Ling 566
Sept 27, 2012

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

- $a^* = \{\emptyset, a, aa, aaa, aaaa, \ldots\}$
- $a^+ = \{a, aa, aaa, aaaa, \ldots\}$
- (D) A* N V ((D) A* N)

Reading Question

- Why can't we represent ambiguity with FSMs?
  - I saw the astronomer with the telescope
  - N V D N P D N

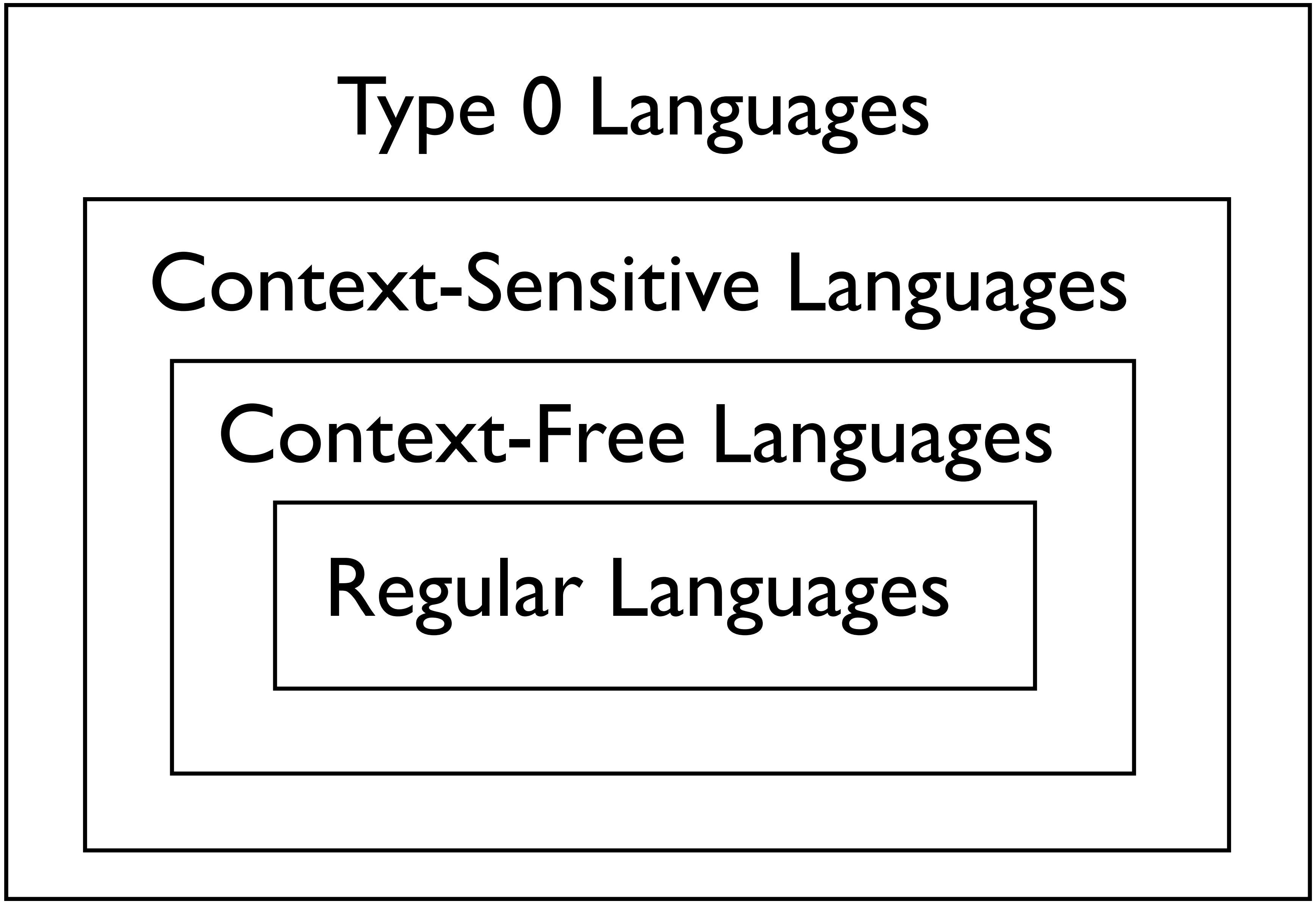
What does a theory do?

- 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



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

$S \longrightarrow NP\ VP$

$NP \longrightarrow (D)\ A^*\ N\ PP^*$

$VP \longrightarrow V\ (NP)\ (PP)$

$PP \longrightarrow P\ NP$

LEXICON

D: the, some

A: big, brown, old

N: birds, fleas, dog, hunter, I

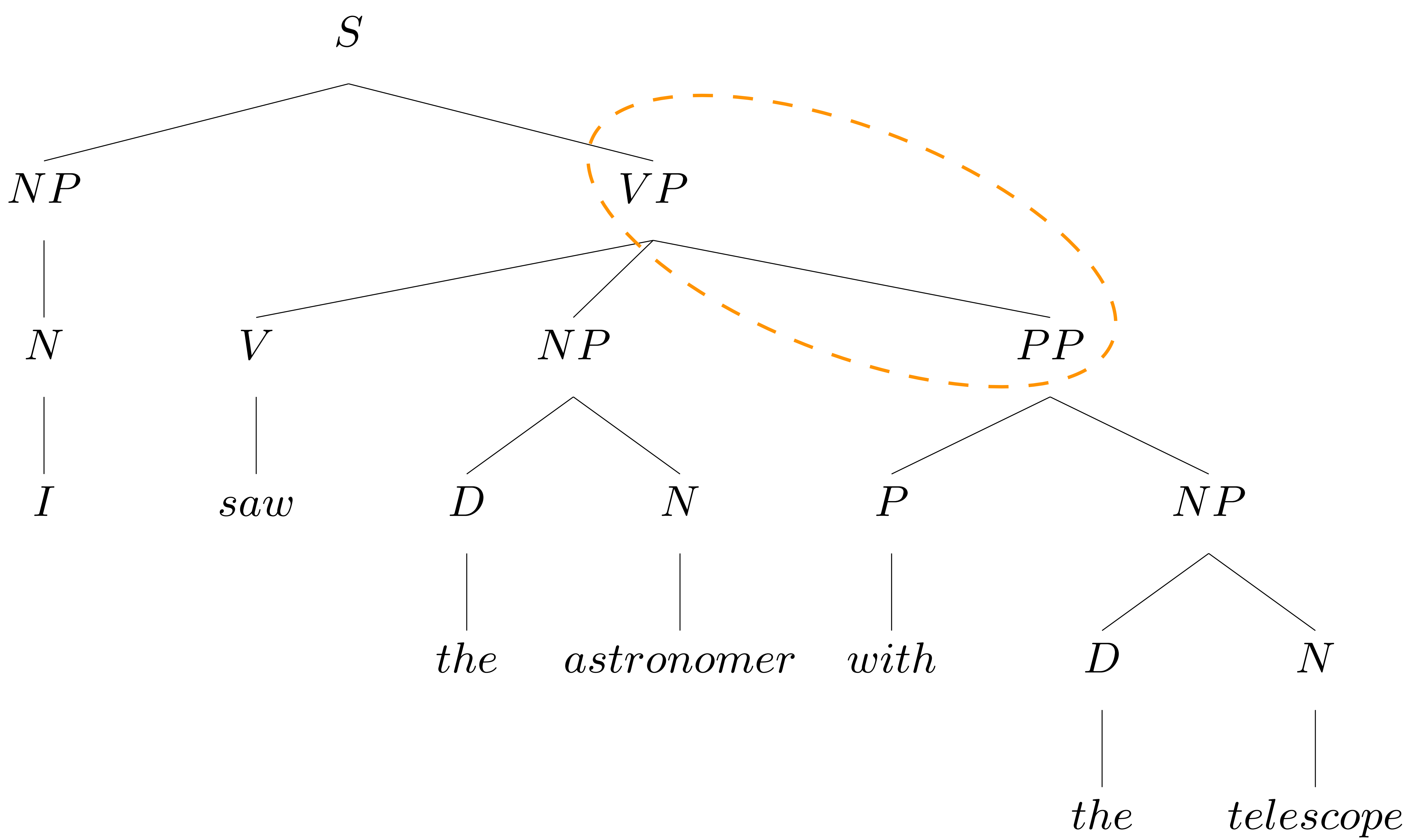
V: attack, ate, watched

P: for, beside, with

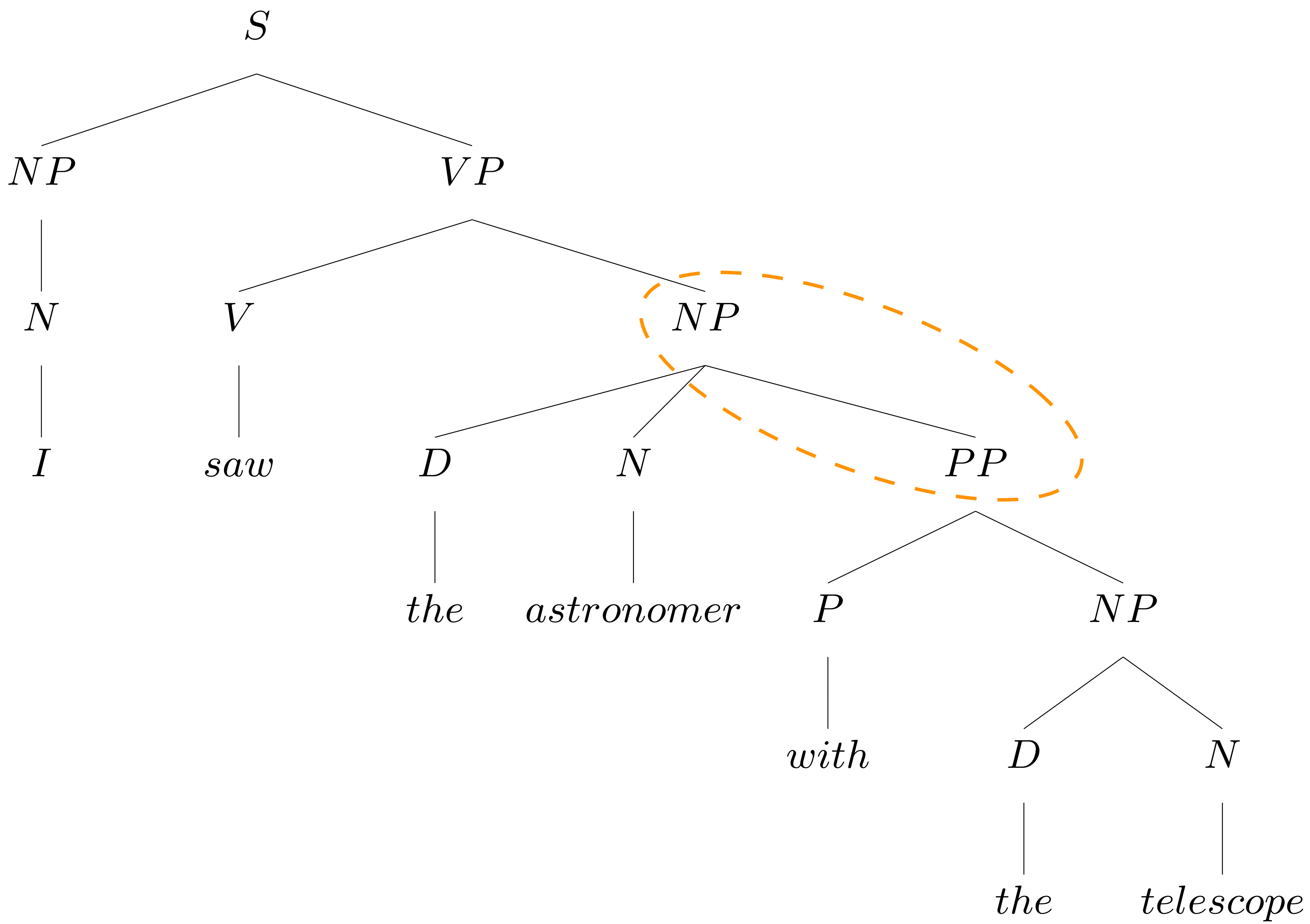
Structural Ambiguity

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.

Reading Question

- What would be an example that fails the constituency tests?

  Kim saw a movie about time travel.

  **A movie about Kim saw time travel.*

  **It was a movie about that Kim saw time travel.*

  Kim saw a movie about and a play on time travel.

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 $A \rightarrow X$, 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

$S \longrightarrow NP\ VP$

$NP \longrightarrow D\ N$

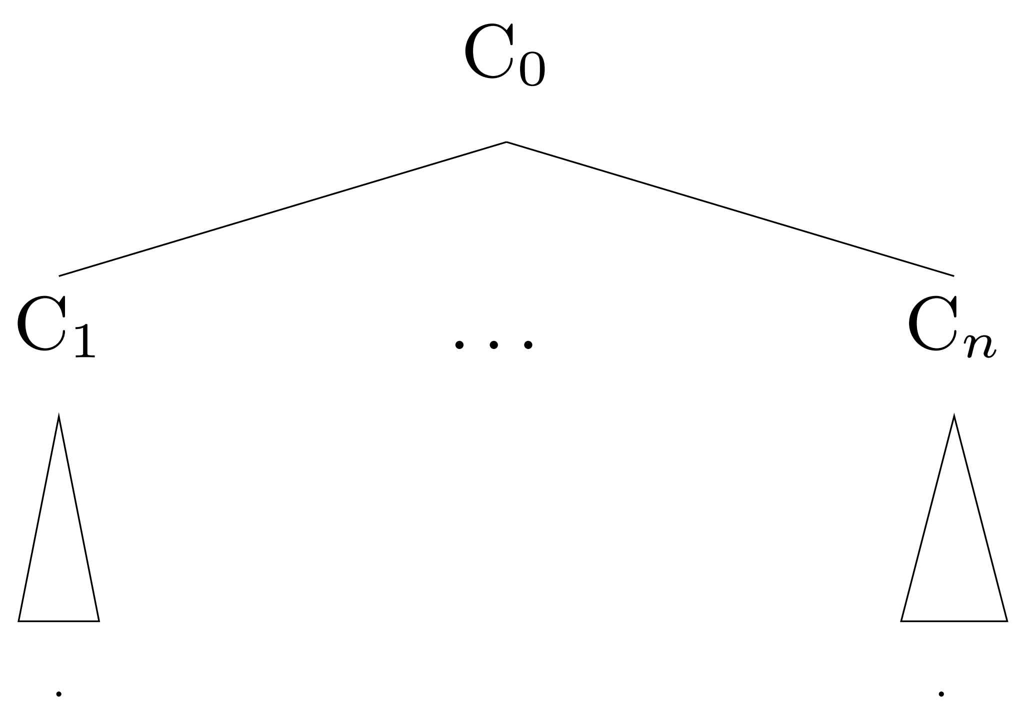
$VP \longrightarrow V\ NP$

D: *the*

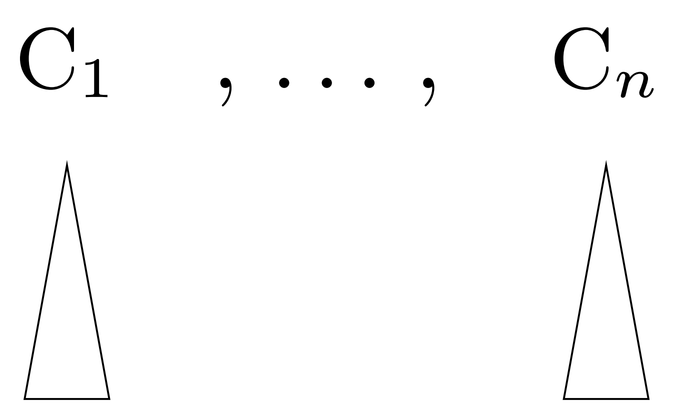
V: *chased*

N: *dog, cat*

Trees and Rules



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

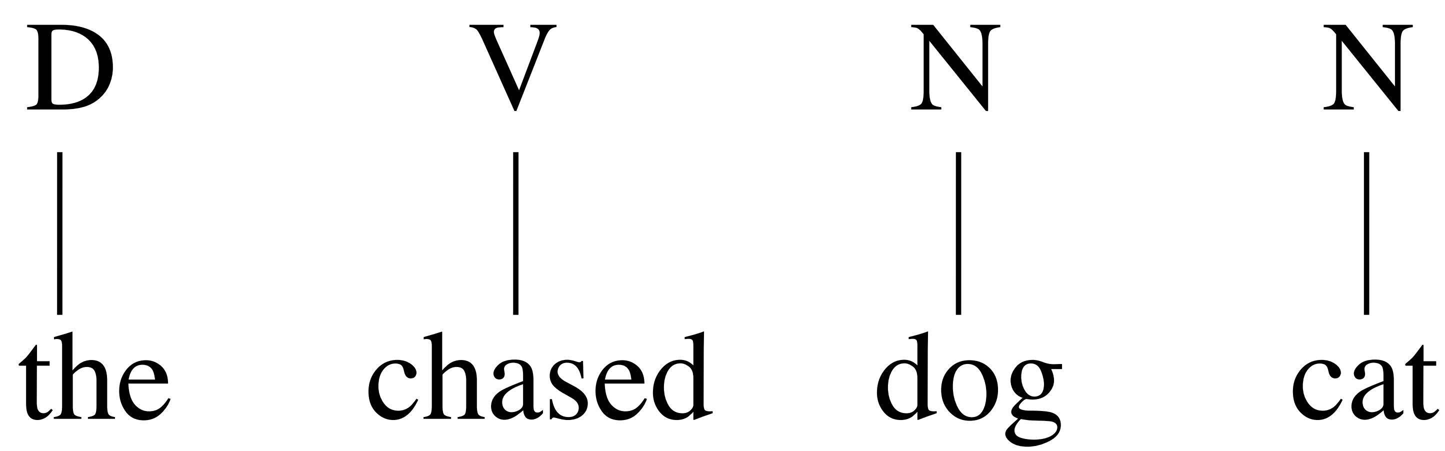


are well-formed trees, and

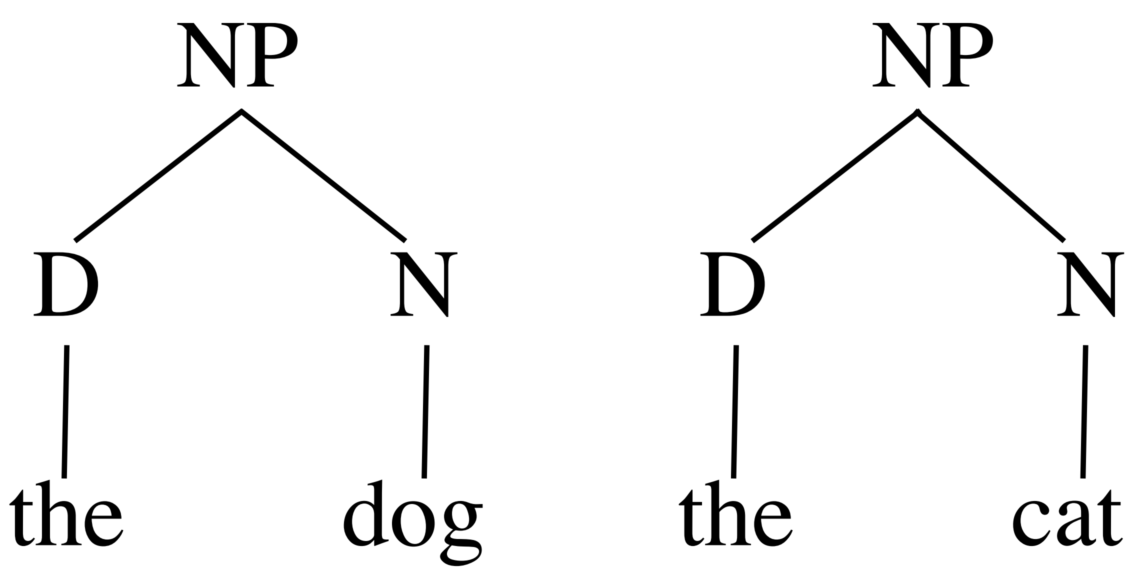
$C_0 \rightarrow C_1 \ldots Cn$ is a grammar rule.

Bottom-up Tree Construction

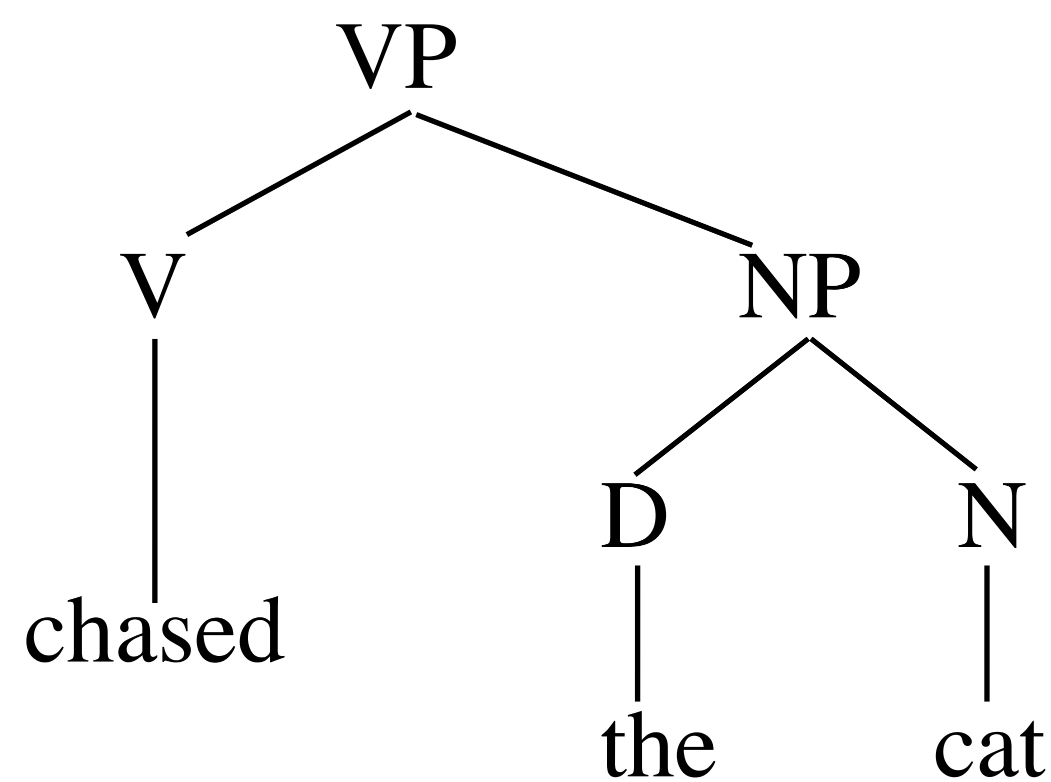
D: *the*
V: *chased*
N: *dog, cat*



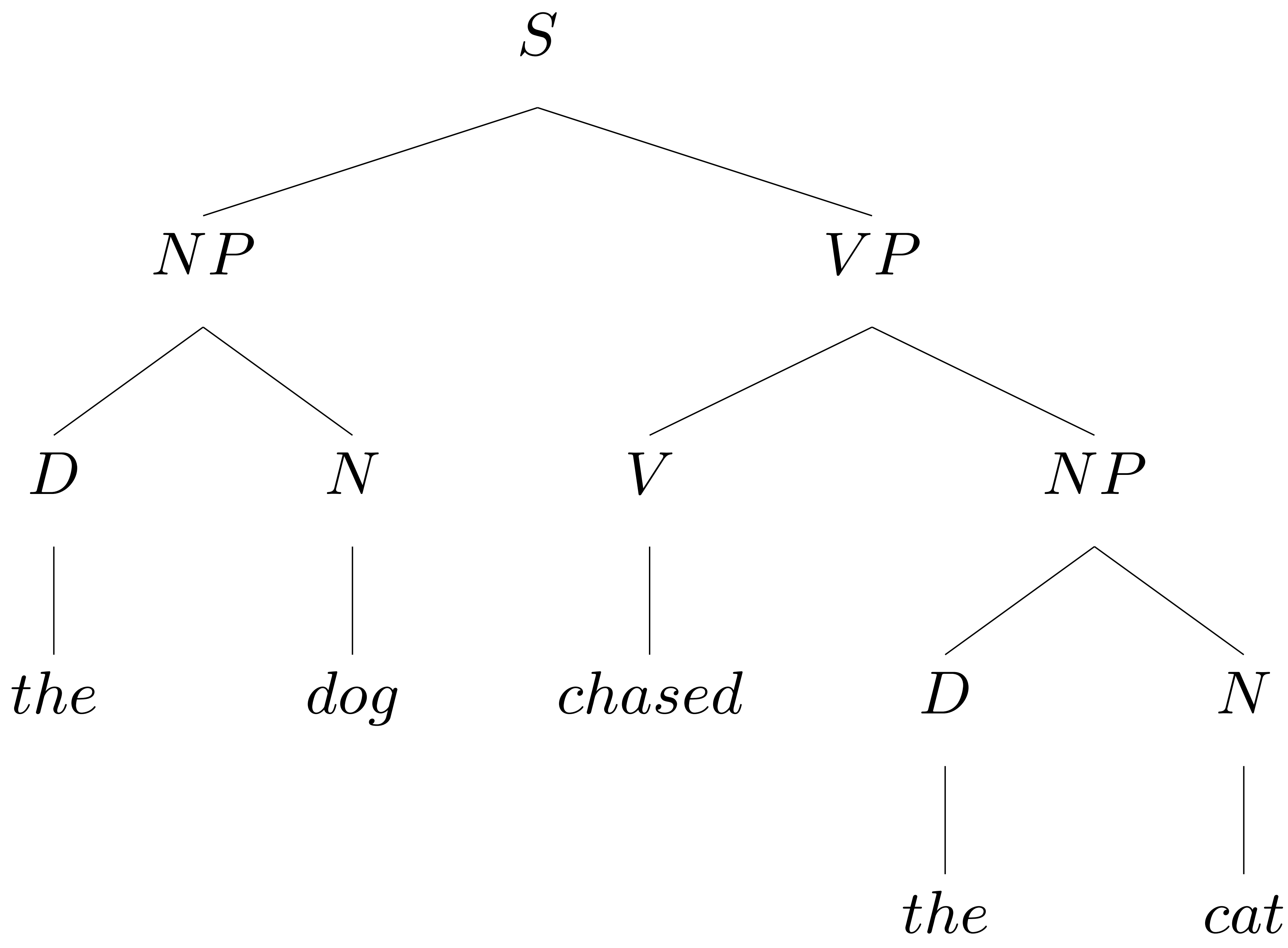
$$NP \longrightarrow D \;\; N$$



$$VP \longrightarrow V \;\; NP$$

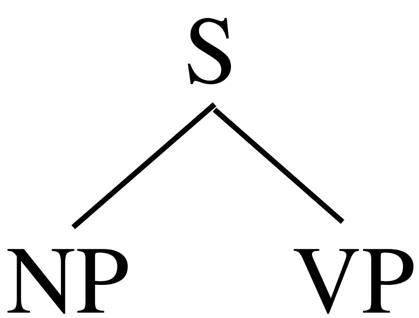


$S \longrightarrow NP\ VP$

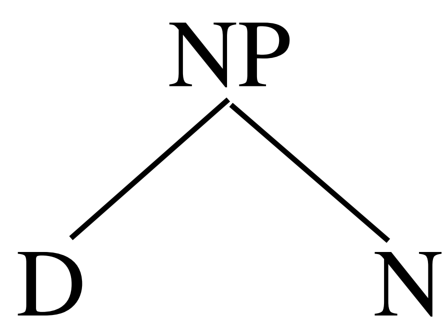


Top-down Tree Construction

$S \longrightarrow NP\ \ VP$

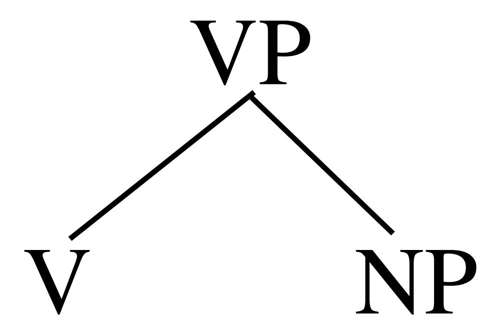


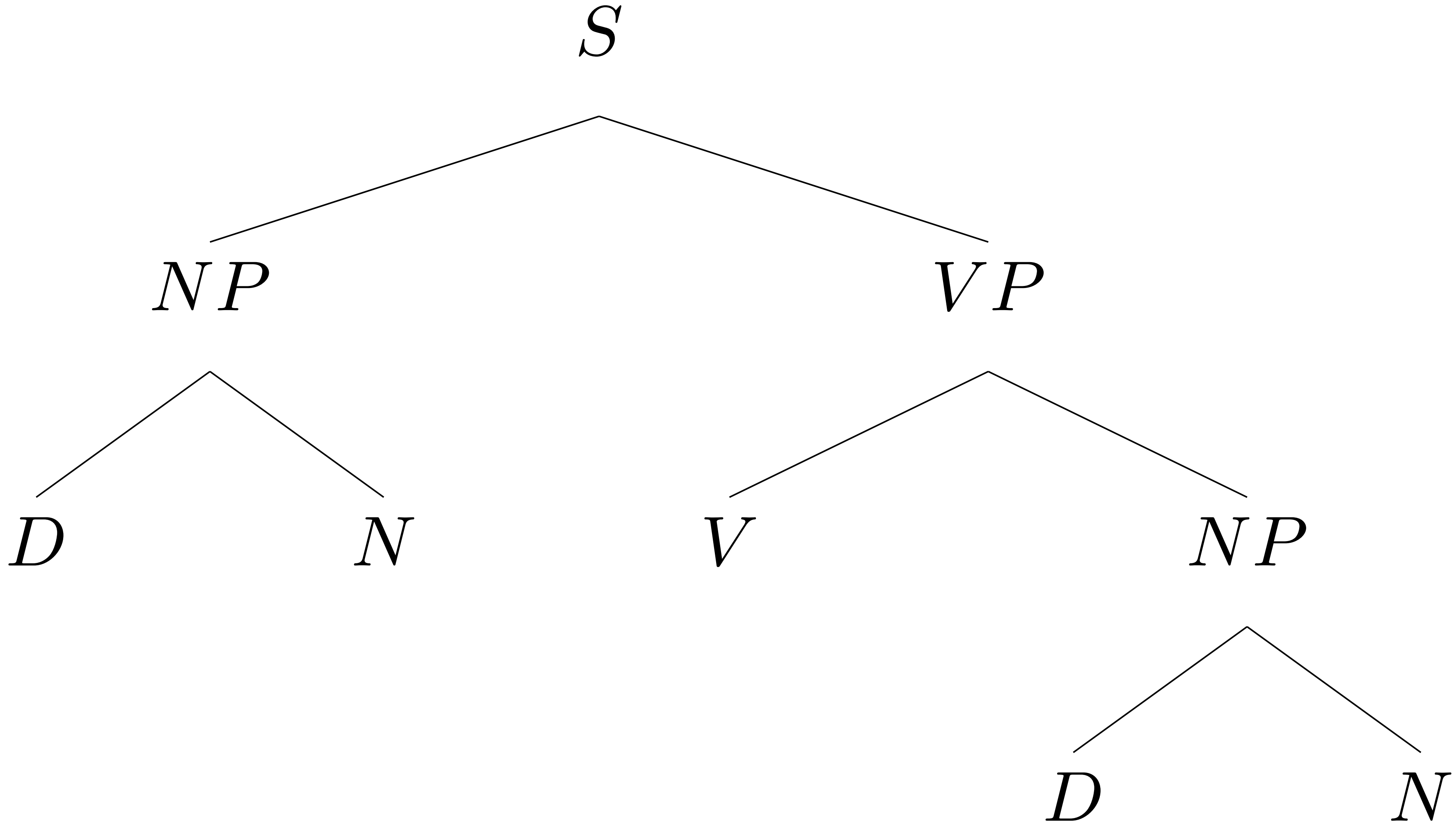
$NP \longrightarrow D\ \ N$

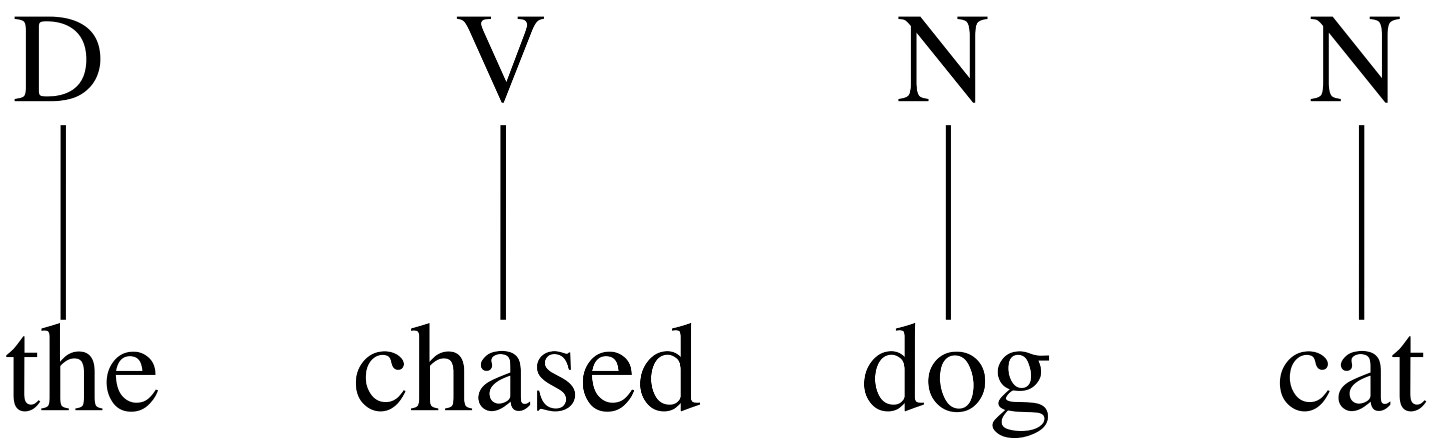


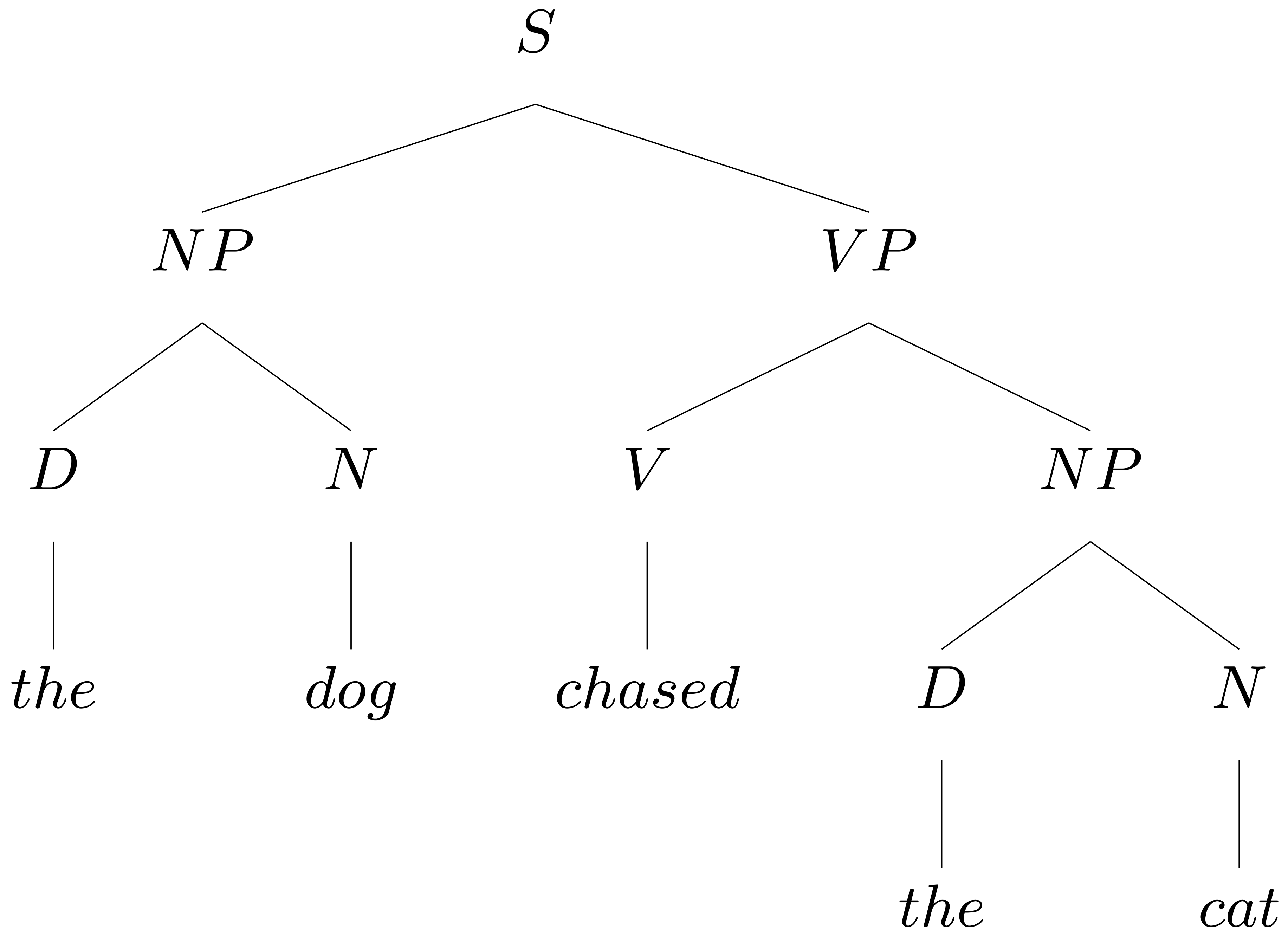
(twice)

$VP \longrightarrow V\ \ NP$




S
NP
VP
D
N
V
NP
D
N


D
V
N
N
the
chased
dog
cat


S
NP
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NP
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dog
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D
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the
cat

Weaknesses of CFG (atomic node labels)

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

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

- 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's the deal with Transformational Grammar?
  - Basic idea: CFG "base" and then rules mapping trees to trees
- What are the arguments against TG?
  - That depends on what you want the grammar to do.
- What's this about order- and process-neutrality?
- Would transformations be good for MT?
- What are the arguments against UG?

Reading Questions

- Why do we need NOM? (And why isn't it called N'?)
- Why not VP -> V (NP) (NP) PP*?
- Can we represent sentences with same/similar structure but different meaning (e.g., indicated by punctuation) in CFG?
- Given two CFGs, how can you measure which one is more correct?
- Is it better to overgenerate or undergenerate?
- Doesn't center embedding mean we need to limit recursion?

Reading Questions

- Does it even make sense to try to model a moving target?
- Can we make grammars of learner language?
- Could a more expressive formalism lead to programming languages more like NL?
- Does HPSG work take frequency into account?
- How do you decide what phenomenon to work on next?

Chapter 2, Problem 1

$S \rightarrow NP\ VP$

$NP \rightarrow (D)\ NOM$

$VP \rightarrow V\ (NP)\ (NP)$

$NOM \rightarrow N$

$NOM \rightarrow NOM\ PP$

$VP \rightarrow VP\ PP$

$PP \rightarrow P\ NP$

$X \rightarrow X^{+}\ CONJ\ X$

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 $f(\text{SG})$:

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

- 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