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A DECISION MATRIX FOR CHOOSING THE PROPER VISUALIZATION TECHNIQUE IN KNOWLEDGE VISUALIZATION

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ABSTRACT
Knowledge workers who want to apply knowledge visualization have to determine which visualization tool is suitable for their needs. To support knowledge workers in this sophisticated problem a systematic approach is presented that matches typical tasks in knowledge management to visualization techniques that support these tasks. Knowledge workers are provided with a three-dimensional decision matrix that enables them to easily identify a suitable visualization technique for a certain knowledge problem. To be able to systematically evaluate and identify adequate visualization techniques a set of evaluation criteria is introduced.

KEY WORDS
Information visualization, knowledge visualization, knowledge management, visualization technique

1. Introduction

Information visualization supports knowledge workers in creation, verification and presentation of knowledge as well as sharing knowledge with others. For example, it assists them in understanding social relationships, financial trends, document library development, and many more [1]. While information visualization ([2], [3], [4], [5]) is a well established field of study a new discipline is forming dealing with visualization techniques utilized for performing tasks of knowledge management – denoted as *knowledge visualization* (KV).
Eppler and Burkhard define knowledge visualization as the use of visual representations to improve the creation and transfer of knowledge between at least two persons [6]. Knowledge visualization is characterized by its multidisciplinary approach since it integrates results from information visualization, cognitive art, communication science, information architecture and knowledge management [7]. Knowledge visualization is an emerging discipline of information visualization and still has to be defined and established [8].

Information visualization – and consequently knowledge visualization – provides knowledge managers with a large variety of visualization techniques and tools that might be applied. However, knowledge managers think in terms of the knowledge management tasks they have to fulfil or in terms of the recipients, but not in visualization terms. For several knowledge management tasks the visualization of knowledge can be extremely helpful, for others it is not. In those cases where visualization can be applied, due to the large number of potential visualization techniques provided by information visualization ([2], [3], [4]) it is difficult to identify the one that suits best. This paper aims at supporting knowledge managers in solving this problem.
Each visualization technique can be applied to certain types of content (information respectively knowledge) and supports only a limited spectrum of applications. There are several criteria with complex interdependencies that determine whether a visualization technique is suitable for a specific knowledge task. Furthermore, it is often not well-defined which visualization should be applied. Knowledge managers are familiar with knowledge management techniques like knowledge maps, concept maps, yellow pages and many more, but they are often not familiar with visualization tools. They should be able to determine an adequate visualization technique easily – without having to perform complicated and time consuming analysis.
In this paper an approach to knowledge visualization will be presented that helps knowledge managers to identify an appropriate visualization technique that supplies their visualization needs. A decision matrix is proposed that associates knowledge management tasks to suitable visualization techniques. To evaluate the suitability of visualization techniques a set of evaluation criteria is introduced.
Section 2 gives a brief introduction to approaches on structuring the research domain of knowledge visualization as a new discipline of information visualization. Section 3 presents an overview of the entire mapping process. In section 4 the two major phases of the mapping process and criteria for evaluating visualization techniques are presented. In section 5 the two previous phases are combined to a single decision matrix. The paper is concluded in section 6 by an outlook on ongoing research.

2. Systematic Approaches to Knowledge Visualization

Since knowledge visualization is an emerging discipline only a few systematic and theory building approaches to this entire new field of study exist. Among these approaches the works by Eppler and Burkhard ([6], [9], [10]) are highly relevant with reference to this paper since they examine knowledge and information visualization from a business knowledge management perspective. Their aim is to develop a conceptual framework that enables practitioners to better use and apply visual representations of knowledge [6]. Thus, they discuss several types of knowledge visualization and their applications and develop a theoretical framework and a model for knowledge visualization [9].

The Knowledge Visualization Framework by Eppler and Burkhard consists of five perspectives that need to be considered when creating visual representations that aim to create and transfer knowledge: a knowledge type perspective (What type of content is visualized?), a visualization goal perspective (Why should the knowledge be visualized?), a target group perspective (Who are the recipients?), a situation perspective (In which context should it be visualized?), and a format perspective (How can the knowledge be presented?) ([10]; previous work in [6], [9]).

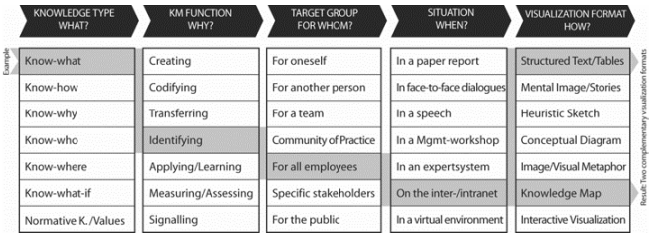

Figure 1: The Knowledge Visualization Framework by Eppler and Burkhard [10]

Eppler and Burkhard distinguish seven reasons why visual representations are used in knowledge management (KM function or KM process): creating, codifying, transferring, identifying, applying, evaluating and measuring, and signalling knowledge (knowledge marketing) [10]. When analyzing the types of visual representations they differentiate between the following types of visualization formats (methods): structured text/tables, mental visualization and story telling, heuristic sketches, conceptual diagrams and concept maps, visual metaphors, knowledge maps, and interactive visualization environments.

Fig. 2 shows how these visualization formats are suitable for different knowledge management areas revealing that knowledge visualization is a good strategy for knowledge creation [10].

As presented by Burkhard and Eppler [10], the aim of this contribution is to develop an instrument that provides practitioners, i.e. knowledge workers and knowledge managers, with an easy to use and simple way of applying visual representations of knowledge. However, in this contribution the main focus is on the decision process to figure out which kind of computer-supported visualization technique or tool suits their needs best, provided that a computer-supported visualization should be reasonable and/or feasible.

Formats / KM Process	Creation	Cocification	Transfer	Identification	Application	Measurement	Marketing
Structured Text/Tables		✓✓	✓			✓	
Mental Image/Stories	✓		✓✓		✓✓		✓✓
Heuristic Sketch	✓✓		✓		✓		
Conceptual Diagram	✓	✓✓	✓				
Image/Visual Metaphor	✓		✓✓				✓✓
Knowledge Map	✓			✓✓			✓✓
Interactive Visualization	✓✓				✓✓		

Figure 2: Application areas of visualization formats for different knowledge management tasks [10]

3. From Tasks to Techniques

Knowledge managers are confronted with different kinds of problems when dealing with knowledge, like finding ways and means of transferring knowledge between individuals or groups of knowledge workers, localizing knowledge and knowledge resources in their organization, supporting the development of new knowledge, making knowledge explicit or simply organizing and preserving knowledge, and many more. Thus, before thinking in terms of visual representations of knowledge they have to identify the problem and specify the knowledge management tasks.

To accomplish these tasks knowledge managers apply different instruments of knowledge management (*KM instruments*), like knowledge maps, knowledge landscapes, competency maps (e.g., yellow or blue pages), mind maps, semantic nets, topic maps, communities of practice, et cetera. Among the large variety of knowledge management instruments they have to choose the appropriate instrument that is particularly suitable for solving their problem.

Some knowledge management instruments are already based on inherent visual representations. However, most of these instruments can benefit from making knowledge visible in order to be better accessed, discussed, developed, or transferred. There are many knowledge management instruments to whom several alternative visual representations and corresponding visualization techniques might be applied, making it hard to decide which one suits best.

Thus, we end up with a decision-making process consisting of three phases:

Phase 1: Specification of the knowledge management task

Phase 2: Identification of an appropriate instrument of knowledge management

Phase 3: Selection of a visualization technique (and/or tool)

Finally, after applying the identified visualization technique we get a visual representation of knowledge that supports the knowledge manager in solving his knowledge management problem, e.g., by analyzing and interpreting the visual representation. Figure 3 illustrates the entire process.

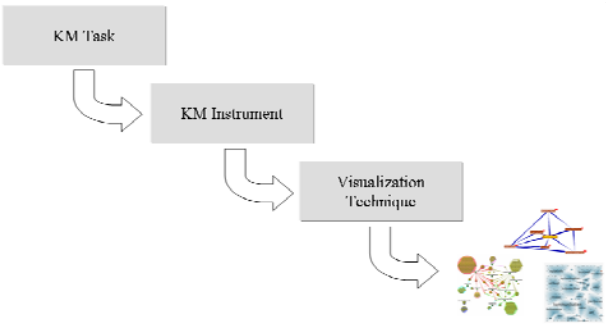

Figure 3: Phases of the decision-making process

4. Mapping

In phase 2 and phase 3 the most suitable knowledge management instruments and visualization techniques have to be identified. In this section two decision matrices are presented that support these phases. They will be combined to a single multi-dimensional decision matrix in section 5.

4.1 Knowledge Management Tasks and Instruments

In knowledge management several concepts, models and frameworks have been developed [11]. Among them the authors identified the *building blocks* of knowledge management, as proposed by Probst, Raub and Romhardt [12], to be most appropriate to describe the basic tasks of knowledge workers.

The building blocks model is made up of an inner cycle and an outer cycle including feedback. The inner cycle is composed of the building blocks of knowledge identification, knowledge acquisition, knowledge development, knowledge distribution, knowledge preservation and use of knowledge. An outer-cycle consists of theses activities plus the setting of knowledge goals and knowledge measurement (Figure 4) [13].

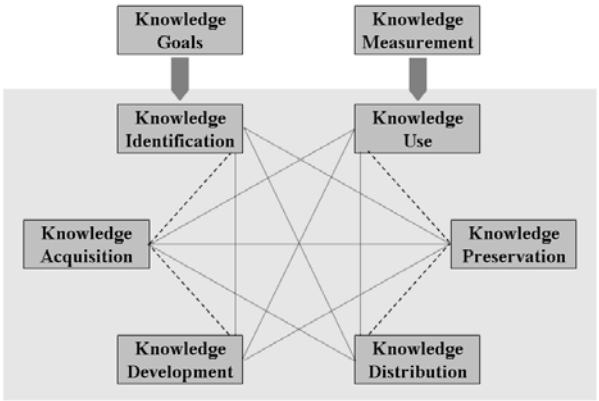

Figure 4: Building blocks of knowledge management [13]

The six building blocks of the inner circle have been chosen as starting point of the main tasks to be performed in knowledge management.

Knowledge managers use a number of instruments like knowledge maps, competency maps or semantic nets. Each of these *knowledge management instruments* can be applied to perform one or more of the previously mentioned tasks. With the help of knowledge management experts for each of the analyzed knowledge management tasks all knowledge management instruments that can be applied to this task are identified.

The building blocks make up one dimension of a two-dimensional structure. The knowledge management instruments make up the second dimension. Thus, we end up with a simple matrix that maps KM tasks (horizontal) to KM instruments (vertical). Table 1 shows an example of such a matrix with a small selection of KM instruments.

Table 1: KM tasks and KM instruments

	Identifi-cation	Acquisi-tion	Develop-ment	Distribu-tion	Preserva-tion	Use
Concept Map	×			×	×	×
Competency Map	×	×		×	×	
Application Map			×	×		×
Development Map			×			
Expertise Directories	×	×				
Skill Planning	×	×	×			
Topic Map	×		×	×	×	×
Semantic Net	×		×	×	×	×

Each mark × in Table 1 denotes that the corresponding KM instrument can be applied, but it does not reveal which instrument fits best. Therefore, a set of evaluation criteria has to be developed that provide a measure of correspondence. The final matching matrix will include in each cell a measured value with ratings in the range of [0% … 100%] (100% perfect match, 0% absolutely inapplicable).

4.2 Visualization Techniques and Knowledge Management Instruments

A large variety of knowledge management instruments is available to knowledge managers, e.g., knowledge map, concept map, competency map, semantic net, etc. [11]. These instruments are used in knowledge management to perform specific tasks. Many of them use visual representations. For each of these KM instruments there might exist one or more visualisation techniques that can be applied. For example, a knowledge map might be visualized by Cone Trees, Hyperbolic Trees, Mindmaps or TreeMaps [14]. Web rendering techniques for the Semantic Web can be found for instance in [15].

To figure out which of the KM instruments might use visualization all relevant visualization techniques have to be gathered and listed at first. Afterwards, for each of the KM instruments the list of visualization techniques is scanned through one by one to identify (based on well-established knowledge, e.g., expert knowledge or found in literature) which techniques can be applied.

Again, a similar approach like in the previous phase is applied. The visualization techniques make up one dimension of a two-dimensional structure. The knowledge management instruments make up the second dimension like they did before. Thus, we end up with another matrix that maps visualization techniques to KM instruments. Table 2 shows a first impression of such a matrix with a small selection of KM instruments and visualization techniques.

Table 2: KM instruments and visualization techniques

	Tree Map	Cone Tree	Hyper-bolic View	Mind-map	Galaxy	Net-work Diag.	Flow Chart
Concept Map	×	×	×	×		×	×
Competency Map		×	×	×		×	
Application Map	×	×	×	×		×	×
Development Map		×	×	×		×	×
Expertise Directories					×	×	
Skill Planning					×	×	×
Topic Map					×	×	×
Semantic Net					×	×	

4.3 Evaluation Criteria

To determine the suitability and quality of a visualization technique and whether it is appropriate for a specific knowledge management instrument, criteria for evaluating the visualization techniques have to be deduced.
On one hand, the visual representation by itself, e.g., the spatial organization of data, the data density, or information coding, has to be evaluated. The authors adapted and extended an approach proposed by Freitas, Luzzardi, et al. [16] to derive an appropriate set of evaluation criteria [17].
The main criteria concerning the visual representation are:

- characteristics of data: data type, data dimension, data format
- cognitive complexity: data density and relevance of information
- object location: logical order and occlusion
- reference context (spatial organization)
- relation: links between objects
- information coding
- state transition
- viewpoint manipulation
- display of details

On the other hand, the expressiveness and the effectiveness of the visualization technique are analyzed [18] which are of high relevance for its applicability. Since users interact with the visual representation by navigating in visual structures or manipulating the data set, in a second step the navigation skills are evaluated, too. However, these results are weighted much less. The following criteria are used to evaluate these interaction mechanisms [16]:

- data set manipulation: filtering, clustering, pruning
- orientation: level of detail, additional information
- navigation: selection of objects, zooming

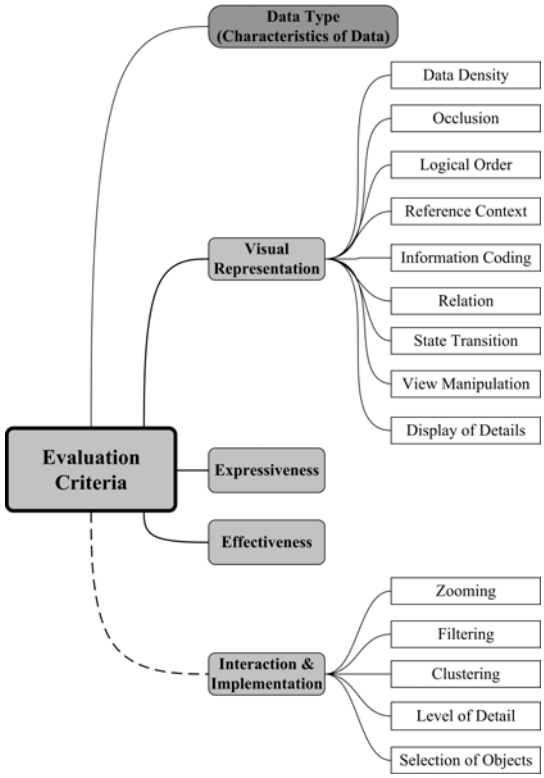

Figure 5: Overview of evaluation criteria

The evaluation criteria have to be weighted to represent their influence on the suitability of the visualization technique and to quantify the amount of match. The highest weight is assigned to the characteristics of data since type and format of data can reduce the pool of visualization techniques that are taken into account. In fact the data type is a knock-out criterion since a mismatch of a data type for a visualization technique excludes the visualization technique from further consideration. Shneiderman [19] provides a selection of data types (e.g. 1-, 2-, 3-dimensional, temporal, multi-dimensional, tree, network) which can be associated to visualization techniques.
Expressiveness and effectiveness can be weighted 25% each. Thus sufficient importance is assigned to the quality of visualization. Criteria describing the visual representation are weighted by the remaining 50%, for example weighting each of the individual criteria equally. Table 3 presents in the second column an example of weights that has been used in experiments [14]. The third column shows an alternative distribution of weights that allocates more influence to the visual representation and distributes weighting factors among the individual representational criteria in an unbalanced way (e.g., relations are more important than transitions). A more differentiated weighting of the criteria pooled in visual

representation might better suit the knowledge management task carried out by the KM instrument.
In our experiments the criteria relating to interaction and implementation have not been considered since they focus on specific implementations and not on the basic features of visualization techniques [14].

Table 3: Weighting of evaluation criteria

Criteria	Weight	Alternative Weight
Characteristics of data	knock out	knock out
Expressiveness	25 %	10 %
Effectiveness	25 %	20 %
Visual representation:	50 %	70 %
Data density	*5,56 %*	*5, 0 %*
Occlusion	*5,56 %*	*15,0 %*
Logical order	*5,56 %*	*12,5 %*
Reference context	*5,56 %*	*5,0 %*
Information Coding	*5,56 %*	*2,5 %*
Relation	*5,56 %*	*10,0 %*
State transition	*5,56 %*	*5,0 %*
Viewpoint manipulation	*5,56 %*	*5,0 %*
Display of details	*5,56 %*	*10,0 %*
Sum	100 %	100 %

5. The Decision Matrix

In the previous sections two single, two-dimensional matrices have been set up. Dimensions are labelled *KM tasks – KM instruments* and *KM instruments – visualization techniques* respectively. Since one dimension appears in both matrices, the single matrices can be combined to a single multi-dimensional structure. Consequently a three-dimensional matrix results that is defined by the dimensions *KM tasks – KM instruments – visualization techniques*: a 3D decision matrix.
Figure 6 demonstrates a simple example made up of six KM tasks, eight KM instruments and seven visualization techniques. Grey cells indicate cells that are listed in Table 1 showing KM instruments suitable for specific KM tasks thus identifying potential candidates for visual representations. By contrast white cells indicate nodes containing visualization techniques that cannot be applied to the corresponding KM instruments and KM tasks.
The numbers in the cells denote ratings in the range [0 … 10] derived from evaluating the previously mentioned criteria (rate 10 → perfect match) based on the work by Edlinger [14]. They indicate the amount of suitability of a visualization technique by applying the evaluation approach outlined in chapter 4.3 to each relevant combination *KM instrument* × *visualization technique* identified in Table 2.
For example, experiments in [14] resulted in the following ratings for Cone Trees that can be found in the second row of the front face of the matrix in Figure 6.

Table 4: Cone Tree

	Concept Map	**Competency Map**	**Application Map**	**Development Map**
Cone Tree	8,3	7,8	8,3	7,2

By viewpoint transformation this 3D matrix can be viewed from different dimensions – indicating different approaches to knowledge visualization. For example, besides searching for the best visualization technique starting with a specified knowledge task, e.g. knowledge acquisition, the matrix can also be used to identify all applicable knowledge management tasks or knowledge management instruments that might benefit from a certain visualization technique, e.g. a Galaxy approach.

6. Conclusion and Future Work

A multi-dimensional decision matrix has been introduced that supports knowledge manager in choosing a suitable visualization technique for a certain problem of knowledge management. The decision matrix provides them with a simple, easy to use tool – without having to perform complicated and time consuming analysis.
The concept of a 3D decision matrix has been demonstrated using only a small number of knowledge management instruments and visualization techniques. However, this also illustrates the strength of this approach, since it can be extended easily by simply adding additional rows and columns (or rather two-dimensional "rows" or "columns") for each additional knowledge management instrument or visualization technique. Due to this flexibility the decision matrix can grow and evolve to a comprehensive tool.
Ongoing research concentrates on improving evaluation criteria and developing a more sophisticated model of weights and influencing factors. Particularly the second phase of matching knowledge tasks to knowledge management instruments requires more elaborate factors of qualification.

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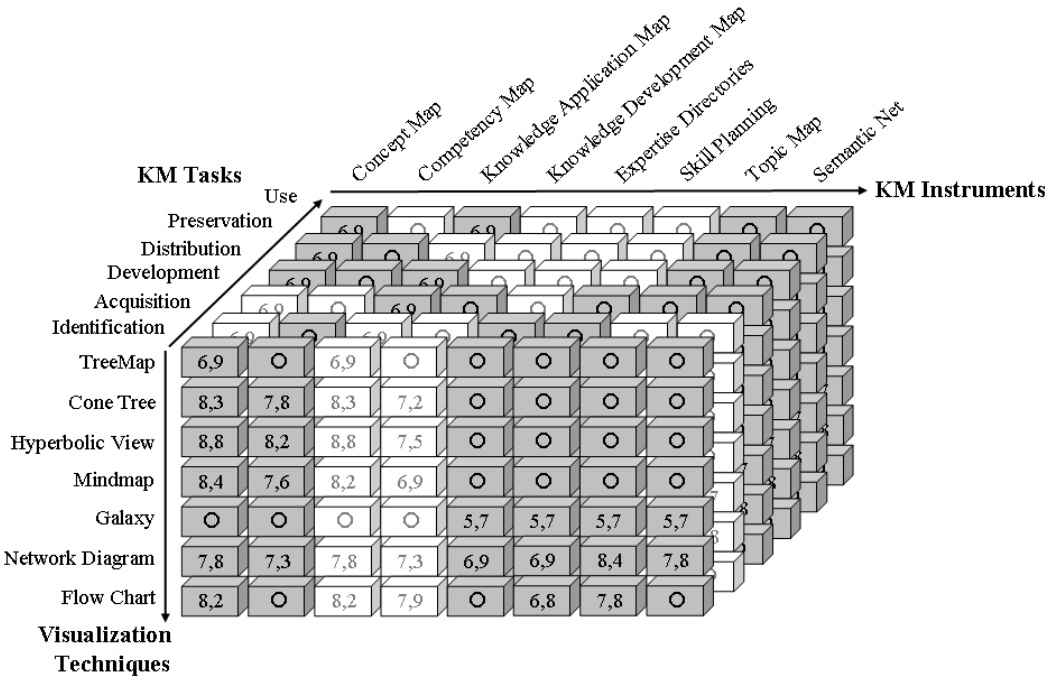

Figure 6: Three-dimensional decision matrix

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