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Improving the quality of conceptual modeling using cognitive mapping techniques

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Abstract

Conceptual modeling involves the understanding and communication between system analysts and end-users. Many factors may affect the quality of conceptual modeling processes as well as the models per se. Human cognition plays a pivotal role in understanding these factors and cognitive mapping techniques are effective tools to elicit and represent human cognition. In this paper, we look at the use of cognitive mapping techniques to improve the quality of conceptual modeling. We review frameworks on quality in conceptual modeling and examine the role of human cognition in conceptual modeling. The paper also discusses how human cognition is related to quality in conceptual modeling, the various cognitive mapping techniques, and how these cognitive mapping techniques can be used in conceptual modeling. Through a case study, the paper describes ways of incorporating cognitive mapping techniques to a popular systems development methodology—Soft Systems Methodology—to improve the quality of conceptual modeling.

Keywords: Conceptual modeling; Quality; Cognitive mapping; Requirements engineering; Systems development methodology

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1. Introduction

Developing information systems (IS) has always been a challenging task. Many factors influence the success of IS development. Among them, being able to accurately and completely capture information requirements during systems development is commonly regarded as one of the most important factors. This point has been shared by both IS researchers (e.g., [8,17,27,63]) and practitioners. As a result, requirements engineering, which is a branch of software engineering concerned with identifying real-world goals, capturing services required, and recognizing constraints, is perceived as an area of growing importance [45]. Conceptual modeling is the cornerstone of requirements engineering. Improving the quality of conceptual modeling processes as well as the models per se has received substantial research attention. Some researchers have taken a systematic approach to develop frameworks for understanding and assessing the quality of conceptual modeling (e.g., [18,32,33,35]).

Requirements engineering is recognized as a social process that is characterized by ongoing sense making among participants, which include managers, end-users, and system analysts [43]. Moody et al. [40] claimed that software development is more like a craft than an engineering discipline during the processes of requirements engineering. In this respect, human cognition plays a pivotal role in understanding human and organizational issues in requirements engineering, and in identifying ways to improve the quality of conceptual modeling.

Cognitive mapping techniques have been widely used in strategic management and political science to depict and explore the cognitive structures of members of organizations [28]. Some researchers, such as Avison and Fitzgerald [4] and Montazemi and Conrath [39], have hinted at the usefulness of cognitive mapping in systems development. However, they have only provided brief coverage on the use of cognitive mapping. In this paper, we have provided a comprehensive review of three widely used cognitive mapping techniques. We also discuss how they can be employed to improve the quality of conceptual modeling, and how they supplement popular systems development methodologies in conceptual modeling.

The paper is organized as follows. Section 2 reviews the literature on requirements engineering and conceptual modeling, and discusses the frameworks for quality in conceptual modeling. Section 3 introduces how human cognition is related to the quality in conceptual modeling. Section 4 reviews and discusses how three popular cognitive mapping can improve the quality in conceptual modeling. Section 5 describes how these cognitive mapping techniques can supplement a popular systems development methodology—Soft System Methodology—to improve quality in conceptual modeling. A conference organizing case was used for the discussion. Section 6 summarizes the research and concludes the paper.

2. Literature review

The IS field has witnessed numerous examples of software development failures. These costly and conspicuous failures cast a serious challenge for IS researchers. Requirements engineering, which is an early stage in the software development life cycle, plays an important role in successful information systems development.

2.1. Requirements engineering and conceptual modeling

Regardless of the systems development methodology used, being able to understand users' information requirements is vital in any IS project and is a key factor in any successful IS implementation. Requirements engineering is a set of activities used by systems analysts to assess the functionality required in a proposed system [8,27,45]. According to Pohl [45], it contains three dimensions—specification, representation, and agreement. The degree of requirements understanding at a given time is measured by the specification dimension (ranging from opaque to complete). The representation dimension (ranging from informal to formal) deals with the different representations that are used for expressing knowledge about the system. The agreement dimension (ranging from personal to common) copes with the degree of agreement reached on a specification. To reflect this three-dimensional view, Bubenko et al. [9] defined requirements engineering as:

> The systematic process of developing requirements through an iterative co-operative process of analyzing the problem, documenting the resulting observations in a variety of representation formats and checking the accuracy of the understanding gained (p. 154).

Four tasks to be performed in requirements engineering have been identified [46]. As shown in Fig. 1, these four tasks are iterative in nature:

- Requirements specification: To understand the organizational situation that the system under consideration aims to improve. It also describes the needs and constraints of the system under development.
- Requirements negotiation: To establish an agreement based on the requirements of the system among the various stakeholders involved in the process.
- Requirements representation: To develop a mapping of real-world needs into a requirements model.
- Requirements validation: To ensure that the derived specification corresponds to the original stakeholder needs and conforms to the internal and/or external constraints set by the enterprise and its environment.

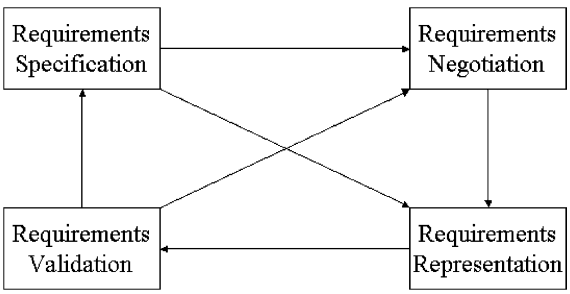

Fig. 1. Tasks in requirements engineering.

Conceptual modeling is the cornerstone of requirements engineering. Some researchers (e.g., Frank [25] and Weber [66]) have even claimed conceptual modeling as being the core of the information systems discipline. Information models, the products of conceptual modeling, not only provide the required representations to facilitate communication among stakeholders, but they also provide a formal basis for developing information systems [25,49–51,53–55]. In particular, conceptual modeling is directly related to two tasks in requirements engineering—requirements representation and requirements validation. In requirements representation, conceptual models are created to map real-world needs. During requirements validation, stakeholders verify whether their needs have been correctly specified by looking at the generated conceptual models. Therefore, conceptual modeling activities are central in requirements engineering. The quality in conceptual modeling has a ripple effect on the quality of the end product (i.e., information systems).

2.2. Quality in conceptual modeling

To find ways to improve the quality in conceptual modeling, the question "What is quality in conceptual modeling?" must be answered first. Some researchers have taken a systematic approach to define quality in relation to conceptual models. Lindland et al. [35] proposed a framework to provide an in-depth understanding of quality in conceptual modeling. This framework extended the prior frameworks that defined the desired properties of a requirements specification (e.g., [18]). Fig. 2 depicts the main points of the framework, which applies three linguistic concepts—semantic quality, syntactic quality, and pragmatic quality.

The main quality types are indicated by solid lines between four aspects of modeling: language, domain, conceptual model, and audience interpretation. According to the framework, semantic quality is the correspondence between the conceptual model and the domain; syntactic quality is the correspondence between the conceptual model and the modeling language; pragmatic quality is the correspondence between the conceptual model and the audience's interpretation of it. Lindland et al. [35] focused on clarifying the goals and means (model properties and modeling activities) of these three types of quality. Offering a more in-depth treatment of quality, this frame-

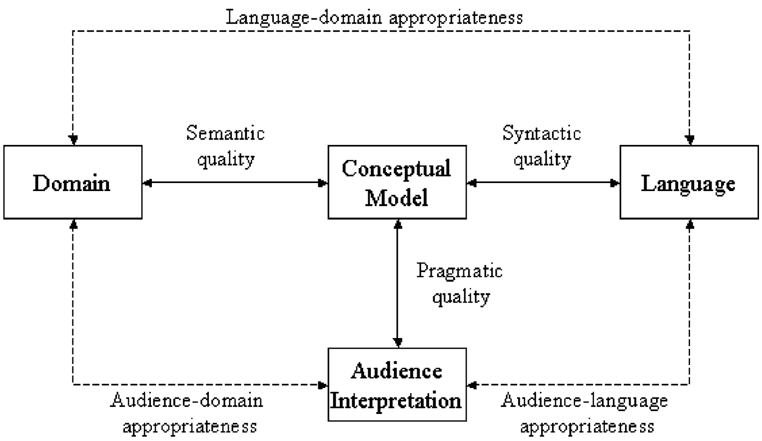

Fig. 2. The framework of quality in conceptual modeling [35].

work has served as the foundation of the International Workshop on Conceptual Modeling Quality (IWCMQ '02, '03, and '04), held in conjunction with the Requirements Engineering conference.

As Krogstie and Sølvberg [34] correctly pointed out, Lindland et al.'s [35] framework of the quality in conceptual modeling, to a great extent, echoes the three-dimensional view of requirements engineering proposed by Pohl [45]. In their deeper structures, the specification dimension corresponds to the semantic quality because both reflect the relationship between the domain and conceptual models. The representation dimension corresponds to the syntactic quality because both deal with using specific languages to express identified specification in the form of conceptual models. The only discrepancy lies in the agreement dimension and the pragmatic quality. Focusing on individual's understanding of conceptual models, Lindland et al.'s [35] pragmatic quality does not sufficiently handle the social aspects associated with Pohl's [45] agreement dimension, i.e., the degree of agreement reached on a specification (conceptual model).

Krogstie [32,34] further pointed out that even though the primary objective of semantic quality is to obtain a valid and complete correspondence between the conceptual model and the domain, this correspondence cannot be built or checked directly. We must go through the participant's knowledge of the domain in order to build a model. This model must also be checked based on the audience's interpretation.

Based on the identified deficiencies of Lindland et al.'s [35] framework, Krogstie and Sølvberg [34] suggested an extended quality framework, shown in Fig. 3.

Compared with Lindland et al.'s [35] framework, Krogstie and Sølvberg's [34] framework added the element of *participant knowledge* on the modeling domain as an additional aspect of modeling. In addition, Krogstie and Sølvberg [34] split the *audience interpretation* into two separate aspects—*social actor interpretation* (i.e., the set of statements that the social audience

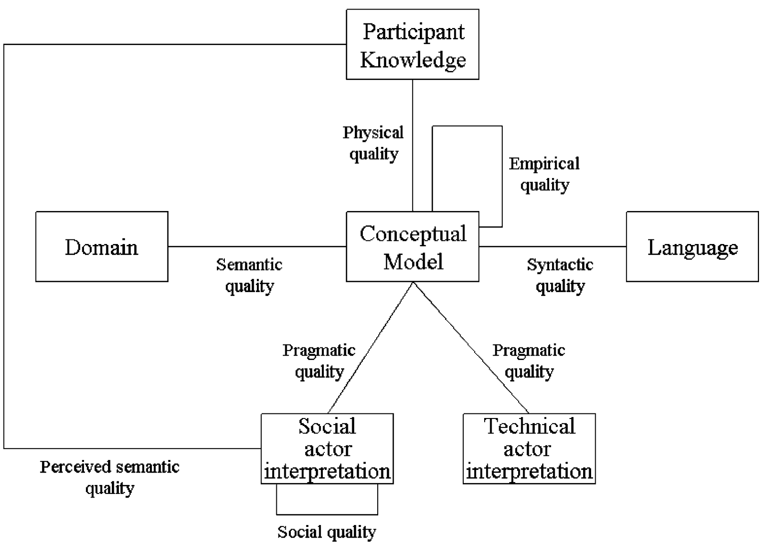

Fig. 3. Framework for discussing quality in conceptual modeling [34].

perceives that the externalized model contains) and *technical actor interpretation* (i.e., the models as interpreted by technical actors in the audience).

Besides the three types of quality (semantic quality, syntactic quality, and pragmatic quality) covered in Lindland et al.'s [35] framework, Krogstie and Sølvberg [34] incorporated four other types of qualities in their framework.

- The perceived semantic quality, i.e., the correspondence between participant knowledge and social actor interpretation, can serve as the surrogate for semantic quality. That is, the comparison of the two imperfect approximations—participant knowledge and social audience interpretation—can be directly observed and assessed, partially reflecting the level of true semantic quality.
- Physical quality involves two basic quality means. *Externalization* refers to the level of externalization of the knowledge of some social actors in the forms of conceptual models. *Internalization* refers to the level of other social actors' knowledge obtained by making sense of the externalized model.
- Social quality refers to the degree of the agreement on participants' interpretation.
- Empirical quality relates to error frequencies when a model is read or written by different users, and coding and ergonomics of computer–human interaction (CHI).

The extended framework by Krogstie and Sølvberg [34] is explicitly based on a constructivistic world-view [6], recognizing that conceptual models are created as part of a dialogue between the participants involved in conceptual modeling. The knowledge of each individual participant on the modeling domain changes as modeling takes place. On the other hand, Lindland et al.'s [35] framework is implicitly based on realistic view, acknowledging that the domain consisting of all possible correct and relevant statements for solving the problem is "right there." As we subscribe to the constructivistic world-view in our research in requirements engineering, we will use Krogstie and Sølvberg's [34] framework (Fig. 3) to discuss the role of human cognition in conceptual modeling.

3. Human cognition and conceptual modeling

The chaotic, nonlinear, and continuous nature of requirements engineering, especially conceptual modeling, warrants extensive investigations on the "people" end. Requirements engineering is characterized by ongoing sense making among stakeholders, including the sponsor of the system (managers), end-users (employees), and system analysts [16,17,32]. A cognitive approach that focuses on sense making processes is helpful for investigating why participants in requirements engineering understand requirements as they do [20] and why their understanding of requirements may change and shift [23].

Cognition refers to the belief systems that individuals use to perceive, construct, and make sense of their world, and to make decisions about what actions to take [23,67,69]. Understanding cognition is becoming increasingly important for a number of management study areas, where chaotic and complex organizational contexts are under scrutiny [64]. In IS field, the interest in studying how people think is growing along with the awareness of human factors when developing information systems. In the following, we review the role of human cognition in requirements engineering and conceptual modeling.

3.1. Cognition at the individual level

Early IS researchers have tapped into the cognition of individuals to understand the problems in requirements engineering. For instance, Davis [19] listed four sources of difficulties in information requirements determination: (i) the constraints on humans as information processors and problem solvers, (ii) the variety and complexity of information requirements, (iii) the complex patterns of interaction among users and analysts in defining requirements, and (iv) the unwillingness of users to provide requirements. Valusek and Fryback [63] labeled these difficulties as communication obstacles "within" individual users, "among" users, and "between" users and analysts. They further identified the underpinnings of these communication obstacles based on cognitive and social psychology.

With the advancement of cognitive psychology, IS researchers have been able to identify many cognitive difficulties of humans, as information processors and problem solvers in requirements engineering. First, the information processing capacity of humans is limited [37]. The working memory of humans can hold only a limited amount of information for processing. In addition, some common cognitive mechanisms may lead to biases in information requirements perception. Some heuristic-driven biases include [62]:

(i) Representativeness: We often mistakenly expect the global characteristics of a process to be represented locally in a specific sequence.
(ii) The availability heuristic: The frequency of an event is estimated to be in direct proportion to the ease with which instances are recalled from memory.
(iii) Anchoring and adjustment: Assessments of needs are based on an initial, often arbitrary value. The value is then adjusted.

Other constraints on humans as information processors and problem solvers include satisficing [56], faulty reasoning [44], and automaticity [57].

These constraints on individual's cognition should not be overlooked. In addition, with the process of cognition, the knowledge of an individual participant on the modeling domain changes as modeling takes place. This is the issue that Lindland et al.'s [35] framework failed to cover, while Krogstie and Sølvberg's [34] framework did. The difficulties in individual cognition and the evolving participant's knowledge are related to only part of the human issues found in conceptual modeling. When we discuss conceptual modeling for an organization's information systems, we must also look at the social aspects inherent in cognition.

3.2. Cognition at the socio-cognitive level

Social cognitive research shares the fundamental tenet that people act on the basis of their interpretations of the world, which is cognitively structured through experience and interaction [68]. Furthermore, socio-cognitive approaches in requirements engineering posit that "requirements for IT applications do not exist a priori but are socially constructed through interaction among (conceptual modeling) participants" (16, p. 331). In developing technological frames for making sense of information technology in organizations, Orlikowski and Gash [43] systematically articulated the role of frames of reference in systems development and use. The frames of reference held by organizational members are implicit guidelines that serve to organize and shape their interpretation of events and organizational phenomena, and give meaning to these events and phenomena [67]. The frames of reference, therefore, become vital to our understanding of the socio-cognitive processes in conceptual modeling.

First, information requirements elicited in an organization will often have high variability among users, especially between the sponsor of the system (managers) and end-users (employees), because they use different frames of reference to perform tasks. Furthermore, the elicited requirements may not be stable due to the ongoing evolution of an individual person's frames of references. Thus, there is variation in requirements both between and within users.

Second, the difference in the frames of reference causes problems between users and analysts. That is, the different backgrounds of the two types of people are the principal reason of communication difficulties between users and analysts. This problem can also be viewed using the Johari Window model of human interaction [36]. The Johari Window highlights the basic communication issues in user-analyst communication. Some researchers [7,11] labeled this problem as the lack of common "language" between users and analysts.

Finally, in the context of emerging businesses, such as e-business or mobile-business, the standardized processes of businesses have not been established. As a result, the frames of reference for users may not be formed adequately. This means that the information requirements are not simply waiting to be discovered, or "mined" from the heads of the users [29].

Furthermore, researchers [22,65] have posited the existence of group-level frames of reference, i.e., shared knowledge and belief systems that formulate expectations and perceptions of the group.

To summarize, the frames of reference, especially the technological frames [43], are of interest to researchers in investigating the socio-cognitive aspects in conceptual modeling. Assessing the frames of reference for various stakeholders (including users and analysts) or different groups may offer an insight to the socio-technical problems.

3.3. Human cognition and quality in conceptual modeling

With the above understanding of quality in conceptual modeling (Section 2.2) and the role of human cognition in conceptual modeling (Sections 3.1 and 3.2), we turn to discuss how human cognition is specifically related to quality in conceptual modeling.

Syntactic quality can be assessed objectively by comparing the models and the language rules. However, when either the models or the languages are very complex, the limitation of human cognition capacity makes it a daunting task to manually generate conceptual models with high syntactic quality, or to check conceptual models in terms of syntactic quality.

Semantic quality can be established indirectly using perceived semantic quality as the surrogate. Perceived semantic quality, i.e., the correspondence between a participant's knowledge and an individual's interpretation, has much to do with human cognition. This is because the social process, i.e., the dialog between participants, is rooted in individual's cognition. In other words, participant knowledge is determined by his/her cognitive structure on the problem, while an individual's interpretation is directly related to the person's cognitive ability in interpreting conceptual models. In addition, the link between the domain and the participant's knowledge is the place where human cognition biases might play an important role. The biases, such as representativeness, the availability heuristic, anchoring and adjustment, satisficing, faulty reasoning, and automaticity, make a participant's knowledge only an imperfect approximation of the domain.

Pragmatic quality relates conceptual models to either a social actor's or technical actor's interpretation. In essence, pragmatic quality affects how to interpret a model with the lowest possible cognitive effort. For example, visualization is a way to improve pragmatic quality because people can easily grasp its meanings.

Physical quality, i.e., externalization and internalization, is greatly influenced by the fit between the modeling language and participants. Due to human cognition preferences, different people prefer different modeling languages [45]. For example, end-users may like natural languages or arbitrary graphics, while systems analysts and developers may prefer formal modeling languages. With appropriate languages, cognition loads in externalizing knowledge into conceptual models will be lower for participants.

Empirical quality deals with error frequencies, coding, and ergonomics of computer–human interaction. Computer-aided modeling tools may incorporate mechanisms, such as automatic layout and organization of multiple models, to decrease error frequencies in creating, reading, and coding conceptual models. This is because those mechanisms are essentially lowering cognition loads for users of modeling tools.

Finally, social quality is related to a person's socio-cognition. The agreement on participant knowledge is dependent on an individual's frame of reference on the problem. The agreement on individual interpretation, especially between system users and system analysts, is also determined by their respective frames of reference.

Table 1 depicts how human cognition is related to quality in conceptual modeling.

There are techniques designed to make sense out of complex, uncertain, confusing, and messy situations. For example, rich picture is one technique used in Soft Systems Methodology (SSM) [15]. Cognitive mapping, as a technique to elicit an individual's belief systems regarding a problem domain, has great potential in overcoming some cognitive problems and facilitating the understanding among stakeholders. Published works (e.g., [4,26,39,47]) have hinted at the usefulness of cognitive mapping in requirements engineering. These studies, however, have only provided brief coverage on cognitive mapping. In our study, we review the utility of various cognitive mapping techniques in the context of conceptual modeling. We also discuss how these techniques can supplement a popular systems development methodology, and thus enhance the quality of conceptual modeling.

4. Enhance quality in conceptual modeling using cognitive mapping

In psychology, "cognitive map" is a term developed by Tolman [60] to describe an individual's internal mental representation of the concepts and relations among concepts that are used to understand the environment. Cognitive maps are regarded as "internally represented schemas or mental models for particular problem-solving domains that are learned and encoded as a result of an individual's interaction with their environment" (58, p. 188). Therefore, cognitive maps

Table 1
Cognition and quality in conceptual modeling

Quality type	Description	How human cognition is related?
Semantic quality	The correspondence between the conceptual model and the domain	Use individual interpretation and participant knowledge to establish imperfect approximations of semantic quality. See perceived semantic quality
Perceived semantic quality	The correspondence between participant knowledge and individual interpretation	Participant knowledge is determined by the individual's cognitive structure regarding the problem; individual interpretation depends on the cognition ability in interpretation
Syntactic quality	The correspondence between the conceptual model and the language	Limitation in human cognition capacity demands for simple models and languages
Pragmatic quality	The correspondence between the conceptual model and the audience's interpretation of it	Good pragmatic quality means interpreting a single meaning with the lowest possible cognitive effort
Physical quality	The correspondence between participant knowledge and the externalized conceptual model	Good physical quality means expressing a single meaning with the lowest possible cognitive effort
Empirical quality	It is reflected by the error frequency when a model is read or written	Heavy cognition loads may cause frequent errors when conceptual models are being written or read
Social quality	The agreement on participant knowledge and individual interpretation	Difference in the frames of reference is the root reason for errors in social quality

provide a frame of reference for what is known and believed, and exhibit the reasoning behind purposeful actions [24].

In contrast, cognitive mapping describes a set of techniques used to identify subjective beliefs and to portray these beliefs externally [24]. The general approach is to extract subjective statements from individuals, in particular within the realm of problem domains, about meaningful concepts and relations among these concepts, and to then describe these concepts and relations in some kind of visuospatial layout [58]. The outcome of a cognitive mapping technique is usually referred to as a cognitive map, which may cause confusion in relation to the conceptual term used in psychology. Eden [22] clarified the nature of cognitive maps as an artifact rather than the conceptual device developed by Tolman [60]. To avoid confusion, we use the term "cognitive maps" to exclusively refer to the outcomes of cognitive mapping techniques in the following parts of this paper.

4.1. Three cognitive mapping techniques

Various cognitive mapping techniques (e.g., [5,13,21]) have been widely used in the study of sociology, political science, organizational behavior, and strategic management. Carley [12] pointed out that cognitive mapping combines elements of both content analysis and procedural mapping. When coding texts into cognitive maps, the researcher will determine what concepts are present (content analysis) and extract the relationships between those concepts (procedural mapping).

Some cognitive mapping techniques have been used in IS research, in particular the requirements engineering research. For example, Montazemi and Conrath [39] suggested the use of causal mapping in information requirements analysis involving ill-structured decision environments. Avison and Fitzgerald [4] introduced causal mapping as a technique used in Strategic Options Development and Analysis (SODA) [1]. Henderson-Sellers et al. [26] proposed the concept mapping technique for requirements analysis. Siau and Tan [52] demonstrated, through a case study, the use of causal mapping, semantic mapping, and concept mapping in requirements determination. Sheetz and Tegarden [47], based on their previous work [48], proposed a distributed system to support the requirements capture process. The system incorporated the causal mapping technique and group support systems (GSS).

These published works have neither provided a comprehensive review of various cognitive mapping techniques nor related their utility to improving the quality in conceptual modeling. In the following, we briefly introduce three commonly used cognitive mapping techniques—causal mapping, semantic mapping, and concept mapping—in the context of conceptual modeling.

4.1.1. Causal mapping

Causal mapping is the most commonly used cognitive mapping technique by researchers in investigating the cognition of decision-makers within organizations [58]. Causal mapping is derived from Kelly's [31] personal construct theory, which posits that an individual set of perspectives is a system of personal constructs, and individuals use their own personal constructs to understand and interpret events. Constructs are expressed using a short single-polar phrase or contextually rich bi-polar phrases, representing salient concepts in which an individual understands the problem domain. As revealed by its name, a causal map represents a set of causal relationships among constructs within a system, i.e., one construct is linked to other thoughts through cause–effect relationships [21]. Through capturing the chains of argument, insights into the reasoning of a particular person are acquired.

The following figure (Fig. 4) illustrates an example of causal mapping technique. This example models a student's accounts of taking an object-oriented systems analysis and design course.

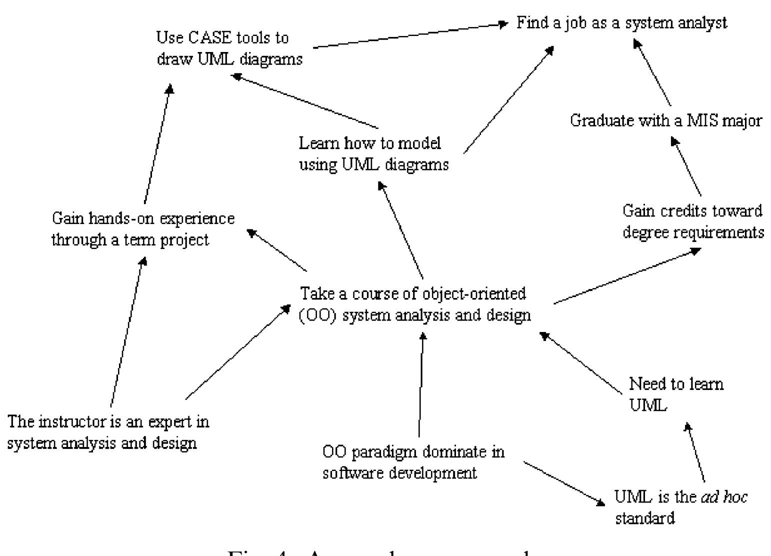

Fig. 4. A causal map example.

4.1.2. Semantic mapping

Causal assertions are only part of an individual's total belief system. There are some cognitive mapping techniques that can be used to identify other relations among concepts. Semantic mapping, also known as idea mapping, is used to explore an idea without the constraints of a superimposed structure [10]. To make a semantic map, one starts at the center of the paper with the main idea, and works outwards in all directions, producing a growing and organized structure composed of key words and key images. Around the main idea (a central word), 5–10 ideas (child words) that are related to the central word are drawn. Each of these "child" words then serves as a sub-central word for the next level drawing [10]. In other words, a semantic map has one main or central concept with tree-like branches. Fig. 5 is an example of a semantic map that depicts related words around the main idea "Unified Modeling Language (UML)".

4.1.3. Concept mapping

Another technique is called concept mapping [41]. Drawing on the theories of Ausubel [2], who emphasized the importance of prior knowledge in being able to learn about new concepts, Novak [41] concluded that existing cognitive structures are critical for learning new concepts. A concept map is a graphical representation where nodes represent concepts, and links represent the relationships between concepts. The links, with labels to represent the type of relationship between concepts, can be one-way, two-way, or non-directional. The concepts and the links may be categorized, and the concept map may show temporal or causal relationships between concepts. Concept mapping is useful in generating ideas, designing a complex structure, communicating complex ideas, aiding learning by explicitly integrating new and old knowledge, and assessing understanding or diagnosing misunderstanding [30]. Fig. 6 is an example of a concept map, which models a user's understanding of the nine diagrams in UML.

In general, these cognitive mapping techniques are commonly used to reveal cognitive structures, i.e., belief systems that individuals or groups used to interpret the problem domain and take actions. Swan [58] suggested distinguishing cognitive mapping techniques in terms of the types of subjective beliefs they intend to describe. For instance, causal mapping and revealed causal map-

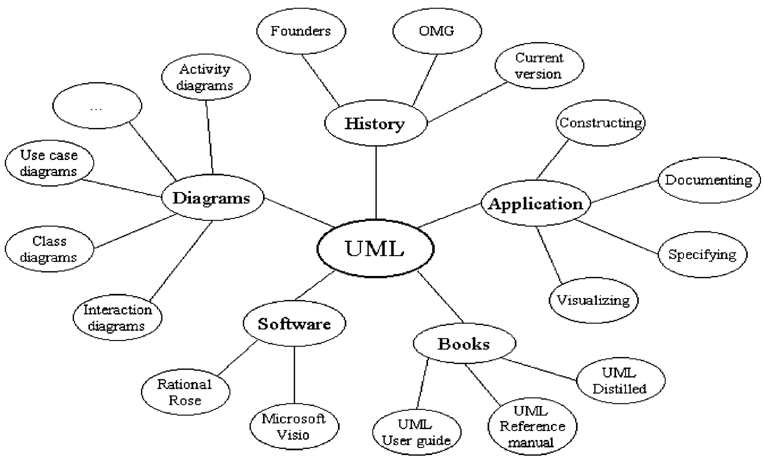

Fig. 5. A semantic map example.

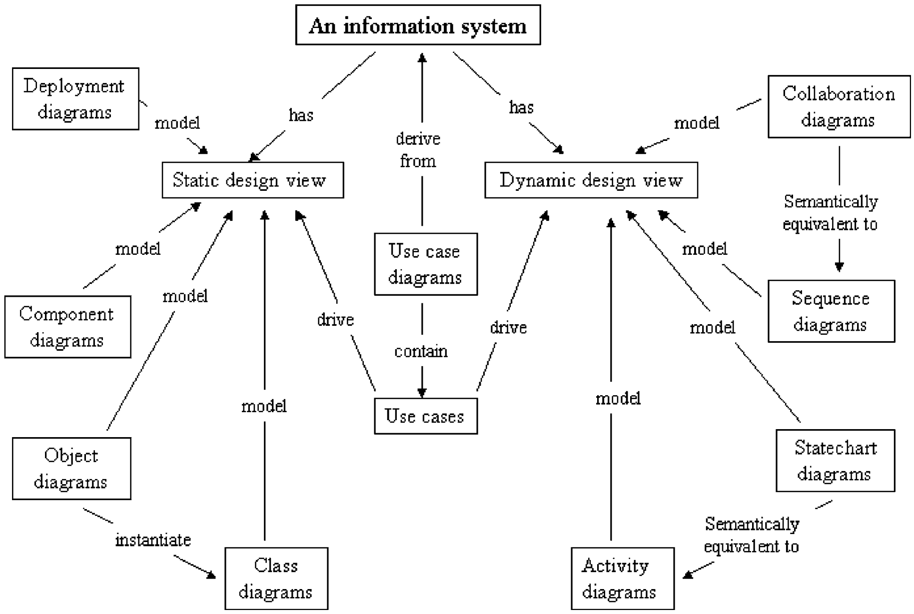

Fig. 6. A concept map example.

ping describe cause–effect relationships, while semantic mapping and concept mapping describe salient concepts and/or their spatial structures. Table 2 summarizes the main characteristics of the three cognitive mapping techniques.

4.2. Enhancing quality in conceptual modeling using cognitive mapping

The produced maps from these cognitive mapping techniques are only a reconstruction of subjective beliefs that people use to interpret the problem domain and take actions accordingly. They are shaped by the specific method used to elicit the map [58]. Eden [22] pointed out the reasonable use of these cognitive maps as:

Table 2
Characteristics of three cognitive mapping techniques

	Causal mapping	Semantic mapping	Concept mapping
Basic elements	Concepts expressed in single-polar or bi-polar phrase, causal relationships among concepts	A main idea and branches of sub-ideas	Concepts and labeled links
Theoretical foundations	Personal constructs theory [31]	Mind map [10]	Knowledge assimilation [41]
Structure	Complex network	Tree-like structure	Complex network
Focus	Cause–effect structure of concepts	Organization of sub-ideas around the main idea	Semantics-rich links among various concepts

> (1) They may represent subjective data more meaningfully than other models and so have utility for researchers interested in subjective knowledge, and (2) they may act as a tool to facilitate decision-making, problem-solving, and negotiation within the context of organizational intervention (p. 262).

Based on a survey of action-oriented research in cognitive mapping, Fiol and Huff [24] summarized a number of important direct functions and the associated indirect impacts of cognitive mapping techniques.

(i) Cognitive maps are able to focus attention and trigger memory.
(ii) Cognitive maps can help highlight priorities and key factors.
(iii) Cognitive maps may supply missing information.
(iv) Cognitive maps can reveal gaps in information or reasoning that need more direct attention.

These diagnostic functions are especially useful for conceptual modeling. In particular, by focusing attention and trigger memory, cognitive mapping can alleviate some cognitive biases, such as availability heuristics, and automaticity. The highlighted priorities and key factors help reduce the burden of anchoring and adjustment. The gaps revealed through cognitive mapping can be used to identify faulty reasoning and wrong representation. This point has been briefly addressed in Byrd et al. (11, p. 130) when they discussed the use of cognitive mapping in requirements analysis and knowledge acquisition. By helping to alleviate cognitive biases, cognitive mapping techniques can improve the correspondence between the domain and participant knowledge in conceptual mapping.

More recently, Topi and Ramesh [61] suggested that the conceptual model used as a communication tool between analysts and users should not be as formal and restrictive as that used between analysts and developers. This point of view was shared by Siau and Tan [52] when they proposed the use of cognitive mapping techniques, in particular, semantic mapping and causal mapping, as a communication tool between analysts and end-users. Through a case study, Siau and Tan [52] discussed the applicability of these cognitive mapping techniques in overcoming the communication obstacles "within" individual users, "between" users and analysts, and "among" users [63]. As cognitive mapping techniques may represent subjective knowledge more meaningfully, they can improve the pragmatic quality and physical quality in conceptual modeling when they (as an informal language) are used to generate conceptual models. This is because relatively less cognitive effort is needed to draw or interpret a cognitive map. Furthermore, the diagnostic quality of the cognitive mapping process can be used to reveal the gaps between participant knowledge and individual interpretation. Therefore, cognitive mapping is also useful to improve the perceived semantic quality in conceptual modeling.

Cognitive mapping can also improve the social quality in conceptual mapping. As a way to elicit an individual's cognitive structure regarding the problem, cognitive mapping facilitates the understanding of different frames of reference among system users, managers, and system analysts. Better understanding will promote the agreement on participant knowledge and individual interpretation.

Finally, graph-layout models, in the form of cognitive maps, can improve the readability of conceptual models. In addition, we can follow the guidelines for graph aesthetics [59] in creating

Table 3
How cognitive mapping can improve quality in conceptual modeling

Quality type or influential factor	How cognitive mapping is used	How quality is improved
Correspondence between modeling domain and participant knowledge	Cognitive mapping is used as a diagnostic and communication tool	Reveal the errors in participant knowledge with relation to the domain Alleviate human cognition limitations
Social quality	Cognitive mapping is used as a diagnostic and communication tool	Help understand the different frames of reference regarding the problem, thus improve the possibility of reaching agreement
Pragmatic and physical quality	Cognitive mapping is used as an informal language	Relatively smaller cognitive effort is needed to create or interpret a cognitive map
Perceived semantic quality	Cognitive mapping is used as a diagnostic and communication tool	Reveal the gaps between participant knowledge and individual interpretation
Empirical quality	Graph-layout models following graph aesthetics guidelines	Improve the readability of conceptual models and reduce error frequencies

cognitive maps to reduce the error frequencies when maps are read by users. As such, empirical quality can be improved by cognitive mapping techniques.

Table 3 summarizes how cognitive mapping can be used to improve quality in conceptual modeling.

5. Using cognitive mapping to supplement popular systems development methodologies

Parallel with the emerging socio-technical approach to the analysis of IS in organizational contexts, many systems development methodologies recognize the discernible impact of human and organizational issues on systems development. Established systems development methodologies, such as organization-oriented Soft Systems Methodology (SSM) [15], are especially useful in managing systems development projects in ill-structured situations. SSM emphasizes on building the right system, which is consistent with the fundamental principle of requirements engineering. Cognitive mapping techniques, with aforementioned functions, can supplement these methodologies as tools to improve the quality of conceptual models.

In this section, we use a case to demonstrate the advantage of using cognitive mapping in SSM. The case is based on a standard case used in the first conference by IFIP (International Federation for Information Processing) WG (Working Group) 8.1. In an effort to compare various systems development methodologies, the conference invited researchers of methodologies to apply their methodologies to this standard case mentioned in [42]. The case is about organizing an IFIP conference (see Appendix A). It must be noted that our case study is not empirical in nature. Therefore, just like those proceedings in [42], a variety of assumptions were made in our case study, of which the objective is to descriptively demonstrate the usefulness of the cognitive mapping techniques. Also, our focus is on improving the quality of conceptual models. As such, we only discuss the activities associated with requirements determination and conceptual modeling.

5.1. A brief introduction of SSM

SSM is an acronym for Soft Systems Methodology, which was developed by Checkland [15]. In essence, SSM is a framework to guide the problem solver to investigate complex situations. The fuzzy, ill-structured situations are common in information systems development in organizations. Instead of attempting to solve a pre-defined problem, SSM fosters learning and appreciation of the problem situation between stakeholders.

SSM Mode 1, described in [14,15], is the version most commonly referred to and the most useful in an information systems context [4]. The stages involved in SSM include:

- Initial work involves interviews and meetings to gain an understanding of the problem situation, which is represented by the use of "rich pictures".
- Systems thinking uses concepts of hierarchy, communication, control, and emergent properties to identify "relevant systems" which may provide useful insights. These relevant systems are logically defined by constructing "root definitions", which are then used to generate "conceptual models" of the selected systems.
- Different conceptual models representing different viewpoints are then used as the basis for discussion among stakeholders, who through an "appreciative process" can reach consensus about the feasibility and desirable change, and then action.

SSM can be fitted in the information systems development process by using it as a "front-end" before proceeding to the physical aspects of systems development [3]. In other words, SSM can be applied as a requirements engineering methodology because it is concerned about "building the right system." SSM provides all actors, including system analysts, users of the system, and owner of the system, opportunities to understand the problem situation.

5.2. How cognitive mapping can supplement SSM in solving the case?

In SSM, rich pictures are used by analysts to express the problem situation. A rich picture is a pictorial caricature of an organization and helps to explain what the organization is about [3]. The problem solver (analysts) constructs a rich picture by observing or interviewing various stakeholders. The three most important components of a rich picture are structure, process, and concerns [38], which are used to identify two main aspects of the human activity system—primary tasks and concerns. Fig. 7 is a rich picture constructed for the case. Key tasks can be identified by the links among actors, i.e., the flow of information or documents. Main concerns are depicted as the think bubbles.

It is obvious that the rich picture is intended to be a broad, high-grained view of the problem situation. Cognitive mapping techniques can be used in two ways. The first is to use cognitive mapping as a communication tool when analysts conduct interviews with various stakeholders. The second way is to decompose a rich picture into cognitive maps of greater detail.

To have a correct understanding of the problem situation, the analyst must be interested in such factors as interfaces, boundaries, subsystems, control of resources, organizational structure, roles of personnel, organizational goals, employee needs, and concerns. A high number of information systems development failures are due to the ignorance of these issues. Before constructing the rich

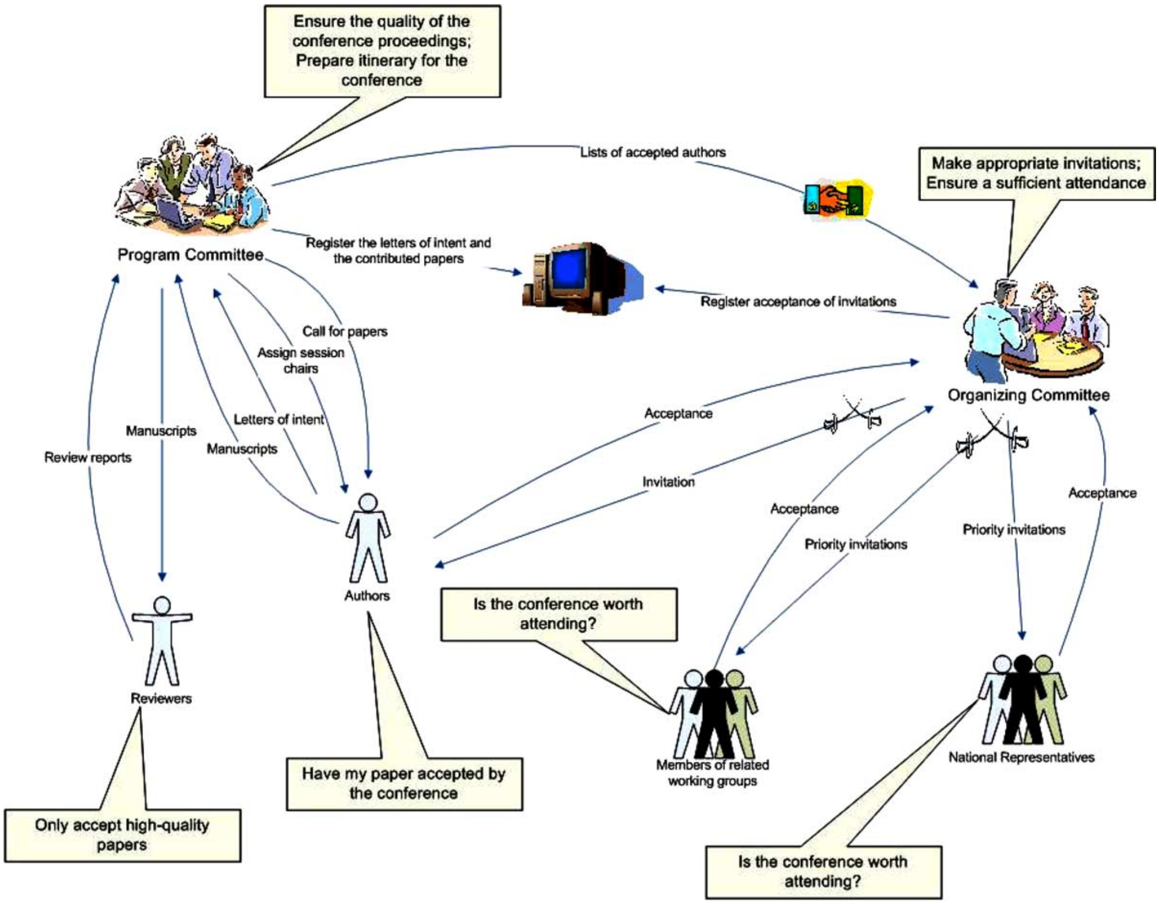

Fig. 7. A rich picture of organizing an IFIP conference.

picture, i.e., the broad understanding of the problem situation, the analyst often interview various stakeholders (users of the system) to understand their specific issues. Here, cognitive mapping can be used, before the construction of the rich picture, as an effective communication tool between the analysts and the users. Fig. 8 shows a causal map of a program committee chair regarding the problem situation (The case description does not include this information. The causal map, for demonstration purpose, is created based on an assumptive interview with a professor who has served on many conferences' program committees).

A rich picture may be very complex in structure, especially when the problem situation is very complex or ill-structured. In some situations, it is not possible to represent the organization with one rich picture. In addition, the complexity of the organization, which the users are familiar with and understand well, may not be apprehended by an outsider looking at the rich picture. In either case, further detail could be shown on separate cognitive maps. The following concept map (Fig. 9) describes the semantic relationships among key entities regarding the paper submission and the review process.

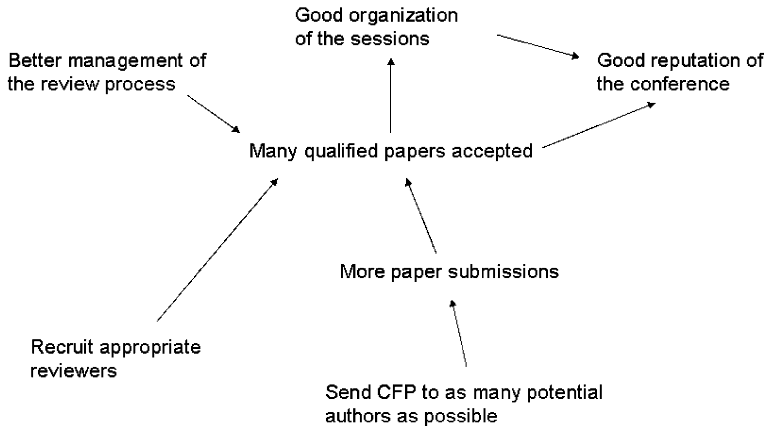

Fig. 8. A casual map of a program committee chair.

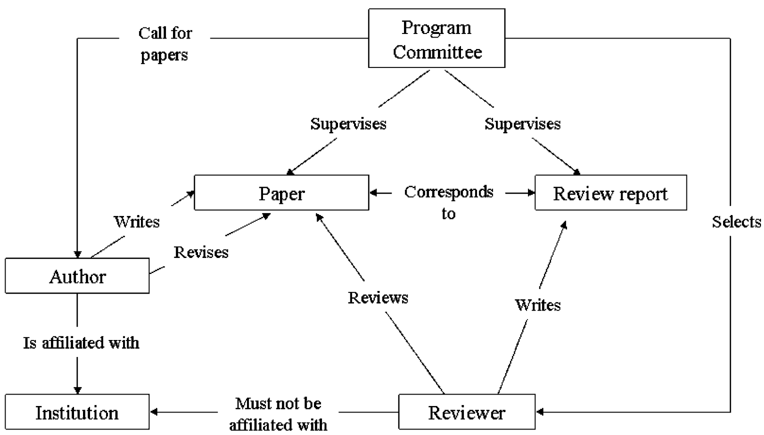

Fig. 9. A concept map of a program committee chair.

5.3. Summary

SSM, as an organization-oriented methodology, can be used for developing information systems when the problem situation is fuzzy and ill-structured. SSM is often used as a front-end before proceeding to the physical aspects of systems development, such as logical and physical design. SSM is implemented by constructing rich pictures, root definitions, and conceptual models. SSM is organization oriented and aims to develop high-quality conceptual models. Cognitive mapping has great potential to supplement SSM to achieve this goal.

The early stages of SSM are concerned with understanding the problem situation. Rich pictures have been proved to be an invaluable tool for this purpose. However, the author of SSM [14] did not specify the tools and techniques used to reach the broad and high-grained view. We suggest using cognitive mapping as a communication tool between the analysts and the users for initial investigation. After the rich picture is created, we can also use cognitive mapping to decompose it into greater detail.

6. Summary and conclusion

In this paper, we examine the use of cognitive mapping as a communication and analytical tool in conceptual modeling. Many frameworks have been proposed to provide better and in-depth understanding of quality in conceptual modeling. Lindland et al.'s [35] framework has gained extensive recognition. Krogstie and Sølvberg [34] extended the framework by highlighting some human-related factors that affect a model's overall quality. We review human cognition at both individual level and socio-cognitive level in order to identify the underpinnings of these human-related factors. We find that cognitive mapping may effectively overcome some human cognitive limitations and biases. In addition, cognitive mapping can facilitate understanding among various stakeholders. In view of its utility in addressing these human and organizational issues, we use a conference organizing case to discuss how cognitive mapping can supplement a popular socio-technical systems development methodology.

Being widely used in the management studies to investigate managerial and organizational cognition, cognitive mapping has great potential to be applied in conceptual modeling process to improve the quality of conceptual models.

Appendix A. Organizing an IFIP Conference

An IFIP Working Conference is an international conference centered on a topic of specific interest to one or more IFIP Working Groups. Participation in the conference is by invitation only. Two objectives of the conference organizers are to ensure that members of the involved Working Group(s) and Technical Committee(s) are invited and that attendance is sufficient for financial break even without exceeding the capacity of the facilities available.

Two committees are involved in organizing an IFIP Working Conference: a Program Committee and an Organizing Committee. The Program Committee deals with the technical content of the conference and the Organizing Committee handles financial and local arrangements, along with invitations and publicity. These committees work together closely and have a need for common information.

When an IFIP conference is to be held, the Program Committee is responsible for several activities. These include preparing a mailing list of potential authors and sending a call for papers to each of these individuals. If the potential authors reply with a letter of intent indicating they will submit a paper to the conference, the Program Committee registers the participant's intent to participate. When the paper is received, the paper is also registered.

After receiving the papers, the Program Committee assigns a set of reviewers for each paper and then sends the papers to the respective reviewers. Reviewers create a review report and send their reports to the committee. The committee then groups accepted papers into sessions and assigns session chairs. The list of accepted authors is forwarded to the organizing committee. This session information makes up the itinerary for the conference.

The Organizing Committee begins by preparing a list of people to invite to the conference. The committee issues priority invitations to National Representatives and to members of related Working Groups. The organizing committee also ensures that each of the contributing authors receives an invitation. Individuals who receive an invitation and who intend to come to the conference must indicate their intent to participate by sending an acceptance of invitation to the Organizing Committee. The final list of participants is then generated by the Committee, who makes an effort to avoid sending duplicate invitations to any individual.

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