Natural Language Processing

SoSe 2017

Syntactic parsing

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Syntactic parsing

- Find structural relationships between words in a sentence

```
(ROOT
  (S
    (NP
      (NP (NNP Steve) (NNP Paul) (NNP Jobs))
      (, ,)
      (NP
        (NP (NN co-founder))
        (PP (IN of)
          (NP (NNP Apple) (NNP Inc))))
      (, ,))
    (VP (VBD was)
      (VP (VBN born)
        (PP (IN in)
          (NP (NNP California)))))
    (. .)))
```

(http://nlp.stanford.edu:8080/parser)

Motivation: Grammar checking

- e.g., when failing to parse a sentence

```
(ROOT
  (NP
    (NP (NNP John))
    (NP (DT a) (JJ new) (NN book))))
```

(http://nlp.stanford.edu:8080/parser)

Motivation: Speech recognition

- e.g., when failing to parse a sentence

```
(ROOT
  (FRAG
    (NP (PRP We))
    (PP (IN by)
      (NP (DT a) (JJ new) (NN book)))))
```

```
(ROOT
  (S
    (NP (PRP We))
    (VP (VBP buy)
      (NP (DT a) (JJ new) (NN book)))))
```

(http://nlp.stanford.edu:8080/parser)

Motivation: Machine translation

- e.g., when failing to parse a sentence

Babel interaktiv: „Ich mag Brot*"

Analyse für den Satz „Ich mag Brot*"

```
            v(fin, ind)
      __________|__________
     /          |          \
n(nom, sg)  v(fin, ind)  n(acc, sg)
     |          |           |
     |          |           |
n(nom, sg)     mag      n(acc, sg)
     |                      |
     |                      |
    ich                    brot
```

Babel interaktiv: „Ich wie Brot*"

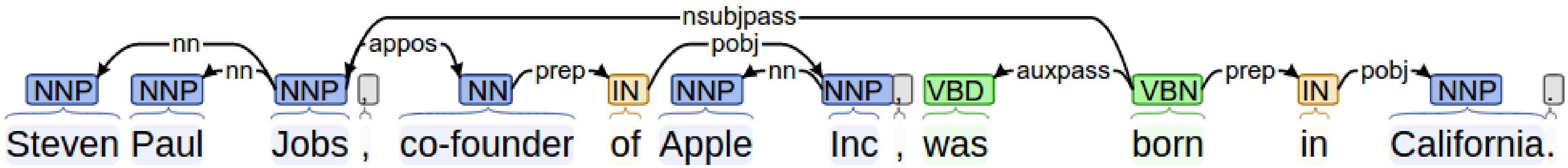
Analyse für den Satz „Ich wie Brot*"

Keine Analyse gefunden! Warum?

(http://hpsg.fu-berlin.de/~stefan/cgi-bin/babel.cgi)

Motivation: Relation extraction

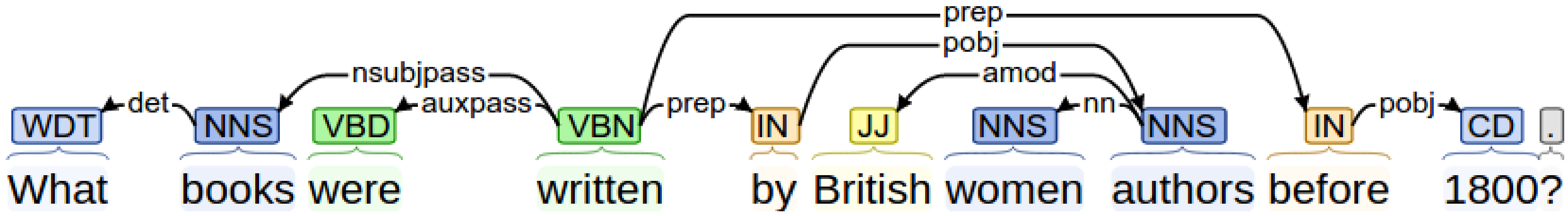
- Support extraction of relations, e.g., using dependency trees



(http://nlp.stanford.edu:8080/corenlp/)

Motivation: Question answering

- Support extraction of the question target and its details, e.g., using dependency trees



(http://nlp.stanford.edu:8080/corenlp/)

Constituency

- Parsing is based on constituency (phrase structure).
  - We organize words into nested constituents.
  - Constituents are groups of words that can act as single units.

```
(ROOT
  (S
    (NP (PRP$ My) (NN dog))
    (ADVP (RB also))
    (VP (VBZ likes)
      (S
        (VP (VBG eating)
          (NP (NN sausage)))))
    (. .)))
```


(http://nlp.stanford.edu:8080/parser)

Constituency

The writer talked to the audience about his new book.

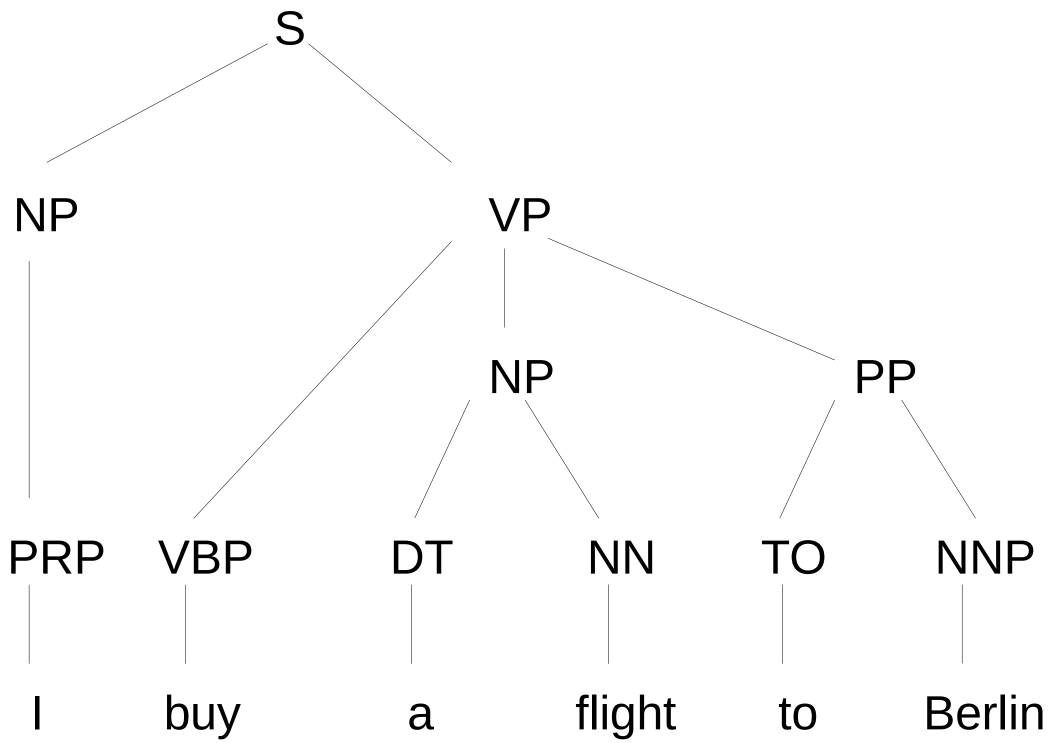
The writer talked about his new book to the audience. ✓

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

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

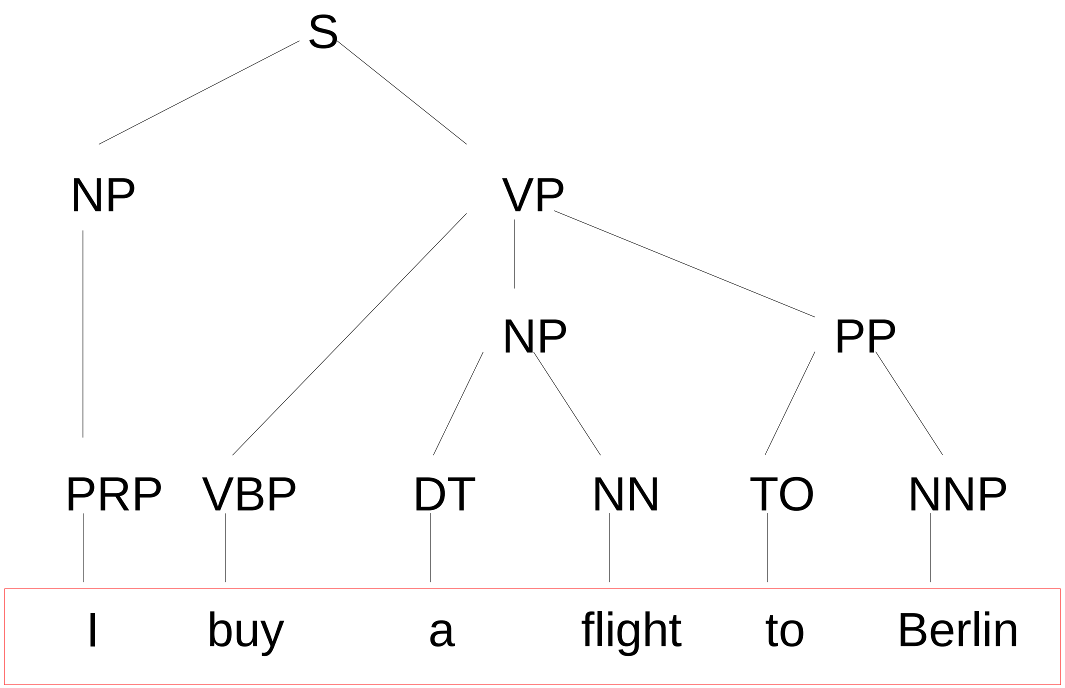
Context Free Grammar (CFG)

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



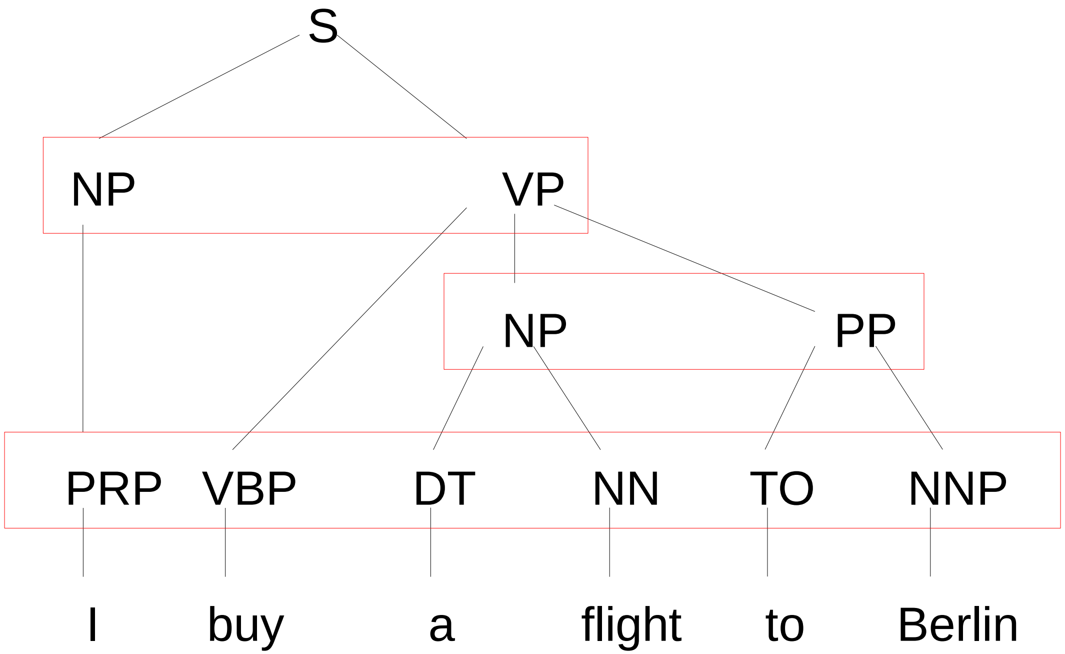
Context Free Grammar (CFG)

- Terminals
  - The set of words in the text



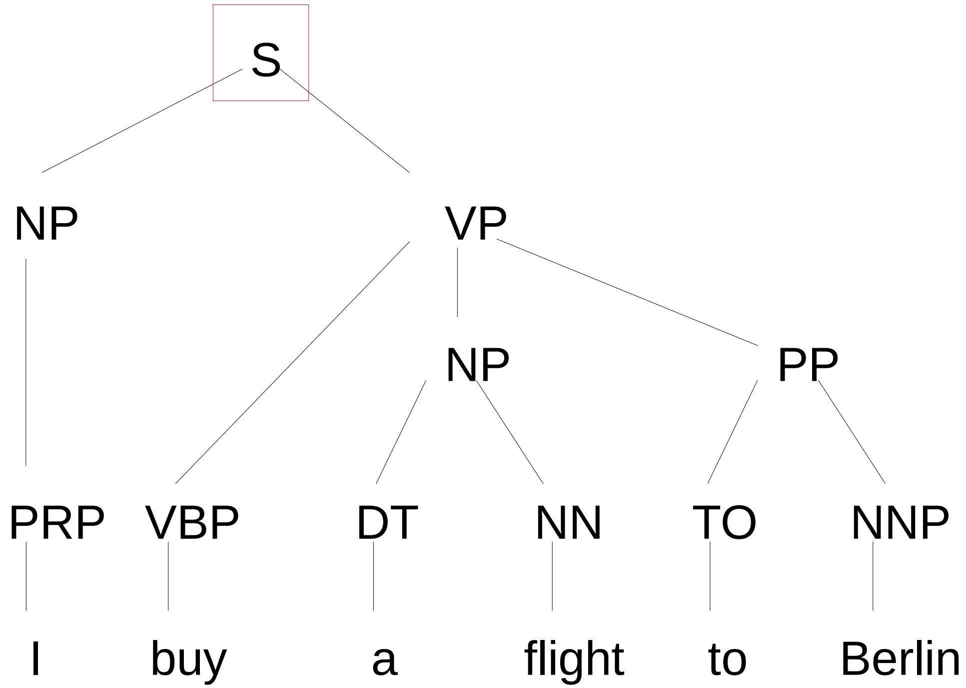
Context Free Grammar (CFG)

- Non-Terminals
  - The constituents in a language



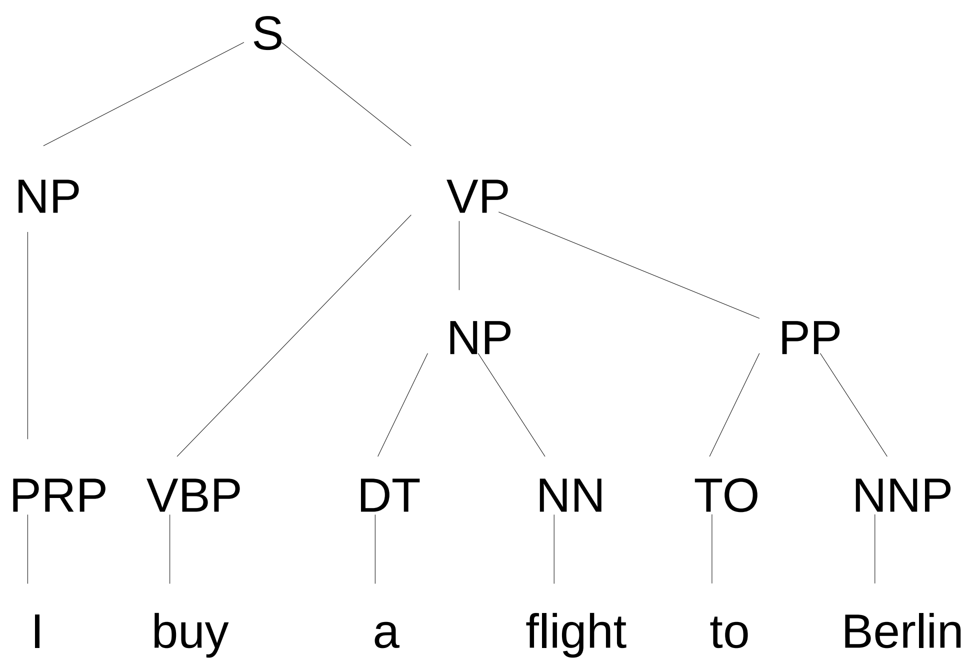
Context Free Grammar (CFG)

- Start symbol
  - The main constituent of the language



Context Free Grammar (CFG)

- Rules (or grammar)
  - Equations that consist of a single non-terminal on the left and any number of terminals and non-terminals on the right



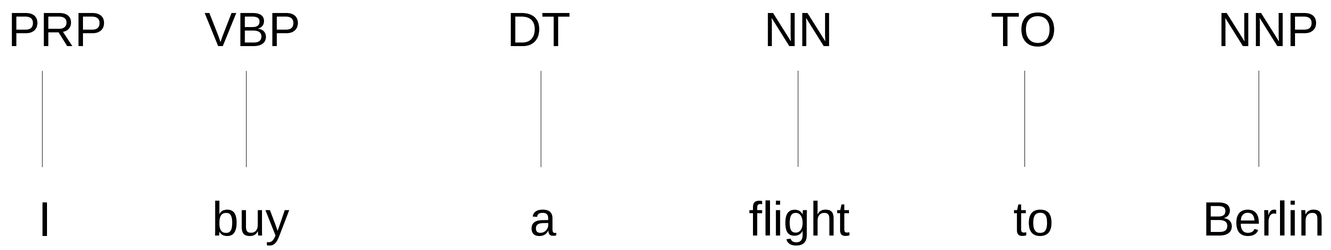
S → NP VP

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

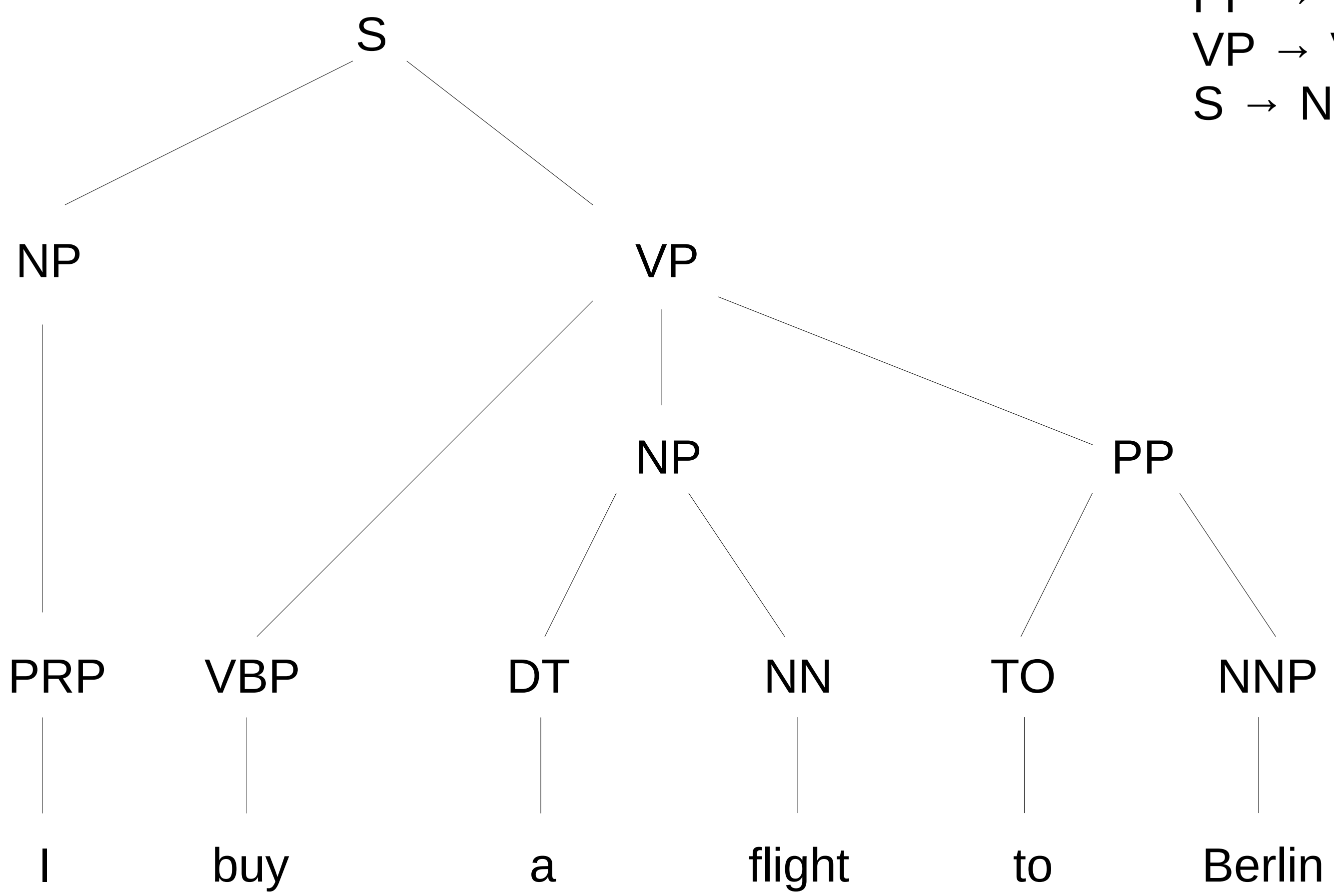
PRP → I
NN → book
VBP → buy
DT → a
NN → flight
TO → to
NNP → Berlin

CFG



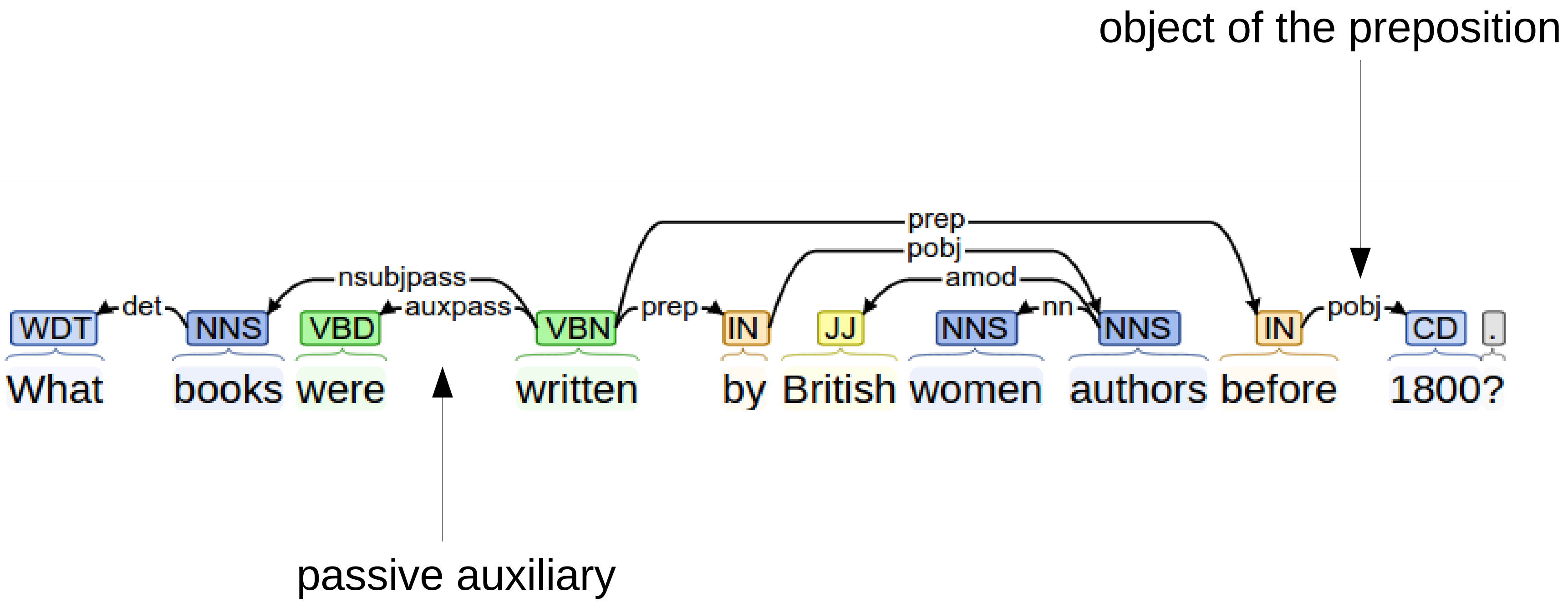
CFG

NP → PRP
NP → DT NN
PP → TO NNP
VP → VBP NP PP
S → NP VP



Dependency grammars

- No constituents, but typed dependencies
  - Links are labeled (typed)



(http://nlp.stanford.edu/software/dependencies_manual.pdf)

Main Grammar Fragments

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

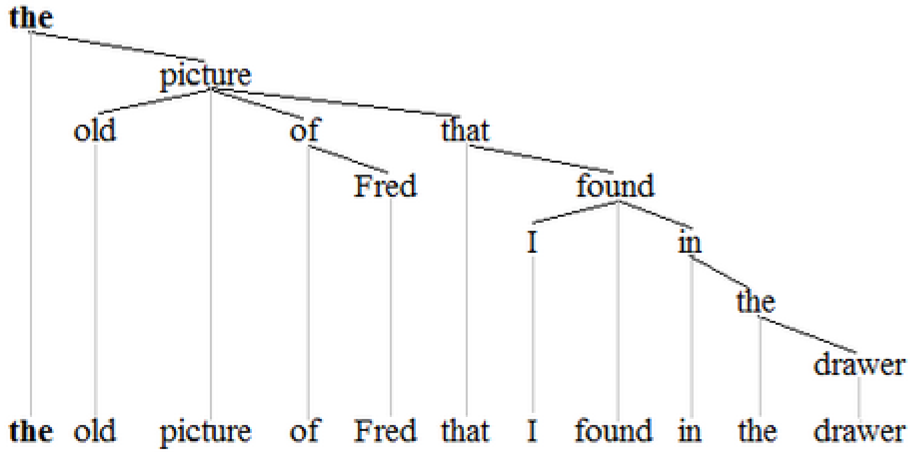
Grammar Fragments: Sentence

- 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: Noun Phrases (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



(http://en.wikipedia.org/wiki/Noun_phrase)

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 from Seattle
  - Non-finite clauses (-ing, -ed, infinitive)
    - There is a flight arriving before noon
    - I need to have dinner served
    - Which is the last flight to arrive in Boston?
  - 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

Agreement

- 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 too 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

- Solution (Sub-categorization):
  - Sub-categorizing the verbs according to the sets of VP rules that they can participate in
  - 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

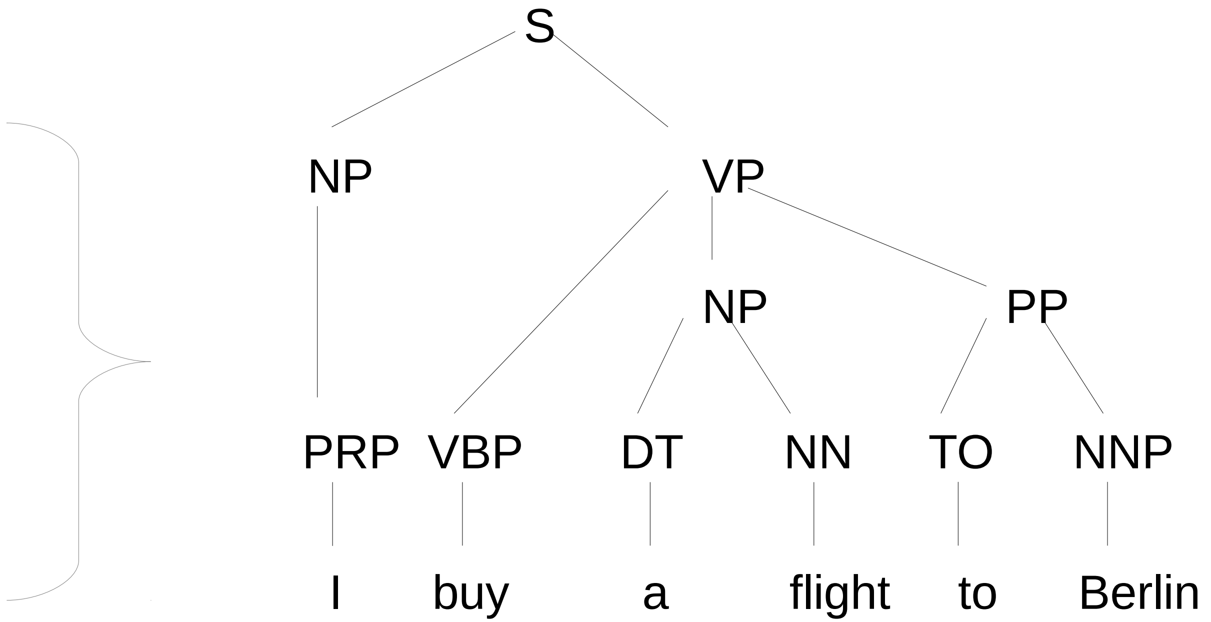
Parsing

- Given a sentence and a grammar, return a proper parse tree.

NP → PRP
NP → DT NN
PP → TO NNP
VP → VBP NP PP
S → NP VP

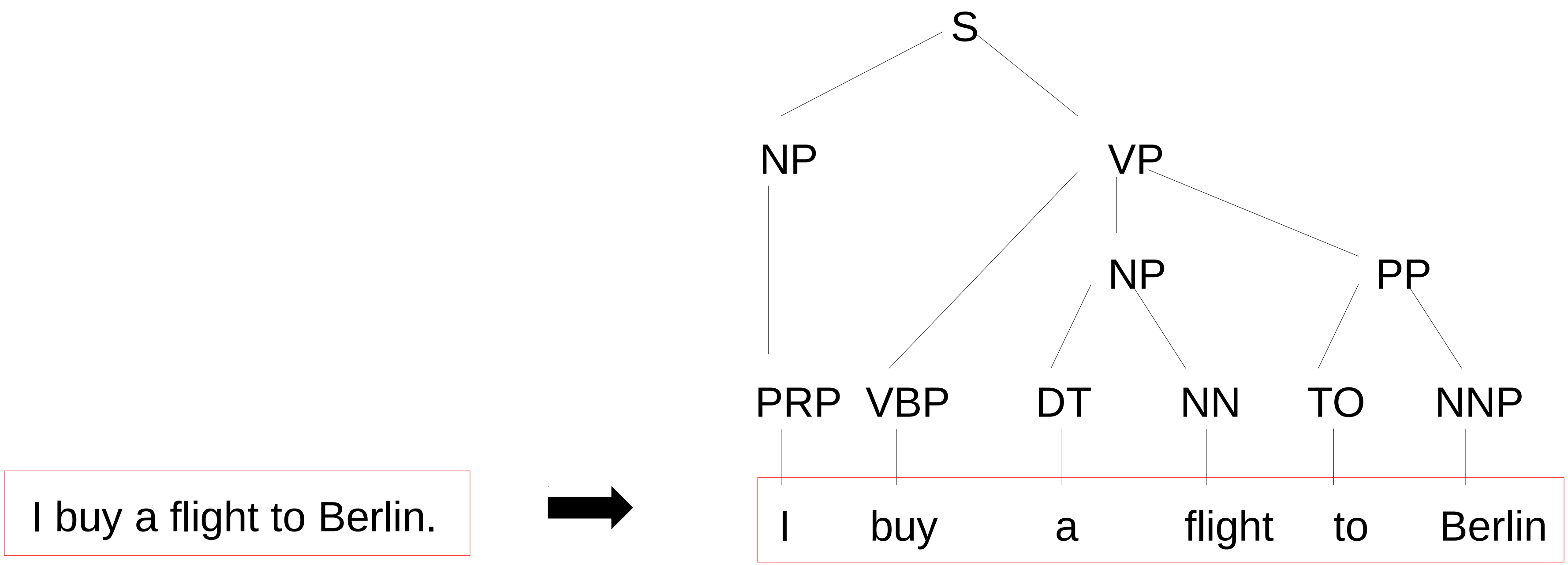
+

I buy a flight to Berlin.



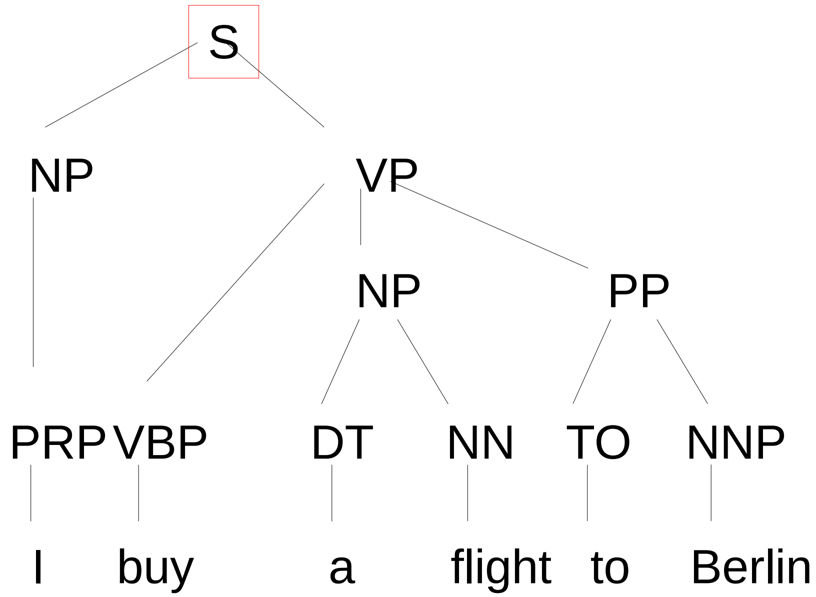
Parsing

- We should cover all and only the elements of the input string.



Parsing

- We should reach the start symbol at the top of the string.

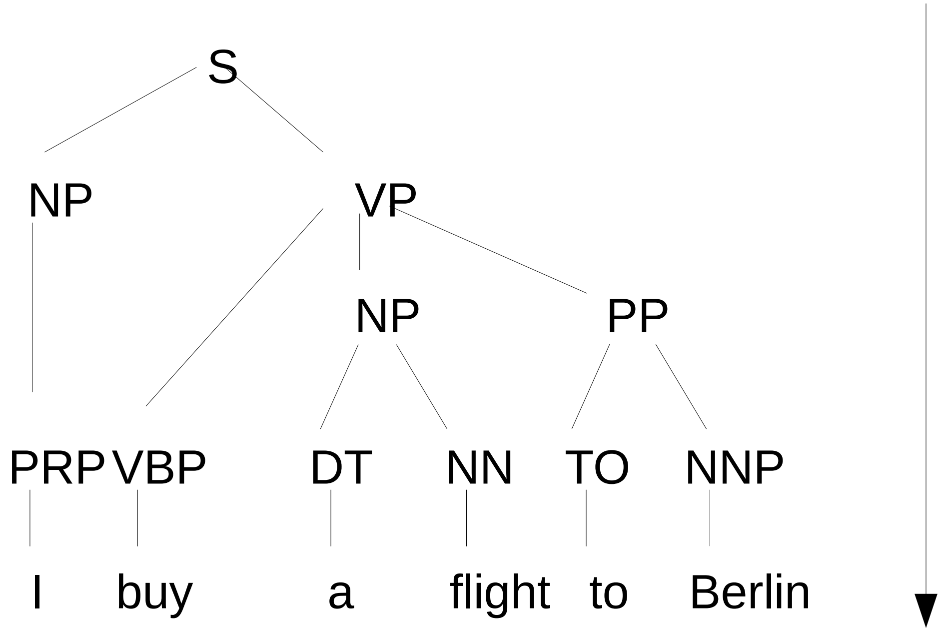


Parsing Algorithms

- Top-Down
- Bottom-up

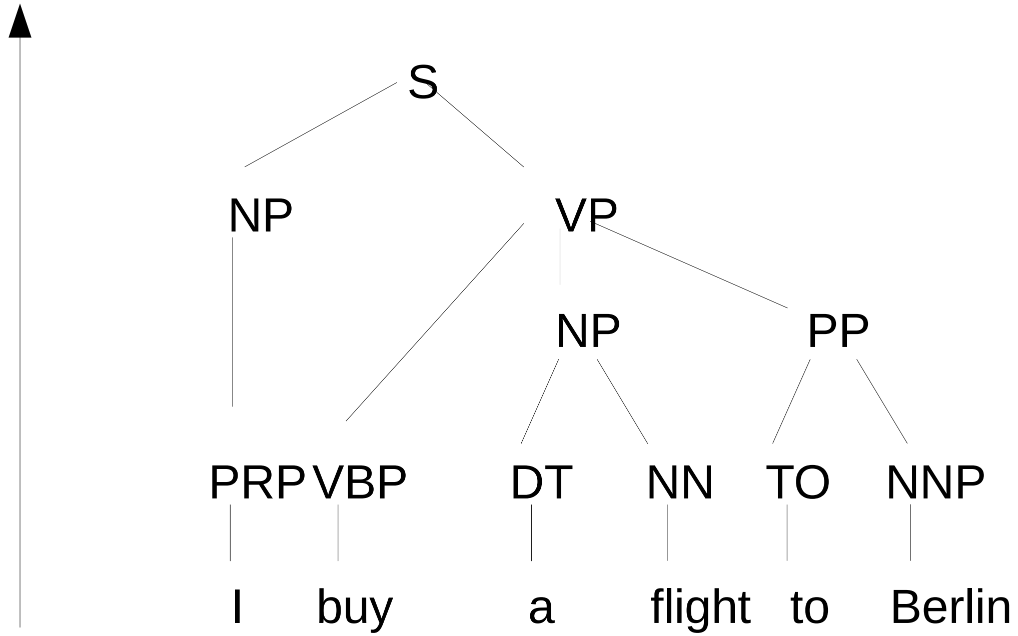
Parsing Algorithms

- Top-Down
  - Start with the rules that contains the S
  - Work on the way down to the words



Parsing Algorithms

- Bottom-Up
  - Start with trees that link up with the words
  - Work on the way up 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
  - Backtracking
    - We make a choice, if it works out, great!
    - If not, then back up and make a different choice (duplicated work)
  - Dynamic programming
    - Avoid repeated work
    - Solve exponential problems in polynomial time
    - Store ambiguous structures efficiently

Dynamic Programming Methods

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

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 non-terminals; w is a terminal

Chomsky Normal Form

- Conversion to CNF:

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

$$X \rightarrow B\ C$$

$$A \rightarrow X\ D$$

Cocke–Younger–Kasami (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*

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

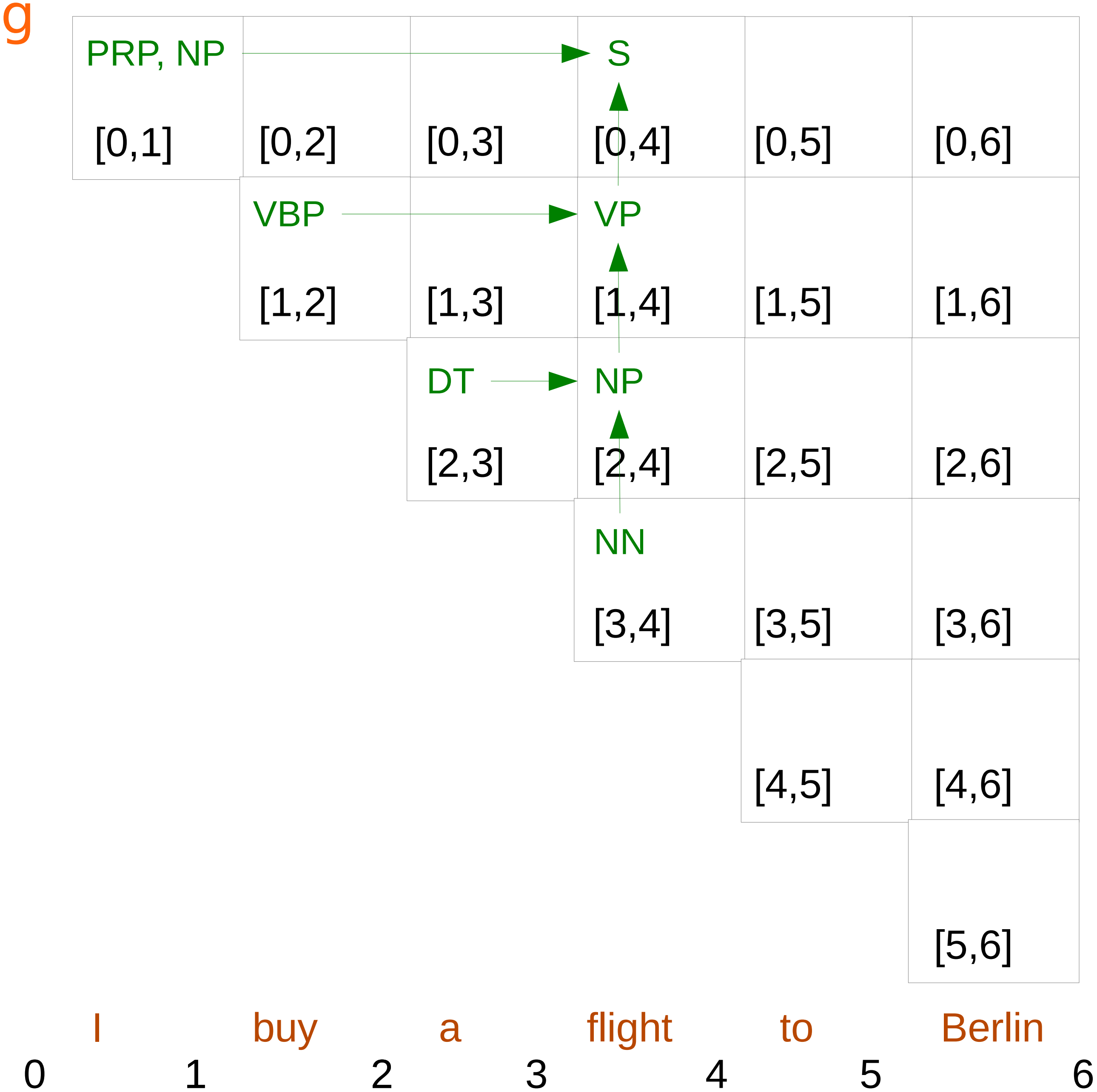
CKY Parsing

PRP → I
NP → PRP

VBP → buy

DT → a

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



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 → I
NP → PRP

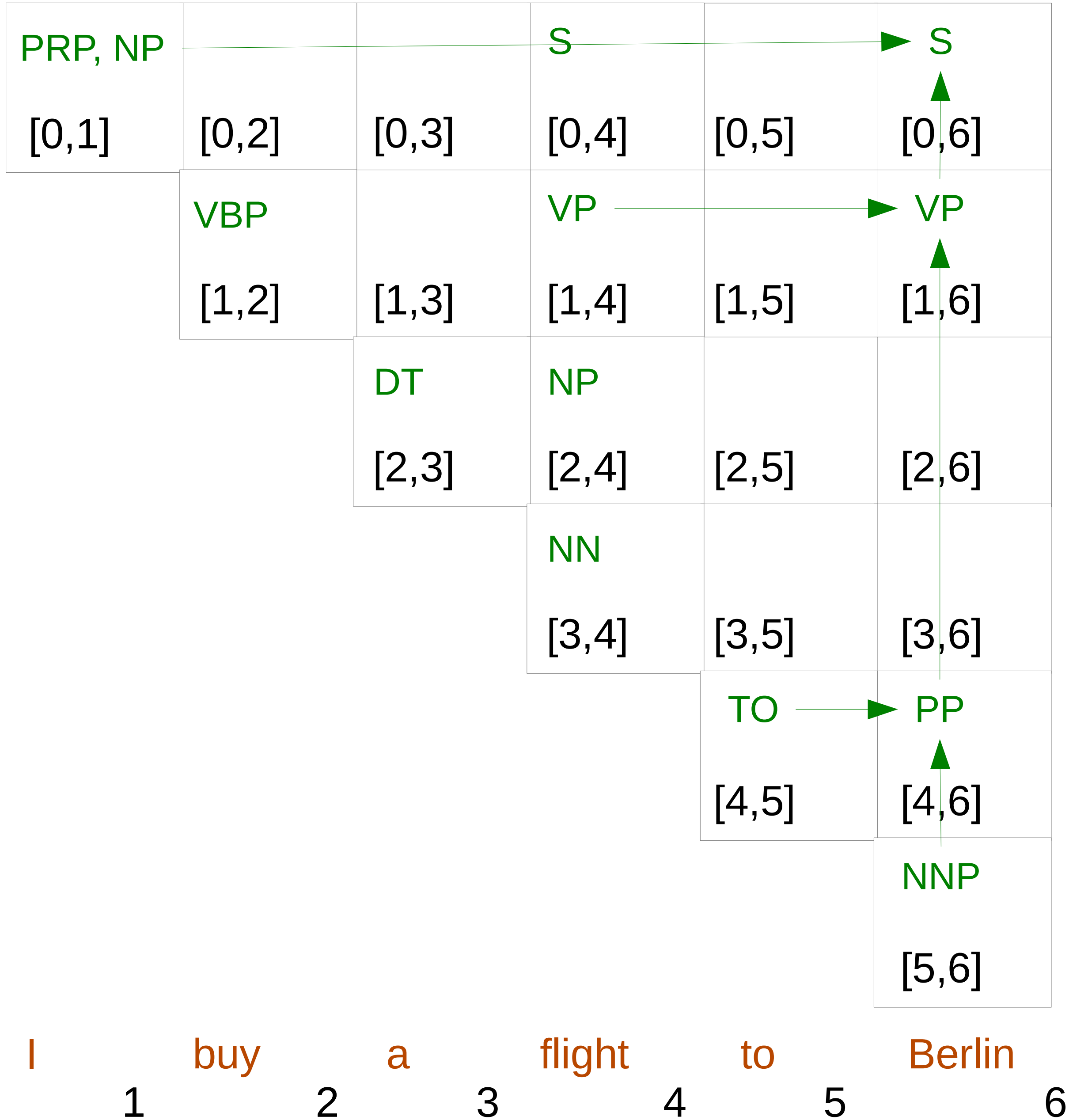
VBP → buy

DT → a

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

TO → to

NNP → Berlin
PP → TO NNP
VP → VP PP



Probabilistic Context Free Grammar (PCFG)

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

Probabilistic Context Free Grammar

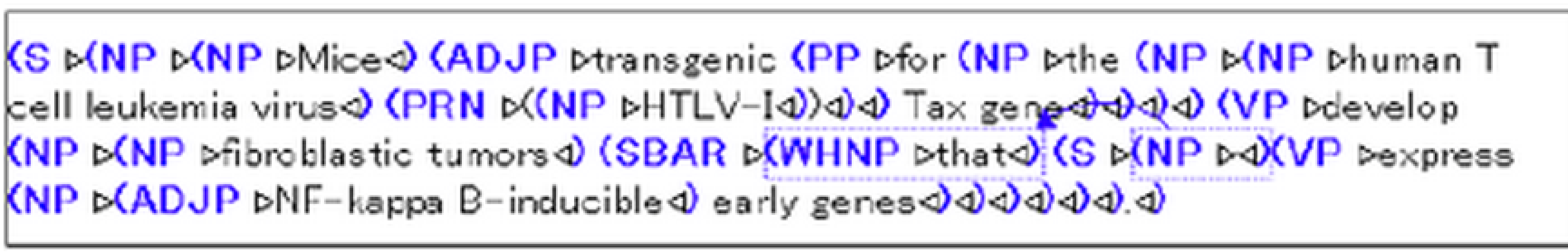
0.9	S → NP VP
0.1	S → VP
0.3	NP → NN
0.4	NP → PRP
0.1	NP → DT NN
0.2	NP → NP NP
0.1	NP → NP PP
0.4	VP → VBP NP
0.3	VP → VP PP
0.5	VP → VP NP
1.0	PP → TO NNP

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

Use a Treebank to calculate probabilities.

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



(http://www.nactem.ac.uk/aNT/genia.html)

Statistical Parsing

- Considering the corresponding probabilities while parsing a sentence
- Selecting the parse tree which has the highest probability

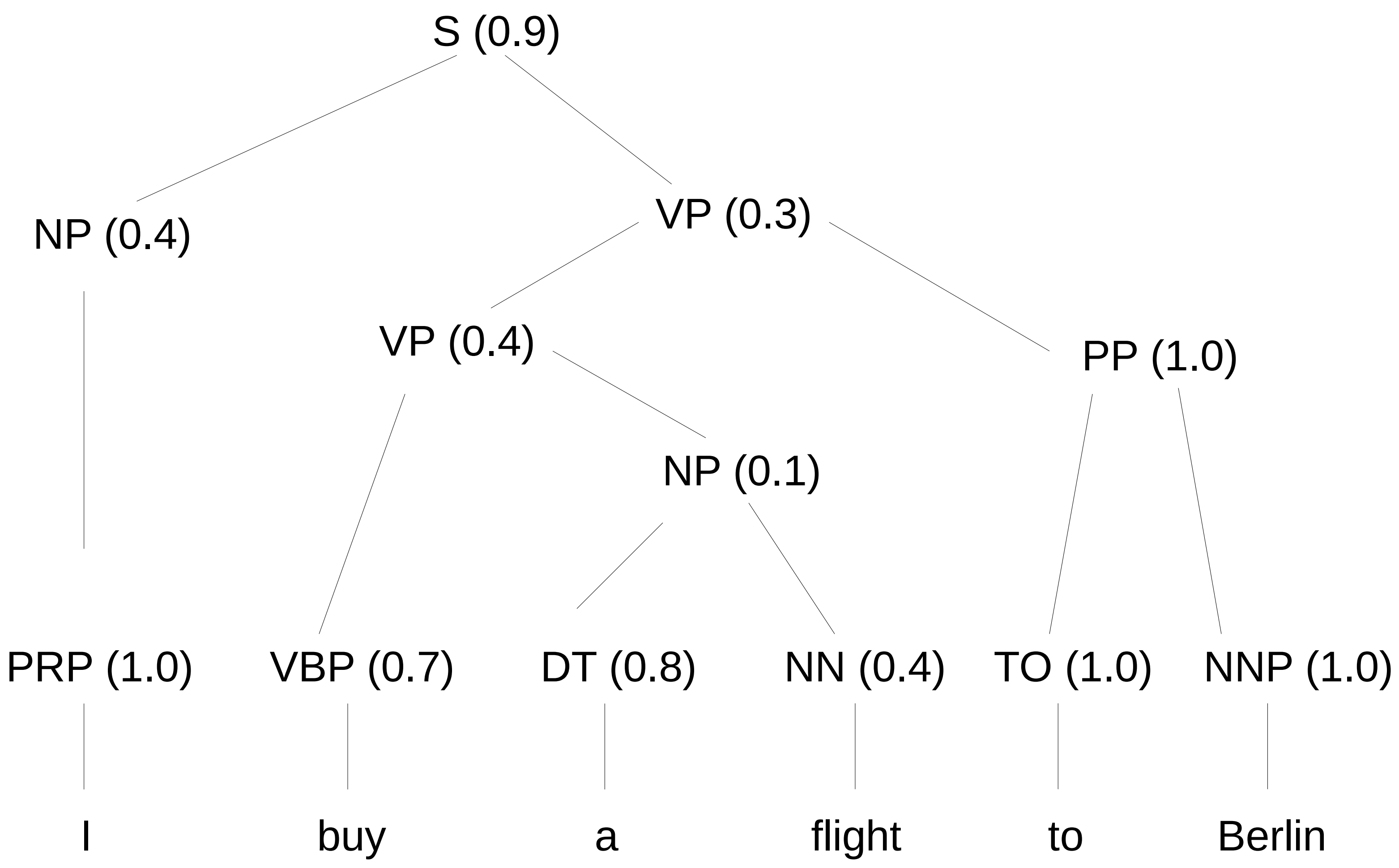
- P(t): the probability of a tree t
  - Product of the probabilities of the rules used to generate the tree

Probabilistic Context Free Grammar

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
0.5	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

Statistical Parsing



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

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 (0.3)

PRP, NP 1.0*0.4 [0,1]	[0,2]	[0,3]	S 1.0*0.4* 0.7*0.8*0.4*0.1*0.4* 0.9 [0,4]	[0,5]	S 1.0*0.4* 0.7*0.8*0.4*0.1*0.4* 1.0*1.0*1.0* 0.3*0.9 [0,6]
	VBP 0.7 [1,2]	[1,3]	VP 0.7* 0.8*0.4*0.1* 0.4 [1,4]	[1,5]	VP 0.7*0.8*0.4*0.1*0.4* 1.0*1.0*1.0* 0.3 [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]

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

Summary

- Constituency parsing
- Context-free grammars
  - Noun phrases, verbal phrases
  - Subcategorization
- Bottom-up and top-down
- CYK algorithm for CFG parsing
- Probabilistic CFG

Tools

- Spacy: https://spacy.io/
- Stanford CoreNLP: https://stanfordnlp.github.io/CoreNLP/
- NLTK Python: http://www.nltk.org/
- and others

Further Reading

- Speech and Language Processing
  - Chapters 12 (grammar), 13 (syntactic parsing) and 14 (statistical parsing)