Carmen: una herramienta de software libre para modelos gráficos probabilistas

Abstract and conclusions

Manuel Arias Calleja

Licenciado en Informática
Universidad Politécnica de Madrid

Departamento de Inteligencia Artificial
Universidad Nacional de Educación a Distancia

Septiembre de 2009

Abstract

In the last two decades there has been a proliferation of computer tools for the construction either manual or automatic of Probabilistic Graphical Models (PGMs). The tools currently available are limited in their maintainability, robustness and efficiency. Our main contribution is a new tool, called Carmen, which has been developped from scratch and is based on the principles of software engineering. Carmen has detailed design, a documentation, and a batch of systematic tests aimed at minimizing the presence of errors.

The development of this software tool has led to several secondary contributions: first, a new design pattern called *permission-execution*, which permits to perform operations on complex models with multiple constraints; second, we have developped a new design which decouples the different concepts that make up a PGM in different parts, allowing subsequent maintenance much easier; third, we have developped a general purpose graph library that can be used in other tools.

Our second main contribution is a new method that significantly improves the performance of basic operations on potentials of discrete variables such as addition, multiplication, marginalization and división. We have also proved, theoretically and empirically, that some compound operations can be performed much more efficiently if they are executed all together rather tan sequentially. This improvement in the low-level operations leads to a reduction in the time and space required by high-level algorithms, such as variable elimination, clique tree propagation, etc.

Finally, the third main contribution is a new method for cost-effectiveness analysis. Current methods can not deal with problems that involve more than one decision. For this reason, we have developped a new method of cost-effectiveness, which can be applied to both decision trees and influence diagrams. Our method is capable of handling several decisions and returns the an optimal strategy as a set of intervals for λ, a parameter usually called *willingness to pay* wich represents the amount of money equivalent to a unit of effectiveness.

Conclusions

The main objectives of this thesis were two: to create an open source tool, called CARMEN, for editing and evaluating probabilistic graphical models (PGMs) and to develop a method of cost-effectiveness analysis for problems involving several decisions. This thesis has also made several secondary contributions.

Independent contributions of the Carmen tool

We detail first the contributions, that have been used in the construction of CARMEN but are independent of it and, therefore, might be used in other tools.

a) Algorithms for basic operations with potentials

We have designed a method that improves the efficiency of operations on potentials of discrete variables. As mentioned in Section 2.6, the analysis of the computational complexity of inference algorithms by measuring only the number of elementary operations, such as addition or multiplication, is incorrect, because we must also take into account the time necessary to access these values. The method that has been developed substantially improves the speed of basic operations such as marginalization, maximization, multiplication and projection, which leads to significant improvements in the time and space costs of the algorithms for PGMs.

b) Cost-effectiveness analysis

We have developed a method for cost-effectiveness analysis, whose main advantage is the possibility of including multiple decision and chance variables in the model, while previous methods only allowed one decision variable, which had to be at the root of the tree (*TreeAge*, the most widely used program for decision analysis, may yield incorrect results when performing cost-effectiveness analysis in a decision tree containing several decisions, as demonstrated by an example in Section 3.2.2) out method presents the results as a set of intervals of the parameter λ, sometimes called *willingness to pay*, which represents the money-effectiveness equivalence, i.e., the amount of money that the decision maker pay to obtain a unit of effectiveness.

CARMEN implements two versions of this method, one for decision trees and the other for influence diagrams. We expect that this method will be used widely, especially in medicine, where there is great interest in this type of studies.

c) New design pattern

We have developed a design pattern, *Permission-Execution*, for controlling the edition of objects subject to restrictions. The main advantages of this pattern is that it allows each object to have a set of constraints associated that define the operations that can be done on it, and these restrictions can be added or removed in a dynamically way. This pattern is a contribution that can be used in other problems than MGPs.

Free software tool for MGP development

a) CARMEN as a free software tool

CARMEN has been developed following the typical phases in software engineering: analysis, design, codification and testing. The main characteristics of Carmen are:

1. **Robustness**: A careful design and a suite of systematics tests, coded with *jUnit*, guarantee a low density of errors in CARMEN.

2. **Efficiency**: As said before, we have taken special care in the implementation of the most time-consumming operations. As result, CARMEN's performance is comparable with that of the best commercial tools available today.

3. **Maintanability**: This attribute is mainly a consequence of a careful design, with an architecture devised to accommodate future extensions. It is also a consequence of having used a set of coding rules that have ensured a homogeneous style.

4. Maintainability is enhanced an by an extensive **documentation**, both internal and external, that currently consists of:

    - A set of HTML pages generated automatically by the tool *Javadoc* from the comments included in the documentation of the code.
    - A paper, presented at the *European Workshop on Probabilistic Graphical Models* (PGM-08), in Hirsthals, Denmark.

- Chapters 4 to 6 of this thesis, which offer an extensive overview of CARMEN, including several types of UML diagrams that graphically show the structure and the dynamics of CARMEN components.

b) CARMEN license

CARMEN is distributed under the LGPL license (see http://www.gnu.org/copyleft/lesser.html), which allows any person, group or enterprise to freely use and modify the software. It also allows to develop new components and plugins, either free or propietary.

c) CARMEN components

CARMEN contains libreries for graphs, for basic operations with potentials of discrete variables, and for creating and editing PGMs. The algorithms implemented so far for bayesian networks are variable elimination, Hugin propagation and lazy propagation; the algorithm implemented for the evaluation of influence diagrams is variable elimination. CARMEN has also the possibility of learning bayesian networks from databases using standard *search and score* algorithms, with several metrics. The graphical user interface of CARMEN is still under development.