Cognitive Modeling (2009–2010)

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Assignment 3

Handed out:	03 March, 2008
Due date:	23 March, 2008
Weighting:	10% of total mark

Please hand in a hardcopy of your solution by 4:00pm on the due date to the Informatics Teaching Organization, Level 4, Appleton Tower. If you have questions regarding the assignment, please contact the lecturer, Sharon Goldwater, at `sgwater@inf.ed.ac.uk`.

Note that there are two paths through this assignment. One is for CM-4, the 4th year undergraduate version of this course, the other one is for CM-5, the MSc version of this course. Please make sure that you answer the right questions for your level!

Please remember that plagiarism is a university offense. Do not show your written/coded solutions to anyone else, or try to see anyone else's, and do not discuss the specifics of your solutions with other students (unless otherwise stated for particular questions). However, please also remember that, on any course, you learn as much or more from your peers as you do from your instructors. You should therefore feel free to discuss the general topics surrounding the problems with one another, ideally after you have considered them yourself. But at the end of the day what you write must be yours, and you must understand what you write, and why you didn't write other things. The approach should be one you have chosen to take. If you don't understand it don't write it — it will generally be obvious you don't understand. And if you have questions or problems involving the specifics of your solution, please contact me rather than your fellow students.

1 Modeling Sentence Processing CM-4 + CM-5

Download the following file, which contains the model that you will work with in this assignment:
`http://www.inf.ed.ac.uk/teaching/courses/cm/assignments/cm_a03.tar.gz`

Use `gunzip` and `tar` to unpack the model file in the `projects` subdirectory of your Cogent directory (this is the user directory you specified during the installation). You should now see a research program called `Assignment 3` in the Cogent root window. Select this program and doubleclick on the only model within this research program, called `Parallel Parser`. This model corresponds to the model developed in Section 7.2 of Cooper (2002).

Open the `Chart` buffer of the subject model and select the tab `Current Display`. This will give you graphical representation of the chart of the parser. Initialize the model and then step through it one cycle at a time by pressing '>' repeatedly. Observe how the chart is being built for each input sentence. Pressing >> will build the chart for an entire sentence at once. The model is not set to re-initialize after each trial, so you can press >> several times to see the chart for each sentence. You will need then need to re-initialize the model by clicking '◯' to start at the beginning of the input again.

The sentences that are presented to the model are stored in the `Stimuli` buffer of the experimenter model. The subject model contains the grammar and the lexicon used for parsing in the buffers `Grammar Rules` and `Lexicon`, respectively.

Question 1 (15%) CM-4 + CM-5
Consider the sentence *mary ate the biscuit in the cupboard*. What are the two different

meanings of this sentence, and what are their syntax trees? Extend the grammar and the lexicon of the model so that it can parse this sentence (in both ways). Give the chart for this sentence and the rules and lexical items you added. Is the ambiguity in this sentence obvious from the chart? Explain.

For this question assume that *in* is a preposition (category `prep`) and that *cupboard* is a common noun (category `cn`). There is no need to assume other lexicon entries.

2 Probabilistic Ambiguity Resolution CM-4 + CM-5

Your task is now to extend the parallel parser with a probabilistic ambiguity resolution component. To achieve this, we first need to turn the context-free grammar that the model uses into a probabilistic context-free grammar (PCFG) by extending the lexicon and the rules with probabilities. First make a copy of the parser from the preceding question, and modify only the copy.

Question 2 (10%) CM-4 + CM-5
Extend the predicate `category` in the `Lexicon` buffer, as well as the predicate `rule` in the `Grammar Rules` buffer so that they can represent the probabilities of terminal and non-terminal rules of a PCFG, respectively. Assume a uniform probability distribution (i.e., all rules with the same left-hand side are equally likely). State the new contents of the two buffers.

We now need to extend the model so that it can compute the probabilities for the edges that it puts into the chart.

Question 3 (20%) CM-4 + CM-5
Extend the process `Elaborate Chart` so that it stores the probability of each edge in the chart. Based on the discussion of PCFGs in the lecture, how should the probabilities of chart edges be computed from the probabilities of PCFG rules? List the rules of the `Elaborate Chart` process and give the chart that your model computes for *mary ate the biscuit in the cupboard*, including probabilities. What are the probabilities of the two readings of this sentence, and which reading is preferred, according to the model? Do you think the model makes the right prediction? What factors that the model doesn't consider might be important for a human in disambiguating this sentence?

3 Pruning the Search Space CM-4

As we have seen in the lecture, probabilistic models of human sentences processing such as the one of Jurafsky (1996) assume that structures are pruned from the chart if they fall below a certain probability threshold. For the sake of simplicity, we will assume that a fixed threshold (rather than a ratio threshold like Jurafsky), which means that a structures is pruned if its probability falls below a fixed value.

Question 4 (15%) CM-4
Modify the model from Sections 1 and 2 so that it prunes all edges whose probability falls below the a threshold of 0.000005. Give the new rules of the `Elaborate Chart` process. How does the pruning effect the results of the model?

Question 5 (20%) CM-4
In Jurafsky's model, a garden path sentence is one where the correct parse has been pruned out of the search space. Give a sentence that causes a garden path in the current model. Why doesn't Jurafsky use a fixed probability threshold for pruning, as we did here?

Jurafsky uses maximum-likelihood estimation to estimate the probabilities of the PCFG rules in his model. Suppose we have a small treebank where the rule counts are as follows (rules generating words are not shown):

S → NP VP	20	VP → V	5
NP → N	8	VP → V NP	12
NP → Det N	30	VP → V NP NP	3

Question 6 (20%) CM-4
Using the corpus above, what is the maximum-likelihood estimate of the probability of the NP → Det N rule? Can you see any potential problems with using maximum-likelihood estimation to compute rule probabilities? What alternatives are available, and how would their estimates be different?

4 Probability Estimation CM-5

The current model simply assumes a prespecified, uniform probability distribution over grammar rules and lexicon entries. It is more realistic to assume that the distribution is non-uniform, i.e., that some rules occur more frequently than others. Also, we probably want the model to be able to learn, e.g., to be able to increase the probabilities of rules it encounters frequently. Make a new copy of the probabilistic parser from section 2 before making any changes.

Question 7 (10%) CM-5
If we know the frequency with which each rule has been used, what is the maximum-likelihood estimate of a rule's probability?

Question 8 (20%) CM-5
Modify your copy of the model from in Sections 2 so that it stores rule frequencies, rather than probabilities. The `Elaborate Chart` process should now access these frequencies and use them to compute probabilities using maximum-likelihood estimation. Also, it should keep track of rule uses, i.e., increment the frequency of a rule if the rule is used. Start with a frequency of one for all rules, and then run your model over the four input sentences. List the parts of the model that you have changed, and give the probabilities of the two readings of the sentence *mary sees the dog in the house*. Do you think this method of computing and updating probabilities is a good one?

A hint for Question 8: consider the fact that the chart-building rules should only fire once for each situation in which a rule can apply, regardless of the rule's frequency. That is, changes to a rule's frequency should not be visible to the rules that determine which edges to add to the chart. This will have ramifications for the way that rule frequencies are represented and stored.

5 Modeling decision-making CM-5

Before answering this question, you will need to read a news story that appeared recently on National Public Radio in the US. The story, *Guns, Tumors And The Limits Of The Human Eye*, can be found here: http://www.npr.org/templates/story/story.php?storyId=122561355. (There is also a link on the Assignments section of the course web page.) Note that there is a typo in the article; for the following question, assume that in the sentence starting *But when he took the exact same*, the 2% figure is correct, i.e., the total number of bags is 1000, not 2000.

Question 9 (25%) **CM-5**
Consider Wolfe's experimental findings regarding detection of guns in images of luggage. Let G be a random variable indicating whether a gun is present or not, and I be a random variable representing the image seen by the screener. Formulate the detection problem as a decision-making problem using Bayes' rule. What is the decision the screener is making? Discuss Wolfe's findings with respect to the predictions of your model and the phenomenon of base rate neglect. According to the model, what would be one way to increase people's ability to detect guns in baggage? If this approach were taken, does the model predict any other consequences?

Literature

Cooper, Richard P. 2002. *Modelling High-Level Cognitive Processes*. Mahwah, NJ: Lawrence Erlbaum Associates.

Jurafsky, Daniel. 1996. A probabilistic model of lexical and syntactic access and disambiguation. *Cognitive Science* 20(2): 137–194.