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Knowledge Visualization

Towards a New Discipline and its Fields of Application

Martin J. Eppler is a professor of information and communication management at the University of Lugano where he teaches Strategy and Organization, Industry Analysis and Knowledge Management. His current research focuses on "Knowledge Communication between Domain Experts and Decision Makers" (www.knowledge-communication.org). He has published over 50 scientific articles and seven books, of which the last deals with the subject of knowledge communication in organizations.
(Martin.Eppler@lu.unisi.ch)

Remo A. Burkhard, dipl.Arch ETH., is the head of the competence center Knowledge Visualization at the University of St. Gallen's =mcm *institute* for media and communications management (www.mcm.unisg.ch). He is co-author of the Science City project of the ETH Zurich. He is also the founder and head of vision of vasp datatecture, a firm in the area of visualizing complex business contents.
(Remo.Burkhard@unisg.ch)   )

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Abstract

In this paper, we establish the concept of knowledge visualization and review the state-of-the-art in this emergent domain. We define the concept and differentiate it from information visualization. We describe select background disciplines and potential application fields. Various knowledge visualization types are distinguished and examples of their real-life application are provided and discussed. Implications and future trends and perspectives are outlined.

Key Words: knowledge visualization, knowledge maps, sketches, conceptual diagrams, knowledge management, information visualization, cognition, metaphors

1. Introduction

Making knowledge visible so that it can be better accessed, discussed, valued or generally managed is a long standing objective in knowledge management (see Sparrow, 1998). Knowledge maps, knowledge cartographies, or knowledge landscapes are often heard terms that are nevertheless rarely defined, let alone demonstrated or described in detail. In this contribution, we review the state-of-the-art in the area of knowledge visualization and describe its background and perspectives. We define the concept and differentiate it from other approaches, such as information visualization or visual communication. Core knowledge visualization types, such as conceptual diagrams or visual metaphors, are distinguished and examples of their application in business are shown and discussed. Implications for research and practice are summarized and future trends in this domain are outlined.

The Concept of Knowledge Visualization

Generally speaking, the field of knowledge visualization examines the use of visual representations to improve the *creation* and *transfer* of knowledge between at least two people. *Knowledge visualization thus designates all graphic means that can be used to construct and convey complex insights.* Beyond the mere transport of facts, knowledge visualization aims to transfer insights, experiences, attitudes, values, expectations, perspectives, opinions and predictions, and this in a way that enables someone else to re-construct, remember and apply these insights correctly. Examples of knowledge visualization formats are complex, reasoned and often theory-driven conceptual diagrams (such as Gartner's magic quadrants or hype curve, Michael Porter's five forces chart or Nonaka's SECI matrix, see Nonaka et al., 2000), concept maps (such as Allen Novak's concept mapping method, see Lansing, 1998), interactive visual metaphors (such as an iceberg of organizational culture or a personnel selection funnel), or knowledge maps (such as Roche's knowledge application map of the new drug approval process, see Wurman, 1996, p. 172). It seems justified to refer to these graphic formats as knowledge visualizations as both their content and their format are distinct from that of regular visual depictions. In terms of their *content*, they capture not just

(descriptive) facts or numbers, but rather (prescriptive and prognostic) insights, principles and relations. In terms of *format*, knowledge visualizations rely on indirect communication that triggers sense making activities in the viewer and motivate him or her to complete the picture him- or herself. Thus, the 'what' and the 'how' of knowledge visualization differs from information visualization, these differences are further described in the following section.

Differences between Knowledge Visualization and Information Visualization

A related field and precursor to knowledge visualization is information visualization. Information visualization is a rapidly advancing field of study both in terms of academic research and practical applications (Bertin, 1974; Card et al., 1999; Chen, 1999a; Spence, 2000; Ware, 2000). Card et al. (1999) define information visualization, as *"... the use of computer-supported, interactive, visual representations of abstract data to amplify cognition"*. This definition is well established and represents a broad consensus among computer scientists active in this field. What is still missing in the current literature, however, is a systematic discussion on the potential of visualizations as a medium for the transfer of knowledge as well as the integration of non-computer based visualization methods, as architects, artists, and designers use them. Information visualization and knowledge visualization are both exploiting our innate abilities to effectively process visual representations, but the way of using these abilities differs in both domains: Information visualization aims to explore large amounts of abstract (often numeric) data to derive new insights or simply make the stored data more accessible. Knowledge visualization, in contrast, aims to improve the transfer and creation of knowledge among people by giving them richer means of expressing what they know. While information visualization typically helps to improve information retrieval, access and presentation of large data sets – particularly in the interaction of humans and computers – knowledge visualization primarily aims at augmenting knowledge-intensive communication between individuals, for example by relating new insights to already understood concepts, as in the case of visual metaphors. This visual communication of knowledge is relevant for several areas within knowledge management, as described below.

Application Areas within Knowledge Management

Knowledge Visualization helps to solve several predominant, knowledge-related problems in organizations:
First, the omnipresent problem of knowledge *transfer* (or rather knowledge asymmetry and how it can be overcome by transfer). Knowledge visualization offers a systematic approach how visual representations can be used for the transfer of knowledge in order to increase its speed and its quality. The transfer of knowledge occurs at various levels: among individuals, from individuals to groups, between groups, and from individuals and groups to the entire organization. At each of these levels, knowledge visualization

can serve as a conceptual bridge, linking not only minds, but also departments and professional groups. Gupta and Govindarajan (2000) have examined knowledge transfer in organizations and they have found that one key issue is how recipients not only acquire and assimilate but also *use* knowledge (Cohen and Levinthal, 1990). To do so, knowledge must be recreated in the mind of the receiver (El Sawy et al., 1997). This depends on the recipient's cognitive capacity to process the incoming stimuli (Vance and Eynon, 1998). Thus, the person responsible for the transfer of knowledge not only needs to convey the relevant knowledge at the right time to the right person, he or she also needs to convey it in the right context and in a way that it can ultimately be used. To achieve theses tasks, text and IT-based methods can be employed (e.g., discussion boards, databases, corporate directories, intelligent agent software, etc.). However, the capacities of our visual channel are rarely fully exploited in these applications (be it as an interface to make knowledge accessible or as a way structure the documented or referenced knowledge itself). In this context, visualization can also facilitate *inter-functional knowledge communication*, as the communication between different stakeholders and experts with different professional backgrounds is a major problem in organizations. Knowledge visualization offers solutions to solve this problem mainly by making differing basic assumptions visible and communicable and by providing common contexts (visual frameworks) that help to bridge differing backgrounds.

As a second application area within knowledge management, knowledge visualization offers great potential for the *creation* of new knowledge, thus enabling innovation. Knowledge visualization offers methods to use the creative power of imagery and the possibility of fluid re-arrangements and changes. It enables groups to create new knowledge, for instance by use of heuristic sketches or rich graphic metaphors. Unlike text, these graphic formats can be quickly and collectively changed and thus propagate the rapid and joint improvement of ideas. The figure below depicts such a visual knowledge communication tool that can be used for idea generation, elaboration and selection – the Ideaquarium (here used to develop a new advertising strategy). Each contributed idea is represented by a fish. The larger the fish, the more people support a proposed idea. The color of the fish indicates the person who has proposed an idea. The criteria by which the ideas are then assessed are visualized as piranha-like fish that approach idea-fishes to see whether the criterion is actually matched or not (a new criterion is about to be entered unto the unlabeled fish). The higher a fish rises, the more pragmatic an idea. Clusters of fish or fish connected by a plant indicate related ideas. The shells on the aquarium's ground indicate contextual starting points; the three rocks indicate thinking vectors that should guide the idea generation process.
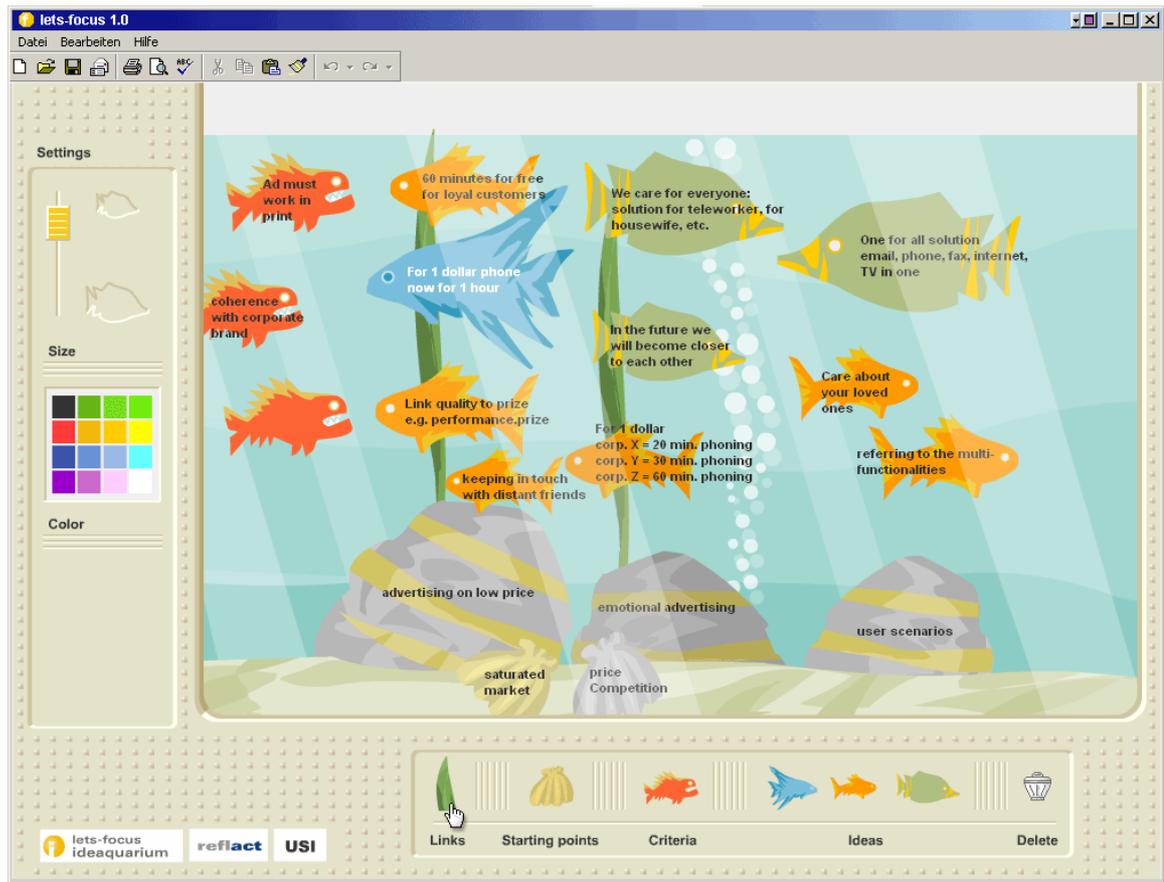
Figure 1: A sample knowledge communication tool to foster knowledge creation

A third, more general, application motive of knowledge visualization is its use as an effective strategy against *information overload*: Information overload (see Eppler, Mengis, 2004) is a major problem in knowledge-intensive organizations and in an information society in general. Knowledge visualizations help to compress large amounts of information with the help of analytical frameworks, theories, and models that absorb complexity and render it accessible. This can be a vital prerequisite for the three application domains mentioned previously (transfer, creation, communication).

Although these application fields have existed for numerous years, the potential of visual representations is often lost because there is little assistance for non-professional visualizers to make use of the power of complex visualization. Therefore a conceptual framework should be developed that enables practitioners to better use and apply visual representations of knowledge. Steps towards such a framework are presented in section three. In the next section, we briefly outline relevant background areas that have paved the way for knowledge visualization as a new discipline.

2. Background

The field of knowledge visualization is an emerging one, merging approaches from information visualization, didactic techniques, visual cognition and visual communication research, as well as more practical approaches, such as business diagramming or visual programming languages.

Information Visualization

Information visualization is a rapidly advancing field of study (Card et al., 1999; Chen, 1999a; Spence, 2000; Ware, 2000). As stated earlier, Card et al. (1999) define it, as "... the use of computer-supported, interactive, visual representations of *abstract data* to amplify cognition". Since the 1990ies, new visualization methods allow to explore *data* by offering different methods to achieve the sequence discussed by Shneideman (1996): "overview first, zoom in and filter, then show details on demand". Examples of such applications are Tree Maps (Johnson and Shneiderman, 1991; Shneiderman, 1992), Cone Trees (Robertson and Mackinlay, 1991), Hyperbolic 3D (Munzner, 1998). Information Visualization helps for information exploration and visual information seeking. Information exploration is the interactive browsing and analysis of data with a visual interface, which allows identifying trends or outliners. It is useful complementary to standard database queries and information retrieval approaches if little is known on the data and if the goals are not clear. Visual information seeking combines the visual representations of information with dynamic user control techniques, which helps to constantly explore visual patterns while exploring the data and on the base of these insights reformulate the goals.

Visual Cognition and Perception

A majority of our brain's activity deals with processing and analyzing visual images. Several empirical studies show that visual representations are superior to verbal-sequential representations in different tasks (Larkin and Simon, 1987; Glenberg and Langston, 1992; Bauer and Johnson-Laird, 1993; Novick, 2001). Miller (1956) reports that a human's input channel capacity is greater when visual abilities are used. Our brain has a strong ability to identify patterns, which is examined in Gestalt psychology (Koffka, 1935). Visual imagery (Kosslyn, 1980; Shepard and Cooper, 1982) suggest that visual recall seems to be better than verbal recall. It is not clear how images are stored and recalled, but it is clear that humans have a natural ability to use images. Instructional psychology and media didactics investigate the learning outcomes of text-alone versus text-picture: (Mandl and Levin, 1989) present different results in knowledge acquisition from text and pictures. Weidenmann (1989) explores aspects of illustrations in the learning process. Cognitive neuroscience discusses the underlying cognitive components of picture processing (Farah, 2000). The use of visual representations are helpful to functions of visual communicate different knowledge types.

Visual Communication Studies

Different isolated research fields contribute valuable results for the visual communication of knowledge. These are contributions in the field of visualizing information in print (Bertin, 1974; Tufte, 1990; Tufte, 1997), cognitive art and hypermedia design (Horn, 1998), information architecture (Wurman, 1996) and contributions in the field of graphics design, interface design, interaction design and human computer interaction. From a theoretical perspective there are different contributions that help to improve the transfer of knowledge, particularly communication science (Fiske, 1982), visual communication sciences (Newton, 1998; Stonehill, 1995) the psychology of learning (Mandl and Levin, 1989; Weidenmann, 1989), and cognitive psychology (Farah, 2000). These contributions show how visual representations affect our social cognition processes both positively (improving understanding) and negatively (manipulating perception and interpretation). Many systematic approaches that examine visualization in communication, however, have so far been rooted in the mass media sector. They have primarily described how newspapers and television use graphic representations to convey meaning. How to use such formats actively for knowledge transfer is rarely discussed in these contributions (for an overview on visual communication studies see Müller, 2003).

We use insights from these and other domains to categorize the main application parameters of knowledge visualization in the next section.

3. A Framework for Knowledge Visualization

For an effective transfer and creation of knowledge through visualization, at least three perspectives (Table 1) should be considered. These perspectives answer three key questions with regard to visualizing knowledge, namely:

1. What type of knowledge is visualized?
2. Why should that knowledge be visualized?
3. How is the knowledge visualized?

Listing possible answers to these key questions leads us to a first conceptual framework that can provide an overview of the knowledge visualization field (see Table 1).

Table 1. Three different perspectives of the knowledge visualization framework

Knowledge Type (what?)	Visualization Goal (why?)	Visualization Format (how?)
Know-what	Sharing or Transferring (clarification, elicitation, socialization)	Heuristic Sketches (e.g. ad-hoc drawings)
Know-how	Creating (discovery, combination)	Conceptual Diagrams (e.g., Toulmin or process diagrams)
Know-why	Learning (acquisition, internalization)	Visual Metaphors (e.g., a tree, bridge, juggling, etc.)
Know-where	Codifying (documentation, externalization)	Knowledge Animations (e.g., ruler, mixer, etc.)
Know-who	Finding (e.g., experts, documents, groups)	Knowledge Maps (e.g., knowledge structure maps)
	Assessing / Evaluating (knowledge rating)	Scientific Charts (e.g., co-citation webs)

The **Knowledge Type Perspective** aims to identify the type of knowledge that needs to be transferred. Different types of knowledge are described in the knowledge management literature. For our framework we distinguished five types of knowledge: Declarative knowledge (Know-what), procedural knowledge (know-how), experimental knowledge (know-why), orientational knowledge (know-where), individual knowledge (know-who) (for this distinction see for example Alavi & Leidner, 2001). Today, no classification exists that links visualization formats and these knowledge types. There is thus no validated prescriptive framework that offers specific representation formats for r particular knowledge types (the horizontal links, drawn as dotted arrows in the above framework are still hypotheses).

The **Visualization Motive Perspective** distinguishes several reasons why a visual knowledge representation is used. Motives for knowledge visualization use that can be anticipated are knowledge sharing through visual means, knowledge crafting or creation, learning from visuals, codifying past experiences visually for future users or mapping knowledge (Vail, 1999) so that experts, for example within a large organization, can be more easily identified.

The **Visualization Format Perspective** structures the visualization methods to six main groups: heuristic sketches, conceptual diagrams, visual metaphors, knowledge animations, knowledge maps and scientific formats. This distinction is derived from

specific formats of representing insight and from different types of insight: *Heuristic sketches* represent the main idea, are atmospheric and help to quickly visualize an idea, thus an unstable (heuristic) format for unstable knowledge. Heuristic sketches support reasoning and arguing and allow room for one's own interpretations. *Conceptual diagrams,* by contrast*,* are abstract, schematic representations used to explore structural relationships among parts. They help to reduce complexity, amplify cognition, explain causal relationships and to structure information. The type of knowledge that is conveyed by conceptual diagrams is analytic and their format is thus highly structured and systematic. *Visual metaphors* combine the creative leap of sketches with the analytic rationality of conceptual diagrams and employ graphic metaphors to structure information and convey normative knowledge through the connotations of the employed metaphor. The knowledge that is conveyed is often (in contrast to the reasoning conveyed through diagrams) procedural, thus motivating to apply the knowledge is a key ingredient of such visual metaphors. *Knowledge animations* also convey procedural knowledge, but not in a static manner like visual metaphors but through interactive animation. *Knowledge maps* do not directly represent knowledge but rather reference it, though the use of cartographic conventions. *Scientific charts* finally, display as content scientific knowledge, such as publications, and show how they are related in terms of mutual influence. These six visualization formats can be matched with adequate knowledge types and motives. Knowledge maps, for example can help to visualize know-who and thus make experts easier to locate. Visual metaphors can foster learning by displaying experiences (know-why) in an accessible way. Conceptual diagrams, for example process charts, can depict know-how (procedural knowledge) in order to share best practices. Heuristic sketches (as shown below) can help to create new knowledge of various forms.

4. Formats and Examples of Knowledge Visualization

Having outlined the key questions of knowledge visualization, we show in this section how they can be answered for specific application contexts.

Heuristic Sketches: Creating new Insights in Groups

Heuristic Sketches are drawings that are used to assist the group reflection and communication process by making unstable knowledge explicit and debatable. Generally a sketch is defined as: "*Traditionally a rough drawing or painting in which an artist notes down his preliminary ideas for a work that will eventually be realized with greater precision and detail.*"[1] In the context of knowledge management we call these sketches heuristic sketches. The main benefits of heuristic sketches are: (1) they

represent the main idea and key features of a preliminary study. (2) They are atmospheric, versatile and accessible. (3) They are fast and help to quickly visualize an idea. (4) The use of a pen on a flipchart attracts the attention towards the communicator. (5) Heuristic Sketches allow room for one's own interpretations and foster the creativity in groups. Figure 2-4 present different examples of heuristic sketches:
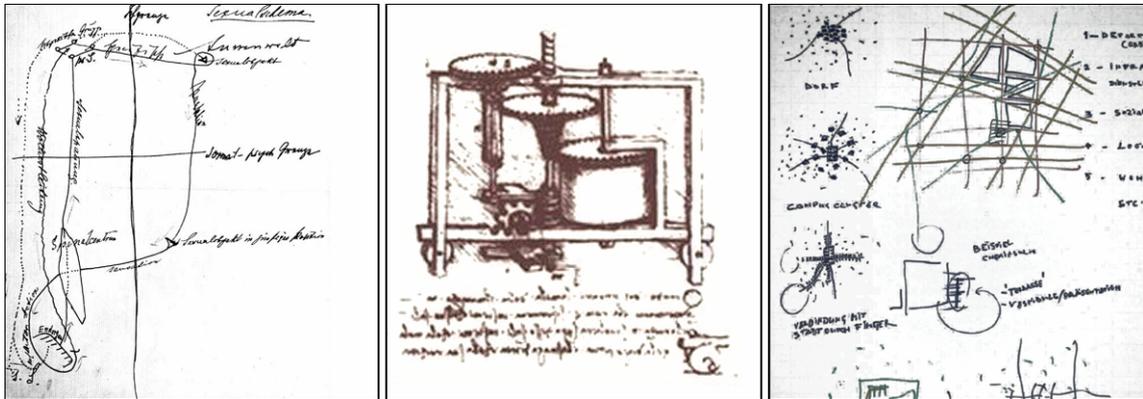

Figure 2: Freud's heuristic sketch as a catalyst for theory development.

Figure 3: Leonardo da Vinci's heuristic sketch to illustrate the main mechanism of a machine.

Figure 4: An ad-hoc heuristic sketch in an urban planning workshop increases the communication quality and fosters the creativity in groups.

Conceptual Diagrams: Structuring Information and Illustrating Relationships

Conceptual Diagrams as seen in Figure 4 are schematic depictions of abstract ideas with the help of standardized shapes (such as arrows, circles, pyramids or matrices) used to structure information and illustrate relationships. Garland (1979) defines a diagram as a "*visual language sign having the primary purpose of denoting function and/or relationship*". For the transfer and creation of knowledge conceptual diagrams help to make abstract concepts accessible, to reduce the complexity to the key issues (Huff, 1990), to amplify cognition and to discuss relationships.

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[1] Sketch. Encyclopædia Britannica. Retrieved August 4, 2003, from Encyclopædia Britannica Premium Service. http://www.britannica.com/eb/article?eu=69864
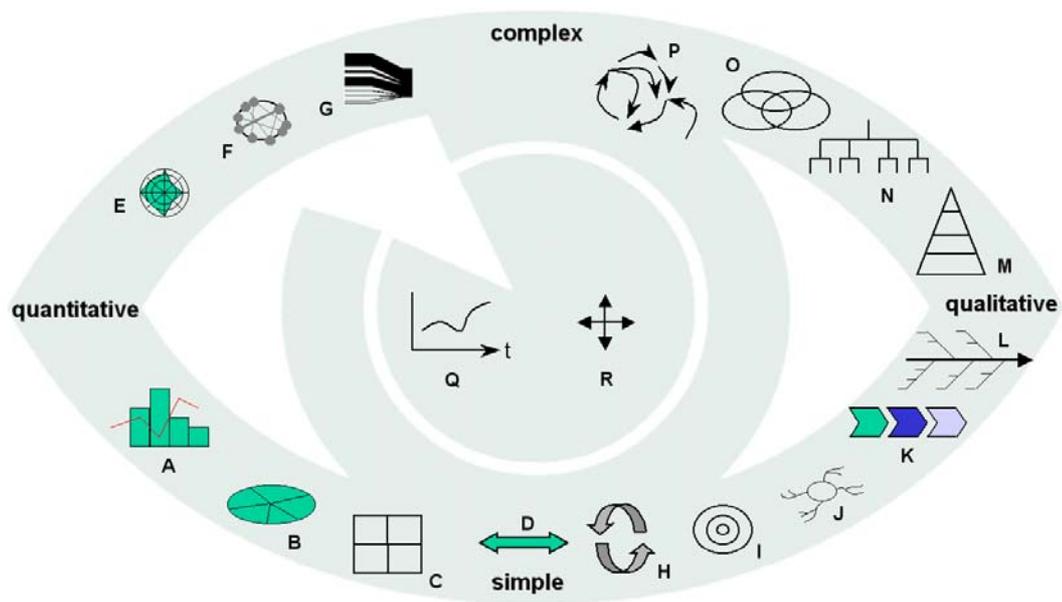
Figure 5: An overview of conceptual diagrams (schematic depictions of abstract ideas which use standardized shapes to structure information, convey insights and illustrate relations) Source: Eppler, 2003

The figure above summarizes many commonly used (quantitative and qualitative) diagrams, such as bar, line and pie charts (A and B), matrices (C), Spectrum charts (D), cycles (H), concentric spheres (I), Mind Maps (J), process (K) and fishbone charts (L), pyramids (M), relevance trees (N), Venn (O), network (P), and Sankey diagrams (G), synergy maps (F), radar charts (E)., or the commonly used coordinate systems (Q and R).

An example of a knowledge-intensive diagram is the Toulmin chart (Figure 5), based on the argumentation theory of Steven Toulmin (1964). Such a chart helps to break down an argument into different parts (such as claim, reasons, and evidence) which is useful when evaluating the validity of a claim. The parts of a reasoned argument can be effectively visualized with a conceptual diagram, as depicted below
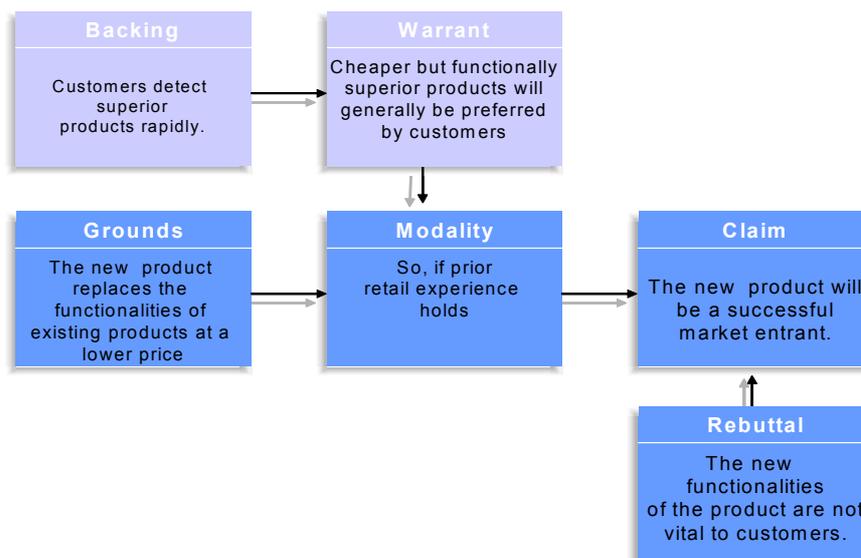
Figure 6: The Toulmin chart as an example of a knowledge-intensive conceptual diagram

Visual Metaphors: Relating Domains to Improve Understanding

Card et al. (1999) state in their research anthology on information visualization that the key research problem in the area of visualization is to discover *expressive and effective visual metaphors mapping abstract data to visual forms*. A metaphor, according to the Oxford Dictionary of Current English, is an example of the use of words to indicate something different from the literal meaning. Metaphors rely on analogies between the qualities of a sign and the comparable attributes of what is signified. The term 'metaphor' is derived from the Greek verb *metapherein* whose meaning can be translated as „carrying something somewhere else". A metaphor provides the path from the understanding of something familiar to something new by carrying elements of understanding from the mastered subject to a new domain. This is why Aristotle calls the metaphor a *tool of cognition*. According to Aristotle, a metaphor provides rapid information and is to the highest degree instructive; it facilitates the process of learning (see also Eco 1984, p. 100 for this point). All of these aspects can be fruitfully used in knowledge communication where visual metaphors offer effective and simple templates to convey complex insights. Sparrow (1998, p. 71) stresses this point in the following quote (my italics):

"A variety of representations can be used as visual analogies/metaphors. Here certain properties of concepts are highlighted by juxtaposing the concepts in a way that *parallels a particular well-known relationship between concepts from another context*. So, for example, two sets of concepts may be depicted as on either side of a 'balance', or set of scales."

Visual metaphors can either be natural objects or phenomena (such as mountains, icebergs, trees, or islands) or artificial, man-made artifacts (such as a house or a temple, a funnel, a chain, or a ladder). Their main feature is that they organize information

meaningfully. In doing so, they fulfill a dual function (Eppler, 2003b): first, they position information graphically to organize and structure it. Second, they convey an insight about the represented information through the key characteristics of the metaphor that is employed. As Worren et al. (2002, p. 1230) have pointed out, one should also not neglect their *mnemonic* (i.e., facilitating remembering) and cognitive *coordination* function (i.e., providing an area of mutual and explicit focus). Visual metaphors can be grouped into four generic groups based on their root domain:

1. Metaphors based on ***natural phenomena*** (mountain, iceberg, tree, abyss, diamond, tornado, waterfall, volcano, river, cave, etc.)
2. Metaphors based on ***man-made objects*** (balance, ladder, wheel, road, temple, bridge, funnel, umbrella, bucket, pendulum, lever, radar, Trojan horse, etc.)
3. Metaphors based on ***activities*** (climbing, fixing, walking, reaching, driving, eating, fishing, hunting, harvesting, juggling, pouring, fencing, etc.)
4. Metaphors based on abstract ***concepts*** (war, family, peace, law, chaos, fractal, sustainability)

The two examples below are of the second group. We use the image of a bridge (Figure 7) to convey how to lead successful negotiations (loosely based on the Harvard negotiation method, see the footnote below) and the picture (taken from the medieval philosopher Ramon Lullus) of stairs leading to a fortress in order to illustrate the necessary steps that lead to market innovations.
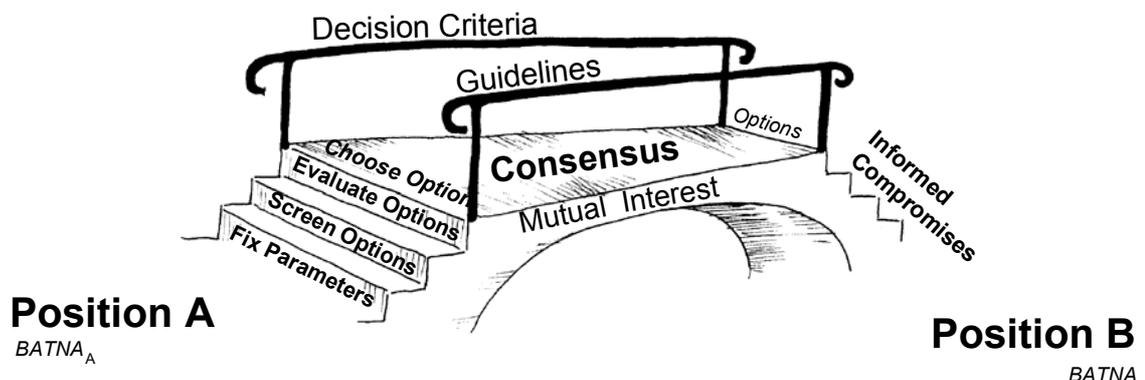

Figure 7: The Negotiation Bridge: A visual metaphor that outlines a negotiation method[2]

[2] BATNA in this context is an abbreviation for Best Alternative to a Negotiated Agreement. See: Lewicki, R.J., Saunders, D. M. & Minton, J. W. (1997). Essentials of Negotiation. Boston: Irwin Mc Graw-Hill or: Fisher, R. & Ury, W. (1981) Getting To Yes. Boston: Houghton Mifflin Company.
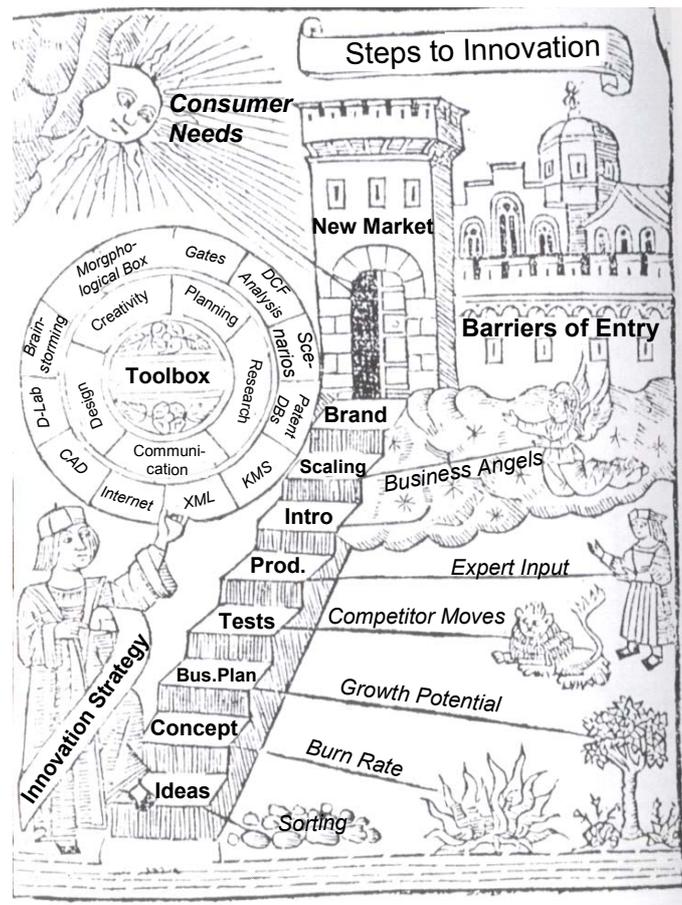
Figure 8: The Market Stairs that lead to successful market entries

In the second metaphor the innovation process is represented as stair steps , the market to be captured as a town protected by city walls and the customer needs as the guiding sun light.

One can extend this use of indirect communication to instil knowledge in others by activating their interpretation effort beyond the domain of metaphors. Other visual tropes can be employed to knowledge communication, such as visual irony, allegory (visual story telling), visual paradoxes (e.g., graphic koans), or visual simile and synecdoche.

The concept of visual metaphors can hence be summarized as graphic depictions of seemingly unrelated graphic shapes (from other than the discussed domain area) that are used to convey an abstract idea by relating it to a concrete phenomenon.

Knowledge Animations: Dynamic and Interactive Visualizations

Knowledge Animations are computer-supported interactive visualizations that allow users to control, interact and manipulate different types of information in a way that fosters knowledge creation and transfer. Figure 7 illustrates an interactive, three dimensional interface that visualizes the data of the New York Stock Exchange. It is a dynamic visualization for managers who are used to supervise and control the New

York Stock Exchange. By interacting with the information, new insights are created. When the user combines information, reduces or aggregates it, newly assembles it, or views it from different perspectives he acquires knowledge about the represented processes that goes beyond the stored data.

Figure 9: An Interactive Visualization helps to supervise the New York Stock Exchange. [3]

Novel animated visual metaphors as the *Infoticle* metaphor (Vande Moere et al., 2004) allow new, instructive ways to interact with information. In contrast to static visualizations or applications in the field of information visualization, where users interact with data, in the infoticle application data-driven particles (= Infoticles) help to explore large time-varying datasets with reoccurring data objects that alter in time. Animating these infoticles leads to a knowledge animation which allows seeing the behaviour of individual data entries or the global context of the whole dataset.

In similar ways, the interactive parameter ruler, depicted in Figure 10, enables teams and individuals to explore alternatives in real-time through the mobile and versatile sliders in the ruler application. By moving the horizontal sliders from left to right, users can change their ratings, their options or their agreement with certain parameters (e.g., of a product configuration, a client rating, a course assessment). By moving the sliders vertically, they can bring the criteria listed in the left row into a new order (reflecting the importance of each criterion, see Eppler, 2004).

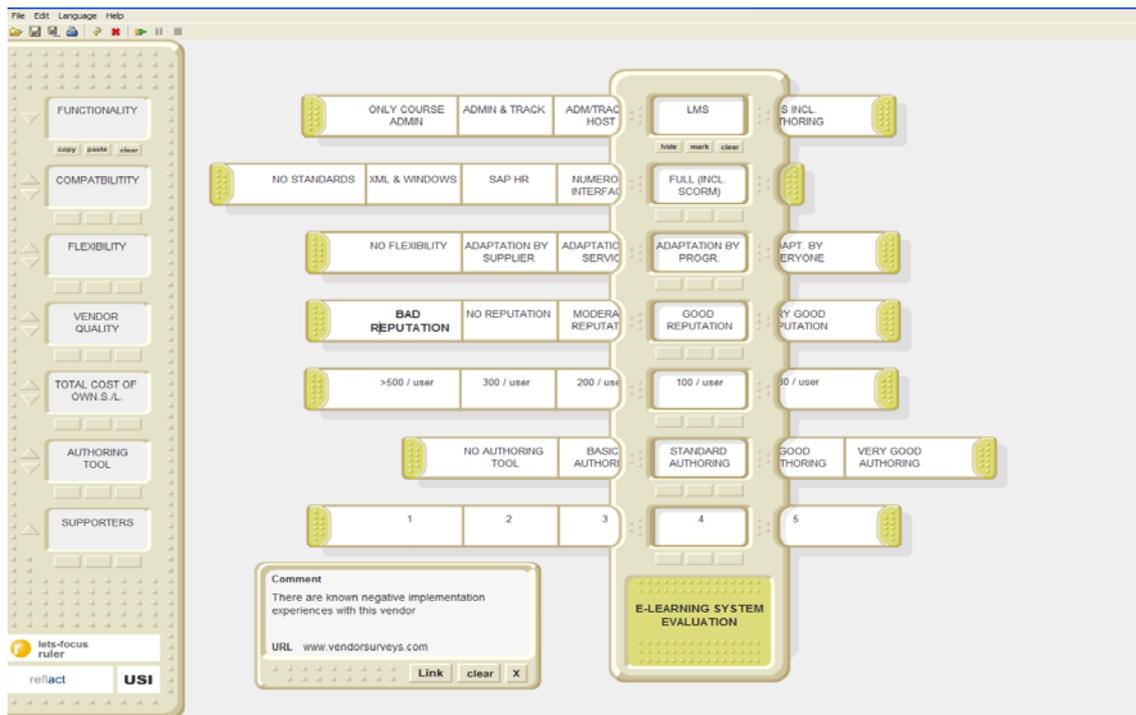3 Retrieved August 4, 2003, http://www.asymptote.net

Figure 10: The interactive parameter ruler enables teams to explore alternate in real-time

The above contributions illustrate that *Knowledge Animations* help to fascinate and focus people, to enable interactive collaboration and persistent conversations, and to illustrate, explore and discuss complex data in various contexts.

Knowledge Maps: Navigating and Structuring Expertise

Knowledge maps (Eppler, 2002) are graphic formats that follow cartographic conventions to reference relevant knowledge. A knowledge map generally consists of two parts: a ground layer which represents the context for the mapping, and the individual elements that are mapped within this context. The ground layer typically consists of the mutual context that all employees can understand and relate to. Such a context might be the visualized business model of a company (e.g., the lending business model of a bank), the actual product (e.g., a vehicle model in the case of a truck company), the competency areas of a company (as in the example of the multimedia company in section three), the value chain of a firm (as in the example of the market research group below), or a simple geographic map. The elements which are mapped onto such a shared context range from experts, project teams, or communities of practice to more explicit and codified forms of knowledge such as white papers or articles, patents, lessons learned (e.g., after action reviews or project debriefings), events (i.e., meeting protocols), databases or similar applications, such as expert systems or simulations. Knowledge maps group these elements to show their relationships, locations, and qualities. In this paper, we refer to knowledge maps as graphic directories of knowledge-sources (i.e., experts), -assets (i.e., core

competencies), -structures (i.e., skill domains), -applications (i.e. specific contexts in which knowledge has to be applied, such as a process), or -development stages (phases of knowledge development or learning paths). Some maps may utilize the conventions of geographic maps, while others (such as the example below) employ symbols from underground maps, parks or public garden maps, fictional (e.g. treasure island) maps, etc.

Example: A quality development process needed to be established in an organization. Traditional project plans, flyers and mails did not manage to get the attention, present an overview and details and motivate the employees to act. A customized *tube map visualization*[4] (Figure 9 and 10) was introduced as ground layer to illustrates the whole process:
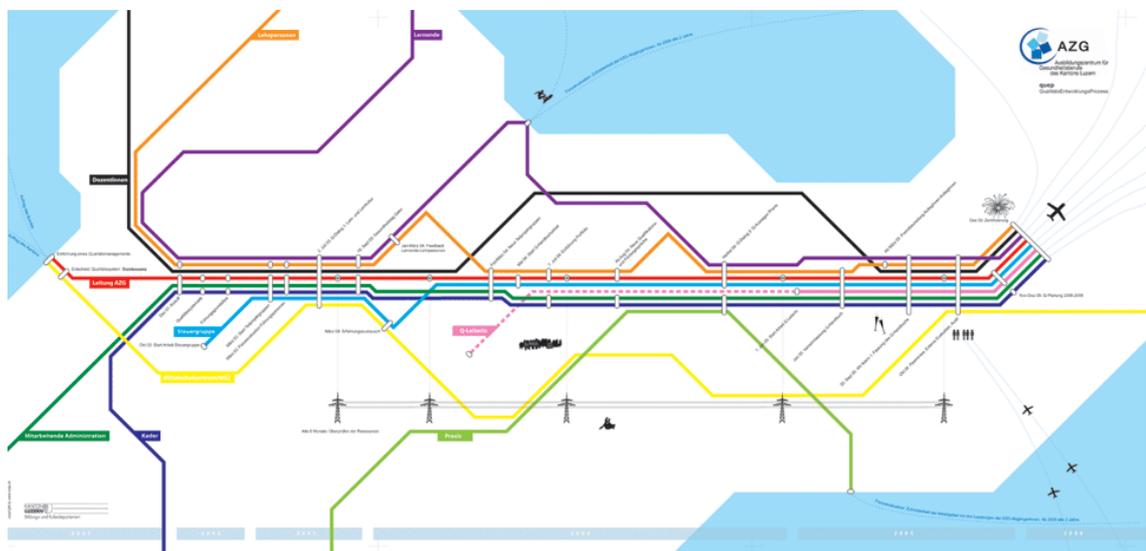

Figure 11: The tube map visualization (1,2 x 2,4 meter) presents an overview and details on a project. Each line represents one target group, each station a project milestone. Each line (target group) stops at the stations (milestones) where the target groups are involved. The stations are tagged with descriptions, dates or instructions.
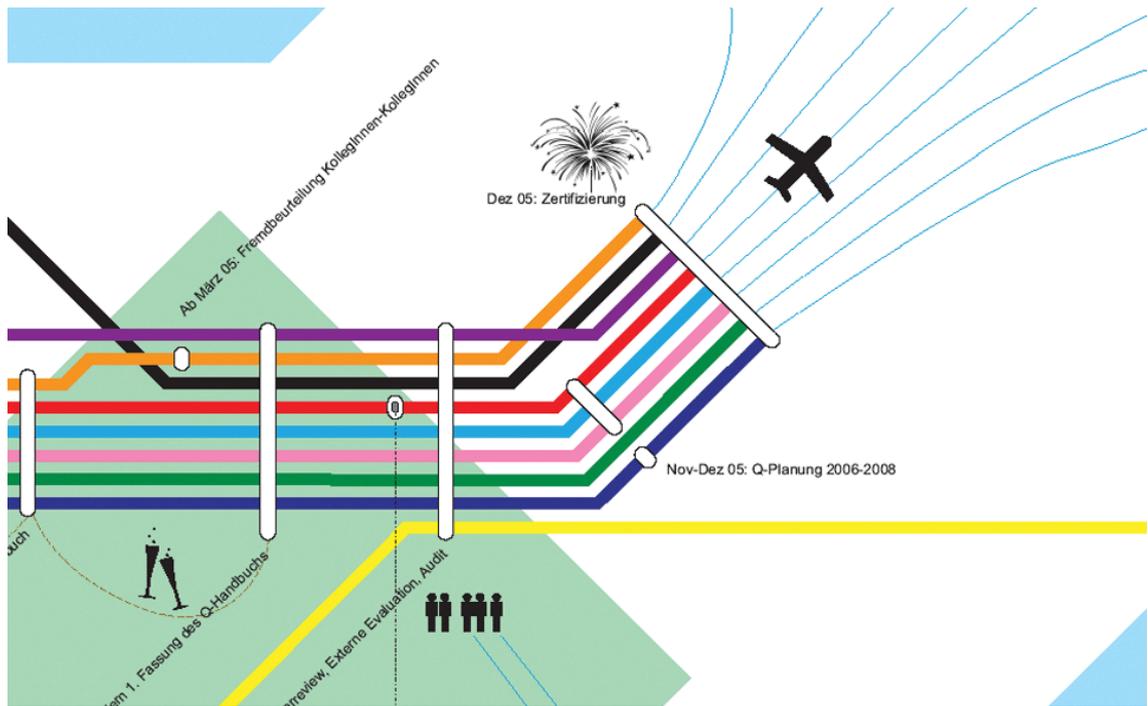
Figure 12: A zoom-in presents and individual and a collective milestone (where different lines pass through).

As individual elements different subway-lines and -stations were used: Each subway-line represents a target group, each station a milestone. The visualization was printed as a poster (2,4 x 1,2 meters) and located at prominent locations in the organization. The evaluation (Burkhard and Meier, 2004) has shown that the tube map visualization is a powerful metaphor to communicate a project to different target groups and to build up a mutual story. The employees considered it useful, because it provides an overview and detailed information in one knowledge map. A similar metro structure was used to document an already completed project and link the various results of the project visually to one another. This interactive map (see below) depicts four years of project events and documentation (taken from Eppler, 2003).
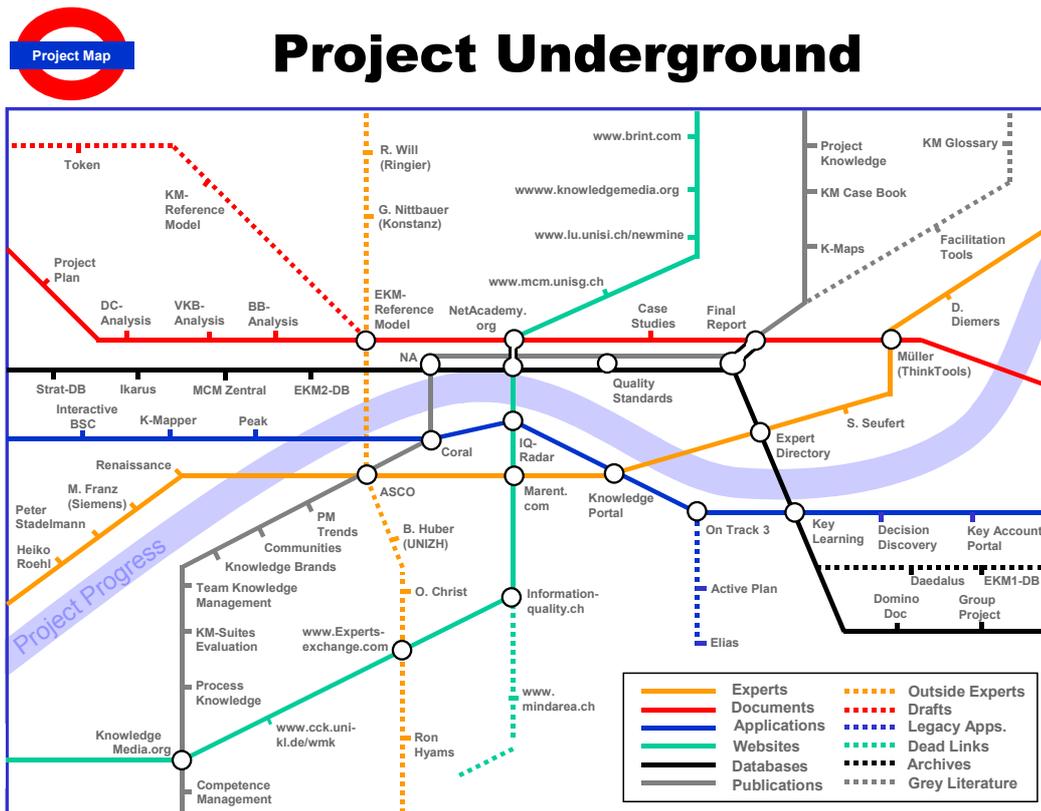
Figure 13: A Metro Map used for Project Knowledge Documentation

In this metro map each line designates a knowledge source, such as experts, documents, software applications, websites, databases, or publications. The project's time line is visualized as a river running through the city from the top left hand corner towards the right side.

Scientific Charts: Visualizing Domain Knowledge and Intellectual Structures

Knowledge Domain Visualization: Visualizing intellectual structures and mapping scientific frontiers has been investigated by scholars from different perspectives and times. Chen presents an excellent overview on this early knowledge visualization domain. (Chen, 2003). Achievements in information visualization and in studying scientific literature were the foundation for a new knowledge visualization direction, which is called knowledge domain visualization or visual co-citation analysis. This research focus investigates new ways of accessing scientific literature in digital libraries (Chen, 1998; Chen, 1999b; Chen, 2000) by visualizing linkage and relationships between scientific literature. Lin et al. (White et al., 2000; Lin et al., 2001; Lin et al., 2003) research in the field of associative search visualization and co-citation author maps. Based on computational algorithms interactive maps are automatically created and present query relevant terms and relationships. In contrast to Chen these visualizations do not illustrate the total system but the immediate environment that is related to the query.

Visual Interfaces for the Exploration of Digital Libraries: With an increasing number of digital documents new information retrieval paradigms become decisive. The need for improved search result visualizations is described in an empirical evaluation of an information retrieval system (Sutcliffe et al., 2000). Traditional text-based retrieval systems are effective for specific searches, but for exploratory tasks users need new and more effective approaches. A new field with it's root in information visualization applies existing or new visualization methods to digital libraries to offer new methods to better exploit existing information repositories. The field examines how our perceptual processes as visual pattern recognition can be used to explore document spaces. Börner and Chen (Börner and Chen, 2002) present an overview on this field. As integral parts of such systems new query-result visualizations are important. The need for improved search result visualization is described in different studies (Kleiboemer et al., 1996; Chen et al., 1998; Sebrechts et al., 1999). Various systems that address these issues and that bring together the advantages of information visualizations and information retrieval are promising. Nowell et al. (1996) presents an overview of such systems, for instance: Envision (Fox et al., 1993; Fox et al., 2002), a digital library of computer science literature that provides an interface with several search result visualizations, *Gridvis* (Weiss-Lijn et al., 2001), which provides manually produced metadata for each paragraph or section level of a document, Roberts et al. (2002), which present a multiple view system with search result visualizations. Another, related type of scientific knowledge visualizations are *visual literature review diagrams*, as the Venn diagram on information overload research depicted below. They are not automatically produced, but designed by a reviewer. The example below illustrates the low degree of interdisciplinary research regarding a research topic (in this case information overload).
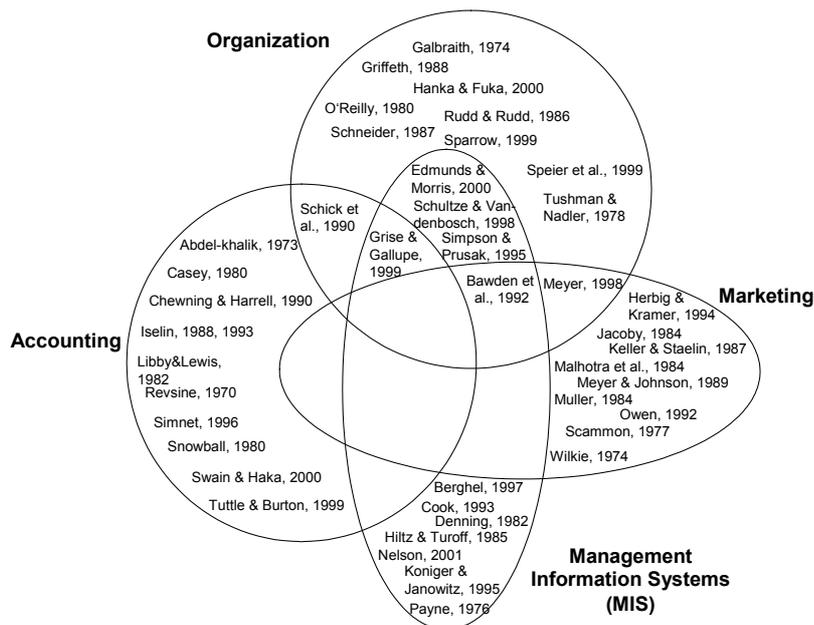

Figure 14: A visual literature review diagram on information overload

5. Conclusion and Outlook

In concluding, we summarize the strengths and disadvantages of knowledge visualization in their various fields of application. In terms of advantages, knowledge visualizations offer cognitive, social, and emotional benefits. We synthesize these strengths in the CARMEN acronym:

- **C** oordination: They help to coordinate the communication of knowledge workers. (Social benefit)
- **A** ttention: They raise awareness and provide focus for knowledge creation and transfer. (Cognitive benefit)
- **R** ecall: They improve memorability and thus foster the application of new knowledge. (Cognitive benefit)
- **M** otivation: They energize viewers to engage in interpretation and explore the graphic. (Emotional benefit)
- **E** laboration: The process of visualizing knowledge leads to further understanding and appreciation of concepts and ideas as one interacts with them. (Cognitive benefit)
- **N** ew insights: Knowledge visualizations can reveal previously hidden connections and lead to sudden insights, a-ha experiences. (Cognitive Benefit)

As far as the limitations are concerned, there is evidence that visualization can have drawbacks with regard to specific contexts. One should thus not neglect the risks inherent in using such forms of visualization, namely the difficult maintenance of the diagrams and maps, the reification of (at times) invalid views, and hence the possible manipulation of users, or the possible distortion of reality through misinterpretations. Future research will have to investigate these potential negative effects empirically in authentic application contexts (see for example Blackwell and Green, 1999, for such a study).

Future Trends and Developments

In this section, we outline areas that we believe to be crucial for the success of the knowledge visualization field. We highlight unresolved issues and future research needs.

A Model for Knowledge Visualization

As this article makes clear, different isolated research areas are investigating the potential of visualizations for the transfer and the creation of knowledge. While

different focus areas and interdisciplinary approaches exist, we believe that a comprehensive framework that focuses on knowledge-intensive visualization is needed. Such a framework should also outline (based on previous evaluation research) which types of knowledge (such as know-why or know-how) are best represented in which visualization format (such as diagrams or metaphors) and which purposes (such as learning or knowledge creation). The knowledge visualization framework we have presented serves as a first step in this direction. Future frameworks must also highlight how complementary visualization, that is to say combinations of these formats, can be fruitfully used.

Knowledge Visualization as Mediator between Strategic Management, Advertising and Marketing

Today in organizations budgets for professional visualizers are allocated mainly for the fields of advertising or corporate identity. Advertising has expertise to get the attention, to address emotions and to illustrate a product/service. Corporate identity has expertise on the use of a visual language to support the creation of a corporate brand. Both fields are important. But they do not exploit the potential of visualizations. When it comes to the transfer and creation of knowledge, especially of business relevant, complex or abstract knowledge, knowledge visualization is powerful, as we discussed in this article. But often budget and time is allocated, when it is too late. In our praxis we have seen that knowledge visualization helps in early stages of projects. In the fields of strategic management, marketing, public relation and advertising imaginary visualizations or mental images (i.e. stories or metaphors) are already used to envision and illustrate strategies, mutual targets or values. Storytelling in management to create and disseminate knowledge is fruitful and discussed for instance by Loebbert (2003). We believe that these stories can be visualized and combined with other visualization formats to trigger and accelerate the creation and dissemination of knowledge. We believe that knowledge visualization can become the function of a mediator of the essential knowledge between strategic management, advertising, marketing, public relations and corporate communication, because it combines imaginary (i.e. stories), physical and digital visualizations. We believe that time and budget for knowledge visualization will be integrated in future initiatives where the transfer and creation of knowledge is important.

Knowledge Ambienting: Moving Knowledge Visualization off the screen

The fact that imaginary visualizations (such as visual tales) are essential in knowledge visualization makes it clear that visualization is already leaving the screen and entering other realms. While visualizations to create and disseminate knowledge in organizations were originally seen as static objects we can now identify two trends:

First, new displays, media and carrier of information are developed. Current user interfaces display information as "painted bits" on rectangular screens. New approaches with its roots in *Ubiquitous Computing* (Weiser, 1991) or *Augmented Reality (Feiner et al., 1993; Wellner et al., 1993)* attempt to change the paradigm of "painted bits" into "tangible bits" (Ishii and Ullmer, 1997). As a consequence, the richness of human senses and skills can be used for a much richer multi-sensory experience of digital information. Computer generated visualizations, that today are presented on screens or video projections, will soon merge with virtual space. An example of this trend is the blue-c[5] project at the Federal Institute of Technology in Zurich. It presents a tele-immersive space for 3D collaboration in virtual environments (Gross et al., 2003).

Second, visualizations are becoming more dynamic and interactive, as discussed in the section on knowledge animation. Visualizations are therefore no longer simply static objects for the transfer of knowledge in the classic sender-recipient model. They establish an iterative, collaborative process where the visualization (and new knowledge) is dynamically co-created.

These two trends - first, that visualization is leaving the 2D computer screen and second that visualizations are becoming dynamic and interactive- will offer new opportunities for the creation and transfer of knowledge in organizations.

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[5] http://blue-c.ethz.ch

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