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A semantic fuzzy expert system for a fuzzy balanced scorecard

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Abstract

Balanced scorecard is a widely recognized tool to support decision making in business management. Unfortunately, current balanced scorecard-based systems present two drawbacks: they do not allow to define explicitly the semantics of the underlying knowledge and they are not able to deal with imprecision and vagueness. To overcome these limitations, in this paper we propose a semantic fuzzy expert system which implements a generic framework for the balanced scorecard. In our approach, knowledge about balanced scorecard variables is represented using an OWL ontology, therefore allowing reuse and sharing of the model among different companies. The ontology acts as the basis for the fuzzy expert system, which uses highly interpretable fuzzy IF–THEN rules to infer new knowledge. Results are valuable pieces of information to help managers to improve the achievement of the strategic objectives of the company. A main contribution of this work it that the system is general and can be customized to adapt to different scenarios.

Keywords: Knowledge-based systems; Expert systems; Ontologies semantic web; Applied economy; Balanced scorecard; Fuzzy logic

1. Introduction

Knowledge management plays a key role in the search for success in the current business world. Increasing specialization and complexity of companies has given raise to the necessity of an integral management of own and foreign resources, which involves and generates huge amounts of valuable data. Empresarial intelligence must be consequently more a cornerstone of the corporative strategy than simply an amalgam of disperse tools and procedures, if decision processes are expected to be faced with guarantees in order to achieve a joint and balanced global performance.

Balanced scorecard (BSC) (Kaplan & Norton, 1992) is a decision support tool at the strategic management level which improves the satisfaction of the strategic objectives. Since it was proposed in the early 1990s, it has demonstrated its suitability to assist decision making in management.

Nevertheless current balanced scorecard-based systems suffer from two problems. Firstly, variables which are to be measured have associated vagueness, being much more natural to refer to their values using a linguistic label instead a numerical value as frequently is done. Secondly, data do not have an explicit representation of their semantics; ad hoc solutions are usually implemented for each problem, making developers duplicate efforts and users cope with their specific details.

Some solutions have been proposed to the first problem. Since fuzzy set theory and fuzzy logic (Zadeh, 1965) have proved to be successful in handling imprecise and vague knowledge, they have been combined with the BSC leads to fuzzy balanced scorecard (see Section 5 for details). However, such approaches also leave room for improvements in several aspects such as interpretability, modularity and accuracy. On the other hand, to the very well of our knowledge, there has not been any effort in the other direction. Thus we have represented balanced scorecard data using an ontology, which allows to add semantics to them

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making easier knowledge base maintenance as well as reuse of components among different organizations.

In this paper we present a new approach to a fuzzy BSC which improves the state of art by extending the number of variables and perspectives. We also present a fuzzy expert system for this fuzzy BSC. Its knowledge base relies on an ontology and its inference system derives new knowledge from fuzzy rules. The system is general and reusable, so every company can personalize it by providing their own meaning for the linguistic labels defined over the variables (e.g. what they consider a "high" value of some variable) and their own rules. The results of the expert system are highly interpretable pieces of information ready to be incorporated to managers' decision making processes.

The remainder of this paper is structured as follows. Section 2 provides some preliminaries on the fundamental theoretical aspects underlying this paper: balanced scorecard, fuzzy logic and ontologies. In Section 3 we present our fuzzy balanced scorecard, describing the variables which take part in it. Implementation details are set out in Section 4. The description of our intelligent system starts by sketching the ontology and then we show how the rule-based engine computes the value of the output variables of the system. Section 5 evaluates our proposal with regard to the related work. Finally, some conclusions and ideas for future research are drawn in Section 6.

2. Background

This section provides some basic background about the topics covered in the paper: Section 2.1 quickly overviews the original balanced scorecard, Section 2.2 refreshes the basic ideas in fuzzy sets theory and fuzzy logic, and Section 2.3 recalls the notion of ontology.

2.1. The balanced scorecard

In 1992 Robert S. Kaplan and David P. Norton proposed the balanced scorecard (BSC) Kaplan and Norton (1992), a widely recognized tool to support decision making at the strategic management level which improves the satisfaction of the strategic objectives. The name reflects the objective of maintaining a balance "between short and long-term objectives, between financial and non-financial measures, between lagging and leading indicators, and between internal and external performance perspectives" (Kaplan & Norton, 1996).

The key innovation of the BSC is, as opposite to traditional approaches which only consider the financial data, to supplement this information with additional non-monetary measures. In words of the authors, "financial measures are inadequate, however, for guiding and evaluating the journey that information age companies must make to create future value through investment in customers, suppliers, employees, processes, technology, and innovation".

In particular, these authors consider four perspectives: *Financial* perspective obviously, measuring the financial performance of the company, *customer* perspective, measuring the satisfaction of the customers preferences, *internal business process* perspective, measuring internal business results against measures from financial and customer perspectives, and *innovation and learning* perspective, measuring the ability of the company to adapt to changes. A more detailed description of the perspectives is out of the scope of this paper. On the other hand, Section 3 depicts the perspectives that we consider.

Since the apparition of the BSC it has become an important field of theory and research. Many companies have successfully applied this tool and several variations to the original proposal have been investigated (for instance, see Section 5).

2.2. Fuzzy sets and fuzzy logic

This section briefly reviews fuzzy sets theory and fuzzy logic; for more details a good reference is (Klir & Yuan, 1995). Fuzzy set theory and fuzzy logic, proposed by (Zadeh, 1965), are acknowledged as an appropriate formalism for capturing imprecise and vague knowledge. While in classical set theory elements either belong to a set or not, in fuzzy set theory elements can belong to a certain degree. More formally, let X be a set of elements. A fuzzy subset A of X, is defined by a membership function $\mu_A(x)$ which assigns any $x \in X$ to a value between 0 and 1. As in the classical case, 0 means no-membership and 1 full membership, but now a value between 0 and 1 represents the extent to which x can be considered as an element of X.

All crisp set operations are extended to fuzzy sets. The complement, intersection and union set operations are performed by a negation function, a t-norm function (typically, the minimum) and t-conorm function (typically, the maximum) respectively.

Several membership functions can be used in the definition of a fuzzy set. Some of the most used are the triangular and the trapezoidal function. A triangular function $tri_{\alpha,\beta,\gamma}(x)$ (see Fig. 1a) is defined over the set of non-negative reals $\mathbb{R}^+ \cup \{0\}$ with $\alpha \leqslant \beta \leqslant \gamma$ being real numbers. A trapezoidal function $trz_{\alpha,\beta,\gamma,\delta}(x)$ is defined over the set of non-negative reals $\mathbb{R}^+ \cup \{0\}$ as in Fig. 1b, with $\alpha \leqslant \beta \leqslant \gamma \leqslant \delta$ being real numbers. Note that a triangular function $tri_{\alpha,\beta,\gamma}$ can be represented using a trapezoidal function $trz_{\alpha,\beta,\beta,\gamma}(x)$.

One of the most important features of fuzzy logic is its ability to perform approximate reasoning (Zadeh, 1973), which involves inference rules with premises, consequences or both of them containing fuzzy propositions. Fuzzy rule-based systems have some advantages over other formalisms: they provide a natural representation for human knowledge as well as a very interpretable model (since the semantics of the rules can easily be understood even for not experts users), are simpler, cheaper and more robust than their crisp versions and, last but not least, have shown to behave very well in practical applications.

A fuzzy IF–THEN system consists of a rule base (a set of IF–THEN rules) and a reasoning algorithm performing