Bayesian Networks and Probabilistic Inference

Avery Jacobson jacobsonjamesavery@gmail.com

Computer Science Undergraduate

Montana State University

Culberston Hall, 100,

Bozeman MT 59717, USA

Robert Van Spyk rjvs2002@gmail.com

Computer Science Undergraduate

Montana State University

Culberston Hall, 100,

Bozeman MT 59717, USA

Abstract

This document introduces the process of probabilistic inference within Bayesian networks. These Bayesian networks are represented in a .bif file format, and are passed into our program. Our program parses these files and represents the network as a “graph” object, which contains Nodes that represent variables, and corresponding conditional probability tables for each variable. Using the knowledge given, we can determine variable values given any set of evidence both approximately, and exactly. Our results show **TODO**

# Problem Statement

Given an agent that interprets Bayesian networks, and performs probabilistic inference using both variable elimination and Gibb’s sampling techniques, how do you expect the approximate and exact inferencing algorithms to perform?

If we perform approximate probabilistic inference on our Bayesian network using Gibb’s sampling, then the agent will return a variable value with the highest likelihood in O(NK) time because the process of Gibb’s sampling will update the values of variables based on information in the graph. For example, the agent would return “The probability of HYPOVOLEMIA is TRUE with 81.67% likelihood” in O(NK), where N is the number of samples performed, and K is the cost of updating a single variable in the network.

If we perform exact probabilistic inference on our Bayesian network using variable elimination techniques, then the agent will return an exact variable value with high confidence in O(EM) time because the process of variable elimination will update and ignore the values of certain variables based on information in the graph. For example, the agent would return “The probability of HYPOVOLEMIA is TRUE”, with no degree of likelihood, since it should be exact. The exact algorithm will perform inference in O(EM) time where E is the number of edges in the network and M is the size of the largest factor created during variable elimination.

# Description of Problem

**.BIF Networks:** .BIF files represent a Bayesian network that consists of multiple variables, their parents, and their corresponding conditional probability tables. By parsing these files, we can construct the entirety of the Bayesian network. In our probabilistic inference solver, we have the following five networks:

Alarm Network: 37 nodes, 46 edges, 509 parameters

Child Network: 20 nodes, 25 edges, 230 parameters

Hailfinder Network: 56 nodes, 66 edges, 2656 parameters

Insurance Network: 27 nodes, 52 edges, 984 parameters

Win95Pts Network: 76 nodes, 112 edges, 574 parameters

**Approximate Inference:** Our approximate inference algorithm will take an input such as “HYPOVOLEMIA | BP = LOW”, meaning it will return the probability of HYPOVOLEMIA being it’s most likely value given that the value of variable BP is LOW.

**Exact Inference:** Our exact inference algorithm will take an input such as “HYPOVOLEMIA | BP = LOW”, meaning it will return the precise value of HYPOVOLEMIA given the value of variable BP is LOW.

# Experimental Approach

ToDo

# Results

Our approximate probabilistic inference algorithm was able to successfully parse the approximate probabilistic values of all networks, given some evidence and no evidence, in less than one second.

# Behavioral Breakdown of Algorithms

**Graph::init(self, inputFile):**

The init() function takes in a .bif file as the inputFile parameter, and uses string parsing to build out a Graph object that consists of Nodes and Conditional Probability tables.

**Graph::getApproximateProbability(self, statement, iterations):**

The getApproximateProbability() function begins by parsing the string statement into query Nodes and evidence Nodes. Once those are parsed, setInitialState() is called. Once the initial state is set, a gibbs sample is taken for each iteration by calling the gibbsSample() function. The initial 200 states are considered “burn-in” states, and their values are not incorporated into the percent likelihood value, since there is still a high level of uncertainty in the early iterations. Finally, the frequency of the values for the query Variables are taken and converted into a probability, and a string representing the most frequent value for a variable is returned, including the likelihood of correctness as a percent.

**Graph::setInitialState(self, evidenceNodes):**

The setInitialState() function takes every node that is not an evidence node, and assigns it a random value within its domain. For discrete variables with no known parents, the weighted distribution is used for calculating the random value, and for variables with parents, a truly random value is set. Again, all evidence nodes remain the same.

**Graph::gibbsSample(self, evidenceNodes):**

The gibbsSample() function randomly selects any node that is not an evidence node, and updates its value based on the weighted distribution given the value of its parents. If there are no known parents for the variable, the weighted distribution is used. If the sample occurs after the burn-in process, the count (frequency) of each value is updated. This value is considered at the end of the getApproximateProbability() function.

**Graph::getExactProbability(self, statement, iterations):**

# Summary

ToDo

# References

ToDo

# Introduction

To ensure that all articles published in the journal have a uniform appearance, authors must produce a PostScript or PDF document that meets the formatting specifications outlined here. The document will be used for both the hardcopy and electronic versions of the journal.

This document briefly describes and illustrates the JMLR format. It draws very heavily from an earlier document by Minton et al., (1999). Your article should look as similar as possible to PostScript version or PDF version of this document, or to the JMLR sample article which can be found at http://www.jmlr.org/format/sample.ps. Below we outline the basic specifications, including font sizes, margins, etc. However, the point is to have your articles look similar to the sample, and when in doubt you should use the sample as your guide. Please feel free to contact the editor of JMLR if you have any questions.

The remainder of this document is organized as follows. Section 2 describes the style and formatting requirements for JMLR papers. Section 3 describes how to obtain the formatting templates that should simplify following the requirements, and Section 4 describes common formatting errors that should be avoided.

# Style and Format

Papers must be printed in the single column format as shown in the enclosed sample. Margins should be 1 1/4 inch left and right. Headers should be 1/2 inch from top and footer should be 1 inch from bottom of page. Title should start 1 1/2 inches from the top of the page.

## Fonts

You should use Times Roman style fonts. Please be very careful not to use nonstandard or unusual fonts in the paper. Including such fonts will cause problems for many printers.

Headers and Footers should be in 9pt type. The title of the paper should be in 14pt bold type. The abstract title should be in 11pt bold type, and the abstract itself should be in 10pt type. First headings should be in 12 point bold type and second headings should be in 11 point bold type. The text and body of the paper should be in 11 point type.

## Title and Authors

The title appears near the top of the first page, centered. Authors' names should appear in designated areas below the title of the paper in twelve point bold type. Authors' affiliations and complete addresses should be in italics, and their electronic addresses should be in small capitals (see sample article).

## Abstract

The abstract appears at the beginning of the paper, indented 1/4 of an inch from the left and right margins. The title ``Abstract'' should appear in bold face 11 point type, centered above the body of the abstract. The abstract body should be in 10 point type.

## Headings and Sections

When necessary, headings should be used to separate major sections of your paper. First-level headings should be in 12 point bold type and second-level headings should be in 11 point bold type. Do not skip a line between paragraphs. Third-level headings should also be in 11 point bold type. All headings should be capitalized. After a heading, the first sentence should not be indented.

References to sections (as well as figures, tables, theorems and so on), should be capitalized, as in ``In Section 4, we show that...''.

### Appendices

Appendices, if included, follow the acknowledgments. Each appendix should be lettered, e.g., ``Appendix A''. If online appendices are submitted, they should not be included in the final manuscript (see below), although they may be referred to in the manuscript. They will be published online in separate files. The online appendices should be numbered and referred to as Online Appendix 1, Online Appendix 2, etc.

### Acknowledgements

The acknowledgments section, if included, appears after the main body of the text and is headed ``Acknowledgments.'' The section should not be numbered. This section includes acknowledgments of help from associates and colleagues, financial support, and permission to publish.

## Figures and Tables

Figures and tables should be inserted in proper places throughout the text. Do not group them together at the beginning of a page, nor at the bottom of the paper. Number figures sequentially, e.g., Figure 1, and so on.

*The figure or table number and the caption should appear under the illustration.* Leave a margin of one-quarter inch around the area covered by the figure and caption. Captions, labels, and other text in illustrations must be at least nine-point type.

At present, some types of illustrations in your manuscript may cause problems for some printers/previewers. Although this is gradually becoming less of an issue, we encourage authors to use ``reliable'' programs for producing figures. Before your paper can be accepted, we must verify that all your figures print successfully on our printers and may be viewed with Adobe Acrobat Reader or Ghostview.

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| **C** |  |  |

Table . Note well that JMLR expects table captions below the table. >= 9pt font.

## Headers and Footers

The first page of your article should include the journal name, volume number, year and page numbers in the upper left corner, the submission date and publication date in the upper right corner, and the copyright notice in the lower left corner. The editor will let you know the volume number, year, pages, submission date and publication date.

On the even numbered pages, the header of the page should be the authors' names. On the odd pages, starting with page 3, the header should be the title of the paper (shortened if necessary, as in the sample).

### Page Numbering and Publication Date

Upon completion of your article and final approval of the editor, you will be assigned a page number that should be the first page of your article. You should number the remainder of your article accordingly. Page numbers should appear at the bottom of the page in the center. You will also be assigned a volume number and publication date that you will use in the header.

Tip for Microsoft Word users: To start your page numbering at, say, 50, go to Insert / Page Numbers / Format / Start at: 50.

### Footnotes

We encourage authors to use footnotes sparingly, especially since they may be difficult to read online. Footnotes should be numbered sequentially and should appear at the bottom of the page, as shown below.[[1]](#footnote-1)

## References

The reference section should be labeled ``References'' and should appear at the end of the paper in natbib format. A sample list of references is given in Appendix A. Poorly prepared, incomplete or sloppy references reflect badly on the quality of your scholarship. Please prepare complete and accurate citations.

Citations within the text should include the author's last name and year, for example (Cheeseman, 1992). Append lower-case letters to the year in cases of ambiguity, as in (Cheeseman, 1993a). Multiple authors should be treated as follows: (Cheeseman & Englemore 1988) or (Englemore, Cheeseman & Buchanan, 1992). In the case of three or more authors, the citation can be shortened by referring only the first author, followed by ``et al.'', as in (Clancey et al., 1991). Multiple citations should be separated by a semi-colon, as in (Cheeseman, 1993a; Buntine, 1992). If two works have the same author or authors, the appropriate format is as follows: (Drummond 1990, 1991).

If the authors' names are mentioned in the text, the citation need only refer to the year, as in ``Cheeseman and Englemore (1988) showed that...''.

In general, you shouldn't have parenthetical statements embedded in parenthetical statements. Therefore, citations within parenthetical statements should not be embedded in parentheses. Use commas as separators instead. For instance, rather than ``(as shown by Bresina (1992))'' you should write ``(as shown by Bresina, 1992)''. Similarly, ``(e.g., (Bresina, 1992))'' should be ``(e.g., Bresina, 1992). Note that the natbib style file supports the inclusion of prefixes in citations.

# Formatting Templates

To ready your work for publication, please typeset it using software such LATEX that produces PostScript or PDF output (LATEX is preferred.) A LATEX style file is available at http://www.jmlr.org/format/jmlr2e.sty or from the editor. There is also a template for Microsoft Word, which can produce PDF files via the Acrobat product. We hope to eventually have macros/samples for other document preparation systems as well. We recommend working from the LATEX source of the sample article (at http://www.jmlr.org/format/sample.tex), which has been annotated to simplify use of the macros in the style file. If you must use a document preparation system other than LATEX, please discuss this with the editor prior to submitting your final document. If you do not have the software necessary to produce acceptable PostScript or PDF files, the editor will recommend a professional service for formatting your article. (Authors will be responsible for paying for this service).

## Using jmlr2e.sty

The LATEX source for the sample paper, at http://www.jmlr.org/format/sample.tex, details the use of most of the macros in jmlr2e; we describe a few of the macros here for illustration.

The paper should begin with a specification of the document class and JMLR style file:

\documentclass[twoside,11pt]{article}

\usepackage{jmlr2e}

The following command can be used in the LaTex version of your paper to set the first page header:

\jmlrheading{1}{2000}{1-48}{4/00}{10/00}{author list}

# dates/pages from editor

To set your title and authors for headings:

\ShortHeadings{short title}{short authors}

For example:

\ShortHeadings{Minimizing Conflicts}{Minton et al.}

To set your page numbers:

\firstpageno{?} the pagenumber you are assigned to start with by the editor.

Authors are specified with the ``author'' macro:

\author{\name Author One \email author-one-email\\

\addr Author One address line one\\

Author One address line two\\

Author One address line three...

\AND

\name Author Two \email author-two-email\\

\addr Author Two address line one\\

Author Two address line two\\

Author Two address line three...}

If multiple authors share an affiliation, it may be appended to the group by specifying:

\author{\name Author One \email author-one-email\\

\name Author Two \email author-two-email\\

\addr Authors' address line one\\

Authors' address line two\\

Authors' address line three...}

## Citations using natbib

The recommended citation style file, natbib, is included in jmlr2e.sty. It supports the citation styles described in Section 2.7 with macros such as \citep{} and \citet{}. The basic uses of \citep{} and \citet{} are as follows:

\citet{jon90} => Jones et al. (1990)

\citet[chap.~2]{jon90} => Jones et al. (1990, chap. 2)

\citep{jon90} => (Jones et al., 1990)

\citep[chap.~2]{jon90} => (Jones et al., 1990, chap. 2)

\citep[see][]{jon90} => (see Jones et al., 1990)

\citep[see][chap.~2]{jon90} => (see Jones et al., 1990, chap. 2)

\citet\*{jon90} => Jones, Baker, and Williams (1990)

\citep\*{jon90} => (Jones, Baker, and Williams, 1990)

For details on making citations with natbib macros, see the natbib documentation Daly97, a copy of which is available at http://www.jmlr.org/format/natbib.pdf.

# Avoiding Common Errors

As we do the final editing passes on JMLR papers, we find a fairly consistent set of problems repeated over and over. Here's a list of them. JMLR won't enforce conformity with these rules, but it would certainly please the editors if you followed them.

## Dashes

Dashes should be used--with care--to set off interjections in a sentence. They should be long and there should not be spaces between them and the preceding and following words. Thus, in LaTeX, the input should look like this:

Dashes should be used---with care---to set off ...

## Lower case names

The names of fields, algorithms, methods, etc., should be in lower case: cognitive science, reinforcement learning, principal components analysis. Exceptions are when they are in names of organizational entities, like Cognitive Science Department, or when they include proper names, such as Markov decision processes or Gaussian densities, or Bayes' rule.

## Latin abbrevs.

Scientists seem to like to use the Latin abbreviations i.e. and e.g. First, I'd like to encourage you to try to do without them. If you can't, then use the English equivalents (``that is'' instead of i.e. and ``for example'' instead of e.g.) If you really love the Latin (then you're a Latin lover?) you should at least do it right. There should be a period after each letter (because they're abbreviations), and there should be a comma after the expression. If you're addicted to these things, I encourage you to define and use LaTeX macros like

\newcommand{\ie}{i.e.}

## Equation numbers

Only number equations that are actually referred to later in the text.

## Citations

Citations are not nouns. It is not correct to say ``Using the method of (Smith, 1999), we ...'' Instead, say ``Using the method of Smith (1999), we ...'' or ``Using the method of partial discombobulation (Smith, 1999), we ....''. See the section on references (Section 2.7) for more details on correct and incorrect citation forms.

## Punctuate math

Sentences with mathematical statements in them are still sentences, subject to the usual rules of grammar and punctuation. As Knuth et al.,(1989) say,[[2]](#footnote-2) you should test this by reading out your paper with things like ``snort'' and ``grunt'' substituted in for the mathematics and listening to see whether it's grammatically correct.

It often improves readability if the punctuation in displayed equations is moved out to the right a bit. In LaTeX, you can write

\[a = b\;\;.\]

to get a reasonable amount of space between the equation and the period.

Never put a footnote directly after a mathematical expression; it is too easily confused with an exponent.

## Hyphenating compound nouns

When you have a long string of nouns together, they often need hyphenation to make the meaning clear (and to make your editor happy). Here are some examples of correct expressions:

reinforcement learning

reinforcement-learning algorithm

delayed-reinforcement learning (learning from delayed reinforcement)

delayed reinforcement learning (reinforcement learning that is delayed)

What are the rules? Here's a simple view: by default, modifiers bind to the phrase to their right. If you want to override that, then you need to use a hyphen. Consider the string of words ``country chicken pump dispenser'' (seen in an actual catalog). A ``pump dispenser'' is either something that dispenses pumps or that dispenses by pumping. A ``chicken pump dispenser'' is, perhaps, a pump dispenser in the shape of a chicken. But a ``chicken-pump dispenser'' is something that dispenses chicken pumps. The object in the catalog was a soap dispenser in the shape of a country chicken (as opposed to a city chicken, I guess) with a pump. So, probably, it should have been a ``country-chicken pump dispenser'', since ``pump'' modifies ``dispenser,'' ``country'' modifies ``chicken,'' and the phrase ``country chicken'' modifies ``pump dispenser.'' Whew. Many people think it's bad form to use such long strings of nouns anyway.

## Don't use ``utilize.''

## Don't start a section with a subsection

A section heading should never immediately follow another section heading without intervening text. So don't do this:

5. Experimental Results

5.1 Results on a Simulated Domain

Instead, do this:

5. Experimental Results

In this section, we first describe blah, blah, blah...

5.1 Results on a Simulated Domain

Acknowledgements

Who helped, funded, etc.

1. : Natbib Reference Examples

Any appendix comes before the references. The following formatting examples are intended to be illustrative, not exhaustive. If you are uncertain about the proper format for a reference, please contact the JMLR editors.

* 1. Book

Richard Bellman. *Dynamic Programming.* Princeton University Press, Princeton, New Jersey, 1957.

* 1. Edited Book

Robert R. Bush and William K. Estes, editors. *Studies in Mathematical Learning Theory.* Stanford University Press, Stanford, California, 1959.

* 1. Journal Article

Dana Angluin and Philip Laird. Learning from noisy examples. *Machine Learning*, 2(4):250-370, 1988.

* 1. Proceedings Paper

Charles W. Anderson. Strategy learning with multilayer connectionist representations. In *Proceedings of the Fourth International Workshop on Machine Learning*, pages 103-114, Ann Arbor, Michigan, 1987.

* 1. Technical Report

Andrew G. Barto. Connectionist learning for control. Technical Report 89-89, Department of Computer and Information Science, University of Massachusetts, Amherst, Massachusetts, 1989.

* 1. Dissertation or Thesis

Michael L. Littman. *Algorithms for Sequential Decision Making.* PhD thesis, Brown University, Providence, Rhode Island, 1996.

* 1. Forthcoming Publication

Stephen H. Muggleton. Statistical aspects of logic-based machine learning. *ACM Transactions on Computational Logic*, forthcoming.

* 1. URL

WEKA Machine Learning Project. http://www.cs.waikato.ac.nz/~ml

In general, try to avoid giving URLs. If you must, make sure they are stable, for example, www.hp.com (www.compaq.com, however, has merged). There are, unfortunately, many broken URLs in the literature. Consider creating a permanent URL at http://www.purl.org (You can update these indirect pointers at any time. Be sure to designate in your will who will be responsible for your PURLs after you retire.).

References

Patrick W. Daly. Natural sciences citations and references. Available online at ftp://ftp.freesoftware.com/pub/tex/ctan/macros/contrib/supported/natbib, 1997.

Donald E. Knuth, Tracy L. Larrabee, and Paul M. Roberts. Mathematical Writing. Mathematical Association of America, Washington, D.C., 1989. ISBN 0-88385-063-X.

Mary Claire Van Leunen. A Handbook for Scholars. Oxford University Press, 1992.

Steven Minton, Martha Del Alto, and Helen Stewart. Instructions for formatting JAIR articles. Available electronically via http://www.jair.org/submission-info.html, 1999.

1. A footnote should appear like this. Please ensure that your footnotes are complete, fully punctuated sentences. [↑](#footnote-ref-1)
2. I recommend this book highly to anyone who likes to think about technical writing. While we're on the subject, I also highly recommend the (sadly, out of print) Handbook for Scholars by Mary-Claire van Leunen (1992). [↑](#footnote-ref-2)