Design and Implementation of Advanced Bayesian Networks with Comparative Probability

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This paper summarizes the major findings, methods, and background theories of the doctoral thesis in [1]. The aim of the thesis has been to enhance the current procedures of designing decision support systems (DSSs) used by decision-makers to comprehend the current situation better in cases where the available amount of information required to make an informed decision is limited. The research resulted in a new innovated theory that combines the philosophical comparative approach to probability, the frequency interpretation of probability, dynamic Bayesian networks and the expected utility theory. It enables engineers to write self-learning algorithms that use example of behaviours to model situations, evaluate and make decisions, diagnose problems, and/or find the most probable consequences in real-time. The new theory was particularly applied to the problems of validating equipment readings in an aircraft, flight data analysis, prediction of passengers behaviours, and real-time monitoring and prediction of patients' states in intensive care units (ICU). The algorithm was able to pinpoint the faulty equipment from between a group of equipment giving false fault indications, an important improvement over the current fault detection procedures. On the ICU application side, the algorithm was able to predict those patients with high mortality risk about 24 hours before they actually deceased.

Povzetek: Predstavljena je disertacija, ki izboljšuje bayesovske mreže s pomočjo primerjalnih verjetnosti.

1 Introduction

We live in an ever-changing world where our convictions about the state of it update with time as we discover new information about our surroundings. As we acknowledge the imperfections of our knowledge repositories regarding the state of the world, we often need to make decisions despite all the missing details and the uncertainty of where our decisions might lead us to. A robot might use its sensory system, for instance, a sonar based sensor, to retrieve cues about its surroundings. Then it might use these cues to decide on which direction is best to turn to. Since the world behind the range of the robot's sensors is unknown, the robot may take a turn that leads to a dead end. Hence, the robot needs to make a decision in an environment where the only available information is that of its immediate surroundings. Even if the robot was in an exceptionally charted environment, its sensors might malfunction or degrade. In this case, the uncertainty arises not from the environment but rather from a lack of trustworthiness of the robot's sensors. In addition, the robot programming may contain bugs, the robot might trip and fall, or its battery may run out of power or be stolen. The list of events that the robot could possibly face in an environment grows infinitely as we consider more details. The problem of specifying all the exceptions a designer needs to consider is called the qualification problem [2]. Probability theory is the main tool used to represent uncertainty arising from laziness and ignorance [1, p 482]. If we consider probability as a measure of how likely an event would be observed in an experiment repeated a certain amount of times, then it could be used as a quantitative representation of our certainty of how likely that event might occur from among all other possible events. In this context, probability is interpreted as a degree of belief rather than a frequency of occurrence.

2 Research Approach

In order to meet the objectives of this thesis, both theoretical and practical approaches were adopted. Firstly, the common approach to decision-making, and in turn knowledge-based decision support systems, is to use probability theory backed by the utility functions to come up with the expected utility of making a decision.

Secondly, as the theory of probability is accepted as the main framework for representing knowledge with uncertainty, many interpretations of probability have been analyzed in order to find the most suitable one that works with as little information available as possible without falling back on a strictly analytical approach or ignorance.

Thirdly, we surveyed the research done in the theory of comparative probability, its axioms, and application to computer science.

3 Results and discussion

We used the Chernoff bounds to come up with a novel approach to updating probability bounds between successive experiment results. Chernoff bounds were used as upper and lower estimates of probability at a given experiment while taking into account all the previous experiment results. As the number of experiments increases, the gap between the upper and lower bounds becomes smaller until it approaches the expectation of the outcome of the experiment. The expectation of an experiment is nothing other than its probability. Hence, a mathematical foundation between Comparative probability (CP) and Kolmogorov probability (KP) was established with a dynamic nature that puts CP as a foreground methodology to evaluate KP.

In addition, we recognized that even with the availability of a simple approach to representing knowledge, the size of the joint probability tables may become too large to process, so we used a Bayesian network to simplify the processing of probabilistic queries and reduced the amount of mathematical backgrounds required to answer them. as probabilistic decision support systems work on averages, it would be unfeasible to attempt to justify the principles of the proposed approach using an example or two. Instead, we adopted two approaches to tackle the issue. Firstly, we used scenario-based validation. Scenarios are ways of generating test data, which can be used to validate system design requirements. The second approach was the ability of the system to predict an output with high accuracy.

Two new enhancements have been suggested to the detection and isolation of faults in aviation and to the optimising the navigation planning. In the first experiment, we proposed a new method for detecting faults that should overcome any limitations that result from using majority vote coming from primary and redundant systems. Whereas, in the second experiment, we proposed a novel application to the BADA database as a DSS for navigation planning. Both experiments where implemented with CP to show the usefulness, admissibility and ascertainability of CP.

Finally, An innovated ICU patient monitoring system was designed. The novel system outperforms all current monitoring systems in terms of its versatility and prediction capabilities. We have shown how it can be used to predict the evolution of patients' physiological parameters over time and how it can predict the mortality risk in patients with a history of cardiac surgery even 24 hours before patients' date of death.

These findings show the development of the reasoning according to which this research was conducted, starting from defining the research question to documenting the results. The research method dictates that a good theory should be able to predict some observations that can be measured and compared to what the theory proposes. In the light of such requirements, it is the belief of the author that the thesis stands on very solid grounds with respect both to meeting the objectives and verifying the soundness of its theory.

4 Final remarks

As the case with any novel proposal, the comparative probability approach proposed in this thesis work summarized here is not yet complete. The best way to show the power of it is through applying it to a wider range of applications and engineering problems while ironing out any issues that arises along the way. While this thesis worked as proof of concept for CP application to DSS and artificial intelligence in general, it is the belief of the author that it has achieved its objectives and still maintaining the de facto interpretation of probability intact. After all, it would not be of benefit to the scientific community to propose the seizure of their very best guide to life.

References

[1] Ali Hilal Ali, "Design and Implementation of Advanced Bayesian Networks with Comparative Probability" Ph.D. dissertation, Lancaster University, 2012.

[2] Russel, S., and Norving, P. "Artificial Intelligence: A Modern Approach". New Jersey: Pearson Education, Inc., 2010.