

University of Amsterdam  
**Elements of Language Processing and Learning**

**Project 1: Statistical Parsing**

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## 1 Introduction

In this project we implemented a prototype statistical parser. Having the given treebank data file we parsed and extracted the rules using this statistical parser (Step 1), resulting to a probabilistic context free grammar (PCFG). Then, given this extracted grammar, we implemented the Cocke-Younger-Kasami (CYK) algorithm, in order to parse some test sentences generating a parse-forest for each one of them. In Section 2, we are going to describe the implementation of our parser. In Section 3, we are going to discuss about our implementation of the CYK algorithm as well as, our assumptions in respect to the unknown words, the unary rules, and a brief explanation of every step of this algorithm through pseudo-code and examples. Section 6,

Finally, section 5, serves as an epilogue to the first two steps of this project.

## 2 Statistical Parsing

Statistical parsing is a parsing method for natural language processing. The key idea behind this procedure, is the association between grammar rules from the linguistics point of view with probabilities for each one of them. Make it feasible for us, to be able to analyze, and compute the probability of a complete parse of a sentence.

### 2.1 Stochastic/Probabilistic context-free grammar (SCFG or PCFG)

A probabilistic context-free grammar is a set of rules in which each production is augmented with a probability. Each rule is represented by the non-terminal left-hand side node, and the right-side node or nodes. In our particular data-set there are only binary and unary rules. A typical example of binary rule is this:  $X \rightarrow \alpha \beta$ . In general, in our treebanks there were mostly binary rules but in some cases we had to handle the unaries which have this form:  $X \rightarrow \alpha$ . Each rule has a probability and this probability is given by:  $P(X \rightarrow \alpha|X)$ , or  $P(X \rightarrow \alpha\beta|X)$ , for the above two examples of rules. So, we can derive that the likelihood of each rule is given by the frequency of the right hand nodes, given the left hand nodes of a rule. Assuming that, the frequency of each specific rule is denoted by  $f_r$ , the non-terminal nodes by,  $N_i$ , and finally the productions which are a sequence of one or more non-terminal or terminal nodes by,  $n_i$ , we have:

$$P(N_i \rightarrow n_i|N_i) = \frac{f_r(n_i|N_i)}{\| N_i \|}$$

, where  $f_r(n_i|N_i)$ , is the number of times that  $n_i$  is produced by the non-terminal node  $N_i$  during the training. In addition,  $\| N_i \|$ , is the number of production this non-terminal have.

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**Algorithm 1** Rule Production

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```
1: Input: Nodes_Table (1)
2: Output: Rules
3:
4: for i  $\in$  (0, length(Nodes_Table) - 1) do
5:   rightSide =  $\emptyset$ 
6:   for j  $\in$  (i + 1, length(Nodes_Table)) do
7:     if (Nodes_Table[j].level - 1 == Nodes_Table[i].level) then
8:       if (rightSide ==  $\emptyset$ ) then
9:         rightSide  $\rightarrow$  Nodes_Table[j].rule
10:      else
11:        rightSide  $\rightarrow$  rule, Nodes_Table[j].rule
12:      end if
13:    end if
14:    if (j == length(Nodes_Table) - 1 or Nodes_Table[j].level == Nodes_Table[i].level) then
15:      if (rightSide ==  $\emptyset$ ) then
16:        save_rule(Rule(Nodes_Table[i].rule, rightSide))
17:      end if
18:    end if
19:  end for
20: end for
```

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## 2.2 Implementation of the PCFG parser

To parse the given treebank and extract the rules with their probabilities, we did not use a third-party parsing library, instead we built our own parsing algorithm. Given the treebank's form,

(TOP (S (NP (NNP Ms.) (NNP Haag)) (S@ (VP (VBZ plays) (NP (NNP Elianti)))) (. .))) )

we parse each tree of the training set, keeping nodes and a piece of information about the level of each node according to the parenthesis level. After this procedure our *Nodes\_Table* (1) looks like this:

TOP 0	VP 3
S 1	VBZ 4
NP 2	plays 5
NNP 3	NP 4
Ms. 4	NNP 5
NNP 3	Elianti 6
Haag 4	. 3
S@ 2	. 4

After the generation of the *Nodes\_Table*, it is time to generate the rules derived from this tree. Algorithm 1, presents in pseudo-code this procedure. This algorithm starts from each node heading towards the end of this list until it comes along with a node of the same level or with the end. In this process if there is a node with level one more than the current node, this node automatically infers that it is its child. The resulted rules derived by the above example sentence are following:

TOP $\rightarrow$ S	VP $\rightarrow$ VBZ NP
S $\rightarrow$ NP S@	VBZ $\rightarrow$ plays
NP $\rightarrow$ NNP NNP	NP $\rightarrow$ NNP
NNP $\rightarrow$ Ms.	NNP $\rightarrow$ Elianti
NNP $\rightarrow$ Haag	S@ $\rightarrow$ VP .
. $\rightarrow$ .	

Table 1: Syntactically Ambiguous Words

Word	Non-Terminal	Probability
down	RP	0.080391
	RB	0.011398
	NN	0.000008
	RBR	0.000566
	VBP	0.000080
	JJ	0.000163
	IN	0.001441
that	NN	0.000008
	VBP	0.000080
	WDT	0.462273
	RB	0.000710
	IN	0.048856
	DT	0.014272
's	VBZ	0.056386
	PRP	0.000459
	NNS	0.000017
	POS	0.928514
	NNP	0.000011
a	DT	0.235392
	FW	0.029915
	LS	0.027778
	SYM	0.172414
	NNP	0.000022

## 2.3 Results

After running our parser in the complete training set, we got all rules, the frequency for every production of each rule, and the number of appearances for every non-terminal node. From this data, we extracted the complete PCFG grammar from the training set in a file with the following form:

<id>	<Non-Terminal>	<Production>	<Probability>
00000	TOP	FRAG%NP	0.000225954658432
00457	NP	ADVP NNS	6.53558462438e-06

### 2.3.1 Syntactically Ambiguous Words

To find the syntactically ambiguous words we used every terminal word and count by how many non-terminal is been produced. Table 1, presents some of the most ambiguous syntactically words in our training data.

### 2.3.2 Most Likely Productions

In addition, to compute the most likely productions for the set of non-terminals {V P, S, NP, SBAR, PP}, we sort the dictionary in respect to the probability of each of those productions and print the four with the biggest probability. Table 2, presents these results.

## 3 CYK Algorithm

In computer science, the Cocke-Younger-Kasami (CYK) algorithm, is a parsing algorithm for context-free grammars. It employs bottom-up parsing and dynamic programming, considering all possible productions that can generate a sentence. In this algorithm, we want to fill a chart with non-terminal nodes in order to be able to produce all possible trees. The CYK algorithm scans the words of the sentence attempting to add non-terminal nodes to its chart. For each production of a non-terminal node that is matched from the PCFG grammar we add this left side node to the chart. To improve its performance we didn't iterate on all possible non-terminal nodes, instead we have used a dictionary to index every node added to the chart.

Table 2: Most Likely Productions

Non-Terminal	Production	Probability
NP	DT, NP@	0.1284
	NP, PP	0.1111
	DT, NN	0.0958
	NP, NP@	0.0888
PP	IN, NP	0.7963
	TO, NP	0.0787
	IN, S%%%%%VP	0.0263
	IN, NP%%%%%QP	0.0128
SBAR	IN, S	0.4537
	WHNP, S%%%%%VP	0.2671
	WHADVP, S	0.0904
	WHNP, S	0.0665
VP	VBD, VP@	0.0767
	VB, NP	0.0663
	VB, VP@	0.0640
	MD, VP	0.0591
S	NP, S@	0.3541
	NP, VP	0.3439
	PP, S@	0.0715
	S, S@	0.0615

### 3.1 Implementation of the CYK Algorithm

Algorithm 2, presents our implementation of the CYK algorithm in pseudo-code. As you can realize, there are some differences to the algorithm as it is described in the *Stanford* slides. This happens because we make use of the dictionaries in *Python* to store the nodes in every chart position. So, we don't iterate over all non-terminal nodes but only over the existing in each chart cell. In this algorithm the first 15 lines of code is for initialization of the chart. In this part, we are looking for unary rules with productions each word of the sentence. If a word does not exist in our rules then we handle it differently. We are going to discuss this later in this report. Then and after this step, we check every updated chart position for unaries that may exist. Algorithm 3, presents the unary handling we have done. According to the algorithm in the *Stanford* slides, we check all nodes in a chart position as productions from another rules and we add these non-terminals to the same chart position. This is done until there is no unary rule to be added.

### 3.2 Unknown Words

As we have seen in the test sentences, there are plenty of words which were not able to associate their-selves to a rule from the PCFG grammar. We have tried to deal with it with a simple approach, associating each one of them with a rule. The following Table 3.2, illustrates this procedure with a few examples. In this way, there are not unknown words anymore and every word can be assigned as a

Format	Examples	Type	Non-Terminal
number, floats	12.3, 12-3-2012	numerical	CD
*ly, *y	fully, difficulty	adverb	ADV
*ing, *ion, *ist(s), *(e)s, *er(s)	criterion, linguistic	noun	N
*-, *able, *ed	capable, drug-seeking	adjective	ADJP
else	ALFO, L.F	$noun^{p=0.2}$ , $name^{p=0.8}$	N, NNP

production of a non-terminal node. Is it obvious, that it is a very simplified way of recognize the type

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**Algorithm 2** CYK Algorithm

---

```
1: Input: RulesRL[], Sentence S[]
2: #RulesRL, is a dictionary in which for every production p, gives RulesRL[p] non-terminal nodes which have
   this production.
3: Output: Chart[length(S) + 1][length(S) + 1]
4:
5: # Chart initialization
6: for i ∈ (0,length(s)) do
7:   if S[i] ∉ RulesRL[] then
8:     handle_unknown_word(S[i])
9:   else
10:    for node ∈ RulesRL[S[i]] do
11:      Chart[i][i + 1].add(node)
12:    end for
13:  end if
14:  check_unaries(Chart[i][i + 1])
15: end for
16:
17: # Fill productions in chart
18: n = length(S) + 1
19: for span ∈ (2,n) do
20:   for begin ∈ (0,n-span) do
21:     end = begin + span
22:     for split ∈ (begin,end) do
23:       for nodeL ∈ chart[begin][split] do
24:         for R ∈ chart[split][end] do
25:           for node ∈ RulesRL[nodeL, R] and node ∉ Chart[begin][end] do
26:             Chart[begin][end].add(node)
27:           end for
28:         end for
29:       end for
30:     end for
31:     check_unaries(Chart[begin][end])
32:   end for
33: end for
```

---

of a word, but we are sure that we are able to build a better system to recognize the type of unknown words, with a more stochastic way, and in respect to the training set.

### 3.3 Results

Our implementation of the CYK algorithm is well optimized and it is neither time or space consuming, speaking about its complexity. For the time being, we have not deal with probabilities during the process of building the parse-forest. So, it is normal, that it the algorithm is not very fast due to the fact that it is constructing all possible trees that may have generate each sentence.

#### 3.3.1 TOP Productions

The covering productions can be generated from an input sentence given the grammar. For example, assuming that we have the sentence:

“*No, it wasn't Black Monday.s*”

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**Algorithm 3** Unaries Handling

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```
1: Input:  $Chart[i][j]$ 
2: Output: Updated  $Chart[i][j]$ 
3:  $added = true$ 
4: while  $added$  do
5:    $added = false$ 
6:   for  $ref\_node \in chart[i][j]$  do
7:     for  $node \in RulesRL[ref\_node]$  and  $node \notin Chart[i][j]$  and  $node$  is "TOP" do
8:        $Chart[i][j].add(node)$ 
9:        $added = true$ 
10:    end for
11:  end for
12: end while
```

---

The productions  $TOP \rightarrow X P$  that cover the whole sentence in the entry  $chart[0, n]$ , after running our CYK parser on this sentence was:

```
TOP → FRAG%%%%NP
TOP → FRAG%%%%ADVP
TOP → PP
TOP → SBAR
TOP → UCP
TOP → SINV
TOP → ADJP
TOP → S%%%%VP
TOP → PRN
TOP → VP
TOP → S
TOP → FRAG
TOP → NP
TOP → X
TOP → ADVP
TOP → SQ
```

## 4 Viterbi

In this section, we are going to present our Viterbi implementation which we built in order to produce the most probable tree for each input sentence. We have already, a Probabilistic context-free grammar extracted for the training sentences (Step 1), and a CYK implementation which gives us a parse-forest for each sentence in the test sentences data (Step 2). From this parse-forest we can build all possibles trees for each sentence.

### 4.1 Most-probable Parse Tree

In order to implement an efficient Viterbi algorithm, we had to reconstruct the CYK algorithm in order to fill its chart with the most probable parse-tree. To do that, we keep in each position of the chart the most-probable production for each left hand side node that appears in the each position. So, each position of the chart is now holding different left hand nodes, each one of them leads us to the most probable production, not to all possible productions. Algorithm 4, presents the pseudo-code for the alternative implementation of the CYK-algorithm. Additionally, in the same manner, we changed the way that handle unary productions in each chart position. This is illustrated in the Algorithm 5. This

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**Algorithm 4** CYK Algorithm for Most-probable Production

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```
1: Input: RulesRL[], Sentence S[]
2: #RulesRL, is a dictionary in which for every production p, gives RulesRL[p] non-terminal nodes which have this production.
3: Output: Chart[length(S) + 1][length(S) + 1]
4:
5: # Chart initialization
6: for i ∈ (0,length(s)) do
7:   if S[i] ∉ RulesRL[] then
8:     handle_unknown_word(S[i])
9:   else
10:    for node ∈ RulesRL[S[i]] do
11:      if node ∉ Chart[i][i + 1] then
12:        Chart[i][i + 1][node] = (S[i], p(node → S[i]))
13:      else
14:        if p(node → S[i]) > Chart[i][i + 1][node].prob then
15:          Chart[i][i + 1][node] = (S[i], p(node → S[i]))
16:        end if
17:      end if
18:    end for
19:  end if
20:  check_unaries(Chart[i][i + 1])
21: end for
22:
23: # Fill productions in chart
24: n = length(S) + 1
25: for span ∈ (2,n) do
26:   for b ∈ (0,n-span) do
27:     e = b + span
28:     for s ∈ (b,e) do
29:       for L ∈ chart[b][s] do
30:         for R ∈ chart[s][e] do
31:           for node ∈ RulesRL[L, R] do
32:             if node ∉ Chart[b][e] then
33:               Chart[b][e][node] = (L, R, p(node → L, R) × Chart[b][s][L].prob × Chart[s][e][R].prob, s)
34:             else
35:               if p(node → L, R) × Chart[b][s][L].prob × Chart[s][e][R].prob > Chart[b][e][node].prob then
36:                 Chart[b][e][node] = (L, R, p(node → L, R) × Chart[b][s][L].prob × Chart[s][e][R].prob, s)
37:               end if
38:             end if
39:           end for
40:         end for
41:       end for
42:     end for
43:     check_unaries(Chart[b][e])
44:   end for
45: end for
```

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**Algorithm 5** Unaries Handling for Most-probable Production

---

```
1: Input: Chart[i][j]
2: Output: Updated Chart[i][j]
3: added = true
4: while added do
5:   added = false
6:   for ref_node ∈ chart[i][j] do
7:     for node ∈ RulesRL[ref_node] do
8:       if node ∉ Chart[i][j] then
9:         Chart[i][j][node] = (node, p(node → ref_node) × Chart[i][j][ref_node].prob)
10:        added = true
11:      else
12:        if p(node → ref_node) × Chart[i][j][ref_node].prob > Chart[i][j][node].prob then
13:          Chart[i][j][node] = (node, p(node → ref_node) × Chart[i][j][ref_node].prob)
14:          added = true
15:        end if
16:      end if
17:    end for
18:  end for
19: end while
```

---

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**Algorithm 6** Viterbi

---

```
1: Input: chart[], x, y, node, words, level
2: Initial values: chart[], 0, length(words) - 1, TOP, words, -1
3: Output: nodes[]
4: if "@" ∈ node then
5:   level− = 1
6: else
7:   if "%%%%" ∈ node then
8:     temp = node.split(unarynode)
9:     nodes.append(temp[0], level, False)
10:    nodes.append(temp[1], level + 1, False)
11:    level+ = 1
12:   else
13:     nodes.append(treenode(node, level, False))
14:   end if
15: end if
16: if node ∈ chart[x][y] then
17:   n = chart[x, y][node]
18:   if (x + 1) == y ∪ n.child == node ∩ n.child ∈ words then
19:     nodes.append(n, level + 1, True)
20:   end if
21:   if n is unary then
22:     Viterbi(chart, x, y, n, words, lvl + 1)
23:   return
24:   else
25:     Viterbi(chart, x, n.split, n[l], words, level + 1)
26:     Viterbi(chart, n.split, y, n[r], words, level + 1)
27:   return
28:   end if
29: else
30:   return
31: end if
```

---

different approach will help us save computational cost during Viterbi algorithm. Imagine, that, if we had kept the old approach, we should have iterate over all possible productions in each non-terminal node to find the most probable one, every time.

## 4.2 Viterbi Algorithm Implementation

TOP 0	PRP 4	n't 5
S 1	it 5	NP 3
NP 2	VP 2	NNP 4
DT 3	VBD 3	Black 5
No 4	S@ 2	NNP 4
, 3	was 4	Monday 5
, 4	ADVP 3	. 2
NP 3	RB 4	. 3

```
( TOP (S (NP (DT No)(, ,)(NP (PRP it)))(VP (VBD was)(ADVP (RB n't))(NP (NNP Black)
(NNP Monday)))(. .)))
```



---

**Algorithm 7** Build Tree

---

```
1: Input:  nodes
2: Output: tree
3: level = -1
4: while i < length(nodes) do
5:   if nodes[i].level ≥ level then
6:     if nodes[i].terminal : then
7:       tree += nodes[i].node + ")"
8:     else
9:       tree += "(" + nodes[i].node
10:      i += 1
11:    end if
12:    level = nodes[i].level
13:  else
14:    tree += ")"
15:    level - = 1
16:  end if
17: end while
18: for i = 1 to level do
19:   tree += ")"
20: end for
```

---

## 5 Conclusion

In this report we have presented a simple but efficient way to extract the PCFG from a treebank data file. Our implementation makes use of the *Python* dictionaries in order to store the rules of the grammar efficiently in order to be used in the most optimized way by the CYK algorithm which generates a parse forest for a sentence based on an existing grammar. Additionally, we have discussed how we implemented the CYK algorithm and how we handled the unknown words which are existed in the test sentences data. More information about the code itself, you can find in the `readme` file attached with our source code.