Parsing, and Context-Free Grammars

Michael Collins, Columbia University

Overview

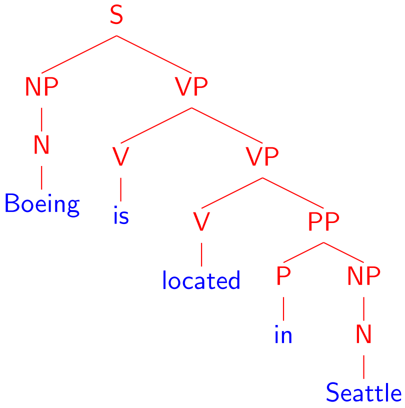
- An introduction to the parsing problem
- Context free grammars
- A brief(!) sketch of the syntax of English
- Examples of ambiguous structures

Parsing (Syntactic Structure)

INPUT:

Boeing is located in Seattle.

OUTPUT:



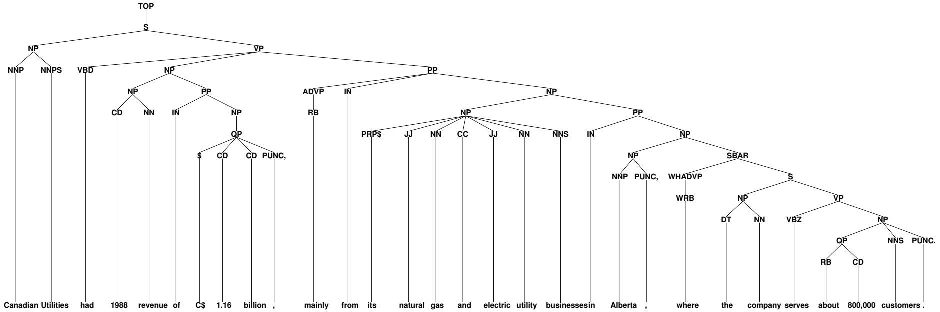
Syntactic Formalisms

- Work in formal syntax goes back to Chomsky's PhD thesis in the 1950s
- Examples of current formalisms: minimalism, lexical functional grammar (LFG), head-driven phrase-structure grammar (HPSG), tree adjoining grammars (TAG), categorial grammars

Data for Parsing Experiments

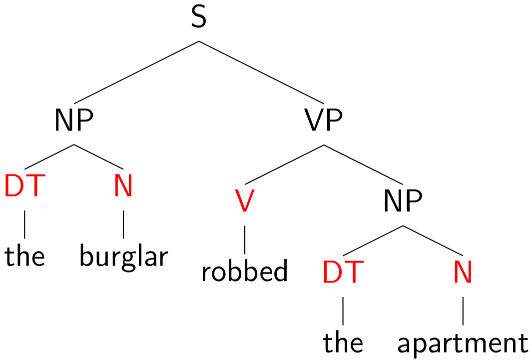
- Penn WSJ Treebank = 50,000 sentences with associated trees
- Usual set-up: 40,000 training sentences, 2400 test sentences

An example tree:



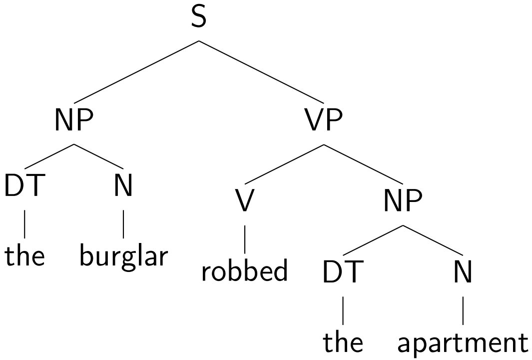
The Information Conveyed by Parse Trees

(1) Part of speech for each word
(N = noun, V = verb, DT = determiner)



The Information Conveyed by Parse Trees (continued)

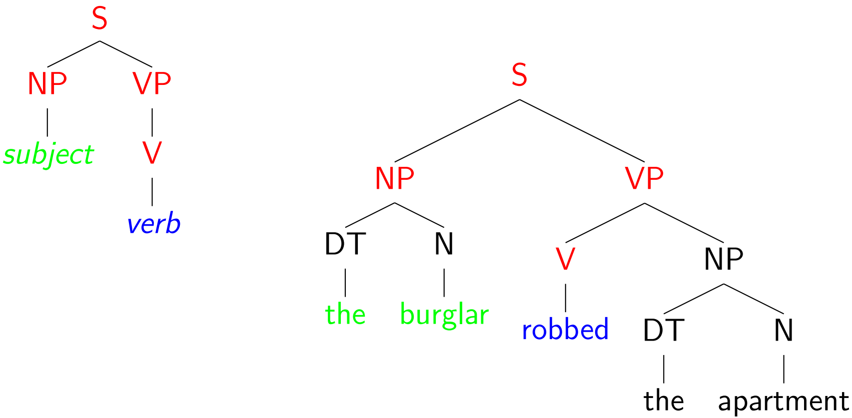
(2) Phrases



Noun Phrases (NP): “the burglar”, “the apartment”
Verb Phrases (VP): “robbed the apartment”
Sentences (S): “the burglar robbed the apartment”

The Information Conveyed by Parse Trees (continued)

(3) Useful Relationships



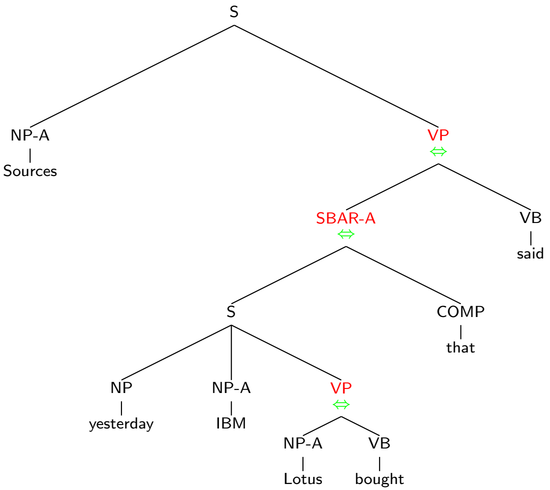
$\Rightarrow$ "the burglar" is the subject of "robbed"

An Example Application: Machine Translation

- English word order is *subject – verb – object*
- Japanese word order is *subject – object – verb*

English:	IBM bought Lotus
Japanese:	*IBM Lotus bought*

English:	Sources said that IBM bought Lotus yesterday
Japanese:	*Sources yesterday IBM Lotus bought that said*


S
NP-A
Sources
VP
SBAR-A
VB
said
S
COMP
that
NP
yesterday
NP-A
IBM
VP
NP-A
Lotus
VB
bought

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Context-Free Grammars

Hopcroft and Ullman, 1979

A context free grammar $G = (N, \Sigma, R, S)$ where:

- N is a set of non-terminal symbols
- Σ is a set of terminal symbols
- R is a set of rules of the form $X \rightarrow Y_1 Y_2 \ldots Y_n$ for $n \geq 0$, $X \in N$, $Y_i \in (N \cup \Sigma)$
- $S \in N$ is a distinguished start symbol

A Context-Free Grammar for English

$$N = \{\text{S, NP, VP, PP, DT, Vi, Vt, NN, IN}\}$$
$$S = \text{S}$$
$$\Sigma = \{\text{sleeps, saw, man, woman, telescope, the, with, in}\}$$

$R =$

S	$\rightarrow$	NP	VP
VP	$\rightarrow$	Vi	
VP	$\rightarrow$	Vt	NP
VP	$\rightarrow$	VP	PP
NP	$\rightarrow$	DT	NN
NP	$\rightarrow$	NP	PP
PP	$\rightarrow$	IN	NP

Vi	$\rightarrow$	sleeps
Vt	$\rightarrow$	saw
NN	$\rightarrow$	man
NN	$\rightarrow$	woman
NN	$\rightarrow$	telescope
DT	$\rightarrow$	the
IN	$\rightarrow$	with
IN	$\rightarrow$	in

Note: S=sentence, VP=verb phrase, NP=noun phrase, PP=prepositional phrase, DT=determiner, Vi=intransitive verb, Vt=transitive verb, NN=noun, IN=preposition

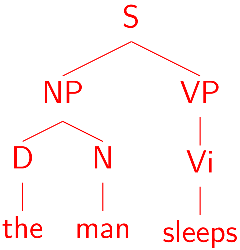
Left-Most Derivations

A left-most derivation is a sequence of strings $s_1 \dots s_n$, where

- $s_1 = S$, the start symbol
- $s_n \in \Sigma^*$, i.e. s_n is made up of terminal symbols only
- Each s_i for $i = 2 \dots n$ is derived from s_{i-1} by picking the left-most non-terminal X in s_{i-1} and replacing it by some β where $X \rightarrow \beta$ is a rule in R

For example: [S], [NP VP], [D N VP], [the N VP], [the man VP], [the man Vi], [the man sleeps]

Representation of a derivation as a tree:



An Example

DERIVATION	RULES USED
S	

An Example

DERIVATION	RULES USED
S	$S \rightarrow NP\ VP$
NP VP	

An Example

DERIVATION	RULES USED
S	
NP VP	S $\rightarrow$ NP VP
DT N VP	NP $\rightarrow$ DT N

An Example

DERIVATION	RULES USED
S	$S \rightarrow NP\ VP$
NP VP	$NP \rightarrow DT\ N$
DT N VP	$DT \rightarrow$ the
the N VP	

An Example

DERIVATION	RULES USED
S	$S \rightarrow NP\ VP$
NP VP	$NP \rightarrow DT\ N$
DT N VP	$DT \rightarrow$ the
the N VP	$N \rightarrow$ dog
the dog VP	

An Example

DERIVATION	RULES USED
S	$S \rightarrow NP\ VP$
NP VP	$NP \rightarrow DT\ N$
DT N VP	$DT \rightarrow$ the
the N VP	$N \rightarrow$ dog
the dog VP	$VP \rightarrow VB$
the dog VB	

An Example

DERIVATION	RULES USED
S	$S \rightarrow NP\ VP$
NP VP	$NP \rightarrow DT\ N$
DT N VP	$DT \rightarrow$ the
the N VP	$N \rightarrow$ dog
the dog VP	$VP \rightarrow VB$
the dog VB	$VB \rightarrow$ laughs
the dog laughs	

An Example

DERIVATION

S

NP VP

DT N VP

the N VP

the dog VP

the dog VB

the dog laughs

RULES USED

S $\rightarrow$ NP VP

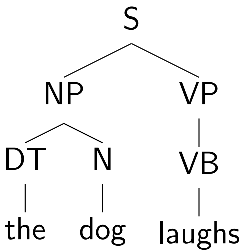
NP $\rightarrow$ DT N

DT $\rightarrow$ the

N $\rightarrow$ dog

VP $\rightarrow$ VB

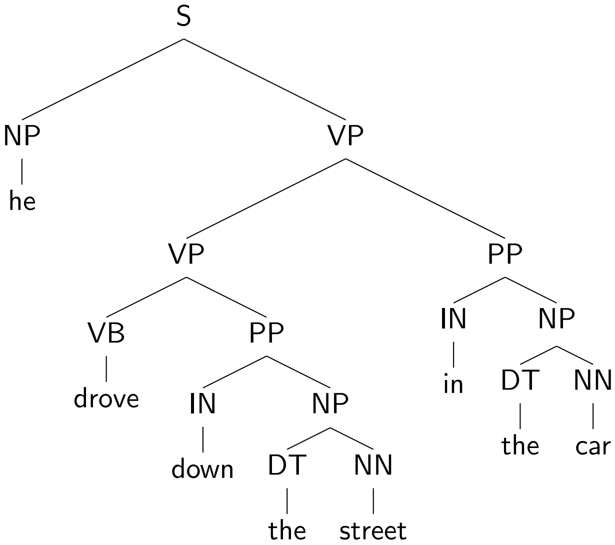
VB $\rightarrow$ laughs



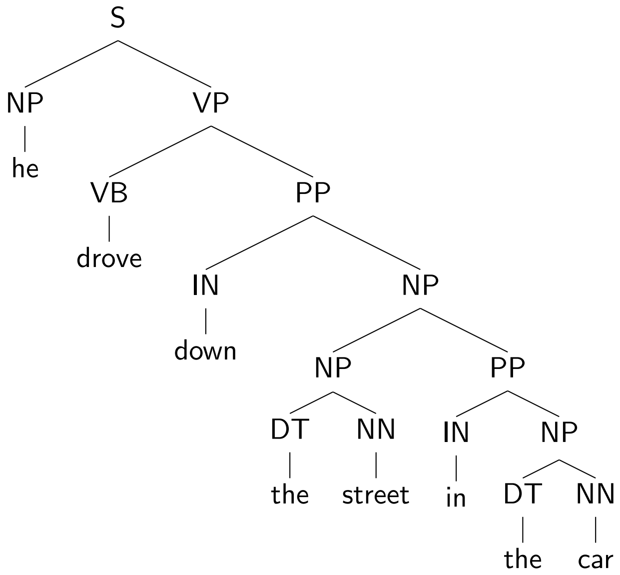
Properties of CFGs

- A CFG defines a set of possible derivations
- A string $s \in \Sigma^*$ is in the *language* defined by the CFG if there is at least one derivation that yields s
- Each string in the language generated by the CFG may have more than one derivation ("ambiguity")

An Example of Ambiguity



An Example of Ambiguity (continued)

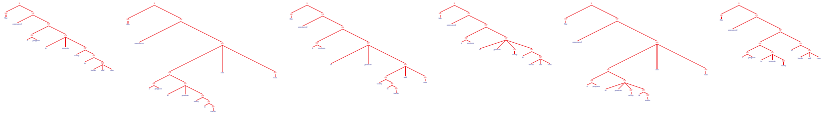


The Problem with Parsing: Ambiguity

INPUT:
She announced a program to promote safety in trucks and vans

$\Downarrow$

POSSIBLE OUTPUTS:



And there are more...

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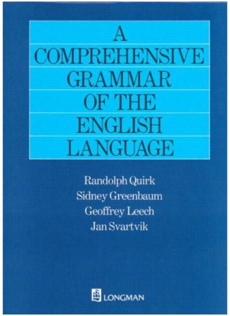

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A Brief Overview of English Syntax

Parts of Speech (tags from the Brown corpus):

- Nouns
  NN = singular noun e.g., man, dog, park
  NNS = plural noun e.g., telescopes, houses, buildings
  NNP = proper noun e.g., Smith, Gates, IBM
- Determiners
  DT = determiner e.g., the, a, some, every
- Adjectives
  JJ = adjective e.g., red, green, large, idealistic

A Fragment of a Noun Phrase Grammar

$\bar{N}$	$\Rightarrow$	NN	
$\bar{N}$	$\Rightarrow$	NN	$\bar{N}$
$\bar{N}$	$\Rightarrow$	JJ	$\bar{N}$
$\bar{N}$	$\Rightarrow$	$\bar{N}$	$\bar{N}$
NP	$\Rightarrow$	DT	$\bar{N}$

NN	$\Rightarrow$	box
NN	$\Rightarrow$	car
NN	$\Rightarrow$	mechanic
NN	$\Rightarrow$	pigeon
DT	$\Rightarrow$	the
DT	$\Rightarrow$	a

JJ	$\Rightarrow$	fast
JJ	$\Rightarrow$	metal
JJ	$\Rightarrow$	idealistic
JJ	$\Rightarrow$	clay

Prepositions, and Prepositional Phrases

- Prepositions
  IN = preposition   e.g., of, in, out, beside, as

An Extended Grammar

$\bar{N}$	$\Rightarrow$	NN	
$\bar{N}$	$\Rightarrow$	NN	$\bar{N}$
$\bar{N}$	$\Rightarrow$	JJ	$\bar{N}$
$\bar{N}$	$\Rightarrow$	$\bar{N}$	$\bar{N}$
NP	$\Rightarrow$	DT	$\bar{N}$
PP	$\Rightarrow$	IN	NP
$\bar{N}$	$\Rightarrow$	$\bar{N}$	PP

NN	$\Rightarrow$	box
NN	$\Rightarrow$	car
NN	$\Rightarrow$	mechanic
NN	$\Rightarrow$	pigeon
DT	$\Rightarrow$	the
DT	$\Rightarrow$	a

JJ	$\Rightarrow$	fast
JJ	$\Rightarrow$	metal
JJ	$\Rightarrow$	idealistic
JJ	$\Rightarrow$	clay
IN	$\Rightarrow$	in
IN	$\Rightarrow$	under
IN	$\Rightarrow$	of
IN	$\Rightarrow$	on
IN	$\Rightarrow$	with
IN	$\Rightarrow$	as

Generates:
in a box, under the box, the fast car mechanic under the pigeon in the box, . . .

An Extended Grammar

$$\left|\begin{array}{llll}
\bar{\text{N}} & \Rightarrow & \text{NN} & \\
\bar{\text{N}} & \Rightarrow & \text{NN} & \bar{\text{N}} \\
\bar{\text{N}} & \Rightarrow & \text{JJ} & \bar{\text{N}} \\
\bar{\text{N}} & \Rightarrow & \bar{\text{N}} & \bar{\text{N}} \\
\text{NP} & \Rightarrow & \text{DT} & \bar{\text{N}} \\
 & & & \\
\text{PP} & \Rightarrow & \text{IN} & \text{NP} \\
\bar{\text{N}} & \Rightarrow & \bar{\text{N}} & \text{PP}
\end{array}\right|$$

Verbs, Verb Phrases, and Sentences

- Basic Verb Types

Vi	= Intransitive verb	e.g., sleeps, walks, laughs
Vt	= Transitive verb	e.g., sees, saw, likes
Vd	= Ditransitive verb	e.g., gave

- Basic VP Rules

$$\begin{array}{lllll} VP & \rightarrow & Vi & & \\ VP & \rightarrow & Vt & NP & \\ VP & \rightarrow & Vd & NP & NP \end{array}$$

- Basic S Rule

$$S \rightarrow NP \quad VP$$

Examples of VP:
sleeps, walks, likes the mechanic, gave the mechanic the fast car
Examples of S:
the man sleeps, the dog walks, the dog gave the mechanic the fast car

PPs Modifying Verb Phrases

A new rule: VP $\rightarrow$ VP PP

New examples of VP:
sleeps in the car, walks like the mechanic, gave the mechanic the fast car on Tuesday, . . .

Complementizers, and SBARs

- Complementizers
  COMP = complementizer   e.g., that
- SBAR
  SBAR $\rightarrow$ COMP S

Examples:

that the man sleeps, that the mechanic saw the dog ...

More Verbs

- New Verb Types

V[5]	e.g., said, reported
V[6]	e.g., told, informed
V[7]	e.g., bet

- New VP Rules

VP	$\rightarrow$	V[5]	SBAR		
VP	$\rightarrow$	V[6]	NP	SBAR	
VP	$\rightarrow$	V[7]	NP	NP	SBAR

Examples of New VPs:

said that the man sleeps

told the dog that the mechanic likes the pigeon

bet the pigeon $50 that the mechanic owns a fast car

Coordination

- A New Part-of-Speech:
  CC = Coordinator   e.g., and, or, but

- New Rules

$$
\begin{array}{lllll}
\text{NP} & \rightarrow & \text{NP} & \text{CC} & \text{NP} \\
\bar{\text{N}} & \rightarrow & \bar{\text{N}} & \text{CC} & \bar{\text{N}} \\
\text{VP} & \rightarrow & \text{VP} & \text{CC} & \text{VP} \\
\text{S} & \rightarrow & \text{S} & \text{CC} & \text{S} \\
\text{SBAR} & \rightarrow & \text{SBAR} & \text{CC} & \text{SBAR}
\end{array}
$$

We've Only Scratched the Surface...

- Agreement

  The dogs laugh *vs.* The dog laughs

- Wh-movement

  The dog that the cat liked ___

- Active vs. passive

  The dog saw the cat *vs.*
  The cat was seen by the dog

- If you're interested in reading more:

  Syntactic Theory: A Formal Introduction, 2nd Edition. Ivan A. Sag, Thomas Wasow, and Emily M. Bender.

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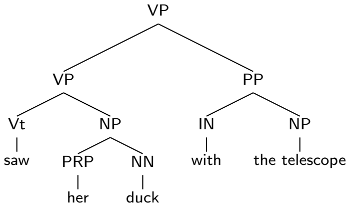
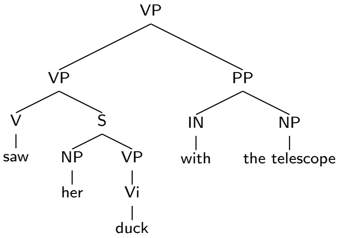
Sources of Ambiguity

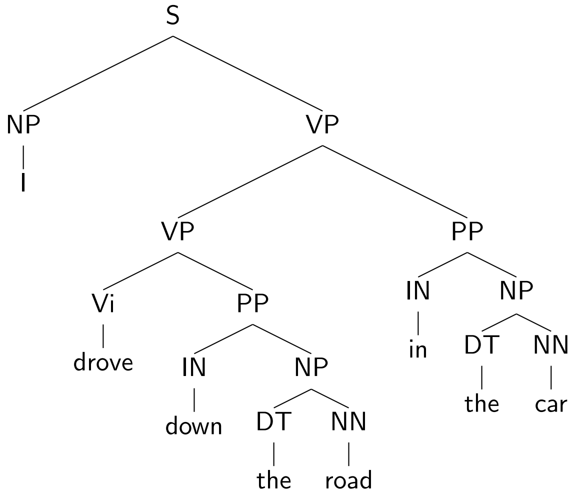
- Part-of-Speech ambiguity

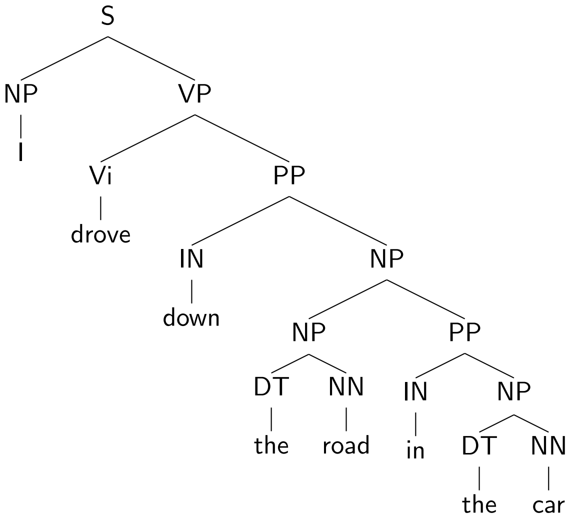
  NN → duck

  Vi → duck






S
NP
I
VP
VP
Vi
drove
PP
IN
down
NP
DT
the
NN
road
PP
IN
in
NP
DT
the
NN
car


S
NP
VP
I
Vi
PP
drove
IN
NP
down
NP
PP
DT
NN
IN
NP
the
road
in
DT
NN
the
car

Two analyses for: John was believed to have been shot by Bill

Sources of Ambiguity: Noun Premodifiers

- Noun premodifiers: