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Deriving knowledge representation guidelines by analyzing knowledge engineer behavior

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ABSTRACT

Knowledge engineering research has focused on proposing knowledge acquisition techniques, developing and evaluating knowledge representation schemes and engineering tools, and testing and debugging knowledge-based systems. Few formal studies have been conducted on understanding the behaviors and roles of knowledge engineers. Applying the theory of mental models, this paper describes a think aloud verbal protocol study to determine an empirical basis for understanding: (1) how knowledge engineers extract domain knowledge from textual sources; and (2) the cognitive mechanisms by which they engage various knowledge representation schemes to represent that knowledge acquired. The results suggest that knowledge representation is not simply a translation of acquired knowledge to a knowledge representation. Instead, it is an iterative process of selective querying of acquired knowledge, and continuous refinement of a model leveraging, not only on acquired knowledge from domain experts, but also from the knowledge engineer. From the findings of empirical studies, a set of guidelines is derived to support the training and development of better knowledge representation schemes, representation processes, and knowledge engineering tools.

1. Introduction

Knowledge-based systems fundamentally store organizational knowledge for retrieval and use, thus providing a way to preserve it independently of an organization's experts [2]. A fundamental challenge is the representation of knowledge to support reasoning and understanding [22], but knowledge representation continues to be a challenge [33].

Knowledge engineering, the process of developing a knowledge-based system, involves three main steps: knowledge acquisition, knowledge representation, and implementation [52]. Knowledge representation schemes capture knowledge in a form that can be used by an information system. Familiar types of knowledge representation include conceptual graphs [50] and ontologies [28].

Knowledge representation requires: (1) a domain expert who provides the knowledge, (2) a knowledge-based system where the knowledge is stored, and (3) a knowledge engineer who extracts and encodes the expertise [54,57]. The goal of knowledge representation is to organize knowledge obtained from domain experts into a knowledge-based system, making the knowledge engineer a critical part of the knowledge engineering process.

A knowledge engineer must represent acquired knowledge in such a way that a human can understand it and a computer system can process it [14]. These are, in essence, fundamentally opposing requirements because humans and computers function in distinct ways. Given that these conflicting requirements have not been reconciled, empirical research in the field is needed.

Empirical knowledge representation research has attempted to bridge the gap between human and machine representation of domain knowledge [54]. Traditionally, empirical knowledge engineering research has focused on: (1) evaluating knowledge acquisition techniques [45], (2) developing and evaluating knowledge representation languages and knowledge engineering tools [10,27,28], and (3) building and testing knowledge-based systems [11,15,44]. However, little research has studied how knowledge engineers actually perform knowledge representation work employing knowledge representation languages. Empirical research has been in the form of exploratory surveys [e.g., 8,36,61] or an analysis of researchers' personal experiences and observations [e.g., 56,60].

Rigorous studies in a controlled environment, where researchers observe how knowledge engineers actually perform knowledge representation, are still needed. This research draws upon the theory of mental models [17,18,24] to explore the roles and behaviors of knowledge engineers in the knowledge representation process. The objectives of this research are to determine an empirical basis for understanding (1) how knowledge engineers extract domain knowledge and (2) the cognitive

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mechanisms by which they engage various knowledge representation schemes to represent the knowledge acquired. We find that knowledge representation is not simply a translation of acquired knowledge into a knowledge representation. Instead, it is an iterative process of selective querying of acquired knowledge, and continuous refinement of a model leveraging not only on acquired knowledge from domain experts, but also from the knowledge engineer.

The paper proceeds as follows. Section 2 reviews existing work on knowledge representation and the theory of mental models. Section 3 presents our research method. Section 4 elaborates on the protocol analysis and the problem behavior graph derived from the empirical studies' results. Section 5 discusses the findings and proposes guidelines for the knowledge representation process and training of knowledge engineers derived from the empirical findings. Concluding remarks are found in Section 6.

2. Knowledge representation

This section reviews prior research on empirical investigations of knowledge representation to demonstrate that systematic empirical work in the field is required. We then draw upon research on the theory of mental models to outline an initial process model of knowledge representation.

2.1. Empirical knowledge representation research

Empirical work on knowledge representation is of two types: (1) exploratory surveys, and (2) personal case studies.

Exploratory surveys employ survey instruments and exploratory factor analysis. These studies abstract the results of numerous projects into a small number of dimensions. They, therefore, do not capture much of the rich information on what actually happens during the knowledge representation process. Although exploratory surveys can identify problems and mismatches between knowledge representation practice and theory, they are unable to critically examine why knowledge engineers encounter problems. Byrd [9], for example, discovered that knowledge engineers viewed knowledge acquisition as particularly challenging. However, his survey instrument could not identify ways to improve knowledge acquisition. Mykytyn et al. [36] identified four generic knowledge engineering roles: technical (designing and developing the knowledge-based system), external (acting as a salesperson, troubleshooter), negotiation (communicating with the domain expert), and organizational (system documentation). Of these roles, only the technical role deals with knowledge representation per se. The other roles deal with managerial and non-technical aspects of the knowledge engineer's job.

Personal case studies provide rich insights into individual difficulties that researchers have using a knowledge representation scheme for a specific project. Welty [60], for example, found that different knowledge engineers believe certain concepts should merit more details than others during knowledge representation. Stephens and Huhns [51] asked 55 subjects to represent the domain of 'people' using the DAML knowledge representation scheme. The subjects produced 55 distinct ontologies. Uschold et al. [55] found that fundamental differences between distinct knowledge representation schemes made them incompatible. Davis et al. [14] observed that many knowledge representation articles:

> … contain claims of how the author was able, through a creative, heroic, and often obscure act, to get a representation to do something …

These observations suggest that knowledge representation schemes are not necessarily aligned with knowledge representation work [5]. Personal case studies, by their nature, reflect the subjective experiences of the researcher, and should be validated by rigorous studies.

2.2. Mental models of knowledge representation

The proper design of conceptual models requires understanding and representing human mental models [39,40]. The theory of mental models posits that humans think by forming representations of the world in their minds [17,18,24]. When humans are called upon to perform a task, they create incomplete models of the basic elements of the task problem and manipulate them in the mind. The end result of that manipulation guides human decision making [24]. Given knowledge representation can be regarded as a form of conceptual modeling so, in turn; mental models should influence the knowledge representation task.

The actual structure of a representation relies upon a human's prior experience and background in addition to the information given for the task problem. The representation itself may be influenced by the presented structure of the problem (e.g., which words appear first), but does not need to correspond to the problem structure. Thus, a person asked to remember "The animal ran towards the bush," may instead recall "The wolf ran towards the bush" [17,18].

In knowledge representation, the person (analyst, designer, and modeler) must acquire knowledge about a domain and map it to a pictorial artifact. This is done using a conceptual modeling scheme, which is a language designed for that purpose. Human beings manipulate the world as mental models, suggesting that modelers do not map directly from an acquired domain to a model. Instead, modelers move through an intermediate step of representing the domain as a mental model, before translating that mental model into the artifact [37,62].

The intermediate step of mental model creation is likely to create distortions in acquired knowledge [17]. The mental models literature points out that: (1) mental models represent, not only information about the stated problem, but also the context and other information the problem solver draws upon based on his or her own experiences; and (2) mental models are simplified views of reality [25]. Thus, even if the modeler accurately captures knowledge from the domain, the mental model the modeler develops will include information from his or her own background, and exclude information the modeler deems irrelevant.

In addition, distortions to acquired knowledge result from incompatibilities between the mental model and conceptual modeling scheme. The *problem space*, or the mental model of a knowledge domain to be represented, is very different from the *design space* of the knowledge representation scheme [20,39,42]. An understanding of the problem space requires domain knowledge [6], whereas an understanding of the design space requires technical knowledge, such as knowing the syntax of the knowledge representation scheme [48]. The syntax of the conceptual modeling scheme can make the mapping of the mental model to the scheme more or less difficult [46]. An ideal scheme should map as closely as possible to the mental model [34]. A one-to-one correspondence between constructs in the modeling language and the mental model is preferred [43,59]. However, given our limited understanding of knowledge engineers' mental models, the fit between existing knowledge representation schemes and knowledge engineers' mental models is likely to be poor.

Based upon the above discussion, Fig. 1 shows the process we infer that knowledge engineers follow when generating the knowledge representation artifact. Here, the knowledge engineer does not simply translate acquired domain knowledge into the artifact. Instead, the knowledge engineer combines his or her acquired domain knowledge with his or her prior experience to create a mental model. In the process of translating acquired knowledge into the mental model, some knowledge will be lost. The knowledge engineer's prior knowledge also shapes the mental model such that it differs from acquired domain knowledge. The knowledge engineer then attempts to translate the mental model to