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 represented with an abstracted knowledge layer. The restriction on mapping conceptual knowledge only conflicts with cognitive theories of information processing and mental representation of knowledge, stressing that knowledge in the head is also coded non-verbally, including visual imagery, analogous representations, sounds, and other sensory information (Kosslyn, 1980; Johnson-Laird, 1983; Baddeley, 1985; Paivio, 1986; Chabris & Kosslyn, in this book).

Due to the shortcoming of traditional concept maps in also representing visual elements of an individual's domain knowledge, there is a "need for imagery-based elements in conceptual maps if we wish to more comprehensively represent one's knowledge of a domain, or use maps to convey new information to (the) learner" (Alpert & Gruenenberg, 2000, p. 316). "The ability to incorporate static and dynamic imagery, as well as sound, in knowledge maps also allows users to portray concrete instances of concepts, adding significantly to the representational and instructional potential of such maps." "When used as a knowledge elicitation tool, wherein students create their own maps to demonstrate their knowledge of a domain, showing their knowledge of examples of a concept provides a more elaborated and complete representation of the student's knowledge of a domain" (Alpert & Gruenenberg, 2000, p. 318).

Another representational shortcoming of traditional concept maps is pointed out by Siemens. He suggests 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 in resource-based learning (Neumann, Graeber, & Tergan, in this book; Tergan, in this book).

With the help of digital concept maps the representation of "know-where" knowledge as well as the representation of the respective information as a potential knowledge resource is no longer a problem. Knowing where to find information relevant for a concept may be represented by means of interactive links leading the user to the information which is associated with a particular concept (Cañas, Carff, Hill, Carvalho, Arguedas, Eskridge, Lott & Carvajal, in this book). For example Coffey (in this book) outlines how digital concept maps could be used for both the representation of knowledge by visualizing different types of knowledge, the semantic relations of concepts, as well as for the information related to the concepts, by linking a concept the information to the concepts, which are used to describe the abstract information structure. It is this functionality of concept maps, which is the focus of contributions aiming at using digital concept maps as the main vehicle for the storage of information in a repository for providing easy access (Weideman & Kritzinger, 2003) and suggesting concept maps as cognitive tools for the management of knowledge and information (Tergan, in this book).

There is another shortcoming of concept maps referring to representational features. Traditional concept maps have been used to describe, define and organize static knowledge for a given domain. The representation of dynamic relationships between concepts was not possible because of the predominance of hierarchical and static relations used for mapping. Hence, for any two concepts how the change in one concept affects the other concept could not be represented. This representational shortcoming prevents concept maps from being used for visualizing for example scientific knowledge, which is based on both static and dynamic relationships among concepts. Only recently Safayeni, Derbentseva & Cañas, in press) suggest cyclic concept maps for representing dynamic relations and hybrid maps for representing both the concept map and the cyclic concept map portion of a knowledge representation in an aggregated map.

Shortcomings of traditional paper and pencil concept maps also refer to usability features. Only computerized concept-mapping tools provide typical office-software usability facilities, e.g. free editing to be used for (re)constructing, (re)organizing, and (re)representing mapped knowledge. They allow for storing, printing, representation in different formats (outline, graphic), e-mailing and web-implementation of concept maps in html format. Only digital concept mapping tools provide facilities suited for the above mentioned kinds of use (Alpert, Cañas et al., Coffey, in this book). These tools are increasingly applied for supporting individuals in navigating databases, communicating ideas and collaborative learning. Many of these tools also offer facilities to represent multiple coded subject matter content knowledge in a map (e.g. text, sketches, diagrams, audio, and video). They make information stored on a PC, in a digital library, and on WWW-servers accessible by means of hyperlinking concepts and information (see Alpert; Cañas et al.; Coffey, in this book). Mapping tools used in this way fulfill requirements necessary for coping effectively with knowledge and information in contexts of knowledge management and may overcome shortcomings inherent in traditional technologies when used in resource-based learning and working scenarios (Cañas, Leake & Wilson, 1999; Dansereau, in this book; Tergan, 2003; in this book).

4.2 Shortcomings in Information Visualization

Shortcomings in information visualization relate to both the technical facilities used for visualizing features inherent to large data structures and the rationale for also taking into account the knowledge needed for making sense of an information visualization. As to the visualization of data structures there are some basic problems: Information visualizations cannot compensate for a deficient data structure with a well-designed visualization (Däßler, 1999). Therefore, information visualizations require well-prepared and well-structured data. Due to the fact that - contrary to hierarchical data structures – network data structures do not have a simple structure, the visualization of this data is still very difficult.

In addition, the visualization of very large data sets is still difficult, as well (e.g. Herman, Melançon & Marshall, 2000). The difficulty is that a computer display is limited in its size. Due to this limitation, it is difficult to visualize a large data set in such a manner that the user can perceive all data elements and can understand the data structure. For an efficient utilization of data included in the visualizations, an understanding of the user with regard to the information visualizations is important. In general, it has to be remarked that it is a big challenge for developers of information visualizations to find a well-suited metaphor or abstraction for a visualization of the abstract data (Le Grand & Soto, 1999), because the metaphor or the abstraction have to map the correct data structure, as well as convey the correct meaning of the data to the users.

Another shortcoming of information visualizations refers to technical problems in information presentation. Due to the limited size of the computer display and on account of the limitations of representing structures of information in a two-dimensional space only, there is a trend in computer science to develop information visualizations that use three dimensions for data representation (cf. Wiss & Carr, 1998). There are a lot of ambitious approaches to advancing information visualization. There is, however, a lack of empirical research showing the advantages of highly sophisticated information visualization approaches. For example, research results are lacking showing an advantage of the inclusion of a third spatial dimension for users (Cockburn & McKenzie, 2001; Hicks, O'Malley, Nichols & Anderson, 2003; Keller & Grimm, in this book). There are different reasons for this, among others, that it is hard to navigate in three-dimensional information visualizations, because three-dimensional information visualizations cause more orientation demands (Keller & Grimm, in this book).

A general shortcoming is that, up to now, mainly technical issues have been the focus of discussion. The prerequisites of the user for dealing adequately with information visualizations and making sense of visualizations have not gained much attention in the past. It is important to develop new technologies in alignment with the changing demands of the user, because the user is the one who has to interact with the information visualizations. Therefore, it is necessary to include the experience and know-how of more user-oriented sciences, like Psychology. According to Marshall (2001), information visualizations often lack comprehensibility. Generally, it is necessary to include textual elements in information visualizations to enhance visual semantics (Sebrechts, in this book) and to assure understanding, because symbols or other graphical object attributes could not mirror the complexity of the data units underlying an information visualization. Without textual additions, the users may have difficulties in getting the correct meaning of the data included. However, reading of texts in graphical displays is difficult for users (Däßler, 1999). As a result, it is important in the context of developing information visualizations to find a suitable trade-off with regard to the amount of textual elements included in the information visualization, because too many textual elements will cause too much extraneous cognitive load for information processing and too few textual additions may cause misunderstandings.

5 Need for Synergistic Approaches

The idea behind all visualization methods is that orientation, visual search, and cognitive processing of complex subject matter may be enhanced if structures behind ideas, knowledge, and information, as well as their relevance for coping with a particular task, are made explicit. Researchers in the fields of information visualization and knowledge visualization are trying to develop and use tools for fostering access to information and knowledge resources. Although there is a common interest in facilitating content accessibility and making sense of represented knowledge and information elements by developing visual artefacts, there are hardly any attempts to search for synergies for enhancing learning. Today, the possibilities inherent in knowledge visualization by means of modern digital mapping tools are still unused in the context of teaching and learning and their potential still uncovered. There is a need for a systematic investigation of their potential, for both supporting self-controlled learning and facilitating individual organization, representation and localization, as well as the use of knowledge and knowledge resources, in self-regulated, resource-based studying and problem solving.

One focus of information visualization and knowledge visualization is to organize information and knowledge in such a way that it may be accessed easily and comprehensively. Up to now, both research approaches have investigated the question of visualization from different perspectives. However, there are some common interests, so that synergy effects can be expected. Synergy effects may result with respect to the user-centeredness of visualizations. For example, both research approaches are concerned with questions of information visualization in the new field of dynamic-interactive visualizations. They both use comparable techniques and methods of visualization and aim to support visual searching, localization, and individual utilization with concise, psychologically reasonable, and functional visualizations. Therefore, they both have to focus on psychological questions of design and utilization of visualizations. Furthermore, synergy effects may be expected with respect to the kind of visualizations used. Information visualization focuses on two-dimensional, as well as three-dimensional (or multi-dimensional), visualizations, whereas knowledge visualization restricts itself mainly to two-dimensional visualizations. However, for knowledge visualizations, there is a current trend to integrate representations of concept knowledge, content knowledge and resource knowledge. Thus, multi-dimensional representations and visualizations of knowledge may sometimes be appropriate. As far as information visualization is concerned, the consideration of knowledge mapping as an add-on or integral part of information visualization may be envisaged as a possible way out (cf. Novak & Wurst, Burkhard, in this book).

This book will contain contributions that focus from different perspectives on how synergy effects may be attained. Starting with contributions, which outline theoretical background information, two perspectives of visualizations are addressed in two coherently interrelated chapters dealing with developments and research on knowledge and information visualization. Synergistic approaches are then presented. These approaches aim at integrating knowledge and information visualization in a coherent manner. We discriminate two kinds of approaches, dealing with visualizations of knowledge and information for fostering learning and instruction on the one hand, and visualizations of knowledge-oriented information organization for fostering information use on the other.

It is our intention that research and development in the field of knowledge and information visualization will get new impulses and the contributions may push the borders of what is feasible now and applicable in resource-based learning scenarios of the future.

6 Preview of the Contributions

Contributions outlining theoretical background information. There are two contributions outlining theoretical background information concerning cognitive processing of visualizations.

In his contribution titled "Visual Queries. The foundation of visual thinking", Colin **Ware** outlines basic insights concerning perceptual processing of visualizations. He presents a model of visual thinking based on current theories of visual perception. The basic assumption of Ware is that humans do not have a visual model of the world in their heads. He claims that with some problems, the solution could be found within the problem itself, and that it is up to visual queries and processes of pattern matching to find elements relevant for solving a problem. In his contribution, Ware provides a theoretical grounding for most of the contributions of this book. Due to the fact that visual pattern matching can be faster and more effective than queries to assess data in the brain, visualizations are suggested to enhance cognitive processing. The position of Ware is very much in accordance with a view of ecological psychology held by Zhang (1997) and the position of Jonassen (in this book), who argue that mental problem representations should be made explicit and be visualized, so that processes of pattern finding may apply. In his approach, Ware outlines insights of research into visual working memory, which has focused on simple geometric objects. This is why in order to receive universal validity, the assumptions have to be validated, also for knowledge-rich problems demanding conceptual background knowledge and a problem representation in a problem solver's head (Reinmann & Chi, 1989; Scaife & Rogers, 1996). In their contribution titled "Representational Correspondence as a Basic Principle of Diagram Design", Christopher F. **Chabris** and Stephen M. **Kosslyn** focus on the question "What qualities make a diagram an effective and efficient conduit of information to the human mind?". The authors argue that the best diagrams depict information the same way that our internal mental representations do. They discuss several examples that illustrate this "Representational Correspondence Principle" as a central principle for visual thinking and consider its implications for the design of systems that use diagrams to represent abstract, conceptual knowledge, such as concept networks, social networks, chess diagrams, or web content hierarchies. The basic assumption that there are "visual images in the brain" reflects results of empirical research. However, it does contradict the assumptions of Ware. Thus, the contribution of Chabris and Kosslyn opens up a principled discussion on the characteristics of visual thinking and the level of cognitive processes involved in processing and using visual representations, which is a central topic that draws through all the articles in this book.

Contributions with a focus on knowledge visualization. Three approaches give an overview of how the concept mapping approach, as a knowledge visualization approach, may be applied for fostering knowledge-based cognitive processing in different contexts.

In his article on "node-link mapping principles for visualizing knowledge and information", Donald **Dansereau** describes the Texas Christian University Node-Link Mapping (TCU-NLM) system, and traces its empirical and applied history from 1972 to the present. The TCU approach is an extension of the traditional concept mapping approach aimed at visualizing knowledge. Concept maps are used to represent a person's (a user's/learner's, or an expert's) structure of ideas, thoughts, concepts, and content knowledge about a domain in a visual-spatial format. The terms "information visualization" and "knowledge visualization" in the TCU approach are used to discriminate different kinds of maps from the perspective of the users/learners. The term "information" refers to data, which are presented to the users'/learners' as external stimuli, which have not yet been cognitively processed more deeply and integrated into the users'/learners' knowledge structure. This meaning is different from the information visualization approach and its focus on the visualization of structures inherent in abstract data.

The focus of David **Jonassen**'s paper - titled "Tools for representing problems and knowledge required to solve them" - is on cognitive tools, which may be used to help learners in solving ill-structured problems and to transfer knowledge to different problems. According to Jonassen, problem solving may be fostered when both the relation between information that is inherent in a problem statement and the knowledge needed to make sense of it, is made explicit by using problem representations. The author distinguishes three types of problem representations: semantic network tools (concept maps), production rule models for representing procedural knowledge, and system modeling tools. The problem representation tools share a common characteristic: they simultaneously represent the information inherent in the problem and the particular background knowledge needed for applying a problem solving procedure appropriately. The term "information" refers to conditions, objects, or relations inherent in a situation, for example, in a problem statement. Abstract data, examples of similar problems, and problem solutions, etc., are not referenced. Jonassen argues that once visualized, information from problem representations can be perceived directly from the problem without mediation from memory, inference, or other cognitive processes. With this argumentation, Jonassen is very much in accordance with the position of Ware (in this book), who focuses on pattern matching as a central perceptual process in dealing with visualizations.

In their paper titled "Collaborative knowledge visualization for cross-community learning", Jasminko **Novak** and Michael **Wurst** describe the conceptual rationale and a prototypical realization of a sophisticated knowledge visualization approach aimed at enabling knowledge exchange between heterogeneous communities of practice. The authors discuss a concrete knowledge visualization model and describe its prototypical realization in the Knowledge Explorer. The Knowledge Explorer is an interactive, semi-intelligent, agent-based tool for both supporting users in generating and using personal and collaborative knowledge maps, as well as sharing knowledge between heterogeneous communities with multiple knowledge contexts and "thought worlds". The authors outline and implement ideas of a synergistic approach. Their conceptual model of a knowledge-based approach of sense-making, structuring, accessing, evaluating and sharing content knowledge and information resources satisfies the discrimination requirement between different aspects of knowledge made in the first part of this article. It also satisfies many features of a concept map-based approach of managing knowledge and information (Tergan, in this book).

Contributions with a focus on information visualizations. The following three contributions focus on information visualization. They give the reader an impression of ongoing research. Some authors also address the question of how knowledge visualizations may complement an information visualization approach.

In the contribution of Gerald **Jäschke**, Martin **Leissler**, and Matthias **Hemmje** titled "Modeling Interactive, 3-Dimensional Information Visualizations Supporting Information Seeking Behaviors", a very convincing approach for the topic of this book is developed: Based on the analysis of the differences and similarities of information visualization and knowledge visualization, the authors derive an idea of how to bring both techniques together. They developed the IKVML – information and knowledge visualization modeling language that is an extension of IVML, an information visualization modeling language. This language is a formal and declarative language for describing and defining techniques of information visualization. It provides "a means to formally represent, note, preserve, and communicate structure, appearance, behaviour, and functionality of information visualization techniques and their applications in a standardized way". In their contribution, they also explain the roots, the development, as well as the specifics of IVML, and outline the application of I(K)VML for educational scenarios.

The contribution of Marc **Sebrechts** titled "Visualizing Information in Virtual Space - Prospects and Pitfalls" discusses the potential advantages and disadvantages of using virtual realities to represent either information visualizations or knowledge visualizations. After an introduction to virtual realities (VR) as visualization tools, he presents different empirical evidence concerning the specific reasons for the benefits of these virtual reality systems for visualization. VR provides a model for learning, in which the target knowledge can be presented by interactive modification of the visualization, as well as integration of non-visual material. Sebrechts discusses the kinds of interactions that are possible with virtual realities and that could be applied to learning scenarios in information visualizations and knowledge visualizations. He presents NIRVE, an information retrieval visualization engine that combines a visual aspect (i.e., dimensional layout) referring to information visualization, as well as a conceptual aspect (i.e., grouping of terms into concepts) referring to knowledge visualization. Sebrechts doubts the general adequacy of pure visual semantics for making sense of information visualizations. He claims that sometimes the incorporation of non-visual, textual semantics in VR may be necessary.

In the contribution of Tanja **Keller** and Matthias **Grimm** titled "The Impact of Dimensionality and Color Coding of Information Visualizations on Knowledge Acquisition", a new application field for information visualizations is discussed. The authors investigated in an experimental study whether and under which conditions, with regard to the factors dimensionality and color coding, information visualizations are suited to support processes of knowledge acquisition in the sense of memorizing and understanding large sets of abstract data and their structures. They could in fact show that some kinds of information visualizations are able to foster knowledge acquisition. With their approach, they take leave of the traditional use of information visualizations for information access and information exploration only. Their approach to information visualizations converges to the learning context that is also the frame of reference for knowledge visualizations. The authors try to outline how information visualizations for knowledge acquisition could benefit from the field of knowledge visualizations.

Synergistic approaches. The synergistic approaches aim at integrating knowledge and information visualization in a coherent approach. Two kinds of approaches may be discriminated:

- Visualization of knowledge and information for fostering learning and instruction
- Visualization of knowledge-oriented information organization for fostering information use

The approaches aiming at *visualizing knowledge and information for fostering learning and instruction* are mainly based on concept mapping technology. Information is conceived as a knowledge resource and associated with the conceptual knowledge represented in the map. In general, information has been pre-selected from a broad range of resources, for example, stored on the Web, on the PC, or in a digital library, and has been evaluated as relevant for backing, verifying, elaborating, and extending the meaning of a particular concept. The map is functioning as a personal repository that has been constructed for facilitating visual search and access to knowledge elements and associated resources. Concept maps in approaches for *knowledge-oriented information organization for fostering information use* focus on a spatial structuring of information elements. They may serve as a developmental aid for course designers or as an information basis for students engaged in self-regulated learning in a resource-based learning environment (Rakes, 1996). Concept maps functioning as organizational tools may also be used as navigational aids for fostering knowledge-based use by providing facilities for the visual search of documents in broad information repositories, for example, the World Wide Web, digital libraries, or hypermedia environments.

Visualization of knowledge and information for fostering learning and instruction. The contribution of Sigmar-Olaf **Tergan** titled "Digital concept maps for managing knowledge and information" aims to open up a new perspective of using concept maps in educational scenarios. The potential of digital concept maps for supporting processes of individual knowledge management is analyzed. The author suggests digital concept mapping as a visual-spatial strategy for supporting externalized cognition in resource-based learning and problem solving scenarios (Rakes, 1996). In fact, many of the contributions of this book, dealing with cognitive demands inherent in a variety of educational, social, and workplace scenarios, refer explicitly to concept maps as a means for bridging the gap between knowledge visualization and information visualization (see the contributions of Alpert, Cañas, Carff, Hill, Carvalho, Arguedas, Eskridge, Lott, & Carvajal Coffey, Dansereau, Novak & Wurst, Fiedler & Sharma). A conceptual model of concept map-based representation and access of domain knowledge and related information is outlined. Based on the model, Tergan analyzes the particular contribution digital concepts maps would have for the processes of knowledge management outlined in the model. The paper is meant as a conceptual framework for synergistic approaches aiming at integrating both knowledge and information in a coherent visualization approach.

In their contribution titled "Concept maps: Integrating knowledge and information visualization", Alberto **Cañas,** Roger Carff, Greg Hill, Marco Carvalho, Marco Arguedas, Thomas C. Eskridge, James Lott, & Rodrigo Carvajal outline in detail the IHMC CmapTools approach. Conceptual knowledge represented in a Cmap may be linked with content knowledge and information resources coded as text, images, sound clips, or videos accessible in personal or public repositories. In CmapTools, the use of concept maps has been extended beyond knowledge representation to serve as a browsing interface to a domain of knowledge and associated information. The authors outline special features of the approach for integrating, making accessible, and using knowledge and information. The basics of the CmapTools approach of Cañas and associates are very much in accordance with the conception of using concept maps used for purposes of managing knowledge and information (see Tergan, in this book). The rationale for knowledge visualization resembles the rationale of Webster, a concept mapping tool described by Alpert (in this book). CmapTools in general is a powerful software package with facilities that make the tool attractive not only for knowledge visualization, but also for information visualization approaches looking for supplements for aiding users in sense-making. Its facilities also make it attractive as a tool for incorporating synergistic approaches integrating both knowledge and information visualization (see Coffey, as well as Ware, in this book).

In his contribution titled "Comprehensive mapping of knowledge and information resources: The case of Webster", Sherman **Alpert** describes a computer-based concept mapping tool aimed at both tapping the full potential of the representational capabilities of digital concept maps, as well as satisfying psychological and pedagogical requirements for a more comprehensive representation of knowledge and information associated with it. The paper proposes a cognitive and educational rationale for the hypothesis that traditional concept maps fall short with respect to representing knowledge comprehensively, because they focus on abstract conceptual knowledge only, leaving content knowledge and associated information unconsidered. The author presents Webster, a Web-based concept mapping tool that permits broad flexibility in terms of the kinds of knowledge and information that may be represented, as well as the codes and modes used for representation. The approach fits well with the rationale of the book. It is an implementation of the idea of bringing together knowledge and information visualization into one single visualization approach. In addition, it draws attention to the fact that human knowledge is more comprehensive than conceptual knowledge, which has long been neglected, not least because of lacking facilities for representing content knowledge and resources associated with it. The rationale of Webster has many features in common with the IHMC CmapTools approach presented by Cañas (in this book) and ideas concerning the integration of knowledge and information in a synergistic manner as outlined by Tergan (in this book).

In his article titled "Towards a Framework and a Model for Knowledge Visualization: Synergies between Information and Knowledge Visualization", Remo **Burkhard** examines the research areas information and knowledge visualization from both a business knowledge management and a communication science perspective. The article presents a theoretical framework and a model for the field of knowledge visualization. The chapters deal with an outline of differences between information visualization and knowledge visualization from an organizational perspective of how information visualization may learn from knowledge management and how both principles of knowledge and information visualization may be integrated in complementary visualizations. The presented framework aims at mediating between different research areas and illustrating how information visualization and knowledge visualization complement one another. Burkhard deals with the central goal of the book "searching for synergies" in close relation to knowledge visualization in the field of organizational knowledge management. The outline of principles for designing effective knowledge visualizations satisfies expectations of how to complement knowledge visualization with ideas and techniques from information visualization. Guidelines for applying the complemented knowledge visualization model may help users to successfully implement principles of the synergistic approach into learning and workplace environments.

Anja **Neumann**, Wolfgang **Graeber** and Sigmar-Olaf **Tergan** present a contribution on "Visualizing ideas and information in a resource-based learning environment. The case of ParIS". ParIS is a learning environment that aims at fostering the development of competencies for self-regulated learning and media competencies as central components of scientific literacy. In ParIS, students solve everyday authentic problems by using Mind Mapping, a visual-spatial strategy to assist planning, gathering, generating, organizing, and using knowledge and knowledge resources. The paper describes the rationale for the design and implementation of ParIS in a 10th grade chemistry class of a German Waldorf school. Preliminary results of a pilot study focussing on acceptance and usability of the instructional approach are outlined. The presented instructional design approach transforms ideas of supporting resource-based learning by helping students visualize their knowledge and relate it to information associated with it. It is a synergistic approach in the sense that it uses a Mind Managing tool for both representing knowledge and related information. The tool supports visualizing the structure of knowledge and provides knowledge-based access to specific data and information as potential knowledge resources.

Visualization of knowledge-oriented information organization for fosterin. information use. Approaches that focus on the visualization of a knowledge-oriented information organization aim at fostering an intelligent information access and information use.

John W. **Coffey** describes in his contribution titled "LEO: A Concept Map Based Course Visualization Tool for Instructors and Students" a learning environment organizer (LEO) that provides students and instructors with information and knowledge visualization capabilities. LEO serves as a meta-cognitive tool for course designers and an advanced organizer for students. It is an extension of the CmapTools developed by Cañas and associates (see above). LEO helps to visualize and plan a course organization by using a concept map. The concept map itself is used as a knowledge-based visualization of the structure of course components and provides interactive access to the materials. The contribution of Coffey meshes well with the goals of this book. It presents an approach integrating both fields of research knowledge and information visualization in a synergistic manner.

In their contribution titled "Navigating Personal Information Repositories with Weblog Authoring and Concept Mapping", Sebastian **Fiedler** and Priya **Sharma** describe the tool "Weblog authoring". It enables the user to represent information spontaneously and to maintain it in personal repositories, as well as to generate a social network and collective information filtering and routing. The authors indicate how the structure and practices of Weblog authoring support the construction of a personal repository of information, as well as the ability to engage in shared dialogue about artefacts. They point out the possibility and the benefits of using concept mapping to make sense of the Weblog representations. In this respect, they make use of a technique of knowledge visualization to handle a problem of information visualizations, which is a good example of how to integrate both perspectives in a synergistic approach.

The contribution of Young-Lin **Lee** titled "Facilitating Web-Search with Visualization and Data Mining Techniques” focuses on design rationales and implementations of an alternative Web search environment called "VisSearch". The author points out its advantages, particularly with regard to cognitive processes, in dealing with ill-structured, open-ended research questions, as compared to conventional Web-search environments. The VisSearch environment facilitates information searching in dealing with such problematic search questions by means of visualizing the knowledge and associated Web resources of both the user and other users looking for useful Web-based information on the same or similar topics. VisSearch employs a single, reusable concept map-like knowledge network, called search-graph for a variety of purposes, for example, visualizing Web search results, the history of Web search engine hits of a variety of iterative Web searches of different users, as well as user comments to Web sites and search queries. The search-graph provides interactive access to all Web resources linked with the elements in the graph. The approach outlined by Lee represents a synergetic approach in the sense of the rationale of this book: It brings together both aspects - information visualization and knowledge visualization - in one coherent approach. The approach picks up and extends a topic also dealt with by Cañas et al. (in this book): Visualizing Web-search results using a map that helps to make sense of the semantic relation between them and that provides a knowledge-based access. Further, it closely matches ideas concerning the relation of information and knowledge as outlined by Tergan (in this book).

In their contribution titled "The Role of Content Representations in Hypermedia Learning: Effects of Task and Learner Variables”, Jean-Francois **Rouet**, Hervé **Potelle**, and Antonine **Goumi** point out the significance of content representations in hypermedia documents as means for supporting orientation and navigation. Content representations refer to different kinds of visualizations of the main concepts, for example, global representations as topic lists, outlines, and concept maps that describe the structure of a compilation of information (e.g. in a hypertext). The authors review empirical studies investigating different types of global representations in the context of comprehension and information search tasks. The results of two empirical studies provide evidence that the choice for a specific content representation should depend on both the kind of user and the kind of task that should be solved. The results suggest that networked concept maps are most effective for users with some level of prior knowledge in non-specific task contexts. They show that the effectiveness of visualization may depend on variables inherent in the user, as well as in the contexts in which they are used. This result is of importance for all approaches on visualizations presented within this book.

In his contribution on "Supporting Self-Regulated E-Learning with Topic-Map Navigation", Andreas **Rittershofer** describes Topic maps as a means to convey knowledge about resources. Looking for a visualization of the relevant parts of the topic maps to guide the students through huge amounts of information led the author to the development of the LmTM-server, an e-learning server for students at school to support resource-based learning. The information stored in the topic maps is represented in several ways, for example, by means of a concept map-like graph, which is created dynamically out of the topic map. The graph enables the user to visually navigate within the topic map-based information and provides access to information resources associated with the map. The approach is a synergistic approach in the sense that it enhances sense-making of information represented in Topic maps, enables a visual search for information, and provides knowledge-based access to the information represented. It is because of these functions that the approach is suggested to support self-regulated, resource-based learning in e-learning environments.

Like Andreas Rittershofer, Hans-Juergen **Frank** and Johannes **Drosdol** also outline a strictly application-oriented approach. The focus of the contribution is on the visualization of knowledge and information management activities underlying the development of the Management Information System (MIS) at DaimlerChrysler. The MIS is for the leaders of the department of research and technology, the central department for technical innovations and the management of technology. It is used not only as a tool with a controlling function, but as a general homogenous information and dialogue platform of high actuality and flexibility, serving as a knowledge and information space. The aim for developing the system was to match the users needs, processes and visions as closely as possible. The authors show how complex processes and problem solutions in the development and maintenance of a MIS may be visualized and used for facilitating dialogue and for working with a large number of content elements, highly complex information structures and large knowledge networks. This contribution opens up a perspective of how visualizations may be used on a large-scale basis for knowledge and information visualization in the application context.

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