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Information Systems Requirements Determination and Analysis: A Mental Modeling Approach

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Abstract

Regardless of the system development methodology adopted, being able to understand users' information requirements is vital to the success of an information systems project. The intrinsic communications obstacles exist within an individual user, among users, and between users and systems analysts. Different requirements determination and analysis (RDA) techniques have been widely used with different outcomes. Some limitations of these techniques can be identified. In this paper, we propose a mental modeling approach to support RDA. Popular in other disciplines, mental modeling techniques have some distinct advantages to overcome some intrinsic communication obstacles in RDA, and to complement other techniques.

Keywords: Information systems development, mental modeling, requirements determination and analysis (RDA), mind mapping, cognitive mapping, concept mapping

Introduction

Information technology (IT) has dramatically changed the world as organizations implement various information systems (IS) projects to facilitate business operations, support decision-making processes, and manage the relationships with business partners and customers. Many organizations consider information systems as either a strategic necessity or a source of core competences. As a result, information systems are costing businesses and nonprofit organizations billions of dollars a year.

Systems development has evolved from i) the non-methodology era (1960s and 1970s), when the emphasis was on programming and solving technical problems, to ii) the early methodology era (late 1970s to early 1980s), characterized by the Software Development Life Cycle (SDLC), to iii) the methodology era (1980s to 1990s), in which proliferate methodologies (e.g. structured approach and object-oriented approach) can be identified, and to iv) the post-methodology era (late 1990s to present), when some organizations continue to find appropriate methodologies whilst others have abandoned methodologies all together (Avison and Fitzgerald, 2003). The evolution reflects not only the sustained efforts to transform systems development from an art form to a discipline of engineering, but also the disappointing productivity and outcomes of systems development projects. The reported statistics on IS projects show that at least one in four projects ends in failure. Cases of software project failure can be easily identified in books (e.g. Flowers 1996; Glass 1998, 1999). In 1995, a Standish Group's report on a study of over 8,000 software development projects revealed that only 16% were completed on time and on budget (Johnson 1995).

IS researchers have been confronting a serious challenge, which arouse from these costly and conspicuous failures of software development projects. The software development processes have to be carefully examined in order for us to understand how better systems are developed. Regardless of the systems development methodology adopted, a thorough analysis of users' information and knowledge requirements is regarded as a critical stage in the successful development of various types of information systems (Guinan and Bostrom, 1986; Holtzblatt and Beyer, 1995; Moody, Blanton, and Cheney, 1998). Many researchers (Ashry and Taylor, 2000; Batiste and Jung, 1984; Byrd, Cossick, and Zmud, 1992; Watson and Frolick, 1993; Zmud, Anthony, and Stair, 1993) have pointed out the significance of the failure to accurately capture information requirements to the failure of the whole information systems' development efforts.

Numerous techniques have been suggested as an aid in determining IS requirements. However, the process of requirements determination and analysis continues to fail despite the availability of these techniques. Many reasons for these failures have been suggested. The most common is probably the intrinsic communication obstacles abound in requirements determination and analysis (Valusek and Fryback, 1987; Byrd *et al*., 1992; Guinan, Cooprider, and Faraj, 1998); another is that many techniques insufficiently address operation concerns (Watson and Frolick, 1993; Batiste and Jung, 1984).

In our paper, we propose a mental modeling approach for determining and analyzing information systems requirements. Mental modeling refers to a collection of mapping techniques that are used to generate a visual representation of people's ideas about a particular issue. The main functions of mental modeling, capturing, eliciting, and structuring ideas, may help overcome intrinsic communication obstacles in requirements determination and analysis, and complement other techniques by addressing very detailed, often ill-structured and dynamic, operation concerns.

Requirements Determination and Analysis (RDA)

Regardless of the methodology used, each information systems project has to go through the planning, analysis, design, and implementation stages. It is well understood that a thorough analysis of users' information needs in the planning and analysis stages is critical for the success of the whole project. Byrd *et al.* (1992) referred to the step as requirements analysis, involving i) working with end users to establish an understanding of organizational information processing needs; ii) developing IS objectives; iii) designing and evaluating IS alternatives; iv) communicating the results of analyses to superiors and end users; and v) performing a systems audit.

Many IS researchers e.g., Davis, 1982; Byrd *et al*., 1992; Watson and Frolick, 1993; Zmud *et al.* 1993) have pointed out that determining correct and complete information requirements is a vital part of designing an IS. Many IS failures can be attributed to a lack of clear and specific information requirements. Mittermeir, Hsia, and Yeh (1982) asserted that proper identification of information needs early in the design process might allow for early correction of errors while the cost of correction is lower. Another study (Shumskas, Askman, and Cunningham, 1987) shows that requirements analysis consumes only 5% of the total cost while affording 50% of the leverage to influence the improvement of quality.

One intrinsic issue related to the requirement determination and analysis (RDA) is communication obstacles. Communication obstacles exist within individual users, among users, and between analysts and users (Valusek and Fryback, 1987). An end user attempting to specify information requirements is subject to the cognitive limitation of humans, such as the limited memory and information processing biases. The communication problems between analysts and users are not only caused by individuals' cognitive limitations but also by the lack of a common language (Davis, 1982; Flynn and Jazi, 1998). Even if both of these problems were solved, the determination of information needs may still be confronted with obstacles associated with balancing the needs of multiple users. The communication obstacles among users involve prioritization and tradeoffs of multiple needs (Byrd *et al*. 1992). Numerous studies and surveys have identified the communication obstacles from similar perspectives. A typical business person does not know what he or she wants and is usually unable to accurately communicate what little they can figure out (McClatchy, 1990). Developers are frequently criticized for being unable to elicit requirements from users (Davis, 1982; Flynn and Jazi, 1998) and unwilling to work with these requirements because they seem to think they know what is best for the user (Bostrom and Kaiser, 1982; Cronan and Means, 1984).

Many methods have been developed to aid determining and analyzing information systems requirements. Four generic strategies for identifying organizational or application-level information requirements can be identified: i) asking, ii) deriving from an existing information system, iii) synthesizing from characteristics of the utilizing system, and iv) discovering from experimentation with an evolving information systems (Davis, 1982). Examples include Cognitive Mapping (Montazemi and Conrath, 1986), Business System Planning (IBM, 1981), Critical Success Factor (Rockart, 1979), and Prototyping (Nauman and Jenkins, 1982). In comparing requirements analysis to knowledge acquisition, Byrd *et al*. (1992) gave a comprehensive review of requirements analysis techniques.

In practice, the above-mentioned methods do not always yield workable IS requirements. Batiste and Jung (1984) claimed that the Critical Success Factor technique could not sufficiently handle some of their operational concerns. In assessing the techniques of determining information requirements for an executive information system, Watson and Frolick (1993) indicated that each approach proposed by Davis (1982) posed some difficulties: i) the asking strategy requires that analysts capture the information requirements of system users, who may not be able to accurately articulate due to cognitive limitations; ii) deriving information requirements from existing systems may be of limited value when existing systems are actually not available; iii) synthesizing from characteristics of the object systems may not sufficiently capture the details of operational requirements; and iv) discovering from experimentation with an evolving information system, like prototyping, which is useful for the ongoing but not the initial version of an information system.

Mental modeling techniques, widely used in strategy development, education, planning and evaluation, and operation research, provide a solution to not only overcome the intrinsic communications obstacles of RDA and enrich understanding, but also complement some of the RDA techniques discussed above.

Mental Modeling Techniques

Mental modeling refers to a collection of mapping techniques that are used to generate a visual representation of people's ideas about a particular issue. These techniques may be used to capture, elicit, and structure the perceptions and attitudes of an individual or a group of people (Ramos, 2001). The common characteristics of various mental modeling techniques are:

- They make ideas explicit and explore the relationships among ideas by generating maps (visual representations), such that ideas can be easily communicated and shared;
- They work on human's cognition to capture ideas and relationships among the ideas.

There are several mental modeling techniques in practice. We give a brief introduction on three of them that are widely used in research.

Mind Mapping

Buzan (1993) developed and copyrighted a mind mapping technique, which is useful for the generation of ideas by associations. Buzan invented mind mapping following his research on note taking techniques. To make a mind map, one starts in the center of the paper with the main idea, and works outwards in all directions, producing a growing and organized structure composed of key works and key images. Around the main idea (a central word) 5 to 10 ideas (child words) that are related to the central word are drawn. Each of those child words then serves as a sub-central word for the next level drawing.

As a result, a mind map is a representation of information, ideas being connected to each other, which can help with retention and learning. Links in a mind map are usually passive, not representing anything more than connectivity. A mind map has only one main or central concept with tree-like branches giving full meaning. Figure 1 is an example of mind mapping, which depicts related words around the main idea "Unified Modeling Language (UML)."

People can make use of the creative potential of a mind map in creative writing, brainstorming sessions, learning, and note taking. However, the hierarchy (tree-like) structure may limit the capability of capturing the complex relations in an individual's cognition concerning information systems requirements.

Cognitive Mapping

Cognitive mapping (Eden 1988; Ackermann *et al*. 1992; Eden and Ackermann, 1998) is a technique used to structure, analyze, and make sense of accounts of problems. The technique is based on Kelly's (1955) theory of personal constructs, which suggests that people make sense of the world in order to predict the future and to decide how to act or intervene. Kelly refers to an individual set of perspectives as a system of personal constructs, which individuals use to understand and interpret events that occur around them. Cognitive mapping helps create a model of the world, which uses concepts and links. Thoughts are held as concepts, which may be a short single-polar phrase or contextually rich bipolar phrases. Links, often directional and used to indicate causal relationships, are more actively used in cognitive mapping, resulting a structure of complex networks (Ackermann *et al*. 1992).

One feature of cognitive mapping is that it can be used in a group environment. In some cases, a group representation (i.e. a shared cognitive map) can be developed by aggregating maps from individuals in the group (See Eden, 1980). In other cases, a group cognitive map is built directly from the group discussion (See Eden, 1990, 1993). Group members' ideas and views can be represented in a single map so that members are able to see their ideas, in the context of others, thus increasing their understanding of others' points of view.

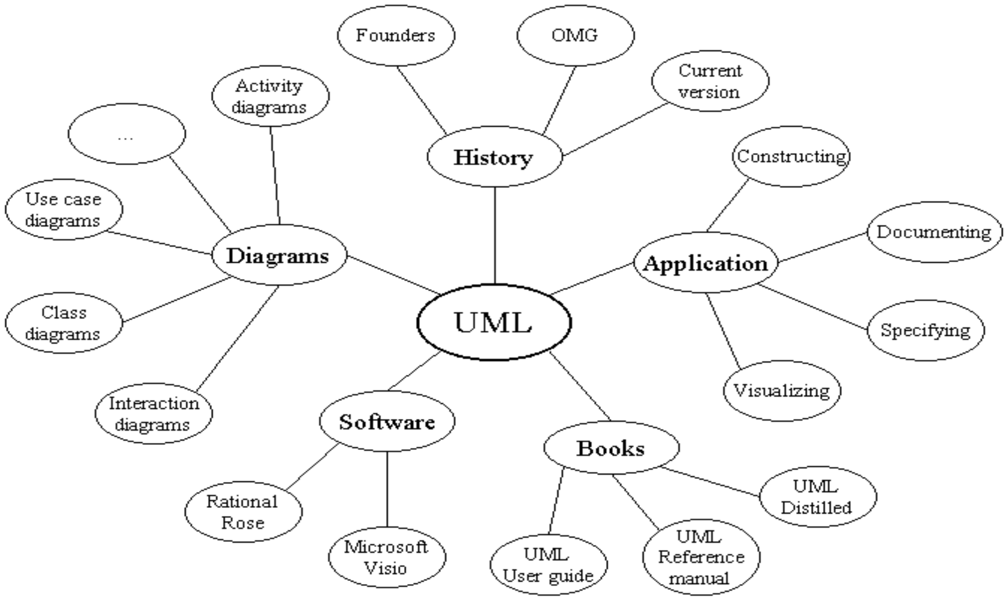

Figure 1. Mind Mapping Example

The following figure (figure 2) illustrates an example of the cognitive mapping technique. The example models a student's accounts of taking an object-oriented systems analysis and design course.

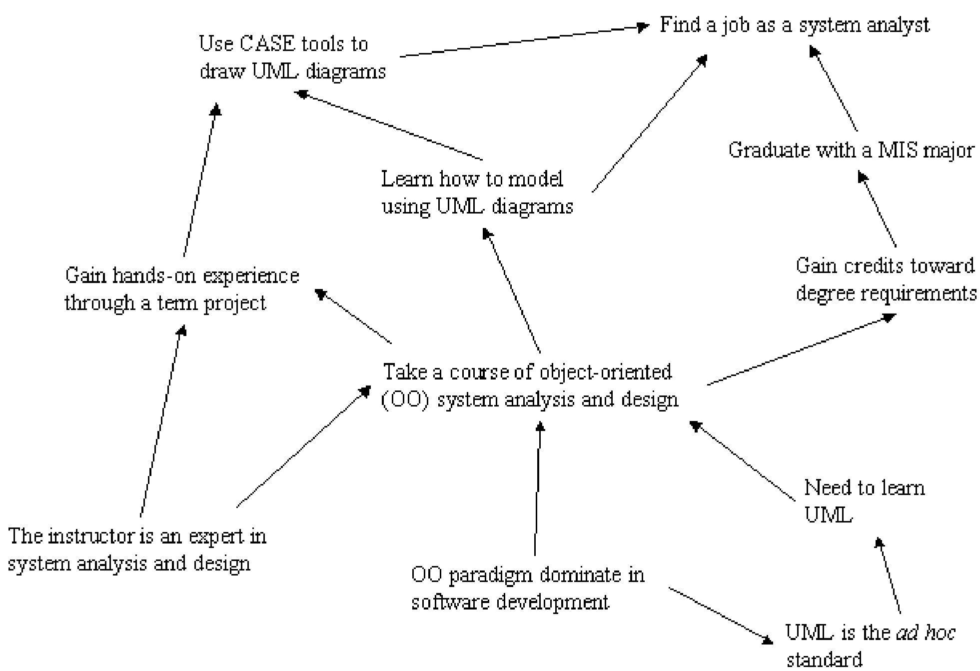

Figure 2. Cognitive Mapping Example

Based on Kelly's (1955) personal construct theory, other cognitive mapping tools, including the repertory grid (RepGrid) and cause maps, can be used to describe how people think about the phenomena in their world. These cognitive mapping tools have been widely used in operation research (Ackermann *et al*. 1992), organizational design (Wacher, 1981), strategy development (Eden, 1993), and policy analysis (Levidow and Tait, 1993).

Concept Mapping

Several different types of mapping methods currently go by the name of "concept mapping." One of them, well known and widely adopted in practice, is the concept mapping technique developed by Novak (in following discussions, concept mapping specifically refers to Novak's method). Novak (1993) based his technique on Ausubel's (1968) theories that prior knowledge is important to learn about new concepts. In a Novak's concept map, the nodes are labeled with descriptive text – a word or short phrase representing the concept, with the links labeled to express a relationship type. Concept mapping is useful to generate ideas, design a complex structure, communicate complex ideas, aid learning by explicitly integrating new and old knowledge, and assess understanding or diagnose misunderstanding (Lanzing, 1996). Figure 3, which models a student's understanding of the nine diagrams in UML, illustrates a map that is created using a concept mapping technique.

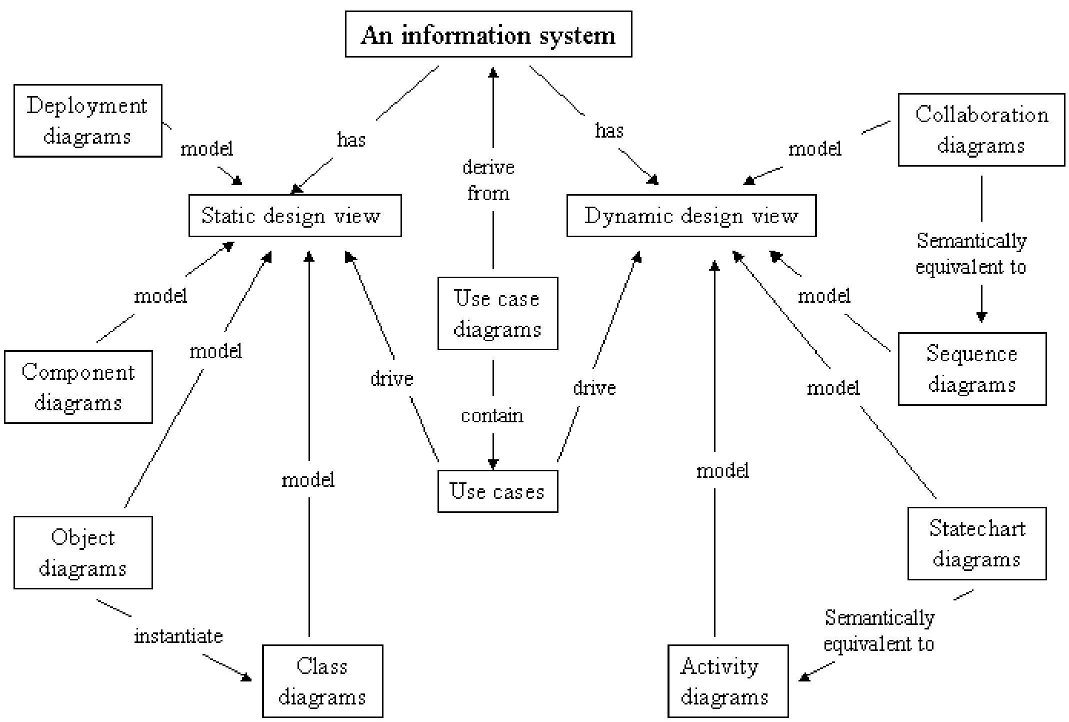

Figure 3. Concept Mapping Example

The comparison of the various mental modeling methods introduced above is summarized in Table 1.

Mental modeling techniques, especially the cognitive mapping techniques, have been widely used in IS research. For example, Latta and Swigger (1992) assessed and validated the RepGrid for the use in modeling knowledge. Hunter (1997) proposed using cognitive mapping to gather interview data. Mental modeling techniques are also used for expert knowledge acquisition (Wright and Ayton, 1987; Phythian and King, 1992), and IS project risk analysis (Moynihan, 1996).

Table 1. Comparison of the Three Mental Modeling Ttechniques

Technique	Major Developers	Map Structure	Map Focus	How Ideas Are Connected	Application Context
Mind mapping	Buzan (1993)	A central concept develops into a tree-like elaboration	Only one central concept	Passive links, representing only connectivity	Mainly for individuals' writing and note taking
Cognitive mapping	Ackermann *et al.* (1992), Eden (1988), Eden and Ackermann (1998)	Concepts are linked to form a structure of complex networks	May have many focuses	Directional links often reflect cause-effect relationship	May work with individuals or groups
Concept mapping	Novak (1993)	Nodes are linked to form a network structure	May have many focuses	Links are labeled to reflect different relationship types	Work primarily with individuals

In view of the great potential of overcoming intrinsic communication obstacles in RDA, IS researchers also advocate using mental modeling techniques in the process of determining and analyzing user IS requirements. Byrd *et al*. (1992) pointed out that the use of mental modeling techniques provides a structured method for users to understand their cognitive processes and, therefore, helps overcome communication obstacles during requirement analysis. Montazemi and Conrath (1986) proposed the use of cognitive mapping in analyzing information systems requirements in ill-structured decision environments. These works discuss the application of the mental modeling techniques in a specific context, focusing on either a specific mapping tool or a particular type of information system. Notwithstanding the contributions made by these papers, our paper provides a comprehensive discussion of applying various mental modeling techniques in the process of RDA. In this stage of research, we use a case study to show the applicability of the three major mental modeling techniques in determining information requirements.

A Case Study Using Mental Modeling Techniques in RDA

Mental modeling techniques have the potential to overcome the intrinsic communication obstacles of RDA and complement other RDA techniques. Visual representations of human cognition elements (concepts and relationships) on user requirements are generated through mapping processes. The resulting maps can be used for verification and negotiation with users, for communication with superiors, and for in-depth requirements analysis.

In this section, we present a case study of applying mental modeling techniques to RDA. Specifically, we illustrate how to use the three mapping techniques (mind mapping, cognitive mapping, and concept mapping) in the process of determining end-user's information requirements for an IS project.

Brief Description of the Project

A nursery company envisioned a Web-based system that would better empower their customers, thus resulting in stronger customer relationships. The existing informational Website did not adequately fulfill customer needs. In addition, inefficiency and inconsistency of the existing system led to low-level integration of various customer relationship management tools. The company, therefore, intended to implement a project to introduce a Web-based system that would address the above issues.

Customers and other end users were interviewed by one of the authors to determine the information requirements. The interviewer is a sophisticated system analyst with adequate experience of conducting requirements determination and analysis. The interviewer drew maps, based on the three mind mapping techniques, to represent the information requirements identified from the interviews.

Maps of Information Requirements

Using mind mapping, cognitive mapping, and concept mapping independently, three maps were generated.

The mind map (figure 4) shows a tree structure of user requirements – in terms of various functions needed in the new system. The links between concepts represent the connectivity only. Requirements on the new Web-based system are categorized in four groups, each of which is related to sub-functions.

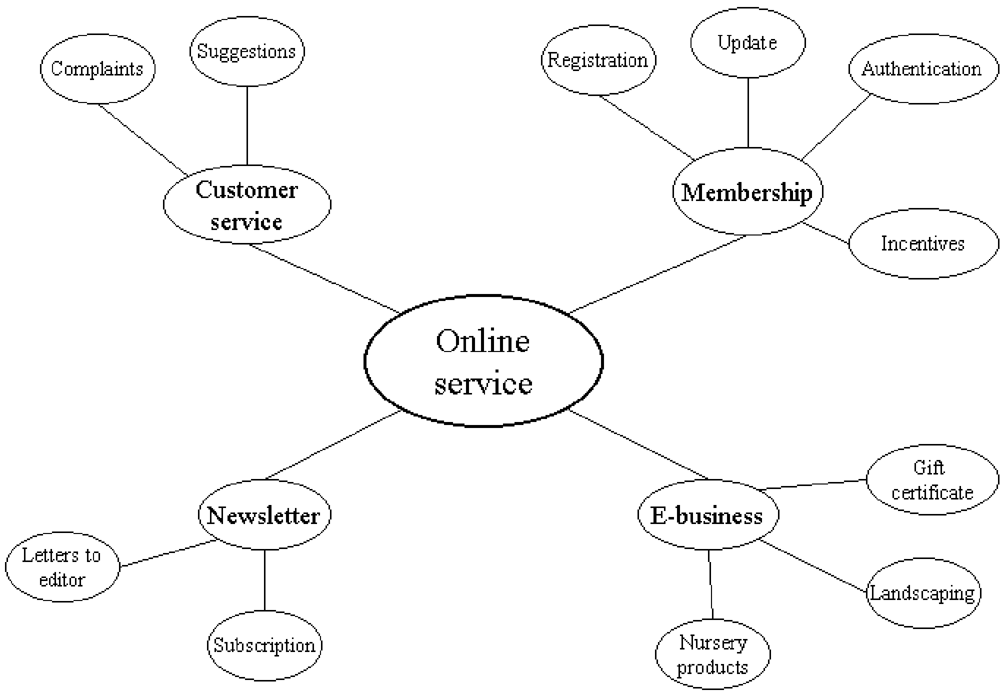

Figure 4. The Mind Map

The cognitive map (figure 5) exhibits the ideas that are linked by cause-effect relationships, reflecting users' beliefs on the cause-effect relationships among different requirements.

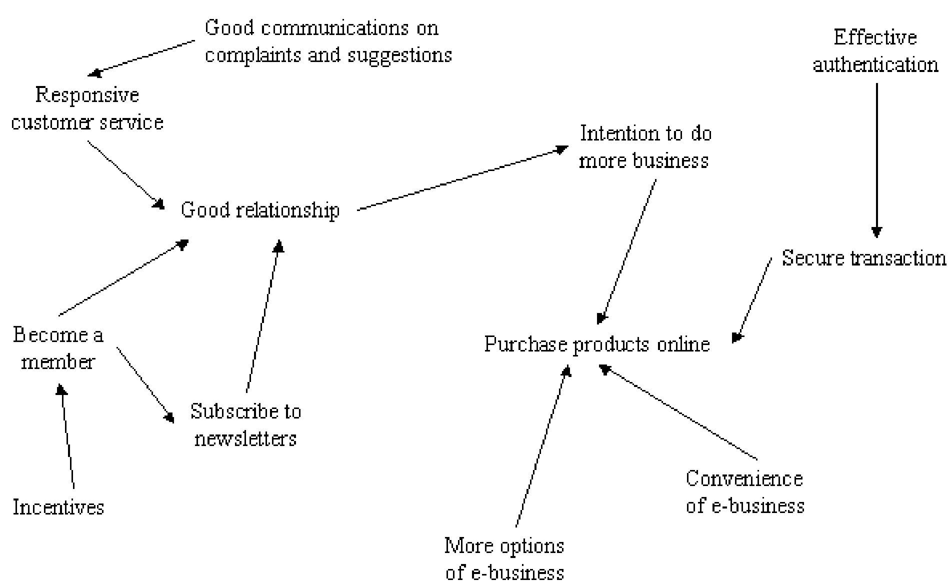

Figure 5. The Cognitive Map

The concept map (figure 6) presents ideas linked by different types of relationships. As a result, the concept map captures many types of relationships among the requirements, such as aggregation (A includes B) and contiguity (A follows B), in addition to cause-effect relationship. Moreover, the explicit labels of links give more semantic information about the relationships among ideas.

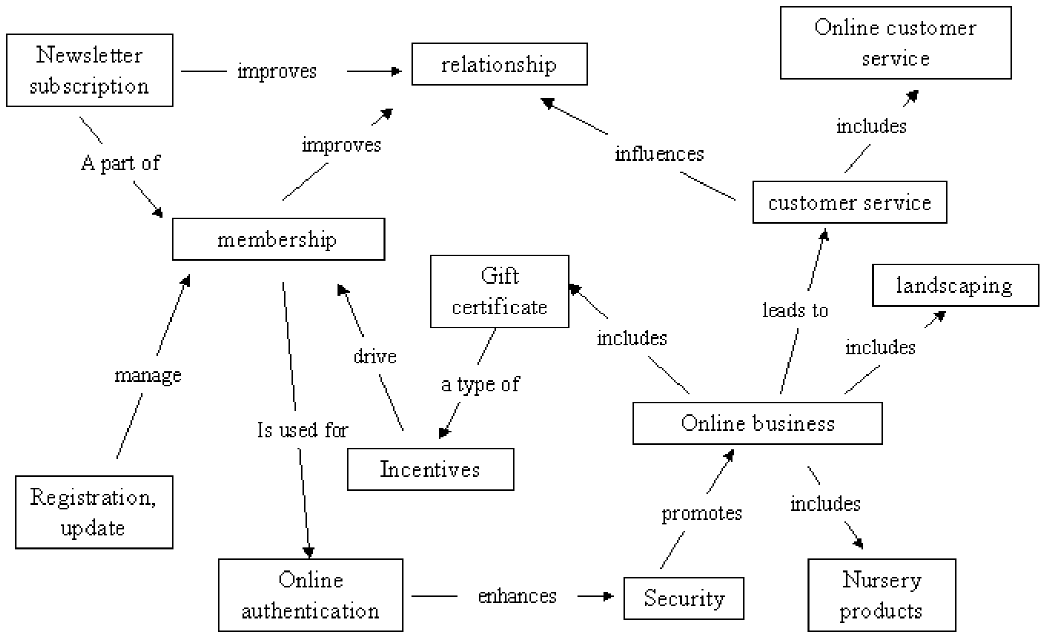

Figure 6. The Concept Map

As this case study is used to reveal the applicability of determining information requirements, the validation of the generated maps was not conducted in this stage of research. Using the example maps generated for the case study, we discuss the applicability of the mental modeling techniques in RDA.

Discussion

Every mental modeling technique has its pros and cons; every technique is good at capturing certain kinds of requirements and is not as good at capturing others. As "consumers" of the generated maps, we should be able to evaluate the techniques and decide which technique provides the best match of strengths to needs. Stillings *et al.* (1987) proposed a list of questions that are useful in evaluating knowledge representation schemes. Three issues that are relevant to our evaluation of mind modeling techniques, which are special schemes of knowledge representation. The three issues are: i) the ease of encoding, ii) expressive adequacy, and iii) acquisitional adequacy. In the following subsections, we discuss some characteristics of the three mapping methods, our experience in applying them in the case study, and the associated implications.

The Ease of Encoding

The mind map took the least effort and time to draw, whilst the concept map consumed the most time and energy. Because the mind map only captured the tree structure (i.e., top-down structure) of user requirements, a system analyst working on it needs to focus on the categorization of ideas and hierarchical relationships. The cognitive map showed cause-effect relationships among ideas, consuming more effort and time for a system analyst to identify the relationships. The concept map includes many different types of relationships among ideas, resulting in the most effort and time consumption.

Expressive Adequacy

The links represent i) connectivity in the mind map, ii) cause-effect relationship in the cognitive map, and iii) multiple types of relationship in the concept map. Furthermore, a map that includes many types of relationship is likely to integrate more concepts. Depending on the types of relationship and number of concepts involved, the mind map has the lowest level of expressive adequacy, and the concept map has the highest level.

Acquisitional Adequacy

The mind map is useful to illustrate the broad structure of the requirements. Without going into details, it categorizes the requirements into groups. Hence, it is suited for communicating with superiors who are concerned with the major categories of user requirements. The cognitive map is useful in addressing requirements associated with the decision process, in which the cause-effect relationship is critical in assessing different alternatives. The concept map, by incorporating such flexible relationship types as proximity (A is close to B), similarity (A is similar to B), cause-effect (A positively or negatively causes B), aggregation (A includes B), category (A is a subset of B), and contiguity (A follows B), is suited in determining very detailed requirements, especially in ill-structured and dynamic situations.

In view of the characteristics discussed above, we propose a contingency approach to the selection of these three mental modeling techniques in RDA. The underlying basis for selecting a technique is uncertainty and communication needs. If the uncertainty level, measured by the system complexity and ill-structuredness, is low, or if the communication with users is concerned about the broad categorization of requirements, the mind mapping method is recommended in view of its ease of use. In circumstances where the uncertainty level is high or the communication with users needs to address internal relationships among requirements, the concept mapping method will be effective. The cognitive mapping method is suited in the situations when the requirements are related to decision process (i.e., alternatives assessment). In a particular IS project, these three mental modeling methods can be used complementarily to meet different communication needs.

Conclusions and Future Research Directions

In this paper, we propose a mental modeling approach to requirements determination and analysis. This approach will overcome some intrinsic communication obstacles in RDA, and complement other RDA techniques. The characteristics of three mental modeling methods (mind mapping, cognitive mapping, and concept mapping) are discussed based on literature review, and our experience applying them to a case study. Based on the evaluation of the three mental modeling techniques, we provide a holistic viewpoint of applying various mental modeling techniques in RDA, depending on system uncertainty and communication needs. The comprehensive discussion will improve our ability of studying information requirements from a cognitive perspective. Future research in this area includes: i) to verify and evaluate the applicability and effectiveness of each mental modeling technique under contingent situations in other real settings, ii) to assess the effectiveness of mental modeling in overcoming particular communications obstacles in RDA, such as those within individual users, and those between users and system analysts.

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