Ling 566
Oct 3, 2011

Context-Free Grammar

Overview

- Failed attempts
- Formal definition of CFG
- Constituency, ambiguity, constituency tests
- Central claims of CFG
- Order independence
- Weaknesses of CFG
- Reading questions
- If time: Work through Chapter 2, Problem 1

Insufficient Theory #1

- A grammar is simply a list of sentences.
- What’s wrong with this?

Insufficient Theory #2: FSMs

- the noisy dogs left

  D A N V

- the noisy dogs chased the innocent cats

  D A N V D A N

- a* = {ø, a, aa, aaa, aaaa, ... }
- a^+ = {a, aa, aaa, aaaa, ... }
- (D) A* N V ((D) A* N)

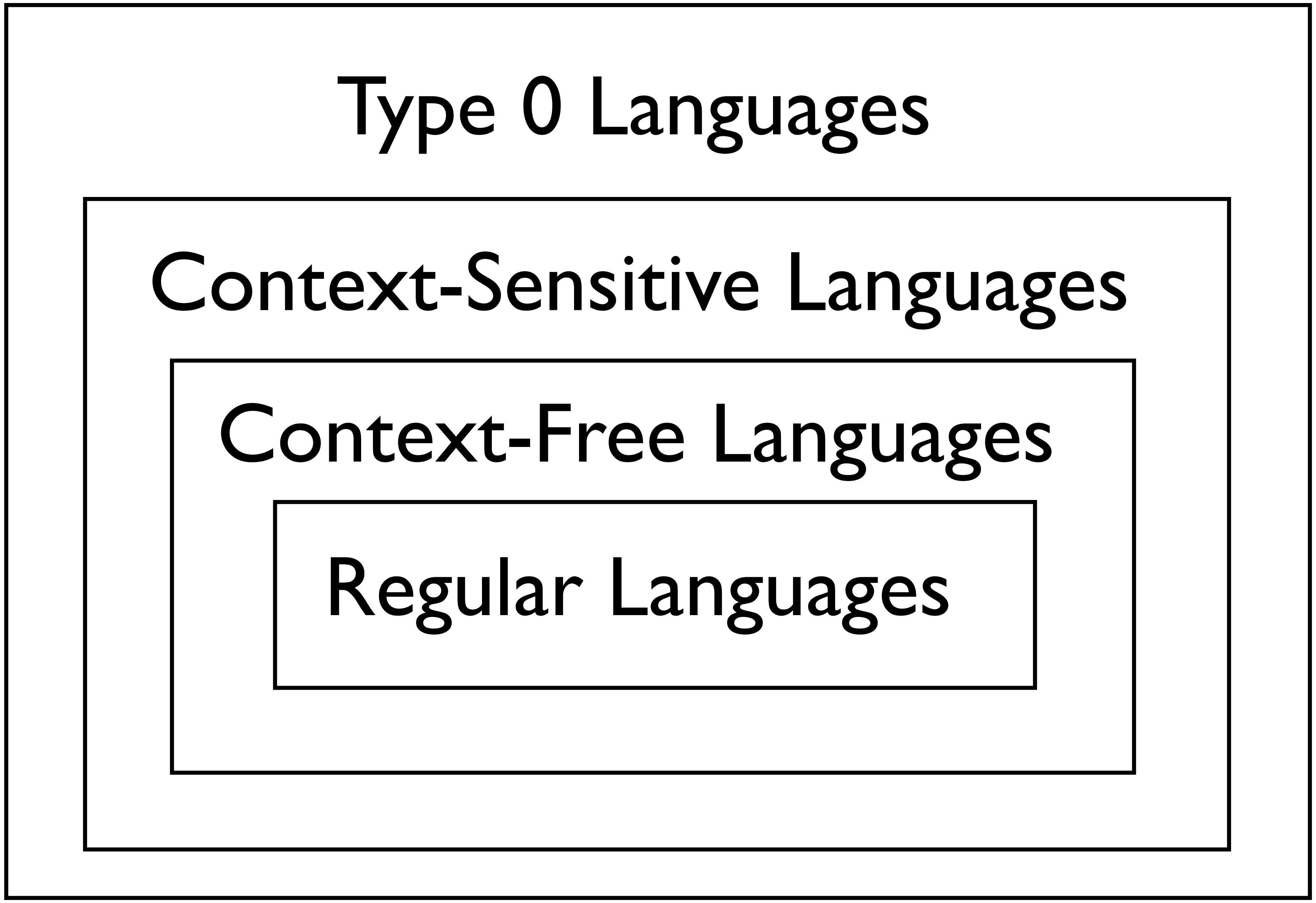
What does a theory do?

- Monolingual
  - Model grammaticality/acceptability
  - Model relationships between sentences (internal structure)
- Multilingual
  - Model relationships between languages
  - Capture generalizations about possible languages

Summary

- Grammars as lists of sentences:
    - Runs afoul of creativity of language
- Grammars as finite-state machines:
    - No representation of structural ambiguity
    - Misses generalizations about structure
    - (Not formally powerful enough)
- Next attempt: Context-free grammar (CFG)

Chomsky Hierarchy



Type 0 Languages

Context-Sensitive Languages

Context-Free Languages

Regular Languages

Context-Free Grammar

- A quadruple: $< C, \Sigma, P, S >$
  - C: set of categories
  - Σ: set of terminals (vocabulary)
  - P: set of rewrite rules $\alpha \rightarrow \beta_1, \beta_2, \ldots, \beta_n$
  - S in C: start symbol
  - For each rule $\alpha \ \rightarrow \ \beta_1, \beta_2, \ldots, \beta_n \in P$
    $\alpha \in C;\ \beta_i \in C \cup \Sigma;\ 1 \leq i \leq n$

A Toy Grammar

RULES

S ⟶ NP VP

NP ⟶ (D) A* N PP*

VP ⟶ V (NP) (PP)

PP ⟶ P NP

LEXICON

D: the, some

A: big, brown, old

N: birds, fleas, dog, hunter, I

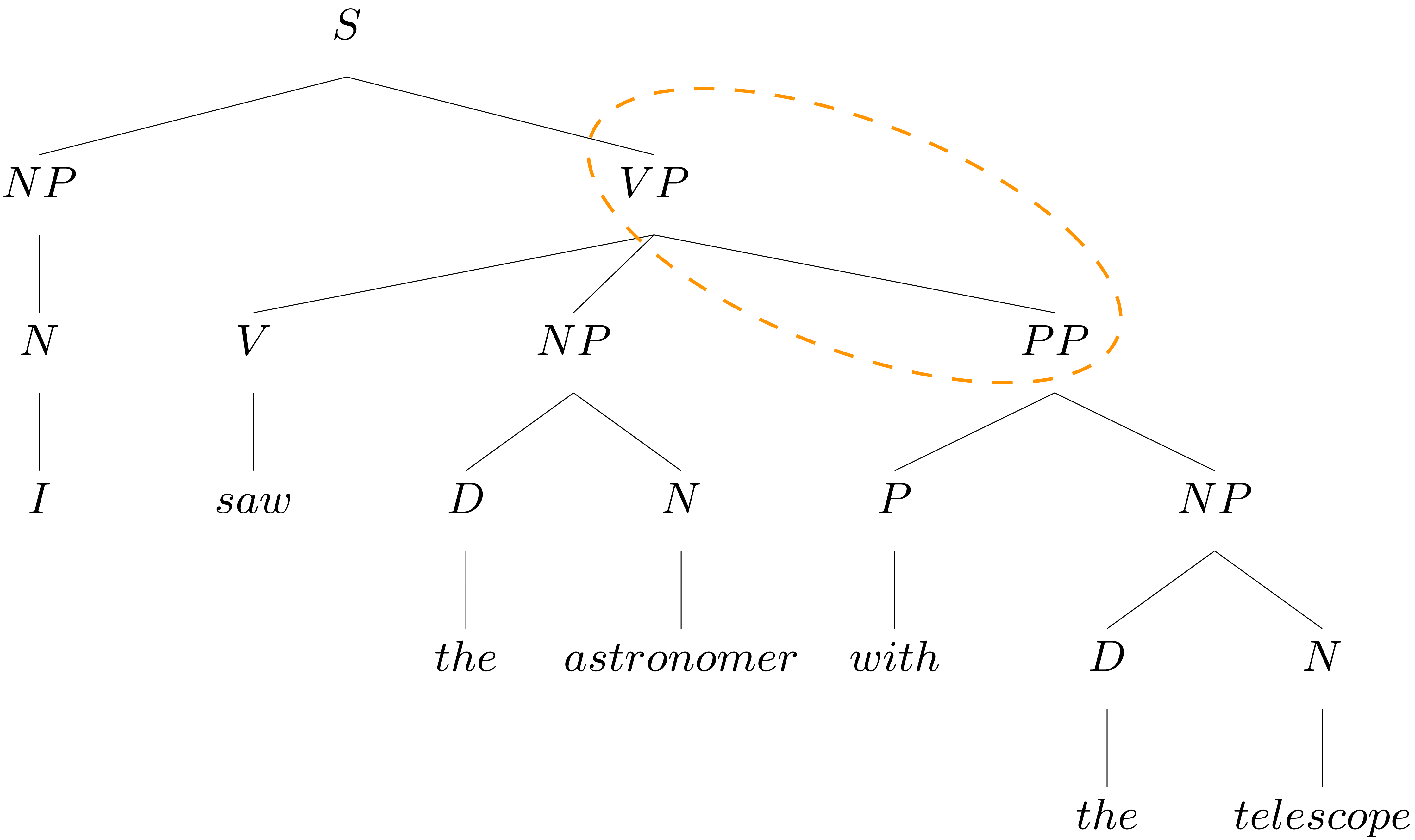
V: attack, ate, watched

P: for, beside, with

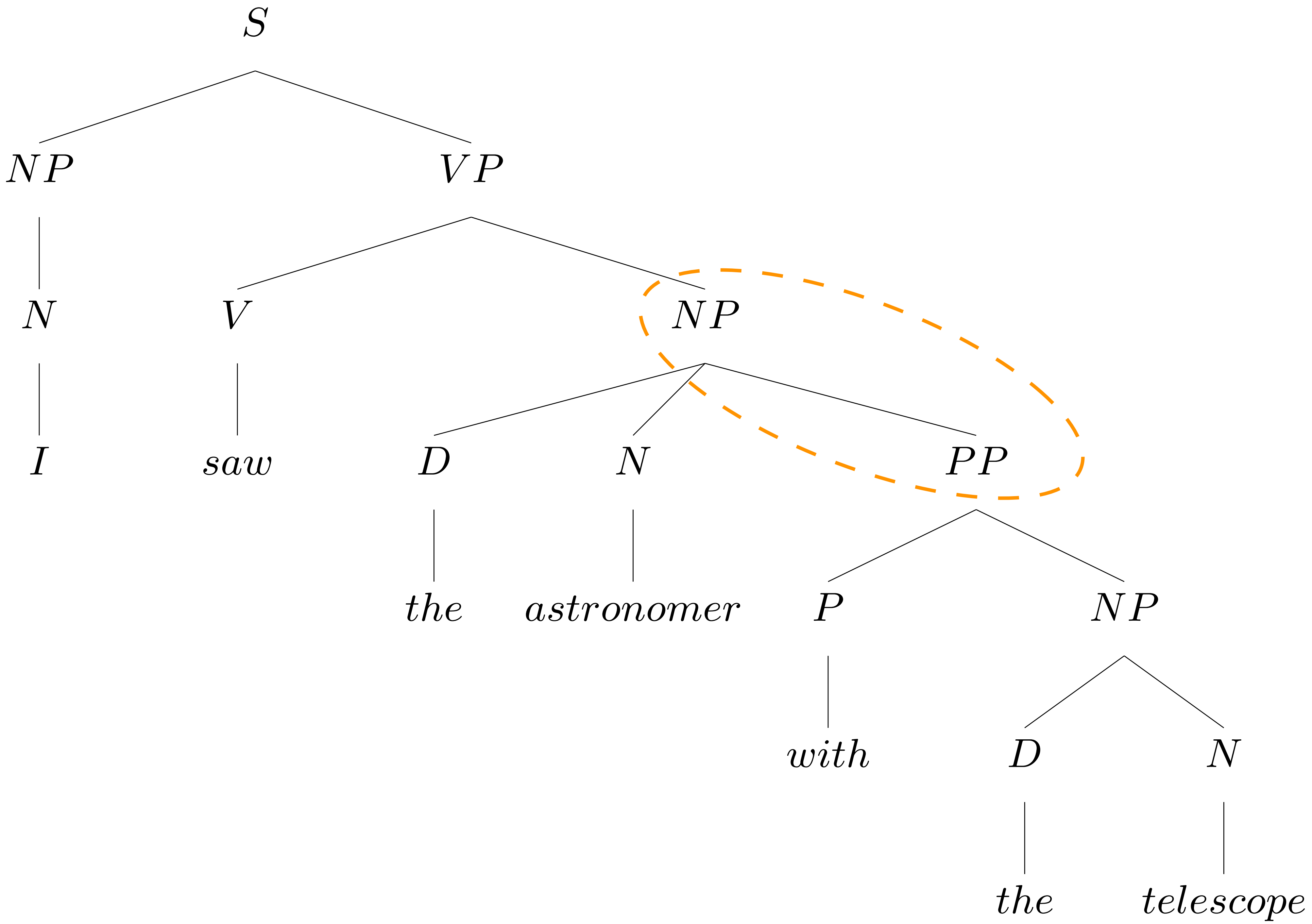
Structural Ambiguity

I saw the astronomer with the telescope.

Structure 1: PP under VP



Structure 1: PP under NP



Constituents

- How do constituents help us? (What’s the point?)
- What aspect of the grammar determines which words will be modeled as a constituent?
- How do we tell which words to group together into a constituent?
- What does the model claim or predict by grouping words together into a constituent?

Constituency Tests

- Recurrent Patterns

  The quick brown fox with the bushy tail jumped over the lazy brown dog with one ear.

- Coordination

  The quick brown fox with the bushy tail and the lazy brown dog with one ear are friends.

- Sentence-initial position

  The election of 2000, everyone will remember for a long time.

- Cleft sentences

  It was a book about syntax they were reading.

General Types of Constituency Tests

- Distributional
- Intonational
- Semantic
- Psycholinguistic

... but they don’t always agree.

Central claims implicit in CFG formalism:

1. Parts of sentences (larger than single words) are linguistically significant units, i.e. phrases play a role in determining meaning, pronunciation, and/or the acceptability of sentences.

2. Phrases are contiguous portions of a sentence (no discontinuous constituents).

3. Two phrases are either disjoint or one fully contains the other (no partially overlapping constituents).

4. What a phrase can consist of depends only on what kind of a phrase it is (that is, the label on its top node), not on what appears around it.

- Claims 1-3 characterize what is called ‘phrase structure grammar’

- Claim 4 (that the internal structure of a phrase depends only on what type of phrase it is, not on where it appears) is what makes it ‘context-free’.

- There is another kind of phrase structure grammar called ‘context-sensitive grammar’ (CSG) that gives up 4. That is, it allows the applicability of a grammar rule to depend on what is in the neighboring environment. So rules can have the form A→X, in the context of Y_Z.

Possible Counterexamples

- To Claim 2 (no discontinuous constituents):

  A technician arrived who could solve the problem.

- To Claim 3 (no overlapping constituents):

  I read what was written about me.

- To Claim 4 (context independence):
  - *He arrives this morning.*
  - **He arrive this morning.*
  - **They arrives this morning.*
  - *They arrive this morning.*

A Trivial CFG

S → NP VP

NP → D N

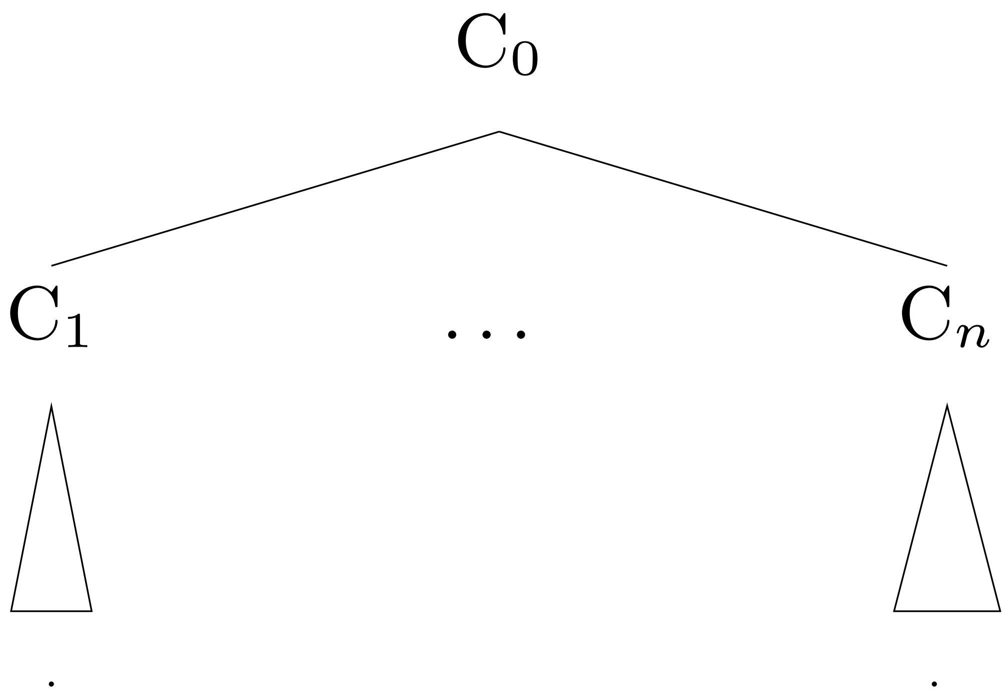
VP → V NP

D: *the*

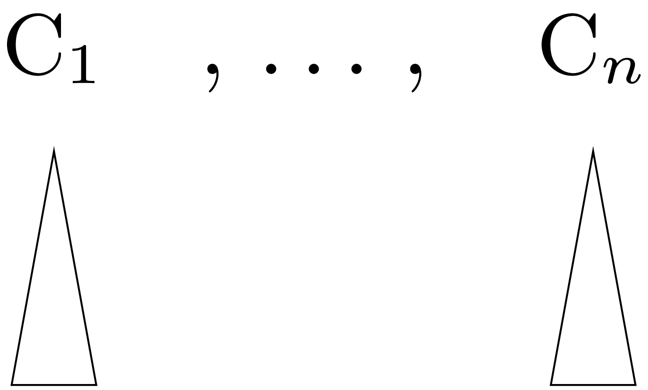
V: *chased*

N: *dog, cat*

Trees and Rules



is a well-formed nonlexical tree if (and only if)

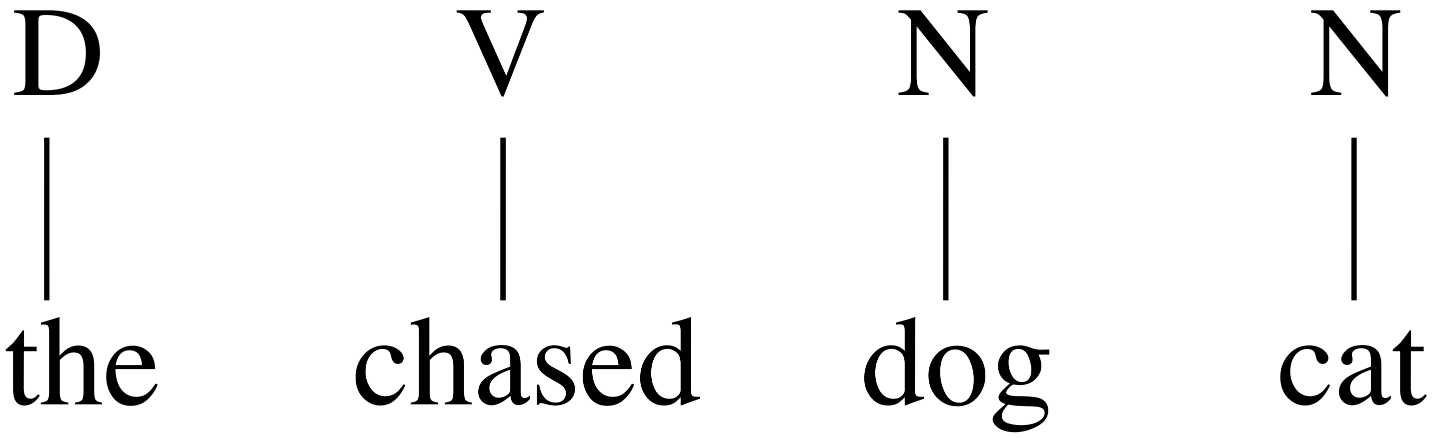


are well-formed trees, and

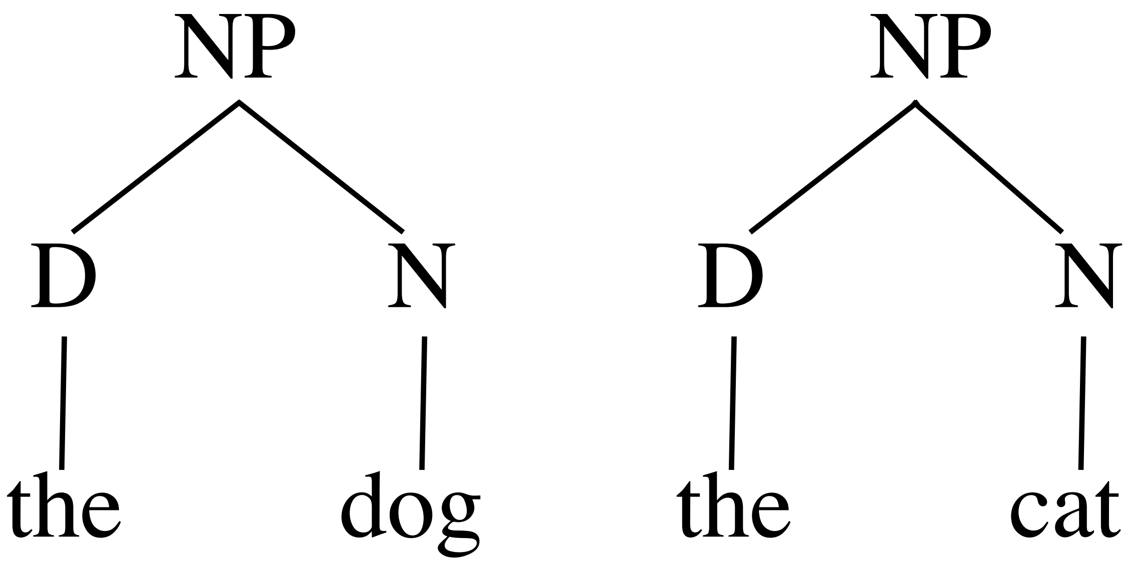
$_0 \rightarrow \quad _1 \ldots \; n$ is a grammar rule.

Bottom-up Tree Construction

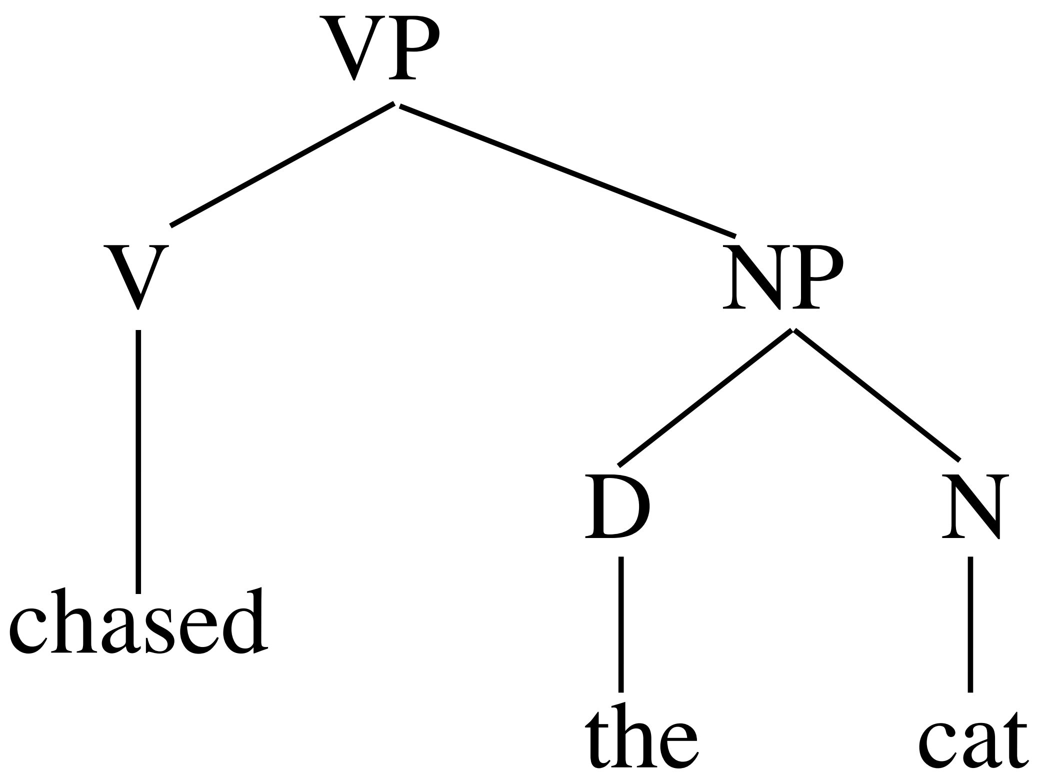
D:	*the*
V:	*chased*
N:	*dog, cat*



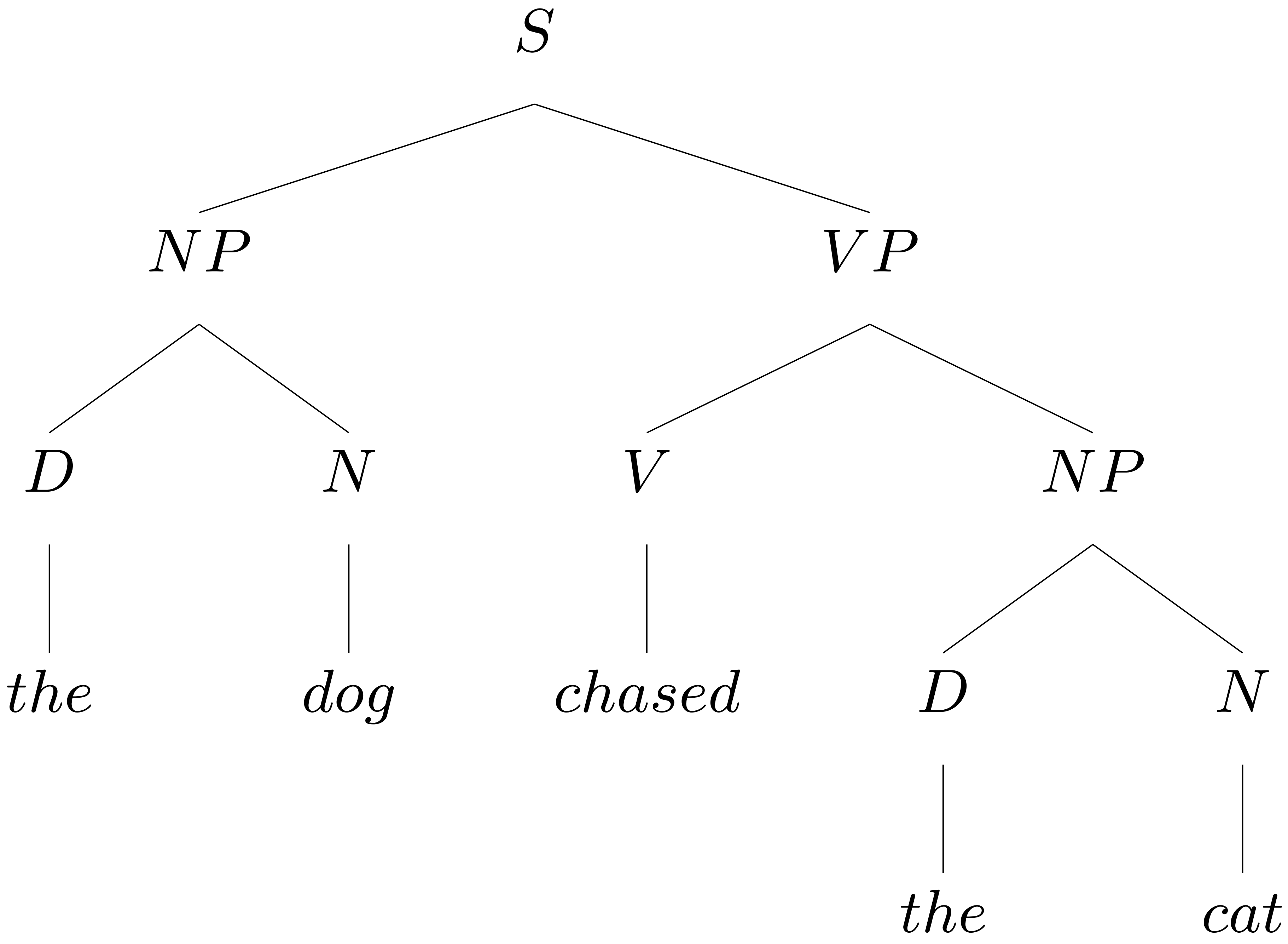
NP ⟶ D N



VP ⟶ V NP



$S \longrightarrow NP\ \ VP$

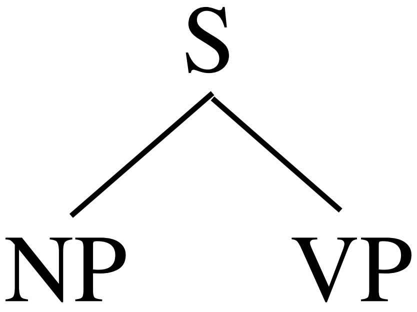


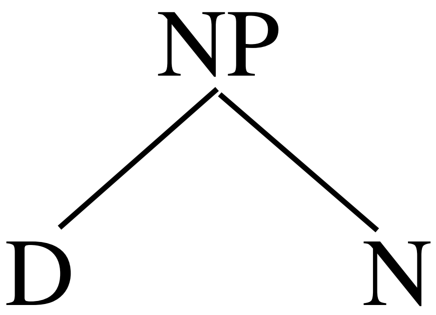
Top-down Tree Construction

S → NP VP

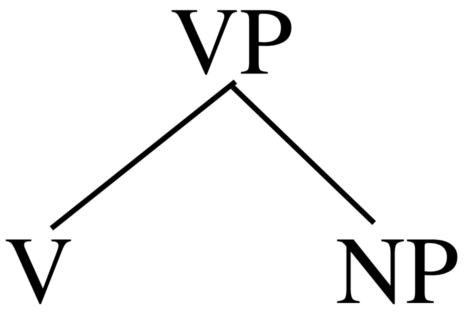
NP → D N

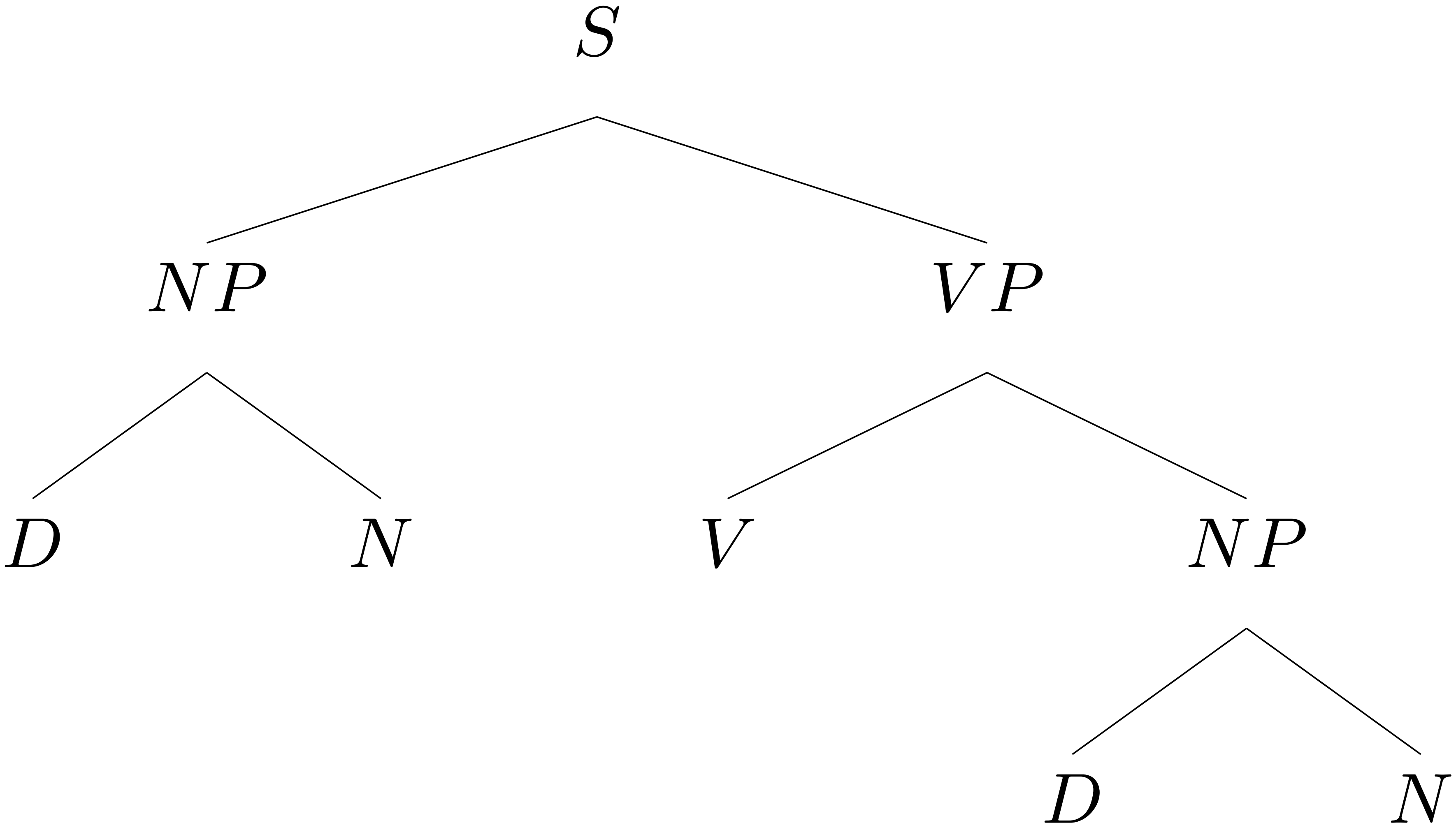
VP → V NP

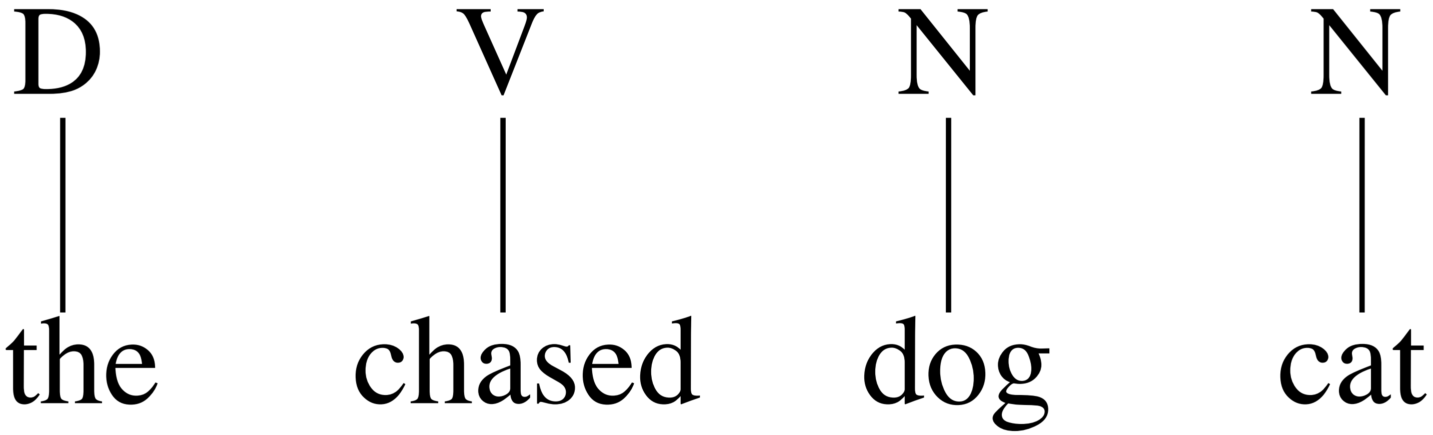




(twice)

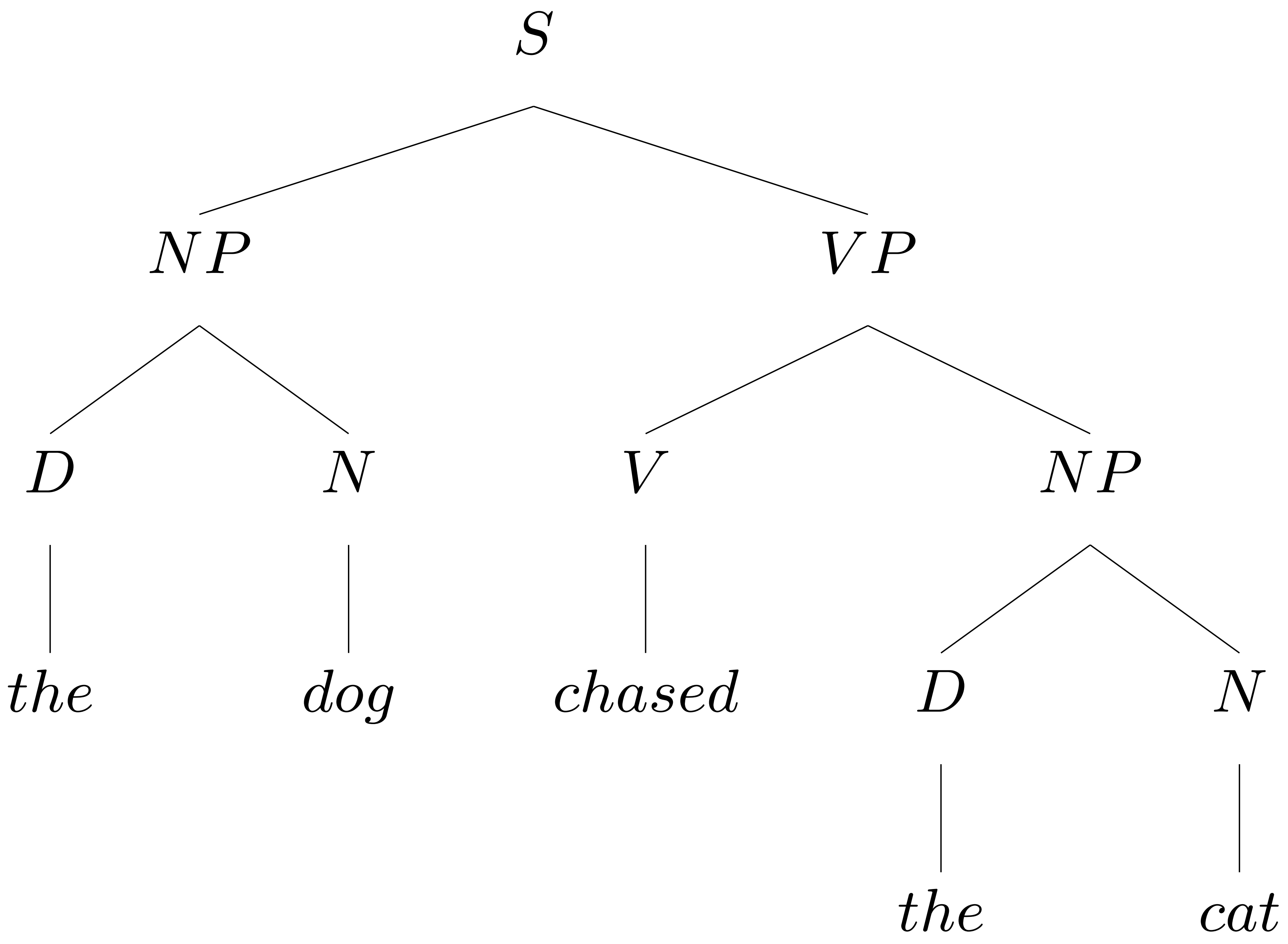



S
NP
VP
D
N
V
NP
D
N



D V N N

the chased dog cat



S

NP VP

D N V NP

the dog chased D N

the cat

Weaknesses of CFG (atomic node labels)

- It doesn't tell us what constitutes a linguistically natural rule

$$\mathrm{VP} \rightarrow \mathrm{P}\ \mathrm{NP}$$
$$\mathrm{NP} \rightarrow \mathrm{VP}\ \mathrm{S}$$

- Rules get very cumbersome once we try to deal with things like agreement and transitivity.
- It has been argued that certain languages (notably Swiss German and Bambara) contain constructions that are provably beyond the descriptive capacity of CFG.

On the other hand....

- It’s a simple formalism that can generate infinite languages and assign linguistically plausible structures to them.
- Linguistic constructions that are beyond the descriptive power of CFG are rare.
- It’s computationally tractable and techniques for processing CFGs are well understood.

So.....

- CFG has been the starting point for most types of generative grammar.
- The theory we develop in this course is an extension of CFG.

Reading Questions

- What can CFGs do that regular expressions can’t?
- What does “Context” mean in “Context-Free” Grammar?
- Why do we need NOM?
- What is a head?

Reading Questions

- Where do the categories we are using (N, NOM, NP, etc) come from?
- How does “X -> X+ CONJ X” fit in the CFG formalism?
- Why not give verbs a number and have nouns agree with them?

Chapter 2, Problem 1

S → NP VP
NP → (D) NOM
VP → V (NP) (NP)
NOM → N

NOM → NOM PP
VP → VP PP
PP → P NP
X → X^{+} CONJ X

D:	a, the
V:	admired, disappeared, put, relied
N:	cat, dog, hat, man, woman, roof
P:	in, on, with
CONJ:	and, or

Chapter 2, Problem 1

- Well-formed English sentence unambiguous according to this grammar
- Well-formed English sentence ambiguous according to this grammar
- Well-formed English sentence not licensed by this grammar
- String licensed by this grammar that is not a well-formed English sentence
- How many strings does this grammar license?

Shieber 1985

- Swiss German example:

. . .	mer	d'chind	em Hans	es huus	lönd	hälfe	aastriiche
. . .	we	the children-ACC	Hans-DAT	the hous-ACC	let	help	paint

. . . we let the children help Hans paint the house

- Cross-serial dependency:
  - *let* governs case on *children*
  - *help* governs case on *Hans*
  - *paint* governs case on *house*

Shieber 1985

- Define a new language $f(\text{SG})$:

$f(\text{d'chind})$	$=$	a	$f(\text{Jan säit das mer})$	$=$	w
$f(\text{em Hans})$	$=$	b	$f(\text{es huus})$	$=$	x
$f(\text{lönde})$	$=$	c	$f(\text{aastriiche})$	$=$	y
$f(\text{hälfe})$	$=$	d	$f([\text{other}])$	$=$	z

- Let r be the regular language $wa^*b^*xc^*d^*y$

- $f(\text{SG}) \cap r = wa^m b^n xc^m d^n y$

- $wa^m b^n xc^m d^n y$ is not context free.

- But context free languages are closed under intersection.

- $\therefore$ $f(\text{SG})$ (and by extension Swiss German) must not be context free.

Strongly/weakly CF

- A language is *weakly* context-free if the set of strings in the language can be generated by a CFG.
- A language is *strongly* context-free if the CFG furthermore assigns the correct structures to the strings.
- Shieber's argument is that SW is not *weakly* context-free and *a fortiori* not *strongly* context-free.
- Bresnan et al (1983) had already argued that Dutch is *strongly* not context-free, but the argument was dependent on linguistic analyses.

Overview

- Failed attempts
- Formal definition of CFG
- Constituency, ambiguity, constituency tests
- Central claims of CFG
- Order independence
- Weaknesses of CFG
- Next time: Feature structures