Natural Language Processing
SoSe 2014

Parsing

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(based on the slides of Dr. Saeedeh Momtazi)

Parsing

- Finding structural relationships between words in a sentence

- Applications
  - Spell checking
  - Speech recognition
  - Machine translation
  - Relation extraction

Outline

- Phrase Structure
- Syntactic Parsing
  - CKY Algorithm
- Statistical Parsing

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Constituency

- Working based on Constituency (Phrase structure)
  - Organizing words into nested constituents
  - Showing that groups of words can act as single units
  - Forming coherent classes from these units that can behave in similar ways
    - With respect to their internal structure
    - With respect to other units in the language
  - Considering a head word for each constituent

Constituency

the writer talked to the audience about his new book.

the writer talked about his new book to the audience. ✓

about his new book the writer talked to the audience. ✓

the writer talked about to the audience his new book. ✗

Context Free Grammar (CFG)

- Grammar G consists of
  - Terminals (T)
  - Non-terminals (N)
  - Start symbol (S)
  - Rules (R)

Context Free Grammar (CFG)

- Terminals
  - The set of words in the text
- Non-Terminals
  - The constituents in a language (noun phrase, verb phrase, ...)
- Start symbol
  - The main constituent of the language (sentence)
- Rules
  - Equations that consist of a single non-terminal on the left and any number of terminals and non-terminals on the right

Context Free Grammar (CFG)

S → NP VP

S → VP

NP → NN

NP → PRP

NP → DT NN

NP → NP NP

NP → NP PP

VP → VBP NP

VP → VBP NP PP

VP → VP PP

VP → VP NP

PP → TO NNP

PRP → I

NN → book

VBP → buy

DT → a

NN → flight

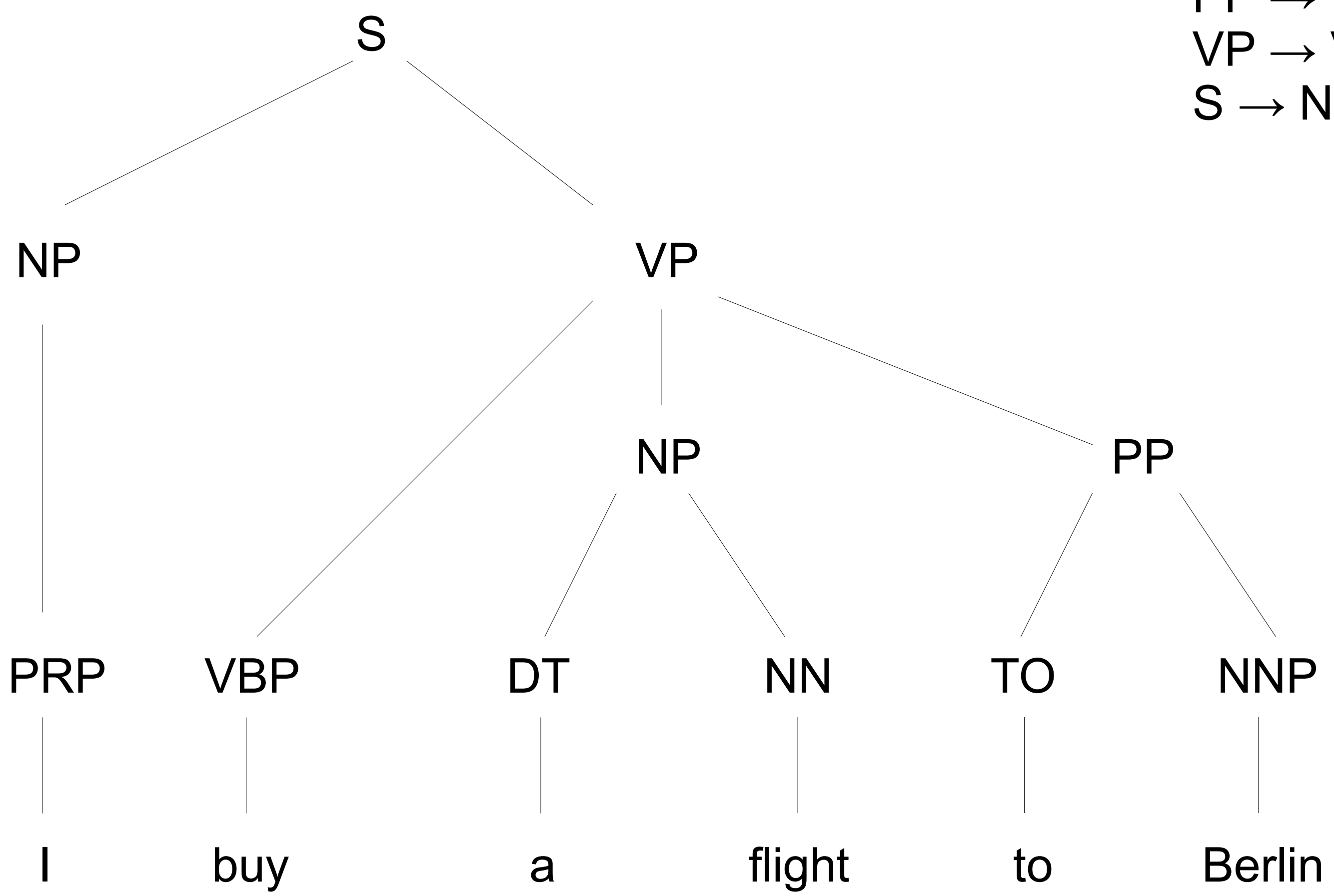
TO → to

NNP → Berlin

CFG

CFG

$NP \rightarrow PRP$
$NP \rightarrow DT\ NN$
$PP \rightarrow TO\ NNP$
$VP \rightarrow VBP\ NP\ PP$
$S \rightarrow NP\ VP$



Outline

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- Syntactic Parsing
  - CKY Algorithm
- Statistical Parsing

Parsing

- Taking a string and a grammar and returning proper parse tree(s) for that string
- Covering all and only the elements of the input string
- Reaching the start symbol at the top of the string

Main Grammar Fragments

- Sentence
- Noun Phrase
  - Agreement
- Verb Phrase
  - Sub-categorization

Grammar Fragments: Sentence

- Declaratives
  - A plane left.
  - S → NP VP
- Imperatives
  - Leave!
  - S → VP
- Yes-No Questions
  - Did the plane leave?
  - S → Aux NP VP
- Wh Questions
  - Which airlines fly from Berlin to London?
  - S → Wh-NP VP

Grammar Fragments: NP

- Each NP has a central critical noun called head

- The head of an NP can be expressed using
  - Pre-nominals: the words that can come before the head
  - Post-nominals: the words that can come after the head

Grammar Fragments: NP

- Pre-nominals
  - Simple lexical items: the, this, a, an, ...
    - a car
  - Simple possessives
    - John’s car
  - Complex recursive possessives
    - John’s sister’s friend’s car
  - Quantifiers, cardinals, ordinals...
    - three cars
  - Adjectives
    - large cars

Grammar Fragments: NP

- Post-nominals
  - Prepositional phrases
    - I book a flight <u>from Seattle</u>
  - Non-finite clauses (-ing, -ed, infinitive)
    - There is a flight <u>arriving before noon</u>
    - I need to have dinner <u>served</u>
    - Which is the last flight <u>to arrive in Boston</u>?
  - Relative clauses
    - I want a flight that serves breakfast

Agreement

- Having constraints that hold among various constituents
- Considering these constraints in a rule or set of rules
- Example: determiners and the head nouns in NPs have to agree in number
  - This flight
  - Those flights
  - This flights
  - Those flight
- Grammars that do not consider constraints will over-generate
  - Accepting and assigning correct structures to grammatical examples (this flight)
  - But also accepting incorrect examples (these flight)

Agreement at sentence level

- Considering similar constraints at sentence level
- Example: subject and verb in sentences have to agree in number and person

- John flies
- We fly
- John fly
- We flies

Agreement

- Possible CFG solution
  - $S_{sg} \rightarrow NP_{sg}\ VP_{sg}$
  - $S_{pl} \rightarrow NP_{pl}\ VP_{pl}$
  - $NP_{sg} \rightarrow Det_{sg}\ N_{sg}$
  - $NP_{pl} \rightarrow Det_{pl}\ N_{pl}$
  - $VP_{sg} \rightarrow V_{sg}\ NP_{sg}$
  - $VP_{pl} \rightarrow V_{pl}\ NP_{pl}$
  - ...
- Shortcoming:
  - Introducing many rules in the system

Grammar Fragments: VP

- VPs consist of a head verb along with zero or more constituents called arguments
  - VP → V (disappear)
  - VP → V NP (prefer a morning flight)
  - VP → V PP (fly on Thursday)
  - VP → V NP PP (leave Boston in the morning)
  - VP → V NP NP (give me the flight number)
- Arguments
  - Obligatory: complement
  - Optional: adjunct

Grammar Fragments: VP

- Even though there are many valid VP rules, not all verbs are allowed to participate in all VP rules
  - disappear a morning flight
- Solution (Sub-categorization):
  - Sub-categorizing the verbs according to the sets of VP rules that they can participate in
  - This is a modern take on the traditional notion of transitive/intransitive
  - Modern grammars have more than 100 subcategories

Sub-categorization

- Example:
  - sneeze: John sneezed
  - find: Please find [a flight to NY]$_{NP}$
  - give: Give [me]$_{NP}$ [a cheaper fair]$_{NP}$
  - help: Can you help [me]$_{NP}$ [with a flight]$_{PP}$
  - prefer: I prefer [to leave earlier]$_{TO\text{-}VP}$
  - tell: I was told [United has a flight]$_{S}$

- John sneezed the book
- I prefer United has a flight
- Give with a flight

Sub-categorization

- The over-generation problem also exists in VP rules
  - Permitting the presence of strings containing verbs and arguments that do not go together
  - John sneezed the book
    - VP → V NP

- Solution:
  - Similar to agreement phenomena, we need a way to formally express the constraints

Parsing Algorithms

- Top-Down
  - Starting with the rules that give us an S, since trees should be rooted with an S
  - Working on the way down from S to the words

- Bottom-Up
  - Starting with trees that link up with the words, since trees should cover the input words
  - Working on the way up from words to larger and larger trees

Top-Down vs. Bottom-Up

- Top-Down
  - Only searches for trees that can be answers (i.e. S’s)
  - But also suggests trees that are not consistent with any of the words

- Bottom-Up
  - Only forms trees consistent with the words
  - But suggests trees that make no sense globally

Top-Down vs. Bottom-Up

- In both cases;
  - keep track of the search space and make choices
- Solutions
  - Backtracking
    - Making a choice, if it works out then fine
    - If not, then back up and make a different choice ⇒ duplicated work
  - Dynamic programming
    - Avoiding repeated work
    - Solving exponential problems in polynomial time
    - Storing ambiguous structures efficiently

Dynamic Programming Methods

- CKY (Cocke-Kasami-Younger): bottom-up
- Early: top-down

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  - CKY Algorithm
- Statistical Parsing

Chomsky Normal Form (CNF)

- Each grammar can be represented by a set of binary rules
  - $A \rightarrow B\ C$
  - $A \rightarrow w$

- A, B, C are noun-terminals w is a terminal

Chomsky Normal Form

- Converting to Chomsky Normal Form

$$A \rightarrow B\ C\ D$$

$$X \rightarrow B\ C$$

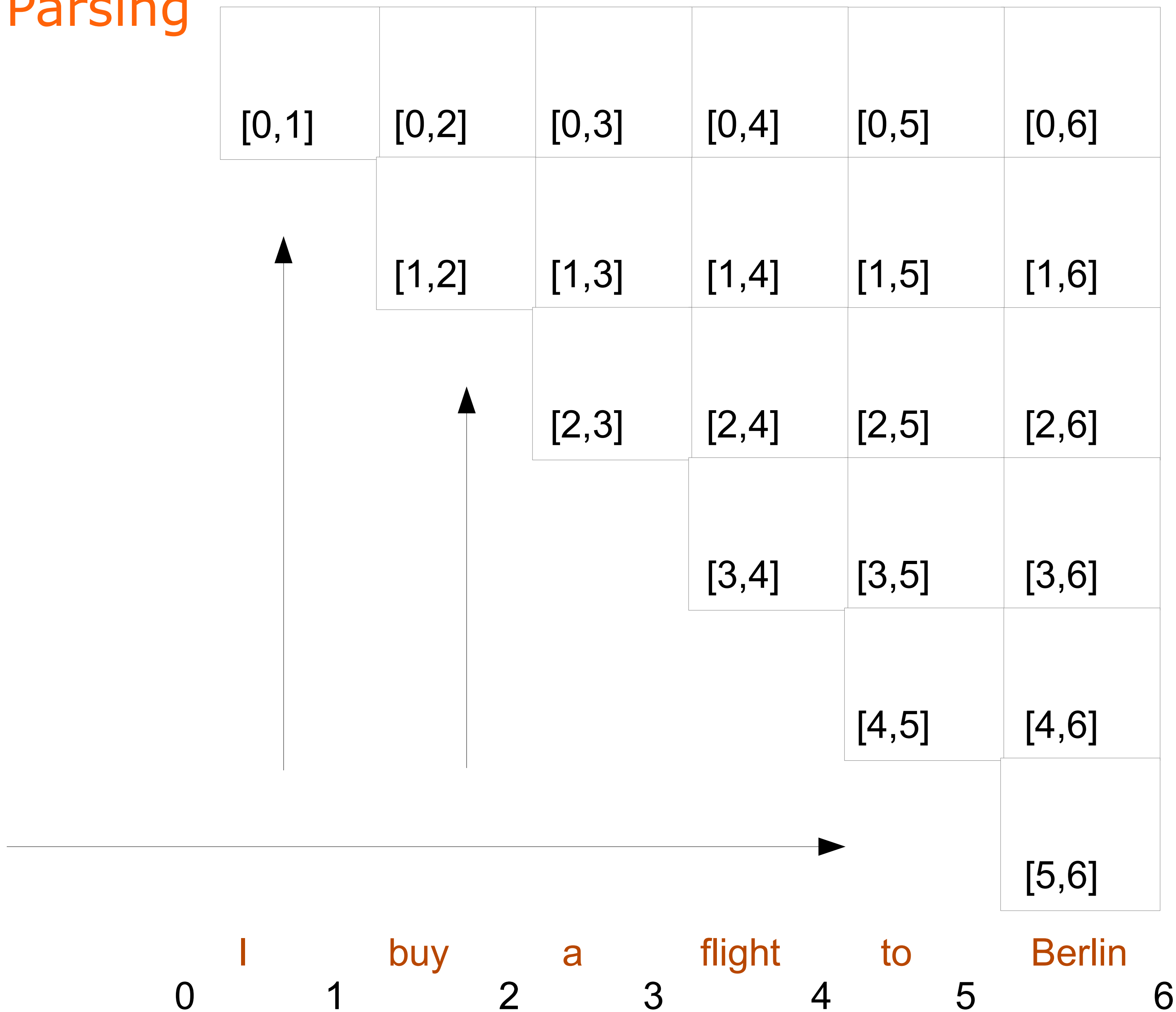
$$A \rightarrow X\ D$$

CKY Parsing

$$A \rightarrow B\ C$$

- If there is an A somewhere in the input, then there must be a B followed by a C in the input
- If the A spans from *i* to *j* in the input, then there must be a *k* such that $i < k < j$
  - B spans from *i* to *k*
  - C spans from *k* to *j*

CKY Parsing


[0,1]
[0,2]
[0,3]
[0,4]
[0,5]
[0,6]
[1,2]
[1,3]
[1,4]
[1,5]
[1,6]
[2,3]
[2,4]
[2,5]
[2,6]
[3,4]
[3,5]
[3,6]
[4,5]
[4,6]
[5,6]
I
buy
a
flight
to
Berlin
0
1
2
3
4
5
6

CKY Parsing

PRP → I
NP → PRP

PRP, NP [0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
	[1,2]	[1,3]	[1,4]	[1,5]	[1,6]
		[2,3]	[2,4]	[2,5]	[2,6]
			[3,4]	[3,5]	[3,6]
				[4,5]	[4,6]
					[5,6]
I	buy	a	flight	to	Berlin

0 1 2 3 4 5 6

CKY Parsing

PRP → I
NP → PRP

VBP → buy

PRP, NP [0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
	VBP [1,2]	[1,3]	[1,4]	[1,5]	[1,6]
		[2,3]	[2,4]	[2,5]	[2,6]
			[3,4]	[3,5]	[3,6]
				[4,5]	[4,6]
					[5,6]
I	buy	a	flight	to	Berlin

0 1 2 3 4 5 6

CKY Parsing

PRP → I
NP → PRP

VBP → buy

DT → a

PRP, NP [0,1]	[0,2]	[0,3]	[0,4]	[0,5]	[0,6]
	VBP [1,2]	[1,3]	[1,4]	[1,5]	[1,6]
		DT [2,3]	[2,4]	[2,5]	[2,6]
			[3,4]	[3,5]	[3,6]
				[4,5]	[4,6]
					[5,6]
I	buy	a	flight	to	Berlin

0 1 2 3 4 5 6

CKY Parsing

PRP → I
NP → PRP

VBP → buy

DT → a

NN → flight
NP → DT NN
VP → VBP NP
S → NP VP

PRP, NP [0,1]	[0,2]	[0,3]	S [0,4]	[0,5]	[0,6]
	VBP [1,2]	[1,3]	VP [1,4]	[1,5]	[1,6]
		DT [2,3]	NP [2,4]	[2,5]	[2,6]
			NN [3,4]	[3,5]	[3,6]
				[4,5]	[4,6]
					[5,6]

0	I	1	buy	2	a	3	flight	4	to	5	Berlin	6

CKY Parsing

PRP → I
NP → PRP

VBP → buy

DT → a

NN → flight
NP → DT NN
VP → VBP NP
S → NP VP

TO → to

PRP, NP [0,1]	[0,2]	[0,3]	S [0,4]	[0,5]	[0,6]
	VBP [1,2]	[1,3]	VP [1,4]	[1,5]	[1,6]
		DT [2,3]	NP [2,4]	[2,5]	[2,6]
			NN [3,4]	[3,5]	[3,6]
				TO [4,5]	[4,6]
					[5,6]

I buy a flight to Berlin

0 1 2 3 4 5 6

CKY Parsing

PRP $\rightarrow$ I
NP $\rightarrow$ PRP

VBP $\rightarrow$ buy

DT $\rightarrow$ a

NN $\rightarrow$ flight
NP $\rightarrow$ DT NN
VP $\rightarrow$ VBP NP
S $\rightarrow$ NP VP

TO $\rightarrow$ to

NNP $\rightarrow$ Berlin
PP $\rightarrow$ TO NNP
VP $\rightarrow$ VP PP

PRP, NP [0,1]	[0,2]	[0,3]	S [0,4]	[0,5]	S [0,6]
	VBP [1,2]	[1,3]	VP [1,4]	[1,5]	VP [1,6]
		DT [2,3]	NP [2,4]	[2,5]	[2,6]
			NN [3,4]	[3,5]	[3,6]
				TO [4,5]	PP [4,6]
					NNP [5,6]
I	buy	a	flight	to	Berlin

0 1 2 3 4 5 6

Outline

- Phrase Structure
- Syntactic Parsing
  - CKY Algorithm
- Statistical Parsing

Probabilistic Context Free Grammar (PCFG)

- Terminals (T)
- Non-terminals (N)
- Start symbol (S)
- Rules (R)
- Probability function (P)

CFG

S → NP VP

S → VP

NP → NN

NP → PRP

NP → DT NN

NP → NP NP

NP → NP PP

VP → VBP NP

VP → VP PP

VP → VP PP

VP → VP NP

PP → TO NNP

PRP → I

NN → book

VBP → buy

DT → a

NN → flight

TO → to

NNP → Berlin

PCFG

0.9 S → NP VP
0.1 S → VP
0.3 NP → NN
0.4 NP → PRP
0.1 NP → DT NN
0.2 NP → NP NP
0.1 NP → NP PP
0.4 VP → VBP NP
0.3 VP → VP PP
0.6 VP → VP PP
0.5 VP → VP NP
1.0 PP → TO NNP

1.0 PRP → I
0.6 NN → book
0.7 VBP → buy
0.8 DT → a
0.4 NN → flight
1.0 TO → to
1.0 NNP → Berlin

Treebank

- A treebank is a corpus in which each sentence has been paired with a parse tree
- These are generally created by
  - Parsing the collection with an automatic parser
  - Correcting each parse by human annotators if required
- Requirement: detailed annotation guidelines that provide
  - A POS tagset
  - A grammar
  - Annotation schema
  - Instructions for how to deal with particular grammatical constructions

Penn Treebank

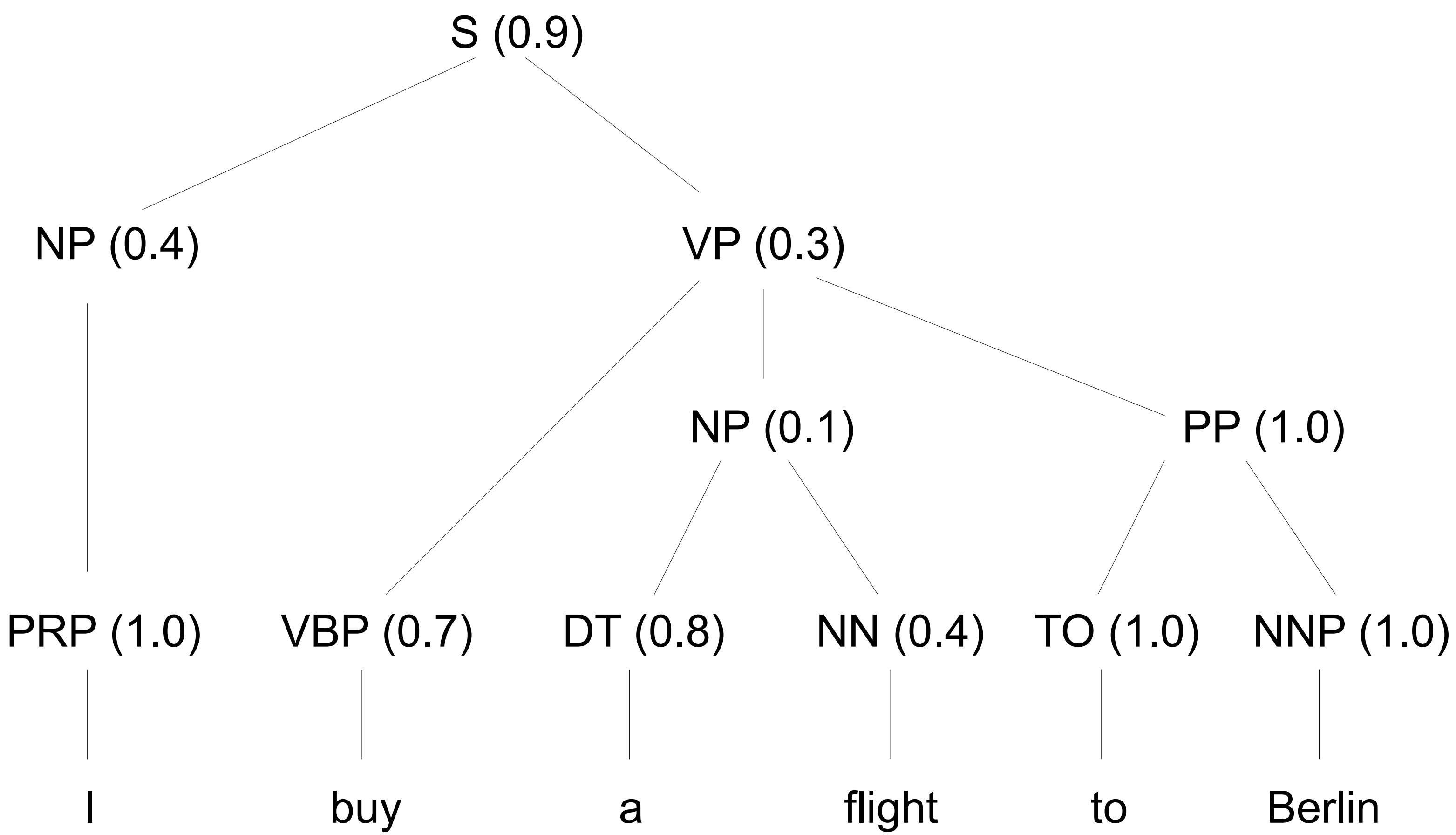
- Penn Treebank is a widely used treebank for English
  - Most well-known section: Wall Street Journal Section
  - 1 M words from 1987-1989

```
(S (NP (NNP John))
   (VP (VPZ flies)
       (PP (IN to)
           (NNP Paris)))
   (. .))
```

Statistical Parsing

- Considering the corresponding probabilities while parsing a sentence
- Selecting the parse tree which has the highest probability
- Tree and string probabilities
  - P(t): the probability of a tree t
    - Product of the probabilities of the rules used to generate the tree
  - P(s): the probability of a string s
    - Sum of the probabilities of the trees which were created to parse the string

Statistical Parsing



$$P(t) = 0.9 \times 0.4 \times 0.3 \times 1.0 \times 0.7 \times 0.1 \times 0.8 \times 0.4 \times 1.0 \times 1.0 \times 1.0$$

Probabilistic CKY Parsing

PRP → I (1.0)
NP → PRP (0.4)

VBP → buy (0.7)

DT → a (0.8)

NN → flight (0.4)
NP → DT NN (0.1)
VP → VBP NP (0.4)
S → NP VP (0.9)

TO → to (1.0)

NNP → Berlin (1.0)
PP → TO NNP (1.0)
VP → VP PP (1.0)

PRP, NP 1.0*0.4 [0,1]	[0,2]	[0,3]	S 0.8*0.4*0.1*0.7*0.4*0.9 [0,4]	[0,5]	S 1.0*1.0*1.0* 0.8*0.4*0.1*0.7*0.4* 1.0*1.0*0.4 [0,6]
	VBP 0.7 [1,2]	[1,3]	VP 0.8*0.4*0.1*0.7*0.4 [1,4]	[1,5]	VP 1.0*1.0*1.0* 0.8*0.4*0.1*0.7*0.4* 1.0 [1,6]
		DT 0.8 [2,3]	NP 0.8*0.4*0.1 [2,4]	[2,5]	[2,6]
			NN 0.4 [3,4]	[3,5]	[3,6]
				TO 1.0 [4,5]	PP 1.0*1.0*1.0 [4,6]
					NNP 1.0 [5,6]

I buy a flight to Berlin

0 1 2 3 4 5 6

Further Reading

- Speech and Language Processing
  - Chapters 12, 13, 14, 15