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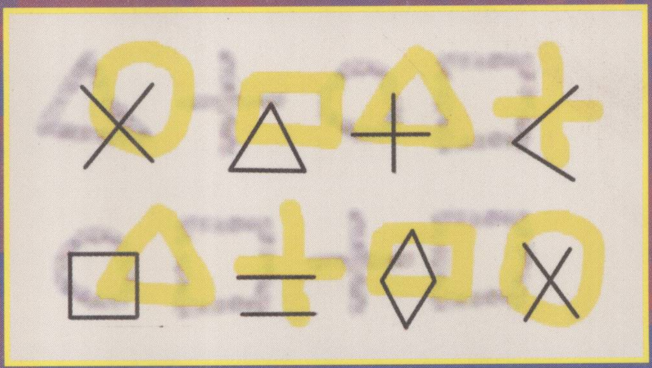
Knowledge and Information Visualization

Searching for Synergies



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Knowledge and Information Visualization

Searching for Synergies

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Volume Editors

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Editors' Note

Until now, knowledge visualization and information visualization investigated the question of visualization from different perspectives. However, as there are some common areas of interest, synergy effects can be expected. In an international workshop titled "Visual Artefacts for the Organization of Information and Knowledge. Searching for Synergies" held in May 2004 at the Knowledge Media Research Center in Tuebingen (Germany), leading-edge researchers tackled the problem of looking for synergies. This book explores the approaches of most of the workshop participants, as well as other invited experts.

The intention of the book is to advance current research and development in the fields of knowledge and information visualization, to push the borders of what is now feasible and applicable to develop synergistic approaches that may represent both knowledge and information in a comprehensive manner.

The editors are indebted to the authors who contributed to the book, to Margot Stoll, who did the layout and formatted the papers, to Waltraud Lenz who checked the references, and to Sebastian Groteloh who assisted in solving technical problems.

March 2005

Tanja Keller
Sigmar-Olaf Tergan

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Table of Contents

Visualizing Knowledge and Information: An Introduction

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Abstract. Visualization has proven to be an effective strategy for supporting users in coping with complexity in knowledge- and information-rich scenarios. Up to now, however, information visualization and knowledge visualization have been distinct research areas, which have been developed independently of each other. This book aims toward bringing both approaches together and looking for synergies, which may be used for fostering learning, instruction, and problem solving. This introductory article seeks to provide a conceptual framework and a preview of the contributions of this volume. The most important concepts referred to in this book are defined and a conceptual rationale is provided as to why visualization may be effective in fostering, processing and managing knowledge and information. The basic ideas underlying knowledge visualization and information visualization are outlined. The preview of each approach addresses its basic concept, as well as how it fits into the conceptual rationale of the book. The contributions are structured according to whether they belong to one of the following basic categories: "Background", "Knowledge Visualization", "Information Visualization", and "Synergies".

1 Introduction

Our present-day society is witnessing an explosion of information and knowledge and an increasing complexity of subject matter in many domains. Influenced by the changes in the amount and complexity of knowledge and information, as well as changes in requirements for coping effectively with increasingly complex tasks, a change in the culture of learning and working is taking place (e.g. Schnurer, Stark & Mandl, 2003). Traditional strategies of learning for comprehension and retention are no longer the central goals in learning and instruction. Learning content is often complex, ill-structured, represented in different information repositories, not pre-selected and pre-designed, and sometimes has to be searched for by the learners themselves (Rakes, 1996; http://stauffer.queensu.ca/inforef/tutorials/rbl/). Having information "at your fingertips" has become a crucial issue. The workflow of receiving, structuring, using, creating, and disseminating information requires information, as well as knowledge management techniques. In order to make a large amount of information easily accessible by users, the information has to be pre-structured. The structure itself has to be communicated to the users. Visualizations of the structures inherent in large amounts of information may help in understanding relations between informa-

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tion elements and visually searching relevant information. Visualizations of knowledge are needed to make knowledge explicit and better usable, as well as to make sense of information structures. Visualizations concerning structures of knowledge and information are suggested to help learners coping with subject-matter complexity and ill-structuredness (Holley & Dansereau, 1984; Jonassen, Reeves, Hong, Harvey & Peters, 1997). They may help students to elicit, (co-)construct, structure and restructure, elaborate, evaluate, locate and access, communicate, and use ideas, thoughts and knowledge about relevant content and resources (Jonassen, Beissner & Yacci, 1993). There is a need for cognitive tools aiming at supporting cognitive processing in generating, representing, structuring and restructuring, retrieving, sharing, and using knowledge. Therefore, there is a need for visualization techniques for making structures of information in large repositories apparent and for helping users in effectively searching and locating task-relevant information elements while coping with large amounts of information in learning and problem solving.

Visualizations of knowledge and information are widely applied in the fields of education and knowledge management to help users in processing, getting access, and dealing effectively with complex knowledge and large amounts of information. Although visualization has been proven to be an effective strategy for supporting users in coping with complexity in knowledge- and information-rich scenarios, knowledge and information visualization have historically been treated as two distinct areas of research, each being developed independently from the other. Whereas knowledge visualization has its origin in the social sciences, particularly in the field of learning and instructional science, information visualization primarily belongs to the field of computer science.

This situation of two research domains developing independently, but nonetheless being heavily interrelated in processes of working, learning, and problem solving, motivated the authors to ask leading edge researchers of both domains to contribute to this book. The authors were challenged to elaborate on their personal view of knowledge visualization and information visualization. At the same time, they were inspired to combine views and approaches from both domains and to look for synergies to enhance cognitive processing and knowledge and information in knowledge- and information-rich scenarios by means of visualization. The idea for this book is based on the rationale and results of the International Workshop on Visual Artifacts for the Organization of Information and Knowledge, which was held at the Knowledge Media Research Center (http://www.iwm-kmrc.de/) in Tübingen in May 2004. The workshop was intended to bring together researchers from both fields knowledge visualization and information visualization - to think about potential synergies by integrating ideas and approaches and to initiate a discussion on synergistic approaches. Selected participants of this workshop as well as renowned international visualization researchers have been invited to contribute to this book. It is hoped that these presentations will contribute to a mutual understanding of the research questions, the common interests, and to an advancement in both the conceptualization and development of synergistic approaches that may improve visualization practices in fields like education and knowledge management.

In the following introductory chapter, the most important concepts referred to in this book are defined. A conceptual rationale is provided detailing why visualization may be effective in fostering the processing and management of knowledge and information. The basic ideas underlying knowledge visualization and information visualization are outlined. In a short preview of the contributions of this volume, the idea behind each approach and its contribution to the goals of the book are outlined.

2 The Basic Concepts of the Book

Three basic concepts are the focus of this book: "data", "information", and "knowledge". There have been numerous attempts to define the terms "data", "information", and "knowledge", among them, the OTEC Homepage "Data, Information, Knowledge, and Wisdom" (Bellinger, Castro, & Mills, see http://www.systems-thinking.org/dikw/dikw.htm):

Data are raw. They are symbols or isolated and non-interpreted facts. Data represent a fact or statement of event without any relation to other data. Data simply exists and has no significance beyond its existence (in and of itself). It can exist in any form, usable or not. It does not have meaning of itself.

Information is data that has been given meaning through interpretation by way of relational connection and pragmatic context. This "meaning" can be useful, but does not have to be. Information is the same only for those people who attribute to it the same meaning. Information provides answers to "who", "what", "where", "why", or "when" questions. From there, data that has been given meaning by somebody and, hence, has become information, may still be data for others who do not comprehend its meaning. Information may be distinguished according to different categories concerning, for instance, its features, origin, status of cognitive manipulation, or format, for example, "facts", "opinions" (present some kind of analysis of the facts), "objective information" (are usually based on facts), "subjective information" (presents some kind of cognitive analysis of the facts), "primary information" (is information in its original form), "secondary information" (is information that has been analyzed, interpreted, translated, or examined in some way). Information may also be distinguished according to its representational format, for example, verbal, print, visual, or audio-visual. Web-based information is often represented in a mixture of different codes and presented in different modes catering to different senses. Information may be abstract or concrete. In the context of information visualization, abstract non-physically based information with no natural visual representation is in focus. Most articles in this book focus on abstract non-physically based information for the representation of subject matter as potential resources to be used in working and instructional scenarios.

Knowledge is information, which has been cognitively processed and integrated into an existing human knowledge structure. Knowledge is dynamic. Its structure is constantly being changed and adapted to the affordances in coping with task situations. The most important difference between information and knowledge is that information is outside the brain (sometimes called "knowledge in the world") and knowledge is inside. Cognition may be based both on "knowledge in the head" and "knowledge in the world." Knowledge in the head refers to different types of knowledge that are represented in different representational patterns (Rumelhart & Ortony, 1977). Knowledge in the world may be both (1) external representations reflecting aspects of knowledge in the head and (2) cultural and cognitive artefacts appearing as sensory stimuli and perceptual inputs, which are automatically processed and interpreted by the cognitive system in terms of knowledge. Knowledge is owned by a person, a group of persons, or by society. Aspects of knowledge may be externalized, for example, its structure by means of structure visualizations. For other people, externalized knowledge is nothing but information. To become knowledge, it has to be processed, furnished with meaning, and integrated into their mental knowledge structure. Even people owning the externalized knowledge have to reconstruct its meaning and reintegrate it into an existing mental structure according to the affordances of a particular task (Bransford, 1979). Based on knowledge, answering "how"-questions is possible. If knowledge is used for synthesizing new knowledge from the previously held knowledge, understanding may result. Understanding builds upon currently held information, knowledge, and understanding itself. Based on understanding, "why"-questions may be answered.

There is one major distinction between knowledge types referring to the cognitive accessibility of knowledge: knowledge may be explicit or tacit. Explicit knowledge can be expressed either symbolically, e.g. in words or numbers, or pictorially, and can be shared in the form of data, scientific formulas, product specifications, visualizations, manuals, universal principles, and so forth. This kind of knowledge can be readily transmitted among individuals, formally and systematically. Tacit knowledge is highly personal and hard to formalize, making it difficult to communicate or share with others. Subjective insights, intuitions, and hunches fall into this category of knowledge. It consists of beliefs, perceptions, ideals, values, emotions, and mental models. Furthermore, tacit knowledge is deeply rooted in an individual's action and experience (Edvinsson & Malone, 1997).

Cognitive scientists (a.o. Rumelhart & Norman, 1983) discriminate between different aspects of domain knowledge: conceptual knowledge (propositional representation of abstract concepts and their semantic relation), episodic knowledge (mental representation of audio-visual perceptions of realistic events, situations, objects), analogical representations (mental models, images that preserve structures of realistic subject matter in an analogical manner), procedural knowledge (represented as condition-action pairs), enactive knowledge (knowledge, which is bound to the action to be performed), and situated knowledge. Situated knowledge is related to and embedded into a socio-cultural context of everyday activities. Knowledge is termed "situated" if it takes account of the social interaction and physical activity in the learning situation where the knowledge was acquired. The importance of learning episodes within everyday work for acquiring knowledge in communities of practice has been noted by Jean Lave and Etienne Wenger (Lave & Wenger, 1991). Recently, it has been suggested that knowledge may not be restricted to "know-what" and "know-how" but has to be supplemented with "know-where" (Siemens, 2005). Know-where means the understanding of where to find knowledge. This notion of know-where is tantamount to the notion of resource knowledge, the knowledge of where to find information, which may be used as a knowledge resource (Tergan, in this book). Most of the contributions of this book dealing with knowledge visualization focus on structures of conceptual knowledge. However, some authors also address episodic, situational, and analogical knowledge (e.g. Alpert, Cañas et al., Coffey, Tergan, in this book).

3 Why Visualization?

Visualizations of knowledge and information may play an important role as methods and tools. One central reason is that visualizations capitalize on several characteristic features of the human cognitive processing system. According to Ware (in this book), the "power of a visualization comes from the fact that it is possible to have a far more complex concept structure represented externally in a visual display than can be held in visual and verbal working memories". In this regard, visualizations are cognitive tools aiming at supporting the cognitive system of the user. Visualizations can make use of the automatically human process of pattern finding (Ware, 2004). They can draw both on the visual and the spatial working memory system (Baddeley, 1998; Logie, 1995). It is suggested that using multiple codes involves cognitive processing in different subsystems of the human working memory and therefore supports processes of learning (Mayer, 2001). External representations visualizing inherent structures of an individual's knowledge and of great amounts of information can help people in the searching and cognitive processing of the structured elements (Potelle & Rouet, in this book; Wiegmann, Dansereau, McCagg, Rewey & Pitre, 1992).

During the process of learning and problem solving, a visualization may help the learner overcome problems that are due to the limitations of working memory in both capacity and duration of stored information. Thus, visualizations may reduce cognitive load (Sweller & Chandler, 1994) and expand the capability of an individual's memory for coping with complex cognitive task requirements (Cox & Brna, 1995; Larkin, 1989; Larkin & Simon, 1987). Combining a computer-based information system with flexible human cognitive capabilities, such as pattern finding, and using a visualization as the interface between the two is far more powerful than an unaided human cognitive process (Ware, in this book). In an educational context, learner-generated visualizations may foster constructive cognitive processing and visuo-spatial strategies (Holley & Dansereau, 1984). This is particularly true for students preferring a visual instead of a verbal learning strategy (Dansereau, in this book).

A further reason why visualizations may help users in processing the visualized elements is suggested by Cox (1999). Visualizations can enhance our processing ability by visualizing abstract relationships between visualized elements and may serve as a basis for externalized cognition (Scaife & Rogers, 1996; Cox, 1999). External representations may also help in "computational offloading" (Rogers & Scaife, 1997). Compared with an informationally-equivalent textual description of an information a diagram may allow users to avoid having to explicitly compute information because users can extract information 'at a glance' (p. 2). "Such representations work best when the spatial constraints obeyed by representations map into important constraints in the represented domain in such a way that they restrict (or enforce) the kinds of interpretations that can be made" (Rogers & Scaife, 1997, p. 2). They can help to exploit the rapid processing capabilities of the human visual system and very easy perceptual judgements are substituted for more difficult logical ones (Paige & Simon, 1966). Thus, external representations can expand the capability of an individual's memory for coping with complex cognitive task requirements (Larkin, 1989). However, particularly with complex subject matter, a visualization alone may not provide sufficient clues for users in sense-making. Often, visual semantics must be augmented with verbal clues to help users fully exploit the meaning of a visualization (Sebrechts, in this book) and use it in an educational context (Keller & Grimm, in this book).

In many cases it is reasonably to assume advantages from using visualizations because of a 'distributed' representation, the internal and external being coordinated in an 'abstract problem space' (Zhang & Norman, 1994). Chabris and Kosslyn (in this book) suggest the principle of 'representational correspondence' as a basic principle of effective diagram design. According to this principle visualizations work best if they depict information in the same way that our internal mental representation do.

3.1 The Idea of Knowledge Visualization

Spatial strategies are needed to help individuals in acquiring, storing, restructuring, communicating, and utilizing knowledge and knowledge resources, as well as overcoming capacity limitations of individual working memory (Holley & Dansereau, 1984; Novak & Gowin, 1984). In order to cope effectively with complex cognitive task requirements, techniques for the external representation of individual knowledge in a visual-spatial format are suggested to facilitate "the coherent representation of new information in semantic memory" (Holley & Dansereau, 1984, p. 14) and acquiring and conveying structural knowledge (Jonassen, Beissner & Yacci, 1993). Helping students to organize their knowledge is as important as the knowledge itself, since knowledge organization is likely to affect student's intellectual performance (Bransford, Brown & Cocking, 1999). Knowledge visualization may help students to organize and reorganize, structure and restructure, assess, evaluate, elaborate, communicate, and (co-)construct knowledge, and to utilize ideas and thoughts, as well as knowledge, about relevant contents and resources (Holley & Dansereau, 1984; Jonassen, Beissner & Yacci, 1993; Tergan, 2003).

Visual external representations of knowledge are often processed more effectively than propositional ones because they "support a large number of perceptual inferences, which are extremely easy for humans" (Larkin & Simon, 1987, p. 88). In mapping approaches, this is accomplished, for example, by means of the spatial layout and highlighting of elements signifying contextual relationships and their relative importance. Spatial representations are often directly related to spatial mental processes, for example, in mathematics and physics (Larkin, 1983; Young & O'Shea, 1981). In this way, visualizations play an important role in "external cognition" during problem solving (Larkin, 1989; Scaife & Rogers, 1996). As Zhang (1997) points out, externalization is beneficial if the cost associated with the externalization process is outweighed by the benefits of using the external representation.

Jonassen (1991) and Jonassen et al. (1993) have described a variety of visualization methods for fostering spatial learning strategies and technologies used for the visualization of knowledge. The most often used methods are mind mapping and concept mapping methods. Mind maps were suggested as a spatial strategy that uses only key words and images to aid students in structuring ideas and taking notes (Buzan, 1995). Visualizations of knowledge based on concept mapping technology may be used for mapping, managing, and manipulating conceptual knowledge (Cañas, Leake & Wilson, 1999). Tergan (2003; in this book) outlines a conceptual model for the implementation of digital concept maps as tools for managing knowledge and information resources.

According to Dansereau, the concept of "knowledge visualization" in a strict sense is restricted to externalizing aspects of knowledge by the individual herself or himself in a "freestyle mapping mode" (Dansereau, in this book). In literature, the term "knowledge visualization" is, however, also used if a knowledge structure of an expert is presented to students as a means for self-assessing knowledge and for aiding comprehension and navigation. Up to now, "knowledge visualization" has been focused on structures of conceptual knowledge. Knowledge visualization methods in the educational context have been used for fostering idea generation, learning, assessment, and instruction. Reviews on the effectiveness of concept mapping have been published a.o. by Bruillard and Baron (2000), Jonassen et al. (1993), and O'Donnell, Dansereau and Hall (2002). The results of empirical research provide evidence that concept mapping bears a high potential in fostering "external cognition" (Scaife & Rogers, 1996) depending on the task requirements, the domain knowledge of the users, and their spatial learning literacy.

We will use the term "knowledge visualization" with a focus on structure visualizations for the representation of conceptual knowledge. Some authors also address the problem of how subject matter knowledge (like episodic knowledge, images, and analogical representations, as well as resource knowledge) is related to conceptual knowledge, and how different knowledge elements may be integrated into a structure visualization in a coherent manner (e.g. Alpert, 2003, in this book; Tergan, in this book). Except for the technologies used for visualization, knowledge visualization differs from information visualization in a variety of aspects, as, for example, goals, benefits, content, or recipients, which are described in more detail by Burkhard (in this book).

3.2 The Idea of Information Visualization

According to the literature, the term "information visualization" is referred to in a variety of contexts of meaning. In general, psychologists use the term to signify a representational mode (as opposed to verbal descriptions of subject-matter content) used to illustrate in a visual-spatial manner, for example, objects, dynamic systems, events, processes, and procedures. In this regard, the term "information visualization" is an umbrella term for all kinds of visualizations. Here, the term is used in the context of processing, comprehension, and retention of information in static, animated, dynamic, and interactive graphics (Ploetzner & Lowe, 2004; Schnotz, Picard & Hron, 1993). However, computer scientists define the term in a more narrow sense and referred to it as "the use of computer-supported, interactive, visual representation of abstract non-physically based data to amplify cognition" (Card, Mackinlay & Shneiderman, 1999, p. 6). In computer science, information visualization is a specific technology. According to Carr (1999), information visualization of abstract data is of particular importance for information retrieval if the underlying data set is very large (e.g. like in the case of searching for information on the World Wide Web) and the goals of the user with regard to information retrieval are not easily quantifiable. Research in this context refers to information visualization as a technology for fostering the recognition of structures in abstract data and supporting information retrieval.

The articles in this book dealing with the topic of information visualization mainly focus on the notion of information visualization in terms of computer science, that is, as a technology for visualizing abstract data structures. The term "information visualization" as a technology for visualizing abstract data structures can be traced back to the Xerox Palo Alto Research Center in Palo Alto (USA) at the beginning of the nineties (cf. Däßler & Palm, 1998). Since then, information visualization has become an autonomous research field in information science and is growing increasingly important (Schumann & Müller, 2004). Endeavors in information visualization generally aim at facilitating the utilization of the information included (Card et al., 1999).

According to Shneiderman (1996), the type of information visualization depends on both the underlying data type and the demands of the users. In his *task by data type taxonomy,* he differentiates between both seven data types and seven tasks. With regard to the data types, he differentiates between one-dimensional, two-dimensional, three-dimensional, temporal, multi-dimensional, tree, and network data. With respect to the tasks that an information visualization has to support, he differentiates between overview, zoom, filter, details-on-demand, relate, history, and extract (see Jäschke, Leissler & Hemmje, in this book, for an overview of the classifications of information visualizations).

Up to now, information visualizations had been developed for utilization by an individual. However, there is a current trend toward collaborative information visualizations (e.g. Mark, Carpenter, & Kobsa, 2003; Mark, Kobsa & Gonzalez, 2002). As to empirical research, there is a current trend toward usability research, a research field, which had not attracted much attention in the past (cf. Schuhmann & Müller, 2004).

4 Shortcomings

From a representational perspective, knowledge visualization and information visualization in the sense of Card et al. (1999) have one feature in common: They aim at *visualizing structures*. The structures refer to either elements of knowledge or information. Both research domains - information visualization and knowledge visualization - have reached high technological standards and offer a variety of useful applications in different working, learning, and problem solving scenarios. However, there are still shortcomings in visualizing information and knowledge. The shortcomings refer to insufficiencies inherent in the single approaches.

4.1 Shortcomings in Knowledge Visualization

Shortcomings in knowledge visualization relate to representational facilities of the visualization tools. In the following we will concentrate on concept maps. In reviewing the potential of concept mapping tools for the representation of knowledge, Alpert and Gruenenberg (2001) ascertain that "existing concept mapping tools are, indeed, very good at visually representing propositional statements - but not necessarily other forms of information in people's heads". Concept maps "are rooted solely in a propositional knowledge representation scheme in which concepts are often described by verbal means alone via textual labels" (Alpert & Gruenenberg, 2001, p. 316). In effect, focusing on conceptual knowledge is a leftover concept of traditional approaches when concept maps were used for visualizing conceptual structures inherent in texts (see Novak & Gowin, 1984; Jonassen et al., 1993). Content knowledge is fully repre-