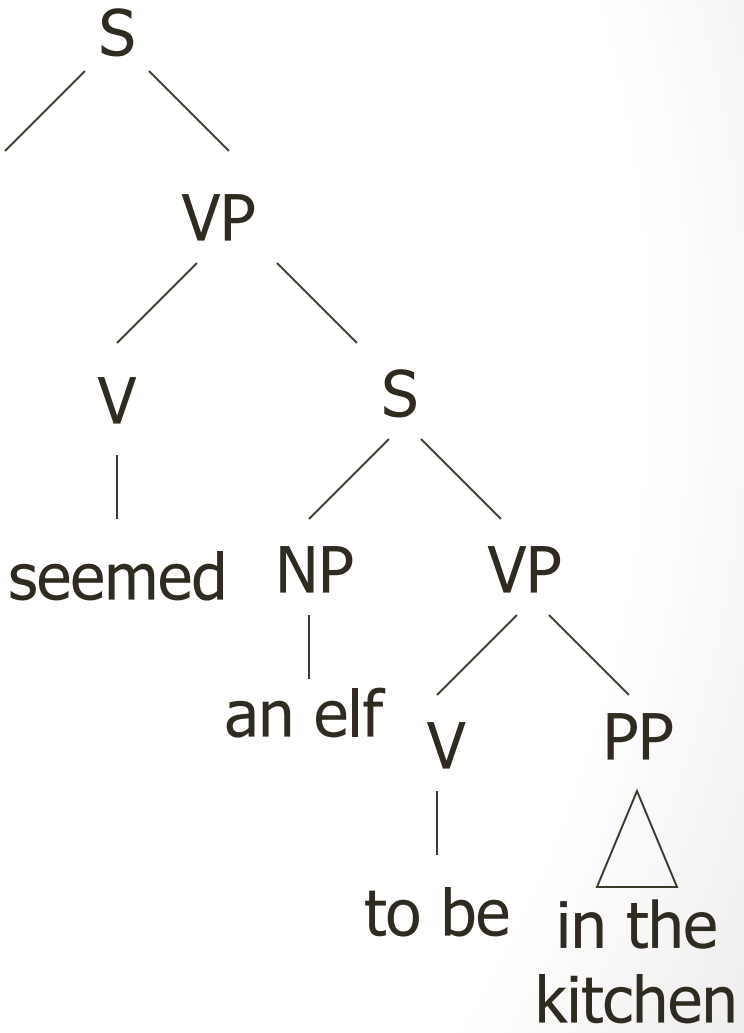

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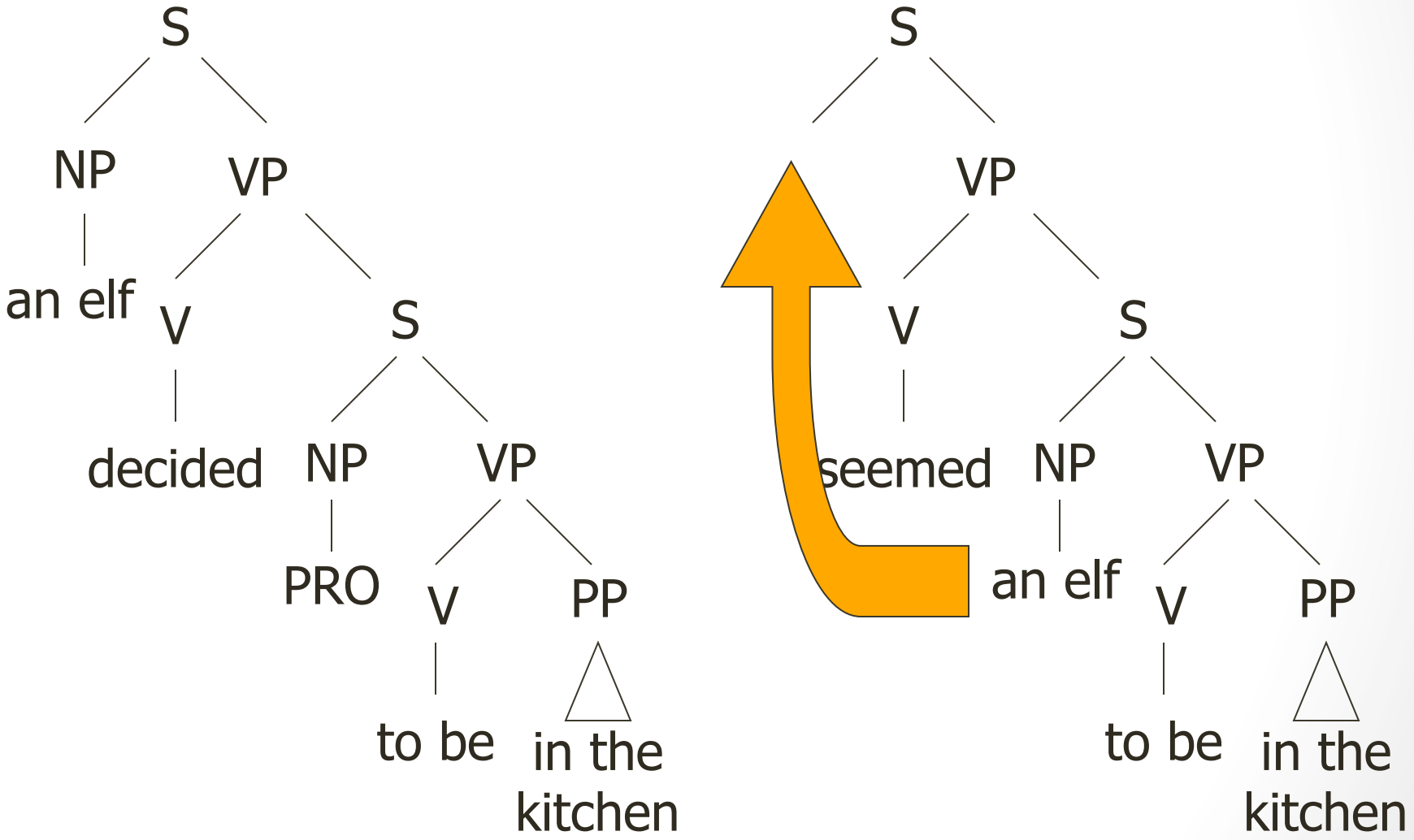

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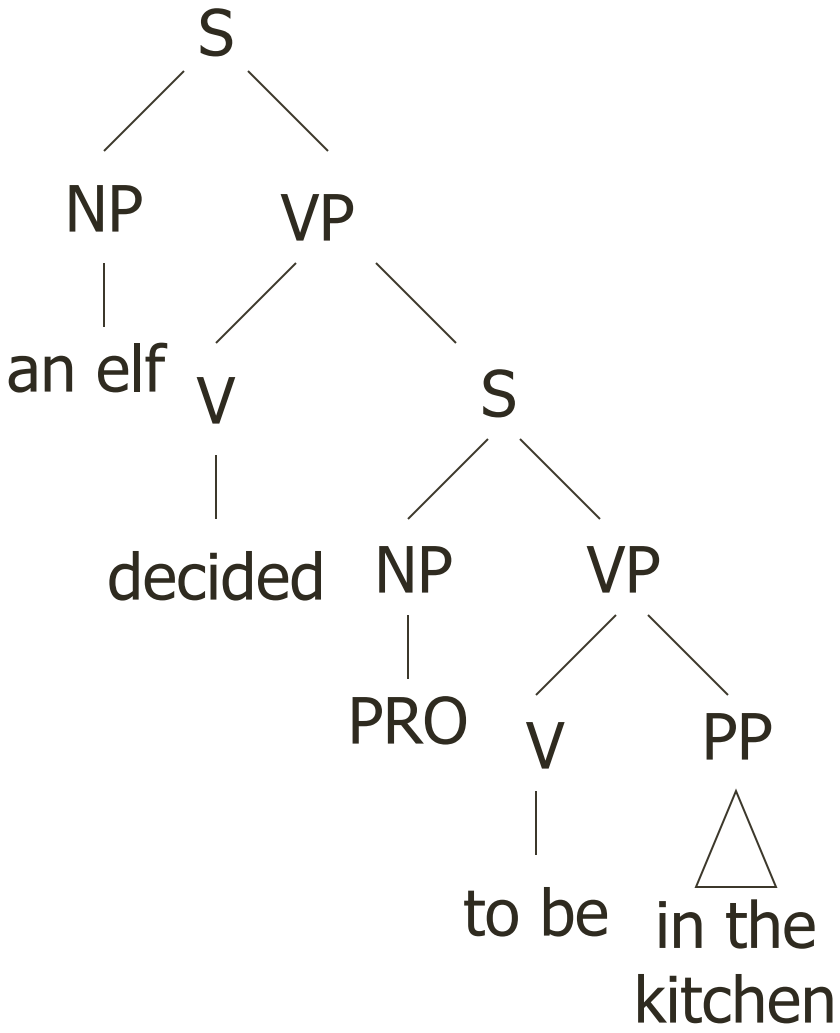
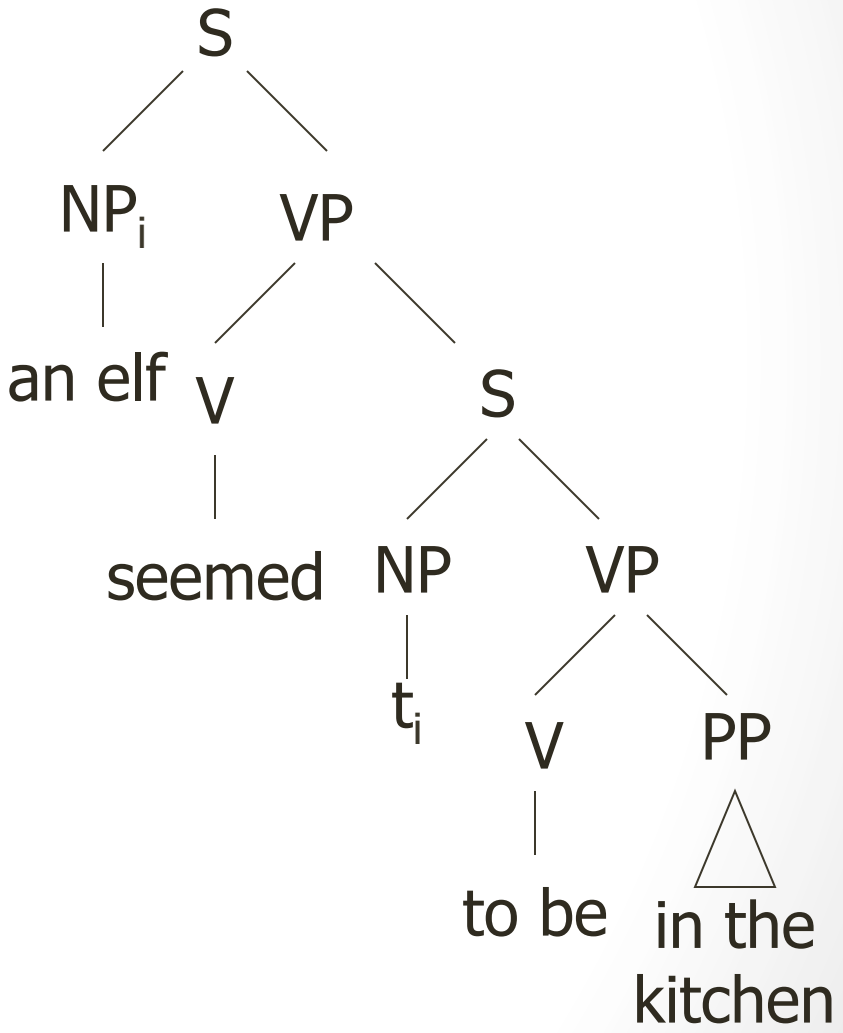




Types of syntactic constructions: Analysis

to seem: lower surface subject **raises** to upper clause; **raising verb**

seems (there to be an elf in the kitchen)

there seems (*t* to be an elf in the kitchen)

it seems (there is an elf in the kitchen)

Types of syntactic constructions: Analysis (ctd)

- *to decide:* subject is in upper clause and co-refers with an empty subject in lower clause; **control verb**

an elf decided (an elf to clean the kitchen)

an elf decided (PRO to clean the kitchen)

an elf decided (he cleans/should clean the kitchen)

*it decided (an elf cleans/should clean the kitchen)

Lessons Learned from the Raising/ Control Issue

- Use distribution of data to group phenomena into classes
- Use different underlying structure as basis for explanations
- Allow things to "move" around from underlying structure -> **transformational grammar**
- Check whether explanation you give makes predictions

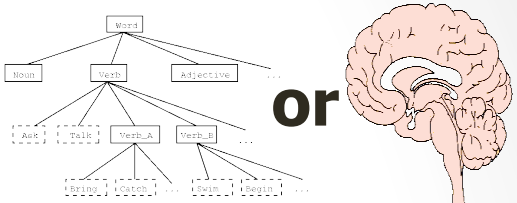
Examples from PTB

```
(S (NP-SBJ-1 The ropes)
      (VP seem
         (S (NP-SBJ *-1)
            (VP to
               (VP make
                  (NP much sound))))))

(S (NP-SBJ-1 The ancient church vicar)
    (VP refuses
       (S (NP-SBJ *-1)
          (VP to
             (VP talk
                (PP-CLR about
                        (NP it)))))
```

The Big Picture

Empirical Matter

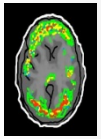


Formalisms

- Data structures
- Formalisms
- Algorithms
- Distributional Models

descriptive theory is about

Maud expects there to be a riot
*Teri promised there to be a riot
Maud expects the shit to hit the fan
*Teri promised the shit to hit the



uses

predicts

explanatory theory is about

Linguistic Theory

Content: Relate morphology to semantics
- Surface representation (eg, ps)
- Deep representation (eg, dep)
- Correspondence