Towards a Framework and a Model for Knowledge Visualization: Synergies Between Information and Knowledge Visualization

Remo Aslak Burkhard

University of St. Gallen, Blumenbergplatz 9,
CH-9000 St. Gallen, Switzerland
Remo.Burkhard@unisg.ch

Abstract. This article presents synergies between the research areas information visualization and knowledge visualization from a knowledge management and a communication science perspective. It presents a first theoretical framework and a model for the new field of knowledge visualization. It describes guidelines and principles derived from our professional practice and previous research on how architects successfully use complementary visualizations to transfer and create knowledge among individuals from different social, cultural, and educational backgrounds. The findings and insights are important for researchers and practitioners in the fields of information visualization, knowledge visualization, knowledge management, information design, media didactics, instructional psychology, and communication sciences.

1 Introduction: Knowledge Visualization in Organizations

This article illustrates the difference between the research areas information visualization (Card, Mackinlay & Shneiderman, 1999; Chen, 1999; Spence, 2000; Ware, 2000) and knowledge visualization (Burkhard, 2004a; Eppler & Burkhard, 2004) from a knowledge management (Alavi & Leidner, 2001) and a communication science (Fiske, 1982) perspective, and aims to illustrate synergies for both fields. To do so, it introduces a *Knowledge Visualization Framework*, a *Knowledge Visualization Model*, and the concept of *complementary visualizations*.

First, this article illustrates related insights from the field of business knowledge management. This section extends the previous contributions in this book with an additional perspective: The organizational perspective.

Second, it presents insights from the field of cognitive neuroscience of vision (Farah, 2000) and visual perception (Goldstein, 2001; Ware, 2000). This section aims to get a deeper understanding of our powerful innate abilities to process visual representations.

Third, it discusses the differences between the research areas information visualization and knowledge visualization from an organizational perspective and introduces an effective concept of architects to create and transfer knowledge: *complementary visualizations* (Burkhard, 2004a, b).

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Fourth, based on the analysis how architects use complementary visualizations to create and share knowledge, the key features for knowledge visualization are derived which allows to propose a first conceptual framework for the field knowledge visualization. The framework consists of four perspectives, and aims to mediate among different research areas and to illustrate how information visualization and knowledge visualization complement one another.

Fifth, this article introduces a first *Knowledge Visualization Model*. The model identifies and relates the salient features in knowledge visualization and complements established models in communication sciences. Further, guidelines for practitioners are discussed.

Finally, this article describes the potential of knowledge visualization for information visualization, both in the larger context of knowledge creation and knowledge transfer.

In concluding, the framework, the model, and the concept of complementary visualizations are the first theoretical approaches that structure the domain of knowledge visualization. The findings and results from this article are relevant for researchers and practitioners in the domain of information visualization, knowledge visualization, information design, knowledge management, media didactics, instructional psychology, and communication sciences.

2 Information Visualization Can Learn from Knowledge Management

Knowledge Management is a management perspective that offers theories, strategies, and methods to manage, i.e., to identify, access, share, and create knowledge in organizations, with the aim to help an organization to compete by being more innovative, effective, and thus more profitable.

Knowledge Management has its roots in organizational learning (Argyris & Schön, 1978; Fiol & Lyles, 1985; Senge, 1990), strategic management, and information science. The *knowledge-based theory* sees knowledge as a key productive and strategic resource, which is embedded in an organizational culture, in systems, documents, and individuals. The knowledge-based theory is described by various researchers (Grant, 1996; Nonaka, 1991; Nonaka & Takeuchi, 1995; Spender, 1996).

As a result of the knowledge-based perspective, research and management practice has become more knowledge-focused, e.g., through establishing knowledge cultures, implementing knowledge strategies, introducing knowledge audits, communities of practice, and knowledge management systems, or sharing lessons learned from project debriefings.

In the past, different knowledge management strategies have been introduced and established. But these strategies and perceptions differ depending on the understanding of knowledge. If knowledge is viewed as an *object*, knowledge management aims to build information repositories. If knowledge is understood as a *process*, the focus is on optimizing the knowledge-intense processes, e.g., identifying, creating, and sharing knowledge. Knowledge seen as a *capability* focuses on the strategic advantage of knowledge, to build core competencies, and to create intellectual capital. If knowledge is seen as a condition of *access* to information, then knowledge management focuses on methods to identify, retrieve, and gain access to information. Finally, if knowledge is seen as a *state* of knowing and understanding, knowledge management supports individuals to expand their knowledge.

In spite of these diverging understandings of knowledge, all perspectives have in common, that knowledge management is seen as a dynamic and continuous task, with three main objectives: (1) to optimize business processes from a knowledge perspective, (2) to introduce systems for storing, identifying, retrieving, and gaining access to information, and supporting individuals to collaborate, (3) to develop a corporate knowledge culture that motivates employees to envision, create, and share knowledge, alone, in teams, or across units and regions.

The main processes in knowledge management can be divided into four processes (Alavi & Leidner, 2001): (1) the creation, (2) the storage and retrieval, (3) the transfer, and (4) the application of knowledge. However, this article concentrates on the process of transferring knowledge, because this process is an important process and a process that has been neglected by information visualization researchers. Thus, they can learn from knowledge management by expanding their focus from the creation of knowledge to the creation and transfer of knowledge.

The transfer of knowledge is a core process in knowledge management and difficult to manage (Probst, Raub & Romhardt, 1997). The transfer of knowledge occurs at various levels: Among individuals, from individuals to groups, among groups, among individuals/groups and an organization. Based on Gupta and Govindarajan (2000) five elements for a successful knowledge transfer can be distinguished: (1) the perceived value of the sender's knowledge, (2) the motivation and willingness of the sender to share his knowledge, (3) the existence and richness of transmission channels, (4) the motivation of the recipient to acquire knowledge from the sender, and (5) the absorptive capacity of the recipient, i.e., the ability not only to acquire but also to use knowledge. To do so, knowledge must be recreated by the receiver, which brings us to the challenge: Individuals who need to transfer knowledge to one or more individuals, from the same or different backgrounds, not only need to convey the relevant knowledge, but also need to convey it in the right context, so it can be used and applied.

Concluding, the process of knowledge transfer is a key process for knowledge-intense organizations and faces various problems. But luckily, for exactly this challenging process we have a very powerful and yet rarely used skill that can be exploited: Our innate ability to effectively process visual representations.

3 Our Innate Abilities to Process Visual Representations

A majority of our brain's activity deals with processing and analyzing visual images. To understand perception, it is important to remember that our brain does not differ greatly from our ancestors, the troglodytes. At that time, perception helped for basic functions, for example for hunting (motion detection), seeking food (color detection), or applying tools (object-shape perception).

To comprehend visual perception, the Gestalt Principles (Ellis, 1938; Koffka, 1935) are helpful to understand how we perceive groups of objects or parts of objects, by identifying various perceptual phenomena. The Gestalt Principles provide descriptive insights into form and pattern perception. But unfortunately they do not offer explanations of these phenomena. To understand how or why we perceive forms and patterns, we need to consider explanatory theories of perception. But before we come to these theories it is introduced how visual information is being processed (Farah, 2000; Goldstein, 2001; Gregory, 1998; Ware, 2000).

Visual information processing can be divided into two stages: In the first stage, information is parallel processed in the eye and the primary visual cortex, where individual neurons in specific areas (called V1, V2, V3, V4, MT) are specialized to identify particular features (e.g., orientation, color, texture, contour, or motion). At this early stage information processing proceeds pre-attentively and very rapidly. In the second stage, information processing is divided into two functionally independent complementary subsystems, "*two cortical visual systems*" in the terminology of Ungerleider and Mishkin (1982): One visual subsystem is more important for object identification (~what) and the other for spatial localization (~where).

But these findings from visual information processing do not explain yet how we visually perceive form. This subject is being investigated by visual perception research (Goldstein, 2001; Ware, 2000), where two complementary theoretical approaches exist: bottom-up (*direct perception*) and top-down (*constructive perception*) theories:

Direct perception (bottom-up) believes that all the information we need to perceive is in the sensory input we receive. Three main bottom-up approaches can be differentiated: (1) The *template-matching theory* states that we have highly detailed templates of patterns stored in our mind, (2) the *prototype-matching theory* believes in classes of prototypes with the most typical features of a pattern, (3) and the *feature-matching theories* suggest that we match features (i.e., line orientation) of a pattern to features stored in memory.

Constructive perception (top-down) (Bruner, 1957; Gregory, 1980; Rock, 1983) in contrast believes that an individual's perception is based on the combination of sensory information with prior knowledge and previous experience.

Above I introduced the theoretical background of visual image processing and visual perception. This background can be important to understand when we want to exploit our innate abilities to process visual representations. Next, several functions of visual representations are discussed. Visual representations help for instance (1) to address emotions, (2) illustrate relations, (3) discover trends, patterns, outliers, (4) to get and keep the attention of recipients, (5) to support remembrance and recall, (6) to present both an overview and details, (7) to facilitate learning, (8) to coordinate individuals, (9) to motivate people and establish a mutual story, or (10) to energize people and initiate actions by illustrating options to act.

Several studies prove the power of visualizations with regard to these functions. Some examples: (1) Miller (1956) reports that a human's input channel capacity is greater when visual abilities are used. (2) Our brain has a strong ability to identify patterns, which is examined in Gestalt psychology (Ellis, 1938; Koffka, 1935). (3) Visual imagery (Kosslyn, 1980; Shepard & Cooper, 1982) suggest that visual recall seems to be better than verbal recall. Yet, it is not clear how images are stored and recalled, but it is clear that humans have a natural ability to use images. (4) Several empirical studies show that visual representations are superior to verbal-sequential representations in different tasks (Bauer & Johnson-Laird, 1993; Glenberg & Langston, 1992; Larkin & Simon, 1987; Novick, 2001). (5) Instructional psychology and media didactics investigate the learning outcomes in knowledge acquisition from text and pictures (Mandl & Levin, 1989), or Weidenmann (1989) who explores aspects of illustrations in the learning process.

This section introduced the theoretical background to help understand, how our innate abilities to process visual representations can be exploited to create and share insights. Understanding these abilities further, allows to distinguish the concept of information visualization versus knowledge visualization, which both exploit this potential, but in different ways.

4 The Difference Between Information Visualization and Knowledge Visualization

In Burkhard (2004a) the first definition of knowledge visualization was introduced, which allowed to discuss the difference between knowledge visualization and information visualization. This first definition also helped to differentiate knowledge visualization and knowledge domain visualization (Börner & Chen, 2002; Chen, 2003). Today the following definition of knowledge visualization is being accepted by information visualization, knowledge visualization, and knowledge domain visualization experts: "*Knowledge Visualization examines the use of visual representations to improve the transfer and creation of knowledge between at least two persons*". (Burkhard, 2004a; Burkhard & Meier, 2004; Eppler & Burkhard, 2004).

Information visualization is a rapidly advancing field of study both in terms of academic research and practical applications. Early information visualization proponents created static paper based visualizations (i.e., a map or a drawing) (Bertin, 1967; Tufte, 1983, 1990, 1997), but recently the research area information visualization is being claimed by a more computer-based community (Card et al., 1999; Chen, 1999; Spence, 2000; Ware, 2000), which define information visualization, as "*... the use of computer-supported, interactive, visual representations of abstract data to amplify cognition*" (Card et al., 1999). This definition is well established and represents a consensus among computer scientists active in this field.

However, four limitations can be identified: First, non-computer based visualizations disappeared from the research field information visualization. Second, knowledge types (e.g., insights, experiences, tacit knowledge) that cannot be put into a digital carrier (i.e., a database) were ignored. Third, the role of the recipient was not studied enough. Fourth, applying the new methods to knowledge and business processes, and real problems, was not investigated systematically.

These issues were the starting point for a new research direction: Knowledge visualization. Researchers in this field therefore often have a background in knowledge management, psychology, didactics, architecture, or communication studies.

In general, researchers in the fields of 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. Next, I try to differentiate the fields by discussing ten differences concerning the goals, origin, and techniques of both fields.

4.1 Goal: Knowledge Creation Versus Knowledge Transfer

1. *Goal*. Information visualization aims to use computer-supported visual applications for exploratory tasks in large amounts of data, with the goal of getting new insights. Knowledge visualization, in contrast, aims to use one or more visual representations with the goal to improve the transfer of knowledge among people and to improve the creation of knowledge in groups.
2. *Benefit*. Information visualization aims to improve information access, retrieval and exploration of large data sets. Knowledge visualization, in contrast, aims at augmenting knowledge-intensive processes (e.g., knowledge transfer, communication) among individuals by using one ore more visual representations.
3. *Content*. Information visualization concentrates on explicit data such as facts or numbers, while knowledge visualization also cares for other knowledge types, such as experiences, insights, instructions, assumptions - knowledge types that answer questions such as why, who, or how.
4. *Recipients*. Information visualization typically supports an individual to get new insights. Knowledge visualization, in contrast, concentrates on supporting individuals or a group of individuals to transfer knowledge and to create new knowledge in collaborative settings.
5. *Influence*. Information visualization provides new insights for the fields of information science, data mining, data analysis, and for problems such as information exploration, information retrieval, human-computer interaction, interface design. Knowledge visualization provides new insights for the fields of visual communication science, knowledge management, and for problems such as knowledge exploration, -transfer, -creation, -application, learning, information quality, information overload, design, interface design, visual communication. However, some of these points also apply to information visualization.

4.2 Origin: Computer Science Versus Architecture

6. *Proponents*. Information visualization researchers typically have a background in computer science. Knowledge visualization researchers, in contrast, mainly have a background in knowledge management, psychology, design, or architecture.
7. *Contribution*. Information visualization is more innovation-oriented; researchers in this field mainly create new technical methods. Knowledge visualization is more solution-oriented and tries to apply such novel, but also traditional visualization methods, to solve predominant problems. Only if no method exists or works, they invent a new method. Knowledge visualization is integrative and offers urgently needed theoretical structures for the whole field of visualization research, with the aim to improve collaboration among these isolated fields.
8. *Roots*: Information visualization is a young field of research that became only possible with the introduction of computers. Knowledge visualization is an even newer term, but grounded in cultural and intellectual achievements, e.g., of architects and philosophers, which use complementary visual representations to transfer and create knowledge, e.g., Aristotle on the power of metaphors in (Eco, 1984). Namely the practice of architects to use complementary visualization is a source for further investigations with relevance for knowledge management, communication science,

and information visualization researchers. Because of three reasons: (1) Architects combine, structure, and integrate different concepts. (2) Architects intuitively use complementary visualizations for knowledge-intense tasks. (3) Architects are experts in interfunctional communication (e.g., among decision makers, site constructors, local authorities). (4) Architects constantly think in and switch among different conceptual levels (e.g., urban scale or detail of a house).

4.3 Technique: Interactive Applications Versus All Visual Representations

9. *Means.* Information visualization uses computer-supported methods. Knowledge visualization, in contrast, uses computer-support, but also non-computer supported visualization methods, like early information visualization proponents, architects, artists, or designers use them.
10. *Complementary Visualizations.* Information visualization combines different visualization methods using the same medium in one interface, by tightly coupling them; this concept is called *multiple coordinated views*. Knowledge visualization combines different visualization methods using one and/or different media (e.g., a software, a poster, or a physical object) with the aim to illustrate knowledge from different perspectives and to exploit different functions of visual representations. In knowledge visualization this concept is called *complementary visualizations*. Complementary visualizations are defined as the use of at least two visual representations that complement each other to augment knowledge-intense processes. This concept is derived from the professional practice of architects and urban planners, who use complementary visualizations to envision, think, innovate, communicate, disseminate and document complex knowledge (Burkhard, 2004a, b).

This juxtaposition of ten points is not exclusive, and should rather be seen as a starting point for others to extend the arguments. It is a first attempt to find synergies for both fields by describing the individual strengths and weaknesses. The juxtaposition makes clear that information visualization and knowledge visualization can benefit from one another and together improve learning, or the creation and transfer of knowledge.

The next section discusses four perspectives that need to be considered when transfer and creation of knowledge are intended and should be optimized.

5 Structuring the Field: The Knowledge Visualization Framework

For an effective transfer and creation of knowledge through visualizations, four perspectives (Fig. 1) should be considered, based on four relevant questions:

- Why should knowledge be visualized? (aim)
- What type of knowledge needs to be visualized? (content)
- Who is being addressed? (recipient)
- Which is the best method to visualize this knowledge? (medium)

These key questions lead to the Knowledge Visualization Framework, which is grounded in previous frameworks (Burkhard, 2004a; Eppler & Burkhard, 2004) as seen in Fig. 1.

FUNCTION	KNOWLEDGE TYPE	RECIPIENT	VISUALIZATION TYPE
Coordination	Know-what	Individual	Sketch
Attention	Know-how	Group	Diagram
Recall	Know-why	Organization	Image
Motivation	Know-where	Network	Map
Elaboration	Know-who		Object
New Insight			Interactive Visualization
			Story

Fig. 1. The Knowledge Visualization Framework consists of four perspectives that need to be considered when creating visual representations that aim to transfer and create knowledge: A *function perspective* answers why a visualization should be used, a *knowledge type perspective* clarifies the nature of the content, a *recipient type perspective* points to the different backgrounds of the recipient/audience, and finally the *visualization type perspective* structures the main visualization types according to their individual characteristics

5.1 The Function Perspective

The Function Perspective distinguishes six functions of visual representations that can be exploited. The social, emotional, and cognitive functions of visualizations can be summarized in the CARMEN-Acronym (Eppler & Burkhard, 2004):

- *Coordination.* Visual representations help to coordinate individuals in the communication process (e.g., Knowledge maps, visual tools for collaboration, heuristic sketches).
- *Attention.* Visual representations allow to get the attention by addressing emotions (e.g., advertising), to keep the attention (e.g., sketching on a flipchart) by identifying patterns, outliers and trends (e.g., information visualization).
- *Recall.* Visual representations improve memorability, remembrance and recall, because we think in images, (e.g., visual metaphor, stories, conceptual diagrams).
- *Motivation.* Visual representations inspire, motivate, energize, and activate viewers (e.g., knowledge maps, mutual stories, instructive diagrams).
- *Elaboration.* Visual representations foster the elaboration of knowledge in teams (e.g., discussing scenarios of a new product by the use of heuristic sketches or a physical model).
- *New Insights.* Visual representations support the creation of new insights by embedding details in context and showing relationships between objects (e.g., information visualization) or lead to a-ha effects (e.g., visual metaphors).

5.2 The Knowledge Type Perspective

The Knowledge Type Perspective aims to identify the type of knowledge that needs to be transferred. Such different types of knowledge are investigated in the field of knowledge management. For our framework, five types of knowledge are distinguished: Declarative knowledge (Know-what, e.g., facts), procedural knowledge

(Know-how, e.g., processes), experimental knowledge (Know-why, e.g., causes), orientational knowledge (Know-where, e.g., knowledge sources), individual knowledge (Know-who, e.g., experts). Today no classification exists that links visualization types to knowledge types.

5.3 The Recipient Type Perspective

The Recipient Type Perspective aims to identify the target group and the context of the recipient which can be an individual, a team, a whole organization or a network of persons. Knowing the context and the cognitive background of the recipient/audience is essential for finding the right visualization method for the transfer of knowledge. Except from human computer interaction researchers (HCI) who focus on task analysis and ethnographic user studies, academic researchers in information design and information visualization do not focus on the Recipient Type perspective.

5.4 Visualization Type Perspective

The Visualization Type Perspective structures the visualization methods into seven main groups: Sketches, Diagrams, Images, Maps, Objects, Interactive visualizations, and Stories. These seven types are grounded and derived from the seven visualization methods architects use to transfer and create knowledge (Burkhard, 2004a). Each visualization type has particular strengths and weaknesses that are discussed next:

Sketches represent the main idea, are atmospheric, and help to quickly visualize an idea (Fig. 2 and 3). Sketches are used to assist the group reflection and communication process by making knowledge explicit and debatable.

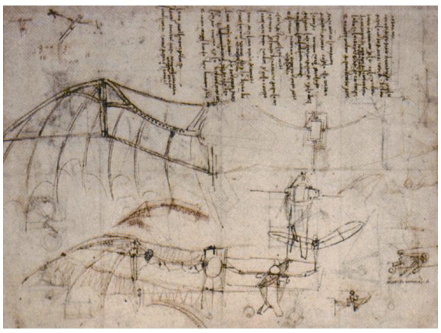

Fig. 2. A sketch from Leonardo da Vinci represents the main idea of a new concept [1]

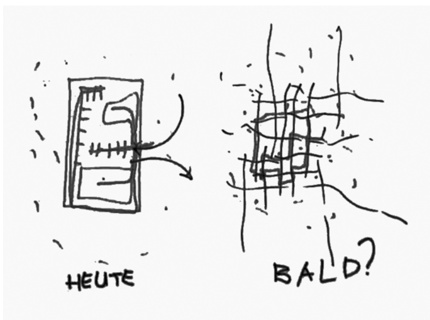

Fig. 3. Various sketches helped to assist the group reflection processes in a workshop for new ideas[2]

For the transfer and creation of knowledge, sketches have five strengths: (1) sketches represent the main idea and key features of a preliminary study and support reasoning and arguing. (2) They are atmospheric, versatile, and universally accessible.

[1] Retrieved on the 20th of August 2004 from http://www.visi.com/~reuteler/vinci/fly3.jpg
[2] ETH Science City: http://www.sciencecity.ethz.ch

(3) They are fast to create, and help to quickly visualize an idea. (4) They keep the attention (e.g., the use of a pen on a flipchart attracts the attention towards the communicator). (5) Sketches allow room for own interpretations and foster the creativity in groups.

Diagrams by contrast are abstract, schematic representations used to explore structural relationships among parts (Fig. 4). Garland (1979) defines a diagram as a "*visual language sign having the primary purpose of denoting function and/or relationship*". The type of knowledge that is conveyed by diagrams is analytic; diagrams are therefore structured and systematic.

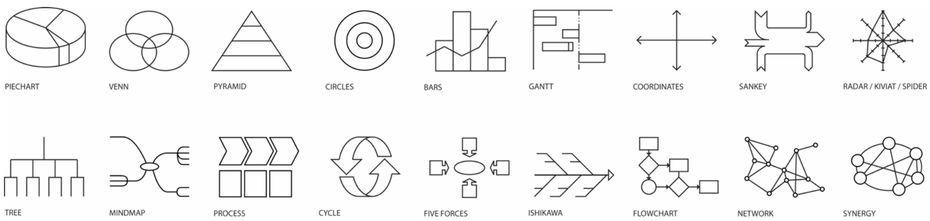

Fig. 4. Diagrams are schematic depictions of abstract ideas that use standardized shapes to structure information and illustrate relations

For the transfer and creation of knowledge, diagrams help to make abstract concepts accessible, help to reduce complexity, amplify cognition, explain causal relationships, structure information, and to discuss relationships.

Apart from established diagrams (Fig. 4) new types of diagrams are currently being developed for the transfer and creation of knowledge in teams. This is done again by architects and urban planners. Why? When it comes to complex factors, such as social, cultural, or economic factors in urban planning, the diagrams discussed above are not suitable to create new insights and to transfer such insights. Therefore architects and urban planners were forced to develop new types of diagrams that allow to illustrate a higher complexity or to represent more variables in a single diagram. Today, almost every leading architecture or urban planning office[3] in the world has developed their own visual diagramming language for knowledge-intense processes.

Maps follow cartographic conventions to reference knowledge. A map generally consists of two elements: A ground layer represents the context (e.g., a network of experts, a project, a city) and individual elements (e.g., experts, project milestones, roads). In the context of knowledge management, maps are called knowledge maps. They illustrate both an overview and details, and interrelationships among these details. Thus knowledge maps are graphic directories of knowledge-sources, -assets, -structures, or -processes. However, knowledge maps can also be fictitious and address visions, or stories, for example to establish a mutual context in an organization. Fig. 5

[3] Examples: Asymptote Architecture (www.asymptote-architecture.com), Morphosis (www. morphosis.net), MVRDV (http://www.mvrdv.archined.nl), The Office for Metropolitan Architecture OMA with its research department AMO (www.oma.nl), Eisenman Architects, (www.eisenmanarchitects.com) or the UN Studio (www.unstudio.com).

presents a fictitious map that improved interfunctional communication of a complex project in an organization, based on the power of visual metaphors.

For the transfer and creation of knowledge, maps help to present the overview and the details, to structure information, to motivate and activate employees, to establish a common story, and to ease access to information.

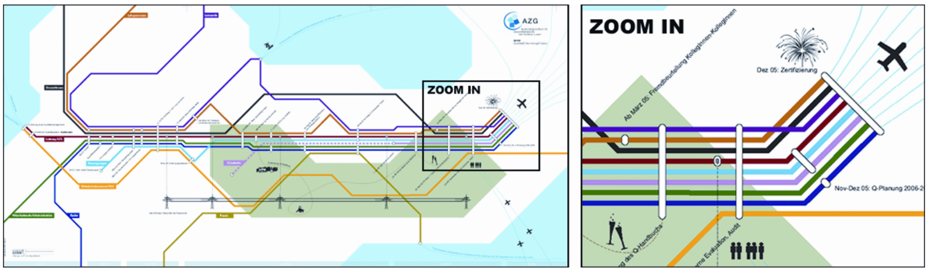

Fig. 5. The *tube map visualization*[4] is an example where a fictitious map was transferred into a business context to improve interfunctional communication in a complex project. The ground layer used the metaphor of a subway system, shown as a tubemap. The individual elements are subway lines (=target groups) and project milestones (=stations)

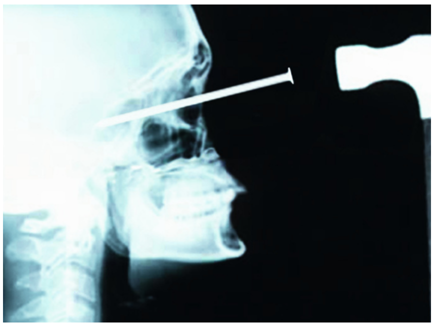

Fig. 6. Images address emotions and are widely used in advertising[5]

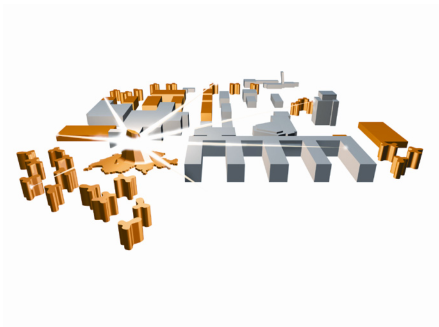

Fig. 7. Images can clarify complex projects and motivate different stakeholders[6]

Images are impressive, expressive, or represent reality. Images address emotions and they are inspiring, appealing, motivating, and energizing. Thus, they are widely used as a key instrument in advertising (Fig. 6). Images can be grasped and recalled in less than a second and sometimes be remembered for decades (i.e., key-images of the war in Vietnam or Iraq). The same effects can be used for the transfer of business related knowledge, e.g., by using visual metaphors (Fig. 7). *"To convert tacit knowledge into explicit knowledge means finding a way to express the inexpressible. Unfor-*

[4] Copyright of the tube map visualization: http://www.vasp.ch
[5] Image for a seminar on the effective use of visualizations: http://www.2sekmanager.ch
[6] ETH Science City: http://www.sciencecity.ethz.ch

tunately, one of the most powerful management tools for doing so is also among the most frequently overlooked: the store of figurative language and symbolism that managers can draw from to articulate their intuitions and insights" (Nonaka, 1991). Visual metaphors support remembrance, lead to a-ha effects, support reasoning, and communication. They are instant and rapid, highly instructive, and facilitate learning. The potential of visual metaphors is discussed in (Eppler, 2003).

For the transfer of knowledge, images help to get the attention (e.g., advertising), inspire recipients (e.g., art), address emotions (e.g., advertising), improve recall (i.e., signs, visual metaphors), or initiate discussions (e.g., satirical comic).

Fig. 8. Objects in this Info-Structure attract people[7]

Fig. 9. Objects and images complement each other, e.g., in an exhibition

Objects in Space exploit the third dimension and allow experiencing materials. Objects in space are helpful for example for information points (Fig. 8), knowledge fairs, or exhibitions (Fig. 9) to complement physical and digital visualizations and to show the content from different points of view.

For the transfer of knowledge, objects help to attract recipients, support learning through constant presence, or allow to integrate digital interfaces.

Interactive Visualizations allow to access, explore, and make sense of different types of information. An example of a visualization application[8] (Fig. 10) allows to explore the data of a survey on the project ETH Science City. This application allows to filter the result sets by using different sliders and is based on previous work, e.g., described in (Brodbeck & Girardin, 2003). Another application, the Infoticle application (Vande Moere, Mieusset & Gross, 2004) uses data-driven particles (*Infoticles*) to explore large time-varying datasets with reoccurring data objects that alter in time in an immersive environment (Fig. 11). Animating these Infoticles leads to an animation that allows to see the behavior of individual data entries or the global context of the whole dataset.

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[7] Fig. 8 and 9: ETH Science City: http://www.sciencecity.ethz.ch

[8] http://www.macrofocus.com

To transfer knowledge, interactive visualizations help to fascinate people, enable interactive collaborations across time and space, allow to represent and explore complex data, or to create new insights.

Stories, the last visualization type, are imaginary (not physical) visualizations that are efficient in transferring and disseminating knowledge across time and space. The use of stories, called storytelling, allows to transport an illustrative mental image by the use of spoken or written language and can be used in organizational practice (Loebbert, 2003).

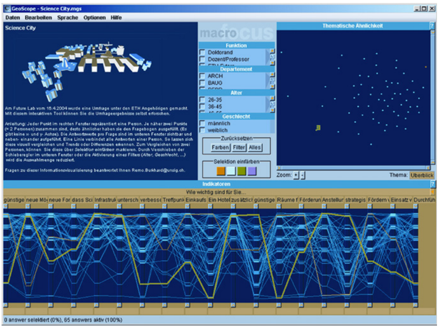

Fig. 10. An interactive visualization allows to get new insights by visually exploring data of a survey based on the method described in (Brodbeck & Girardin, 2003)[9]

Fig. 11. The Infoticle application allows to explore large time-varying datasets in an immersive environment (Vande Moere et al., 2004)[10]

To transfer knowledge, imaginary visualizations complement the other six visual formats and are valuable to establish a shared vision, a mutual story, to motivate and activate individuals.

6 Synthesis: The Knowledge Visualization Model

The analysis of the previous examples and the argumentation has shown that the use of visual representations can serve for different functions, and is an effective strategy for the transfer and creation of knowledge. However, choosing the right format demands skills and experience. To assist practitioners and to mediate among different fields, a first conceptual model is introduced next. The model identifies and relates the features that contribute most to a successful behavior when complementary visualizations are used to transfer and create knowledge.

Such a *Knowledge Visualization Model* is needed for three reasons: First, communication science models (Gerbner, 1956; Jakobson, 1960; Lasswell, 1948; Newcomb, 1953; Shannon & Weaver, 1949) are too general with regard to the use of visual representations. Second, visualization scientists do not offer a holistic model for the

[9] http://www.macrofocus.com
[10] http://blue-c.ethz.ch

transfer and creation of knowledge with visual representations. Third, it complements the Knowledge Visualization Framework and together can achieve the goals of knowledge visualization discussed above.

6.1 The Knowledge Visualization Model

The *Knowledge Visualization Model* (Fig. 12) is divided into three parts: a sender, a medium, and a recipient. These three parts are all interlinked in an interaction and communication loop.

The model describes inter- and intrapersonal iterative processes: The process starts with a *sender* who wants to transfer some of his knowledge (*knowledge)* to a *recipient*. His mental model of this knowledge (*mental model sender*) is being externalized into various explicit and *complementary visual representations*, which can be divided into three sub processes (*1, 2, 3*) following a temporal sequence: First, the sender needs to get the *attention* (*1*) of the recipient, for instance by using a provocative image. Second, the sender needs to illustrate the *context* (*2*), provide an *overview* (*2*), and present *options to act* (*2*). Only then the sender can point to selected *details* (*3*), which ideally happens in a dynamic dialog with the recipient (*D*), who re-constructs (*C*) similar knowledge (*Knowledge'*) with these complementary visualizations and an own mental image (*mental model recipient*). But due to different assumptions, believes, or backgrounds, inferences and misinterpretations can occur (*E*), which can lead to a failure of the knowledge re-construction. In this process, the sender iteratively refines or adds further visual representations (*F*), until the knowledge transfer process was successful.

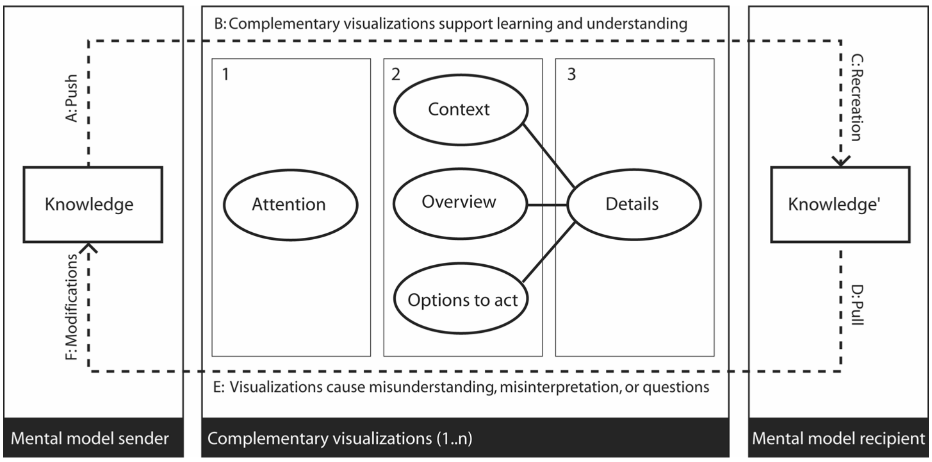

Fig. 12. The Knowledge Visualization Model with a sender, a recipient and complementary visualizations as a medium

The model introduces the salient features that need to be considered when complementary visual representations are used to transfer or create knowledge. Next, I discuss ten principles that should be considered when applying this model.

6.2 Guidelines for Applying the Knowledge Visualization Model

To design effective visualizations, different principles should be considered. These principles are derived from our practical work[11]:

1. *Know your data*. A designer must first understand and evaluate the information that is the basis for a visualization, and decide whether the data is complete, reliable, and relevant.
2. *Know your audience*. A designer should be aware of the diversity of the audience, their different needs and various social, cultural and educational backgrounds. People think, understand, and solve problems in different ways. It is further important to know whether an individual, a group, an organization, or a network is being addressed.
3. *Prevent misinterpretation*. The visualization should prevent misuse, misinterpretation, or misunderstanding. It is important to address the context, to present an overview, and to present options for how the knowledge can be applied. Visualizations should further be combined with text to prevent misuse.
4. *Compress your knowledge*. To increase the information quality and prevent information overload, a designer should concentrate on the quality, rather than the quantity, and concentrate on the essence. Tufte suggests compressing as much information into an as small space as possible.
5. *Present an overview and details*. Shneiderman's Mantra "*overview first, zoom in and filter, then show details on demand*" (Shneiderman, 1996) for information visualization interfaces is also valid for knowledge visualization. A designer should present both an overview of the data, and allow the user to access details.
6. *Be consistent*. Complementary visualizations should be consistent. Consistent in regard to the logic, the way to interact with it (e.g., in interactive applications), and the use of visual elements. Elements such as color, shape, size, symbols, or fonts should be similar for similar types of data in all visualizations.
7. *Avoid decoration*. The visualization should cause thinking about the content rather than the visualization itself. Therefore one should be careful with decorations or the unnecessary use of elements such as clip-arts or strong colors.
8. *Don't distract your audience*. Do not use visualizations to distract your audience unless this is your intention. A lot of visualizations (i.e., clip arts) do nothing but divert the attention of the user, and distract the user from their knowledge acquisition or problem-solving tasks.
9. *Use natural representations*. Natural representations mean that the visualization can be associated with the real-world, which allows using a recognition-based approach instead of one that requires recall. This is important because recognition-based tasks are faster and need less energy.
10. *Motivate your audience*. Visual representations should be designed to envision, to cause thinking, and to encourage users to elaborate knowledge. Use imaginary visual representations to establish a shared vision.

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[11] The author is a partner in a knowledge visualization company: vasp datatecture GmbH, www.vasp.ch

7 Conclusion: Architects Are Knowledge Visualization Experts

Knowledge visualization offers opportunities for synergies with the field of information visualization. Because (1) it extends the field with regard to other knowledge types, (2) knowledge processes other than information exploration (namely knowledge transfer and knowledge creation in groups), and (3) additional computer based and non-computer based visualization methods, (4) because it points to psychological, social, and cognitive factors of different recipients, and (5) integrates findings from other research fields such as knowledge management, communication science, architecture, or psychology.

Knowledge visualization is defined as *the use of complementary visual representations to transfer and create knowledge between at least two persons* and differs from the field of information visualization with regard to - among other points - the goals, means, and background of the proponents, as well as its roots.

This article presented both a theoretical framework and a theoretical model for the domain of knowledge visualization, and guidelines for practitioners to overcome the current intolerable situation, where individuals learn for years how to write and calculate, but not how to visually communicate. Further, this article explained how information visualization and knowledge visualization can learn from the expertise of architects, in regard to interfunctional communication, the use of complementary visualizations in collaborative innovation and design processes (collaborative knowledge creation), or new conceptual diagrams to map complexity.

In conclusion, the *Knowledge Visualization Framework*, the *Knowledge Visualization Model*, and the concept of *Complementary Visualizations* presented in this article are important to researchers and practitioners in the fields of information visualization, knowledge visualization, knowledge management, information design, media didactics, instructional psychology, and communication sciences.

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