Development of a Web-Based Strategic Management Expert System Using Knowledge Graphs *

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Abstract. In this paper, we present the development of a web-based expert system, *StrategyAdvisor Cloud*, to support strategic management decision-making. The system was developed using a multistage methodology that builds upon knowledge graphs, where knowledge acquisition and rule base construction by project members with different roles, capabilities, and skills can be facilitated through customized visual languages. The methodology systematizes knowledge acquisition and knowledge representation for each stage, coupled with algorithms for the transformation of knowledge graphs between successive stages. The developed expert system and the development process are described in detail in the paper and its supplement, to serve as guidance in the development of similar systems in the future.

Keywords: Knowledge Graphs · Knowledge Representation · Decision Support Systems · Expert Systems · Strategic Management.

1 Introduction

This paper reports the development of StrategyAdvisor Cloud[7] (Figures 1, 2, and 3), an expert system in the domain of strategic management. The developed

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[7] https://strategyadvisor.herokuapp.com/

web-based expert system acquires information through a series of diagnostic questions and makes strategic policy recommendations based on the answers.

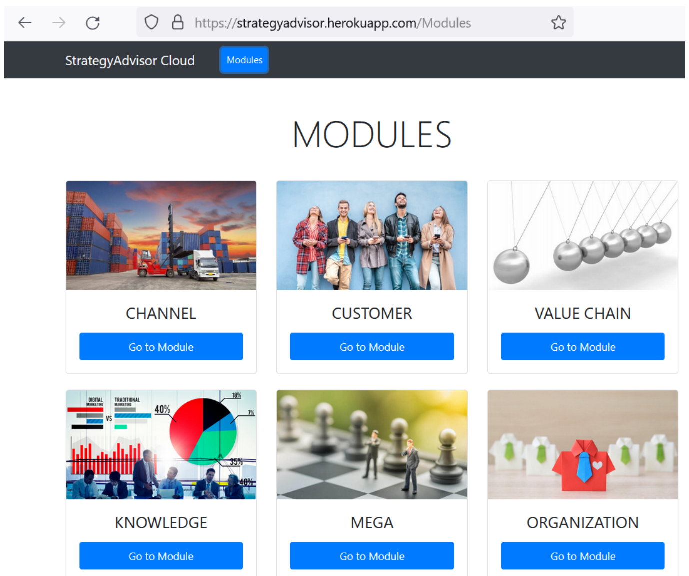

Fig. 1. The home Modules page of StrategyAdvisor Cloud, from where the module of interest can be selected.

An *expert system (ES)* can be defined as “a computer system that simulates the decision-making ability of a human expert” [5]. Expert systems have been used extensively to support decision-making in diverse domains, such as medical, military, chemistry, engineering, manufacturing, and management [17]. In expert system development, tacit knowledge from experts is extracted and encoded as explicit codified knowledge in a knowledge base.

A *rule-based expert system (RBES)* encapsulates expert knowledge as IF-THEN *rules*, also called *production rules*.

RBES can help significantly in turning data and information into reusable and scalable knowledge assets, forming the engine of decision support systems (DSS). The integration of rule engines into Enterprise Resource Planning (ERP) systems, such as SAP BRM [9] and Oracle BPM [12], signals the increasing future adoption of rule-based systems for industry, business, and government applications.

This paper describes an expert system developed through the representation of knowledge in RBES through knowledge graphs. The applied multistage methodology supports the differentiated stages, processes, and team members in the development of expert systems. The motivation and objective is to facilitate knowledge acquisition and rule base construction by project members, each of

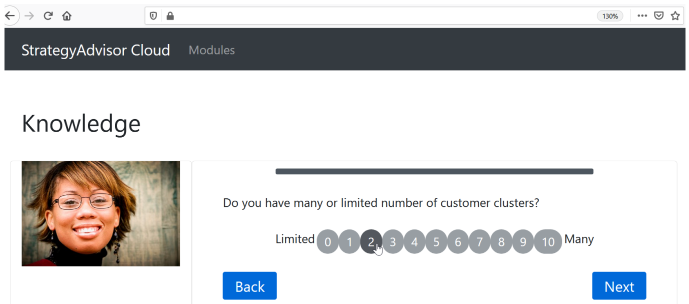

Fig. 2. The Question page in StrategyAdvisor Cloud, which acquires facts through questions.

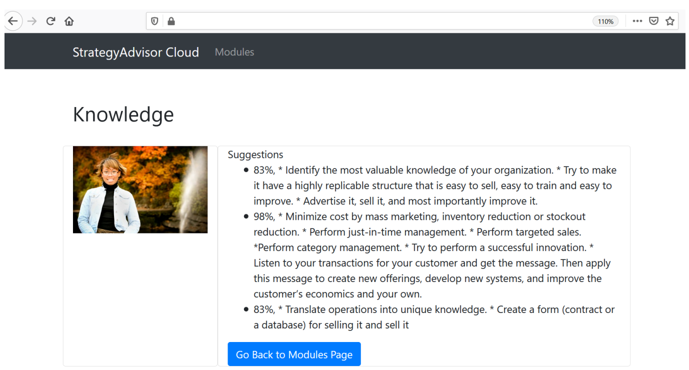

Fig. 3. The Suggestion page in StrategyAdvisor Cloud, which suggests business strategies.

whom has differing roles, tasks, priorities, capabilities, cognitive preferences, and technical competencies. Another primary motivation of the project was that there was no such web-based system reported in the literature until now.

2 Background

This section provides a background on the challenges of developing expert systems and knowledge graphs as viable solutions. First, as the research motivation, challenges of knowledge acquisition in expert system development are discussed. Second, visualization and visual languages are identified as solution to the mentioned challenges. Third, the research gap in the literature, which the present research aims to fill, is identified and described.

2.1 Challenges of Knowledge Acquisition

Wagner *et al.* (2001) [18] reported that knowledge acquisition is the greatest bottleneck in the expert system development process because of the unavailability of experts and knowledge engineers, as well as the difficulties of the rule extraction process.

The fact that rules are eventually represented within the expert system detaches the domain expert from the knowledge representation, once the domain expert's tacit knowledge becomes codified explicitly as a text-based rule base. Furthermore, the expert system development process is not transparent to the domain expert and the eventual user, who typically have less technical rigor than business analysts and system designers. However, explicit rule representation *is* inevitably needed to process the knowledge by the rule engine, creating a dilemma. Similar problems may arise in the subsequent stages of the development process, where the agents may suffer from the cognitive overload of not being able to model or work with the constructs that match their roles, tasks, priorities, capabilities, cognitive preferences, and technical competencies. The mainstream expert system development environments support only one or two stages and roles, resulting in a mismatch between functional requirements and cognitive capabilities.

2.2 Visualization and Visual Languages

Visualization can be a feasible and viable solution for the development and implementation of management information systems (MIS), which also include DSS and ES. Kernbach *et al.* (2015) [8] suggest that graphically visualizing strategies helps managers to consider strategies better and even remember them further. The authors conducted an experiment with 76 managers to identify the impact of three types of visual formats on the effectiveness of strategy communication. Zabukovec and Jaklič (2015) [19] discussed the significance of modifying visualizations for different categories of users and situations to facilitate better handling of business data. Nissen (2019) [10] analyzed organizational knowledge through a system for visualizing and measuring it using knowledge flow principles.

While visualization has several advantages for knowledge assimilation, visual languages possess several advantages over text-based languages for software development (Corral et al., 2019 [4]). Given such advantages, visual languages are adopted in the present study for expert system development, which visualize knowledge in different structures at different stages.

2.3 Research Gap

An extended review of the strategic management expert systems (SMES) literature revealed the incongruence between the technical capabilities of experts and existing knowledge acquisition methodologies. The review also revealed the incongruence between the expert systems development languages and the skills of the human agents (project team members and end-users) using them. While visualization can potentially help in knowledge acquisition, representation, and processing, a gap was identified in the research literature regarding the use of visualization and visual languages to resolve the mentioned incongruence in the selected domain of strategic management. Finally, a gap of well-documented know-how was identified regarding the development of web-based expert systems for strategic management consulting.

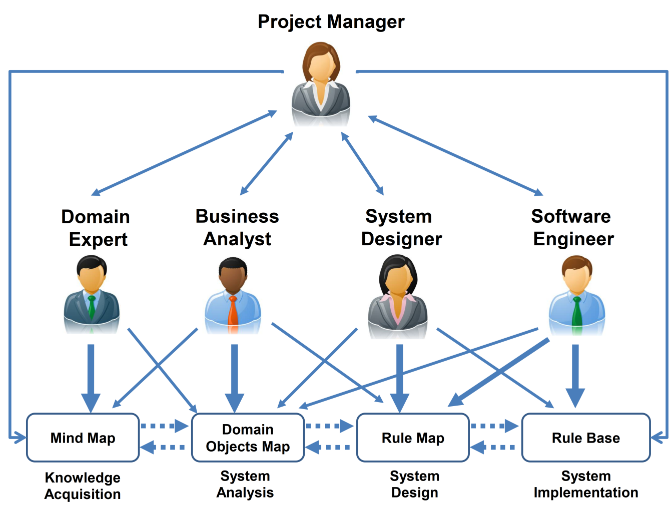

Fig. 4. The agents and the stages in expert systems development and the knowledge representations suggested for each stage by the methodology.

3 Research Topic and Contributions to Literature

The topic of this research is the development of an expert system for strategic consulting using a multistage methodology (Figure 4) built on knowledge graphs.

The contributions of this research are as follows: 1) The developed expert system, *StrategyAdvisor Cloud*, is a digital SaaS (Software as a Service) platform that performs strategic management consulting (Figures 2 and 3). 2) The integrated multistage multi-agent methodology that is applied is used for the first time for strategic management domain. 3) For the first time in strategic management literature, visual representations suitable for each stage of the system development lifecycle are identified, and formally specified through visual languages and mathematical notation. These representations are the *mind map*, *domain objects map* (DOM), and *rule map* (Figures 6, 7, and 8, respectively). The visual representations are in accordance with the goals and tasks of that stage and the attributes of the agents in that stage; 4) For the first time in SMES literature, and possibly the larger expert systems literature, the transitions between the knowledge graphs of the successive stages are formally described as formal graph transformation algorithms. One of these algorithms, the transformation algorithm that transforms the Stage 1 mindmap into Stage 2 DOM is presented in 5 as an illustration. Other transformation algorithms are fully provided in the Supplement [7] .

The idea of customized visual languages for different stakeholders in SMES was first introduced by İrdesel (2008) [6]. The cited work also includes the application of the idea for strategic management through an early version of the StrategyAdvisor desktop software, as well as the testing of the software through field studies involving more than 200 companies. However, the aforementioned work lacked a theoretical foundation, impeding its generalization and applicability in other applications within strategic management and the field of management at large, as well as in other diverse domains. The supplement [7] to our paper presents a strong theoretical foundation, where the knowledge graphs and the transformation between them are described through mathematical formalism. Graph transformations can be used for knowledge representation and verification, especially when the knowledge is dynamic [3]. Through the theoretical abstraction and foundation introduced in the current paper, it is possible to formally and methodologically apply the framework not only in strategic management but also in other domains. Transforming knowledge in any domain or application area into assets can be facilitated through the visual modeling of rule-based expert systems.

output G_2 **Transform_MindMap_to_DOM**(input G_1)
initial DOM is a replica of the mind map
$G_2(N_2, A_2) \leftarrow G_1(N_1, A_1)$
create a list of all paths that fire a suggestion
$P^* = \langle m, s, l, o, a_1, a_2, \ldots, v^* \rangle$
remove all arcs that emanate from logic nodes and terminate at object nodes
remove $\forall (l, o) \in A_2$
reverse the direction of all arcs from module nodes to logic nodes
$\forall (m, s) \in A_2$
    $(m, s) \leftarrow (s, m)$
reverse the direction of all arcs from suggestion nodes to logic nodes
$\forall (s, l) \in A_2$
    $(s, l) \leftarrow (l, s)$
an arc is drawn from every firing value to the suggestion that it fires
$\forall p^* = \langle m, s, l, o, a_1, a_2, \ldots, v^* \rangle \in P^*$
    $A_2 \sqcup (v^*, l)$
the transformation is complete, and the DOM can be returned as the output
return G_2

Fig. 5. Transformation algorithm that transforms the mindmap into DOM.

Contribution 1, which is the development of *StrategyAdvisor Cloud*, an expert system for selecting business strategy, is a case study application and illustration of the methodology. The system is developed through the acquisition of strategic management (SM) knowledge in the *Profit Patterns* book by Slywotzky et al.

(1999) [14]. The selected book is structured such that it facilitates knowledge extraction and representation of tacit knowledge as explicit. While there are many more recent high quality books and other sources for strategic management, the strategies in the Profit Patterns book [14] are still strongly applicable after two decades, cementing the book as an evergreen classic of strategic management. Contribution 1 is novel in several ways: even though there have been other applications in the strategic management domain, the presented work is the only one that replicates the knowledge acquisition process in strategic management consulting. Similar to Surma (2015) [16], the present research builds on strategic patterns or cases. Thus, the case study described in this paper follows a "case-based patterns" approach [1] [13]. However, in contrast to earlier studies, the case study here is based on the cases and patterns formulated by a leading thinker in strategic management. To the best of our knowledge, this is the first study in which profit patterns formulated in the *Profit Patterns* book are codified as an expert system.

The novelties with contributions 2, 3, and 4 are explained in detail in the Supplement [7].

The present study is the first in the strategic management literature with all four listed contributions. An extensive review of relevant research is provided in the Supplement [7], where the study in this paper is compared to earlier related work.

4 Methodology

In this section, the stages of the applied graph-based methodology (Figure 4) is described and discussed in further detail.

4.1 Overview

Figure 4 displays the steps of the methodology with reference to the human agents involved. The involvement of each agent at each stage is shown through arcs. The thicknesses of the arcs denote the level of involvement, with thicker arcs denoting a higher level of involvement. The round boxes are the knowledge representation schemes, and the texts below the boxes are the primary tasks at that stage. In Figure 4, dashed arrows between the stages denote the translation of the rule base to the neighboring stages through graph transformation algorithms.

4.2 Agents and Stages

The applied methodology is agent-oriented; it caters to the tasks and goals of the human agents (project team members) involved in expert system development. These agents are *project managers, domain experts, business analysts, system designers,* and *software engineers.* The knowledge representation scheme for each stage (visual languages in the first three stages) is determined based on the focus of the primary team member active at that stage: In **Stage 1**, the task is knowledge acquisition, and mind map is suggested for this stage. The mind map first branches into the profit strategies, reflecting the focus of the domain expert (Figure 6). In **Stage 2**, the task is system analysis and design, and Domain Objects Map (DOM) is suggested. The DOM branches first into the domain objects, reflecting the focus of business analysts, who focus on identifying the elements in the system (Figure 7). In **Stage 3**, the task is to model the logic for expert decision-making, and a rule map is suggested (Figure 8). The rule map appeals to the system designer, who distinguishes between logic (rule base) and flow (rule engine) in designing the expert system. Finally, in **Stage 4**, the task is to transform the expert system into a stand-alone software or service, the principal task of the software engineer. Figure 9 illustrates a database structure that can support this stage and Figures 2 and 3 illustrate an example implementation.

4.3 Stages

The stages of the methodology are described in detail in the Supplement [7].

5 Analysis

The domain of strategic management was represented in StrategyAdvisor Cloud using the different visual languages of the applied methodology and eventually turned into a web applicaton designed, developed, and deployed, to serve as a digital consultant for strategic management. This section analyzes the expert system and the process through which it was developed.

The developed StrategyAdvisor Cloud expert system (Figures 1, 2, and 3) suggests strategies for middle and top managers of companies to increase their profits, based on the facts that they provide. For various categories and functions of business planning (such as value chain, channel, and customer) (Figure 1), the system gathers facts through convenient questions (Figure 2). Once the system obtains sufficient facts to reach conclusions, it displays the suggested profit patterns as actions to take (Figure 3).

The methodology was implemented manually (without automation) in the case study, including the drawing of the graphs, transforming the graphs in the forward direction, creating the rule base in a database format, and constructing the text for questions and answers.

In populating the knowledge base of StrategyAdvisor Cloud, the *Profit Patterns* book, by Adrian J. Slywotzky and his colleagues at Mercer Management Consulting (Slywotzky et al., 1999), was used as the principal source. The *Profit Patterns* book was selected as the pilot knowledge base for this study, primarily because the book is structured after patterns of profit, readily discussing the strategy rules, and presenting the strategy suggestions corresponding to each pattern. The principal challenge in transforming the book's knowledge into the rule base was making the transition from an essay style to a rule style, and this challenge was conveniently overcome through the mind maps of Stage 1.

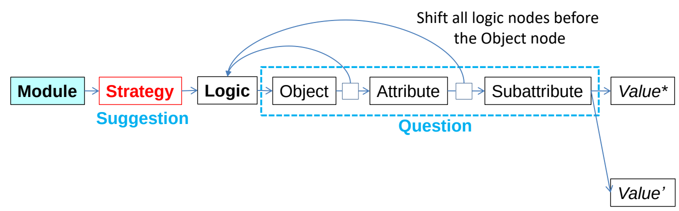

Fig. 6. The node types (vocabulary) and the sequence of nodes (grammar) in the mind map (Stage 1).

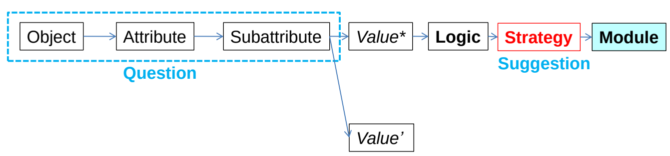

Fig. 7. The node types (vocabulary) and the sequence of nodes (grammar) in the domain objects map (Stage 2, DOM).

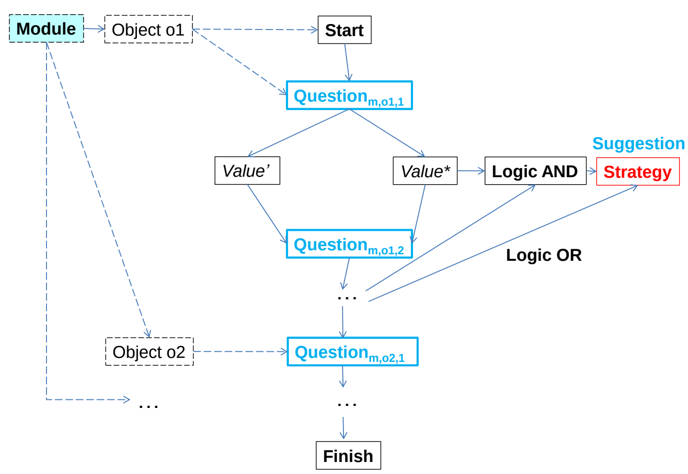

Fig. 8. The node types (vocabulary) and the sequence of nodes (grammar) in the rule map (Stage 3).

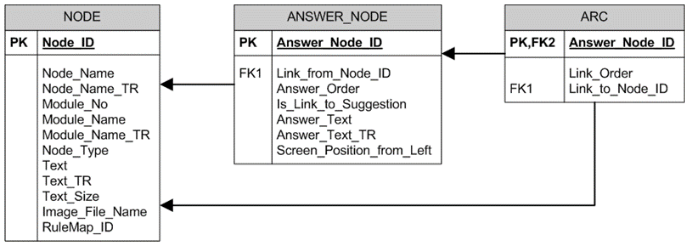

Fig. 9. The database structure used in the case study (Stage 4).

The book *Profit Patterns* presents to business professionals 31 patterns observed to change the landscape of almost every industry. After the identification of key concepts and ideas in the book, strategy rules were extracted through mind maps, following the structure in (Figure 6). The knowledge base was, therefore, initially represented in mind maps, then in domain object maps (DOM) (Figure 7) and finally in rule maps (RM) (Figure 8). A cloud software application, StrategyAdvisor Cloud (Figures 1, 2, and 3), was then designed and created using the database structure in Figure 9.

StrategyAdvisor Cloud is illustrated with examples from the **Knowledge to Product** profit pattern, where knowledge is converted into a product. This pattern is suitable for communicating the application of the methodology in the case study, because the case study itself actually follows this pattern: the knowledge of business thinker Adrian J. Slywotzky on strategic management [14] and the research team's knowledge and experience of expert system development and other fields (graph theory, information visualization, knowledge representation, database systems, strategic management) were transformed into the final product, the StrategyAdvisor Cloud software.

The final stage of the methodology is the creation of an expert system using a mainstream technology stack, including a programming language and its libraries. This stage is required if one does not wish to use an expert system language or engine as the production software. This last stage was pursued in the case study, and a cloud application was designed and created. The database structure for the rule base is shown in Figure 9, the home Modules page is given in Figures 1, and sample snapshots for fact gathering and strategy suggestions are illustrated in Figures 2 and 3, respectively. The developed system mimics a consultancy service for strategic management and can be used by any company anywhere in the world, free of charge. Technology selection decisions for the cloud software are explained in detail in the Supplement [7].

The StrategyAdvisor Cloud software reads the strategy rules from the rule base, that are stored in a relational database. When the software is initially launched, it displays the module selection page, where the user is expected to select one module at a time to run. The modules in the system are *Channel, Customer, Value Chain, Knowledge, Mega, Organization*, and *Product.*

The facts are gathered in the StrategyAdvisor Cloud through the *question pages*. Figure 2 shows a question page during the execution of the **Knowledge** module.

For each question in the StrategyAdvisor Cloud, the answers are rated on a scale from 0 to 10. The boundary values of 0 and 10 are labeled with descriptive text, such as **Limited** and **Many** in Figure 2.

Once all the relevant questions in a module have been completed, computer reasoning is carried out, and the suggestion window is displayed (Figure 3). The window successively lists every suggestion that was found "applicable" based on the computation of a ratio for that suggestion. The numerator of this ratio is the number of arcs to that suggestion in the rule map traversed (an answer arc is traversed if the answer to its question takes values 1, 2, 3, or 4). The denominator of the ratio is the number of arcs in the rule map that terminate at that suggestion. Instead of displaying the scores, a threshold score can also be used. For example, if the score of a suggestion is greater than or equal to the crucial value of 0.6 (60%), then the suggestion can be displayed in the suggestion window. This particular threshold value is also used by Balch *et al.* (2007) [2] and de Souza *et al.* (2012) [15].

The suggestion window presents the strategies suggested to the user by StrategyAdvisor Cloud. For example, in Figure 3, the **Knowledge to Product** strategy is suggested, and the actions to take for the strategy are outlined.

The Supplement [7] presents an assessment of StrategyAdvisor Cloud by the research team. The assessment provides strong evidence for the potential success of StrategyAdvisor Cloud, because all but one of the applicable criteria listed by Nurminen *et al.* (2003) [11] are satisfied by StrategyAdvisor Cloud.

6 Conclusions

A multistage methodology, built on knowledge graphs, was applied solve the challenges of knowledge acquisition in developing SMES. The applied methodology caters to the priorities and tasks of each team member in an expert systems project. Graph transformation algorithms allow the representation of the same rule base in various graph structures, allowing flexibility in the rule base development process. The methodology was then employed in a case study in which an expert system was developed to support strategic decision-making. The project experience and a formal assessment against success criteria suggest that the methodology has enabled the rapid development and deployment of an usable and potentially successful expert system. The special importance of StrategyAdvisor Cloud in small-medium enterprises (SMEs) is discussed in the Supplement [7].

7 Future Work

The present study can be extended to the future with respect to both methodology and application, as summarized below and elaborated in the Supplement [7].

- Visual specification of more complicated rules in knowledge graphs.
- Use of fuzzy reasoning and multi-criteria decision-making (MCDM) for scoring and ranking suggestions.
- Automated extraction of information and representation in knowledge graphs using text mining techniques.
- Integration of all the stages of the methodology in a single expert system modeling software.
- Automatically generate the source code of the desktop or web applications and the executable of the desktop application.
- Analysis of logged data that users input into the system.
- Extension of the knowledge base to include other information sources.
- Addition of new modules in other functions of management, such as finance, supply chain management (SCM), and human resource management (HRM).
- Usability tests, which would include user surveys, to assess the applicability of StrategyAdvisor Cloud in business and industry.

Data Availability The domain objects map (DOM) knowledge representation of the rules is publicly available under https://ertekprojects.com/new-knowledge-in-strategic-management/data-yed-graphs/ as yEd graph files.

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