Algorithms for AI and NLP (Fall 2015), Problem Set (3b)

High-Level Goals

- Understand probability estimation for PCFGs, and implement PCFG training.
- Appreciate generalized chart parsing, and implement the fundamental rule.
- Understand how the Viterbi algorithm works over a packed parse forest.
- Investigate various aspects of parser performance and how to evaluate them.

Background

This is the second and *final* part of the third obligatory exercise in INF4820. You can obtain up to ten points for this problem set, and you need a minimum of twelve points (or 60,% of the total available) for (3a) and (3b) in total. If you have any questions on this problem set, please email `inf4820-help@ifi.uio.no` and make sure to take advantage of the laboratory sessions.

Solutions must be submitted via Devilry by the end of the day (i.e. before 23:59 h) on Thursday, November 19. Please provide your code and comments in a single '`.lisp`' file. For the theoretical questions, you can either include your answers as Lisp comments in the same file, or submit an additional text file.

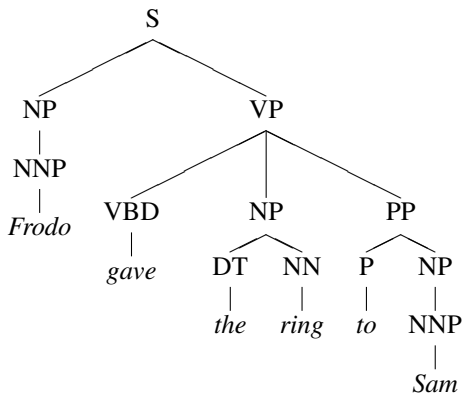
Necessary Files

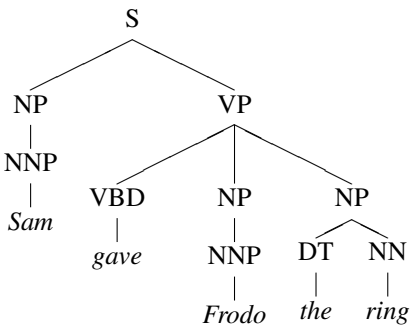
For this exercise we provide four files—`chart.lsp`, `toy.mrg`, `wsj.mrg`, and `test.mrg`. The file `chart.lsp` is skeleton code, which you are expected to complete during this exercise. The files of type '`.mrg`' are data for training and testing your parser and contain PTB phrase structure trees in the form of Lisp s-expressions.

To obtain our data files and code for this problem set, please obtain updates from the SVN repository for the course, using the same basic procedure as for previous problem sets. You will find the data and skeleton code inside the new sub-directory '`3b/`' of your SVN checkout. Note that `wsj.mrg` and `test.mrg` are parts of the Penn Treebank, for which UiO holds a license for unlimited research use at the university. Please do not re-distribute these files.

1 Theory: PCFG Maximum Likelihood Estimation

Given the following treebank, list the rules, their counts and the maximum likelihood estimation of their conditional probabilities. Hint: You should find six lexical rules and six syntactic rules.





2 Training a PCFG from Treebank Data

In this section you will define a grammar structure and write a function to train the grammar from a treebank. You will also implement two accessor functions for the grammar that are required by our parser. Read the whole section before starting to code, since your grammar definition will be influenced by the accessor functions we need.

(a) The skeleton code contains structures for representing syntactic rules (*rules*) and lexical rules (*lexemes*), and a partially defined *grammar* structure. Using these structures (augmenting as necessary), implement the `read-grammar()` function, which takes a treebank file as an argument and returns a *grammar* object. This function should:

- Read in each tree—since the trees are represented as s-expressions, you might the Lisp function `read()` useful here—and
- recursively process each tree, extracting the rules it represents, and recording the counts in the probability slots.
- For lexical rules, add a *lexeme* to the grammar (indexed by the word) if this rule has not been seen before. Otherwise increment the count of the appropriate lexeme.
- For syntactic rules, add a *rule* to the grammar, if this rule has not been seen before and the rule is not a unary recursive rule (e.g. NP $\rightarrow$ NP). If the rule has already been added, just increment the count. Note that in the next step you will write an accessor function that retrieves rules by the first element of the right hand side. This may influence how you store or index your rules.
- Turn the *rule* and *lexeme* counts we just collected into estimates of conditional probabilities, using the standard relative frequency calculations. Store the probabilities as log probabilities.

(b) Our parser requires two accessor functions to retrieve the necessary rules from the grammar efficiently.

- `rules-starting-in()` takes a *category* and a *grammar* and returns a list of all rules in *grammar* which have *category* as the first element of the right hand side (i.e. the first non-terminal after the arrow).
- `get-lexemes()` takes a *word* and a *grammar*, and returns the list of lexemes relevant for *word* in *grammar*.

Implement these accessor functions. Consider if your *grammar* definition could be changed to make these functions more efficient.

To test your grammar implementation, first train a grammar on the `toy.mrg` file.

```
? (setf toy (read-grammar "~/toy.mrg"))
? (rules-starting-in 'NP toy)
→ (#S(RULE :LHS START :RHS (NP) :PROBABILITY -1.5404451)
 #S(RULE :LHS S :RHS (NP VP) :PROBABILITY 0.0))
? (get-lexemes "flies" toy)
→ (#S(LEXEME :CATEGORY VBZ :PROBABILITY -1.9459101)
 #S(LEXEME :CATEGORY NNS :PROBABILITY -2.0794415))
```

Once you are getting the right outputs, try the larger file `wsj.mrg`. This will take longer, but should still finish in under a minute (remember to compile your code first.) If it takes significantly longer, re-work your code to make it more efficient. You should end up with just under 15,000 rules and a little over 44,000 lexemes. If we check the usage of *flies* in this grammar, you should see that The Wall Street Journal rarely writes about insects:

```
? (setf wsj (read-grammar "~/wsj.mrg"))
? (get-lexemes "flies" wsj)
→ (#S(LEXEME :CATEGORY VBZ :PROBABILITY -8.192017))
```

However, the Penn Treebank analyses have many more rules with a noun phrase as the first element on the right hand side:

```
? (length (rules-starting-in 'NP wsj))
→ 1783
```

3 Generalized Chart Parsing

The second part of the skeleton code implements a version of the generalized chart parser we discussed in lectures (with some more theory to come in the lecture on Wednesday, November 11). While it may appear complicated, most of it maps fairly clearly to the algorithm we went through. There are the three structures—*chart*, *edge* and *agenda*—and the main `parse()` function. Look at the `parse()` function and identify our three stages: initialization, main loop, termination. Also look at the `pack-edge()` function and try to understand how it helps us deal with ambiguity.

(a) When does a new edge get added to the agenda? For each of the situations where a new edge is pushed on to the agenda, in a few sentences describe the conditions that must be true (if any) and the properties of the new edge.

(b) Implement the `fundamental-rule()` function. In the context of our skeletal code, the function is called with an active and passive edge which we already know to be adjacent. If your implementation is correct, you should see:

```
? (setf toy (read-grammar "~/toy.mrg"))
? (pprint (edge-to-tree (parse '("Frodo" "lives") toy)))
→ (START (S (NP (NNP "Frodo")) (VP (VBZ "lives"))))
```

4 Viterbi over a PCFG Parse Forest

The `parse()` function produces a packed edge, which could represent multiple trees. Our previous example only has one complete analysis according to our toy grammar. Now we can try an ambiguous input:

```
? (pprint (edge-to-tree (parse '("Frodo" "adores" "the" "ring" "in" "Oslo") toy)))
→ (START
    (S (NP (NNP "Frodo"))
     (VP (VBZ "adores")
        (NP (DT "the") (NN "ring") (PP (P "in") (NP (NNP "Oslo")))))))
```

Depending on how the rules are stored in your grammar, you may see a different tree, since only the first tree found will be printed. The `viterbi()` function runs the Viterbi algorithm over the packed forest represented by an edge (which can contain packed alternatives) and returns a new edge representing the most likely tree:

```
? (pprint (edge-to-tree (viterbi (parse '("Frodo" "adores" "the" "ring" "in" "Oslo") toy))))
→ (START
    (S (NP (NNP "Frodo"))
      (VP (VBZ "adores") (NP (DT "the") (NN "ring"))
       (PP (P "in") (NP (NNP "Oslo"))))))
```

(a) Study the `viterbi()` function in our skeleton code. In a few sentences, describe what the function is doing.

(b) Compare how the Viterbi algorithm works over a packed forest and an HMM trellis. What is the same? What is different?

5 Testing the Parser

To test our Viterbi algorithm, we evaluate how well the parser output compares to gold standard annotations in our test set. The function `pcfg-evaluate()` reads in gold standard trees from a test file, extracts the leaves of the tree and provides them as input to our `parse()` function, and then compares the output against the original tree, using the ParsEval metric. A keyword argument `:baseline` allows us to evaluate how well the parser would do without Viterbi, i.e. just returning the first tree found. Run the evaluation function with and without the `:baseline` option. On an average laptop, it might take one to two minutes each time.

```
? (setf wsj (read-grammar "~/wsj.mrg"))
? (pcfg-evaluate "~/test.mrg" wsj :baseline t)
? (pcfg-evaluate "~/test.mrg" wsj)
```

(a) What does the output mean? Is Viterbi making a difference to the parser accuracy? Even if you cannot run the commands, briefly explain what ParsEval measures, and also what is meant by coverage.

(b) The `pcfg-evaluate()` function has another keyword argument `:maxlength`, which defaults to `10`. Only sentences with a length less than or equal to `:maxlength` are evaluated. Using `time()`, compare the difference between using a `:maxlength` of `9` or `10`.

```
? (time (pcfg-evaluate "~/test.mrg" wsj :maxlength 9))
? (time (pcfg-evaluate "~/test.mrg" wsj :maxlength 10))
```

How many inputs are parsed each time? What is the total evaluation time for each evaluation run?

(c) In a few sentences, discuss factors that can affect parsing time. What could we do during training to improve parsing time?

Happy coding!