Fraunhofer Institut
Techno- und
Wirtschaftsmathematik

T. Hanne, H. L. Trinkaus

knowCube for MCDM – Visual and Interactive Support for Multicriteria Decision Making

Berichte des Fraunhofer ITWM, Nr. 50 (2003)

ISSN 1434-9973

Bericht 50 (2003)

Die Veröffentlichungen in der Berichtsreihe des Fraunhofer ITWM können bezogen werden über:

Fraunhofer-Institut für Techno- und
Wirtschaftsmathematik ITWM
Gottlieb-Daimler-Straße, Geb. 49

67663 Kaiserslautern

Telefon: +49 (0) 6 31/2 05-32 42
Telefax: +49 (0) 6 31/2 05-41 39
E-Mail: info@itwm.fraunhofer.de
Internet: www.itwm.fraunhofer.de

Vorwort

Das Tätigkeitsfeld des Fraunhofer Instituts für Techno- und Wirtschaftsmathematik ITWM umfasst anwendungsnahe Grundlagenforschung, angewandte Forschung sowie Beratung und kundenspezifische Lösungen auf allen Gebieten, die für Techno- und Wirtschaftsmathematik bedeutsam sind.

In der Reihe »Berichte des Fraunhofer ITWM« soll die Arbeit des Instituts kontinuierlich einer interessierten Öffentlichkeit in Industrie, Wirtschaft und Wissenschaft vorgestellt werden. Durch die enge Verzahnung mit dem Fachbereich Mathematik der Universität Kaiserslautern sowie durch zahlreiche Kooperationen mit internationalen Institutionen und Hochschulen in den Bereichen Ausbildung und Forschung ist ein großes Potenzial für Forschungsberichte vorhanden. In die Berichtreihe sollen sowohl hervorragende Diplom- und Projektarbeiten und Dissertationen als auch Forschungsberichte der Institutsmitarbeiter und Institutsgäste zu aktuellen Fragen der Techno- und Wirtschaftsmathematik aufgenommen werden.

Darüberhinaus bietet die Reihe ein Forum für die Berichterstattung über die zahlreichen Kooperationsprojekte des Instituts mit Partnern aus Industrie und Wirtschaft.

Berichterstattung heißt hier Dokumentation darüber, wie aktuelle Ergebnisse aus mathematischer Forschungs- und Entwicklungsarbeit in industrielle Anwendungen und Softwareprodukte transferiert werden, und wie umgekehrt Probleme der Praxis neue interessante mathematische Fragestellungen generieren.

Prof. Dr. Dieter Prätzel-Wolters
Institutsleiter

Kaiserslautern, im Juni 2001

knowCube for MCDM – Visual and Interactive Support for Multicriteria Decision Making

Hans L. Trinkaus*, Thomas Hanne
Fraunhofer Institute for Industrial Mathematics (ITWM)
Department of Optimization
Gottlieb-Daimler-Str. 49
67633 Kaiserslautern
Germany
e-mail: trinkaus@itwm.fhg.de, hanne@itwm.fhg.de

Abstract

In this paper, we present a novel multicriteria decision support system (MCDSS), called `knowCube`, consisting of components for knowledge organization, generation, and navigation. Knowledge organization rests upon a database for managing qualitative and quantitative criteria, together with add-on information. Knowledge generation serves filling the database via e.g. identification, optimization, classification or simulation. For "finding needles in haycocks", the knowledge navigation component supports graphical database retrieval and interactive, goal-oriented problem solving. Navigation "helpers" are, for instance, cascading criteria aggregations, modifiable metrics, ergonomic interfaces, and customizable visualizations. Examples from real-life projects, e.g. in industrial engineering and in the life sciences, illustrate the application of our MCDSS.

Key words: Multicriteria decision making, knowledge management, decision support systems, visual interfaces, interactive navigation, real-life applications.

1 Introduction

Usually, real-life decision problems are characterized by several criteria or objectives to be taken into consideration. Despite the fact that "multiple objectives are all around us", as Zeleny (1982) points out, the dissemination of methods for multicriteria decision making (MCDM) into practice can still be regarded

*Corresponding author

as insufficient. A basic reason for that situation might be that practitioners are just not familiar with MCDM methods, which often are difficult to understand and to work at. One main difficulty for an easy and explorative usage of methods might be caused by the user interface, i.e. the handling of interactions with a corresponding computer program. Zionts (1999) is pointing out the necessity of user-friendly software in the following way: "I strongly believe that what is needed is a spreadsheet type of method that will allow ordinary people to use MCDM methods for ordinary decisions."

In this paper, we present a novel multicriteria decision support system (MCDSS), called `knowCube`, which mainly originates from focussing on user-specific needs. Therefore, the first aspect of the system is the provision of visualizations and interactivity in categories well understandable by non-expert users. All technical stuff, necessary for this comfortable presentation of and access on knowledge, is hidden in the background, combined in a so-called navigation component. Its integration with further components, for generating and managing knowledge data required for decision processes, is another main feature of this MCDSS.

The paper is organized as follows: Section 2 introduces some notation for multicriteria decision problems. (Here we restrict ourselves to tasks dealing only with quantitative criteria, other types of criteria will be topics of a paper to follow.) In Section 3, we present a survey of components of `knowCube`, and additionally some details on the generation and organization of decision knowledge. MCDM-specifics of `knowCube`, including a short excursion to human cognition, are discussed in Section 4. Two examples show the application of `knowCube` in real-life projects, one in the field of industrial engineering (Section 5), another one in medical radiation therapy (Section 6). The paper ends with some conclusions and an outlook to future work (Section 7), acknowledgements and references (Sections 8 and 9), and an appendix (Section10), meant to convince the "sceptical" reader of some ideas presented in the paper.

2 Multicriteria Decision Problems

In the following we assume multicriteria decision problems

$$(A, f)$$

defined by a feasible set of alternatives A and a vector-valued (q dimensional) objective function

$$f = (f_1, ..., f_q).$$

For an alternative $a \in A$, $f_j(a), j \in \{1, ..., q\}$, represents the evaluation of the jth objective (also called criterion or attribute). Each objective function f_j is assumed to be either maximized: $max_{a \in A} f_j(a)$, or minimized: $min_{a \in A} f_j(a)$.

If A is a finite set, i.e.

$$A = \{a_1, ..., a_r\},$$

we also use the concise notation

$$z_{ij} = f_j(a_i)$$

for denoting the jth criterion value for alternative a_i. Here, $Z = (z_{ij})_{i=1..r,j=1..q}$ is also denoted as decision matrix. In other cases, A may be a subset of a vector space, $A \subset R^n$, defined by a vector-valued restriction function $g : R^n \to R^m$:

$$A = \{x \in R^n : g(x) \leq 0\}.$$

In practice, such a problem may be rather complex. For instance, restrictions defining the feasible set may be given by analytic formulas or differential equations.

Usually, there does not exist a solution which optimizes all q objectives at the same time. Therefore, from a mathematical point of view, one may consider the set of efficient or Pareto-optimal solutions as results to the above problem. For two solutions $a, b \in A$, we say that a dominates b, if $f(a) \neq f(b)$ and

$$\begin{cases} f_j(a) \geq f_j(b), & \text{if } f_j \text{ is to be maximized,} \\ f_j(a) \leq f_j(b), & \text{if } f_j \text{ is to be minimized,} \end{cases}$$

for each $j \in \{1, ..., q\}$. The efficient set is then defined by

$E(A, f) := \{a \in A : \nexists b \in A : b \text{ dominates } a\}$.

Since this efficient set normally contains too many solutions, its computation does not really solve the multicriteria decision problem from a practical point of view – because a decision maker usually wants to get a single "good" solution, e.g. by choosing one from an easily to survey set of meaningful alternatives.

For that purpose, an enormous number of methods for practically solving multicriteria decision problems has been developed in the meantime. Overviews and details referring to this are given, for instance, in Hanne (2001), Steuer (1986), Vincke (1992), or Zeleny (1982).

One idea for example, common to some of these solution approaches, is to use additional preference-related information (stated by the decision maker) on the multicriteria problem, which then may result in obtaining a single solution. Popular concepts of these methods are taking specific values of the objectives (which may or may not correspond to feasible solutions) to compare solutions with. The earliest technique in MCDM using a desired solution ("the goal") and minimizing the alternatives' distance to it is goal programming, developed as an extension of linear programming. Today, there are many new methods which

utilize various kinds of desired and undesired solutions, different metrics, and additional features. Usually, these methods are called reference point approaches (Wierzbicki (1998)).

In absence of user-specified reference points, the following two concepts are frequently used: The utopia (or ideal) point u is defined by the component-wise best values of the alternatives in objective space, i.e.

$$u_j = \begin{cases} max_{a \in A} f_j(a), & \text{if } f_j \text{ is to be maximized,} \\ min_{a \in A} f_j(a), & \text{if } f_j \text{ is to be minimized,} \end{cases}$$

for $j \in \{1, ..., q\}$. The nadir (or anti-utopia) point v is defined by the component-wise worst values, but considering only efficient alternatives, i.e.

$$v_j = \begin{cases} min_{a \in E(A,f)} f_j(a), & \text{if } f_j \text{ is to be maximized,} \\ max_{a \in E(A,f)} f_j(a), & \text{if } f_j \text{ is to be minimized,} \end{cases}$$

for $j \in \{1, ..., q\}$.

Based on Simon's (1957) theory of satisfying, which was developed as an alternative to utility maximization, concepts using aspiration and reservation levels (or thresholds) became popular in multicriteria decision making. Taking aspiration levels for MCDM has first been pointed out by Tversky (1972a, 1972b). His approach of a successive elimination by aspects, is based on the idea that human decision making frequently works as a stochastic process for exploring alternatives. By choosing minimum requirements for the outcomes in specific criteria, the decision space A is reduced while the decision maker learns more about the feasible alternatives. Some features of the navigation process described below in this paper may be considered as an extension and user-friendly implementation of Tversky's basic concepts.

Considering the limited capabilities of real-life decision makers, nowadays there is a significant number of methods providing ergonomic interactivity and means for visualization. Some of these are, for instance, described in Belton and Vickers (1993), Korhonen (1987, 1988), Korhonen and Laakso (1986a, 1986b), Korhonen and Wallenius (1988).

A specific visualization technique used in our MCDSS, is called radar chart, spider web or spider chart. It is based on the idea of representing several axes in a star-shaped fashion. An object characterized by multiple attributes then may be represented in the diagram as a polygon, resulting from connecting lines between the attribute scores on neighboring axes. Although such kinds of diagrams are rather common in statistics and brainstorming techniques, only few MCDM methods so far utilize this approach. And – there are some additional new features in our MCDSS, as for example the fact, that the polygon representing an alternative by its objective values as corner points "has got life": Online

mouse-manipulations on the screen enable an interactive navigation through the database of decision alternatives.

By talking so much about visualization, it should be appropriate just to do this – as the sketch shown in Figure 1 perfectly illustrates the scope of `knowCube`: A decision maker, comfortably interacting (by ear, eye, mouth, or hand) with an MCDSS!

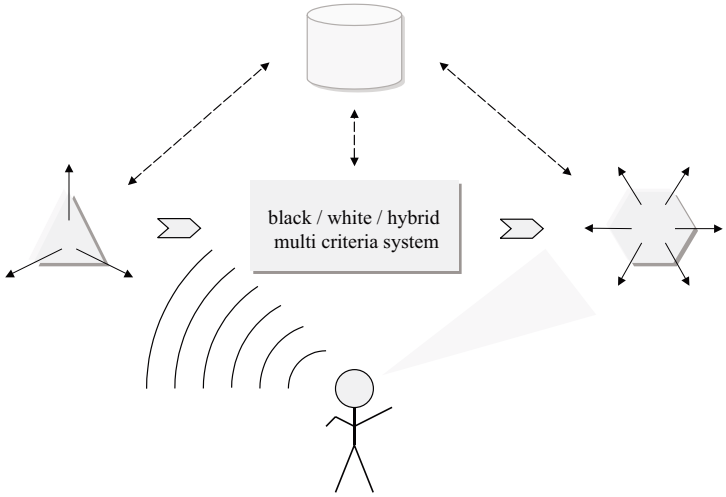


Figure 1: "One picture means more than thousand words."

More explanations and especially practical details will be given in the next sections, here we only want to look still somewhat closer on the core of the multicriteria decision task, where we distinguish the following cases: If the description of the problem is known and completely given, it is called a "white" (box) multicriteria problem. This is the case mostly assumed in multicriteria optimization methods, applied for finding "the best of all possible solutions". If nothing is known about structure of or dependencies within the multicriteria problem, it is denoted as "black". Typically, outcomes of such systems are, for example, found by trial and error, or won by general inquiries. Frequently, such results are not reproducible, and in many cases all results are evolving in the sense that the problem settings are changing with time. Most real decision situations however are somewhere in between "black and white", which lead to "hybrid" multicriteria problems. Then carrying out costly experiments and importing the results obtained into the database are the means chosen very often. But also simulation methods gain in increasing significance for getting decision suggestions.

As already indicated in Section 1, here we are considering only quantitative criteria variables – to keep it simple, to introduce the main concepts of `knowCube`,

as a first step, and to have place for explaining the basics by examples. For working with other types of criteria – like qualitative, objective/subjective, rational/irrational, active/passive, dependent/independent, deterministic/statistic, hard/soft, timely, ..., and all mixed together – the topics introduced so far must be slightly extended. This will happen in a paper to follow.

3 Scope of `knowCube`, Knowledge Organization and Knowledge Generation

`knowCube`, seen as a general framework of an MCDSS, consists of three main components: `knowOrg`, `knowGen`, and `knowNav` (knowledge organization, generation, and navigation). These are put together with their sub modules into a common box, showing to various decision makers varied views – like the different faces of a cube. This gives a hint at the term "knowledge cube", abbreviated `knowCube`, taken as a "logo" for the complete MCDSS. Figure 2 illustrates its structure.

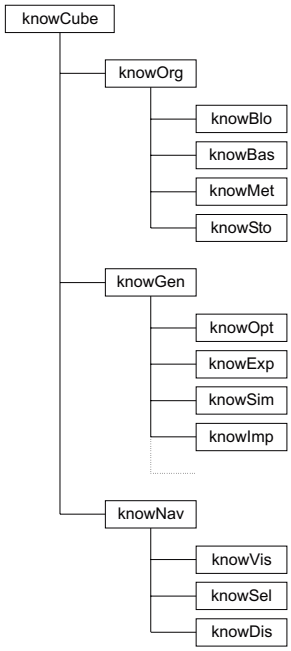


Figure 2: The Structure of `knowCube`.

The "bricks" shown there may act self-contained up to a certain extent, but they also are designed for efficient interaction in the configuration of special

"buildings" for specific needs. So `knowCube` is customizable for use as a decision support system in various application domains. This will become more evident in Sections 5 and 6, where two examples are presented, one in the field of industrial engineering, another one from among medical applications.

For an easy integration of `knowCube` into an institution's workflow, the component `knowOrg` provides comfortable tools for data collection, recording, administration, and maintenance – and all that with comparatively little effort. Open data interfaces enable information exchange with external data sources, such that the database of `knowCube` may be extended by arbitrary "external", and also "historic", decision support information. These topics mainly are handled by the modules `knowBas` (knowledge base) and `knowSto` (knowledge storage). (More details will be worked out in a future paper.)

Making decisions presupposes some knowledge. So, in any case, a data base must be filled with decision information, where its fundamental unit is called `knowBlo` (knowledge block). Such a block consists of two parts, one containing all those criteria values corresponding to a specific decision alternative (e.g. a row of the decision matrix Z, in case of a finite set of alternatives A), the other one references to additional information attachments. Those may be, for instance, documents, diagrams, graphics, videos, audios, ..., any media are allowed. The usage of criteria and attachment information is best explained within application contexts, which will be shown later in the examples already mentioned.

The last "brick" in the `knowOrg` component to talk about is `knowMet` (knowledge metric). Here, the singular of the word "metric" is a bit misleading: There is not only one metric or one class of similar metrics defined on the data base, but additionally a big family of metric like orderings. For instance, all l_p metrics ($1 \leq p \leq \infty$) may be used, at least for quantitative criteria blocks, together with superimposed priority rankings – which furthermore are "online user adaptive". Besides that, certain filtering functions allow some clusterings and inclusions or exclusions of sets of data blocks.

So far for the first component of `knowCube`, corresponding to the data base symbol on the top in the sketch of Figure 1. There the dotted lines indicate, that the decision maker usually does not take care about these interrelations, they must act silently on the back stage.

An engaged decision maker or, at least, the decision provider and analyst will show more interest in the second component `knowGen` (knowledge generation), which comprises the framework for producing decision information to fill the data base for a given multicriteria problem. Thereby, the main tasks are to formulate and answer questions such as e.g.:

- What kind of system will model the decision situation?
- Is the model static or does it change in course of time?

- Which criteria are identifiable?
- How may the criteria variables be arranged in groups?
- Could information be aggregated following a top-down approach?
- Which add-on media should be attached for supporting decision processes?

After these "preliminaries" the interfaces between the acute knowledge generation domain and the components `knowOrg` and `knowNav` are adjusted. Then, one or more of the following activities may be started, corresponding to the "bricks" of `knowGen` in Figure 2:

- Optimization calculations (in the "white system" case) – delivering e.g. Pareto solutions as outcomes of the module `knowOpt` (knowledge optimization).
- Performing experiments (in the "hybrid system" case) – observing results, e.g. from optimal experimental design methods, as produced by `knowExp` (knowledge experiments).
- Doing simulations (again in the "hybrid system" case) – getting e.g. data records with a mixture of some hard/soft criteria, where the input and output values are generated by some standard simulation software tools, gathered in `knowSim` (knowledge simulation).
- Collecting data "events" (in the "black system" case) – e.g. by reading information from external sources via `knowImp` (knowledge import).
- Using some other problem specific method – which is not discussed above, and indicated in Figure 2 by dotted lines.

In any case, the modules `knowMet` and `knowSto` are closely working together, if some newly generated or acquired decision knowledge (`knowBlo`) is put into the data base (`knowBas`). The data base filling processes may be organized via batch procedures, interactively, and also in an evolving way, i.e. within several time slots and under various external conditions – exactly as in real life, and also with the well known effect that "old" decisions are overtaken by "new" ones.

As illustrated in Figure 1, knowledge generation happens mainly in the center of `knowCube`. So for example, by feeding or controlling the black/white/hybrid-system (possibly also by acoustic commands), and by receiving or observing corresponding system answers.

A more distinct explanation of so far introduced concepts will be given below, especially in context with the two already mentioned application examples – after a short break:

4 About Visual Data Processing and Human Cognition – Towards `knowCube` Navigation

Some simple tests (as given by the Appendix in Section 10) and thereof derived conclusions will motivate the design and functionalities of the visual interface of `knowCube` in general, and especially the ideas of the so-called `knowCube Navigator`.

Let us summarize some basic principles of visual data processing – which are well known long ago, and may be found e.g. in Cognitive Psychology by Wickelgren (1979) – by three statements:

Statement 1: Reading text information or listening to a speaker is not sufficient to generate knowledge for solving problems or making decisions!

Statement 2: The human visual system has a highly efficient information processing architecture. It allows inferences to be drawn based on visual spatial relationships – fast and with small demands on "working space capacity"!

Statement 3: The human visual system is also highly sensitive for moving objects and changing shapes!

Quintessence: Supporting decision making should appeal to the human visual system, transforming complex situations into time-animated, spatial presentations!

So, visual spatial relationships, moving objects and changing shapes – all these general topics should be integrated in a tool for supporting decision making, at the least. But, additionally to that, such a tool asks for some more specific and practical demands on its man/machine interface. These requirements, gained by experience and evaluated by experiments, will be formulated in the sequel as axioms, and visualized by easy examples.

The first step in the process of optical perception is the division of a "picture" into a "figure", which comes by a filtering process to consciousness, and into the "background", which is no longer of interest. The main question for designing visual interfaces based on "figures" is: What are the main principles for recognizing figures out of arbitrary forms?

Many of the answers given below as axioms already have been discovered during the development of Gestalt Psychology, as a theory of perception by Wertheimer (1923) and others, during the 1910s and 20s. Nowadays, these ideas are common knowledge, and extensively used in multimedia applications; cf. Macromedia Director 7 (2000).

Axiom 1: Closedness. The most elementary forms that are interpreted as figures are surrounded by closed curves.

Axiom 2: Closeness. Objects close together are seen as figures, distant objects are assigned to the background.

An example is given in Figure 3. Each sketch contains eight domains, which are all closed. But they are hardly perceived all at the same time. The sketch on the left shows a cross standing upright, on the right it is inclined. Narrow parts are taken together as the arms of the crosses, broader parts within the sketches are seen as interspaces or background. (Only with a certain effort it is possible to discover an upright cross with broad arms in the sketch on the right, too.)

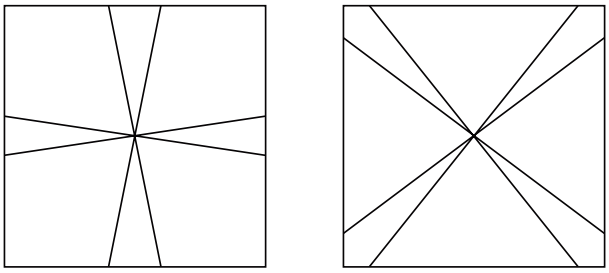


Figure 3: Picture, Figure and Background.

Now knowing the two basic principles of "identifying" figures: closedness and closeness, the question arises: Which principle dominates?

Axiom 3: Closedness versus closeness. If closedness and closeness are competing, it's more likely that closed forms are taken as the figures looked for.

Figure 4 should convince us: Broader domains become figures, because they are closed. The narrow sectors no longer appear as arms of a cross, since little parts of their boundaries are missing.

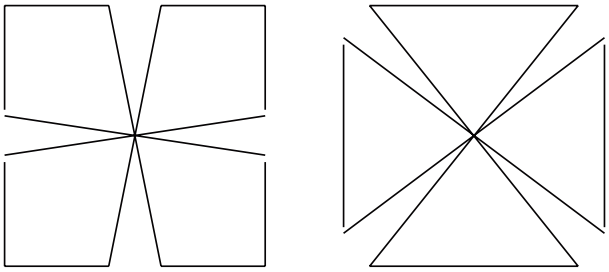


Figure 4: Closedness versus Closeness.

Finally, to get closer to our goal: the `knowCube Navigator`, we present as a last concept needed:

Axiom 4: Convexity. All convex forms – or roughly convex forms as e.g. star-like shapes – are particularly easy recognized as figures.

This was already realized by v. Hornbostel (1922). Here is an example:

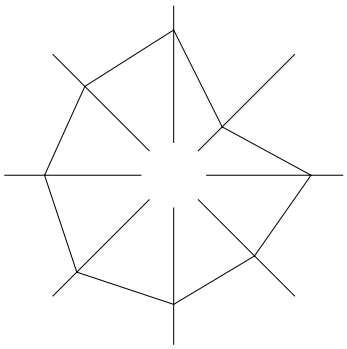


Figure 5: Star-like Shape – or "Nearly Convexity".

Though not looking quite nice, the polygon bounding a nearly convex domain is eye-catching. The line segments, oriented radially towards a common invisible center, are obtaining less attention. This contrast will still increase, if "the line segments stay at rest, and the polygon starts to move". Such a polygonal representation is the most central visualization tool of `knowCube`'s main component `knowNav`, which provides the core navigation tools.

So, we are getting closer now towards `knowCube` navigation:

Each variable is related to a line segment, the line segments are arranged like a "glory", each segment shows a scale (linear or something else), where small values always are put towards the center to avoid confusion. Each segment gets an arrow-head pointing towards that direction (bigger or smaller values), which is preferred by the decision maker for the corresponding criterion.

Little circles on the segments represent the current parameter values of a data base record – or decision alternative, respectively. Adjacent circles are connected by straight lines, all together defining a closed polygon, which bounds a convex or at least star-shaped region. By this little trick the observer or decision maker comprehends "what belongs together".

Summing all up: A closed polygon within a star-shaped scale arrangement visualizes a record in the data base `knowBas`.

Figure 6 corresponds to a decision task, where eight criteria are involved.

Three of them are to be minimized, the other ones are to be maximized. (For the sake of simplicity, the scales on the segments are omitted here – but they are shown in the second application example in Section 6.) The order of the criteria's arrangement may, for instance, reflect their importance, or it may be chosen interactively according to the user's preferences.

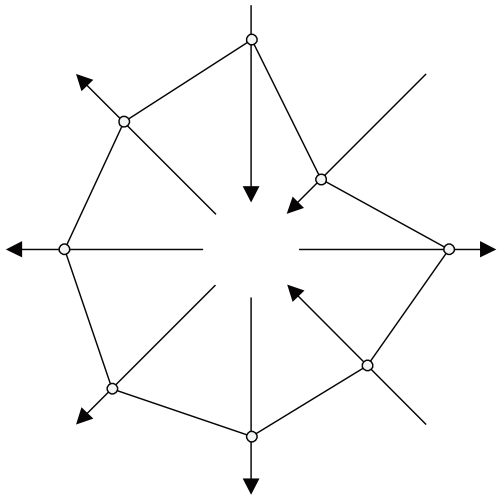


Figure 6: A Decision Alternative, Represented in `knowCube`.

To the end (of this Section) two questions still are open: How are information attachments supporting the decision making? What about the dynamic behavior of polygons?

Best answers will be given by two already announced real-life applications:

5 Designing "Best" Trunking Devices

We consider the industrial engineering problem of designing the profile of a new electrical trunking device – that is usually fixed at the wall, and used for a comfortable laying of multitudes of cables. The problem is to find a best cross-section profile for such trunking devices.

Many objectives are to be taken into account in such a development process. Among them there is one group of criteria, which should be minimized: a_m, the total amount of material needed for one unit of the trunking device; t_p, the time to produce one unit; c_u, the overall cost for one unit. For a better understanding of a second group of variables, Figure 7 will help, showing in

front the approximately U-shaped cross-section of a trunking device. r_p points to the resistance of the trunking device against pressing from opposite sides, r_t to its resistance against torsion. These two variables should have big values, of course.

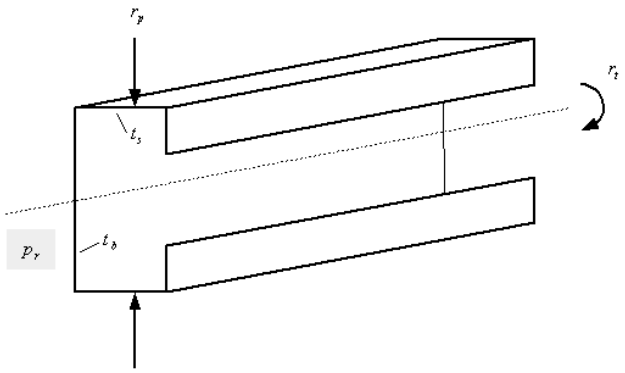


Figure 7: A Trunking Device.

The five criteria introduced so far may be considered as characterizing the outcome of a specific design for a trunking device. Their resulting values obviously are caused by a third group of (in a certain sense "independent") variables: t_b denotes the thickness of the bottom face, t_s the thickness of the side face of the device. A last variable p_r (not visualized, but only mentioned in Figure 7) specifies the portion of recycling material, used e.g. for producing PVC trunking devices. All these eight variables are "working together", in nontrivial, highly nonlinear, and partially conflicting combinations.

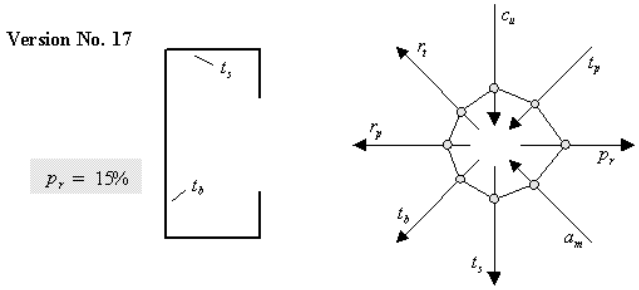


Figure 8: Visualization of an Alternative.

Assuming now, that the engineering team has designed plenty of different profile versions, evaluated them virtually (e.g. by some finite element methods out of `knowSim`), according to the above criteria (which correspond to $f_1, ..., f_8$, as introduced in Section 2), and put all together with some operational data into the data base, then some data blocks could be presented as shown in Figures 8-10.

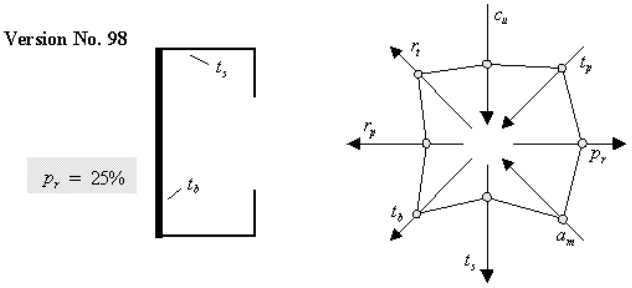


Figure 9: Design Alternative 98.

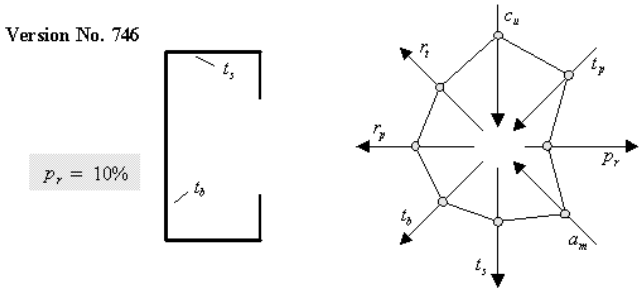


Figure 10: Design Alternative 746.

With the generation of these data, the job of the engineering team is done. Now the time has come for the management of the enterprise to decide which new type of trunking devices is going to be launched. But, of course, a top manager would not want to look over hundreds of data sheets.

Here the `knowCube Navigator` supports the user to "stroll" easily, quickly, and goal oriented through the data base. By pulling at a vertex of the navigation polygon, at a so-called grip point, towards smaller or larger values (inwards or outwards), the polygon moves or transforms to a neighboring polygon, representing another element of the data base.

In the background the module `knowMet` is looking online for that "new" data record, which in the first place is different but closest to the "old" one, with respect to the criterion that was gripped, and which in the second place is

"closest" to the "old" record, with respect to all other criteria.

It certainly would be an essential advantage for the top manager always to know "where he/she is", and which goals are achievable in the best case. An additional graphical assistance will help here:

For each criterion there are taken the respective values from all records in the data base. Virtually, the resulting point set is plotted on the corresponding line segment. The smallest interval containing such a set defines a decision range of potential alternatives for that specific criterion. Then connecting "inner" (neighboring) interval endpoints by straight lines determines the inner decision boundary, the outer decision boundary results by analogy. Both together "construct" the decision horizon. The metaphor "horizon" is used, because the decision maker knows and "sees" in advance that each possible alternative, respectively selection of a data record or corresponding polygon representation, will lie somewhere within this area – that is emphasized in the sketch in Figure 11 by some color shading. (The utopia point u, mentioned in Section 2, corresponds to that polygon, which connects those boundary points of the shaded area, lying on the variables' line segments and closest to their arrow heads. The nadir point v results vice versa.)

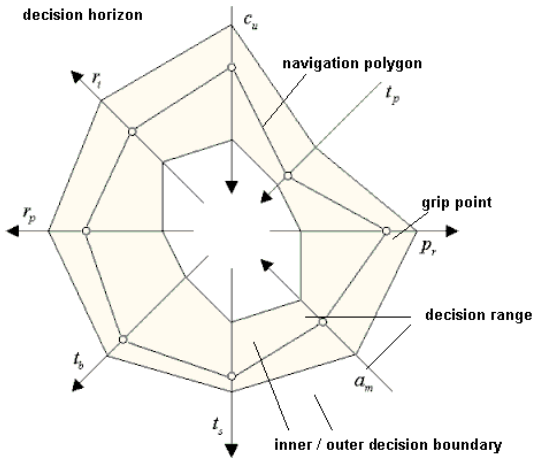


Figure 11: "What Is Achievable – What Not?".

By the way, the decision horizon serves as an ideal base for discussions at meetings, where many decision makers are fighting with plenty, usually conflicting, arguments. Acute viewpoints may be ranged in easily by the "location" of the navigation polygon, extreme positions may be estimated by the inner and outer boundaries. Alternatives, their pros and cons, are visualized interactively. The attachment knowledge, as e.g. the sketches of the cross sections in

Figures 8-10 or the visualizations in Figure 12, helps to get to more objective conclusions.

Furthermore, there are some additional tools for facilitating the process of decision making:

- Locking parts of decision ranges.

  Some criteria values may not be acceptable in any way, already from the beginning of the "decision session". Some other criteria values may no longer be of interest, after exploring and discussing a certain amount of alternatives. In any case, locking subintervals on the decision ranges (e.g. via clicking on it with the mouse and pulling along the criteria segment) leads to a restricted decision horizon, corresponding records in the database are set inactive. Unlocking of locked parts is possible at any time, of course. By such a process of consecutive lockings and unlockings, a decision maker may find within the decision horizon his/her own decision corridor, enclosing only those candidates being of interest furthermore – while the rest is put into the background.

- Logging navigation paths.

  Everybody has experienced, that a situation of the past seemed to be "better" than a present one – but the way how to get to that place has been forgotten. To avoid such problems, there is written automatically a log-file, memorizing all steps of the navigation path walked so far. Walking through this log-file then may be done by using interactive recorder buttons with their well-known functionalities.

- Storing and viewing "good" alternatives.

  The decision maker may memorize every alternative evaluated positively by a store button, writing the corresponding reference into a memo-file. This file specifically may be used at presentations, e.g. for visualizing the process of coming to a certain final decision. Here the successive alternatives may be combined and animated as a "movie". Each singular "picture" consists of a snapshot of the acute navigation polygon, together with (user dependent, selectable) attached information. The changes between the pictures are done by slow cross-fadings, a technique that fits well to the human cognitive system.

- Clustering decision alternatives.

  Combining the functionalities described above allows to construct clusterings within the data base interactively. Starting with a chosen alternative, e.g. by means of the view-button, and then using two-sided lockings successively on each decision range, constructs a temporary inner and outer boundary. All navigation polygons lying within define a cluster – by the way, pointing to a new way for visualizing clusters and their centers.

All tools described above may be used by the top management, that has to decide, which design version of profiles should be produced by the company in future. Figure 12 shows some parts of the navigator's graphical user interface for this specific example. Several steps (e.g. locking) in the decision process already have taken place, the acute alternative is represented by the polygon lying within the lightly shaded corridor.

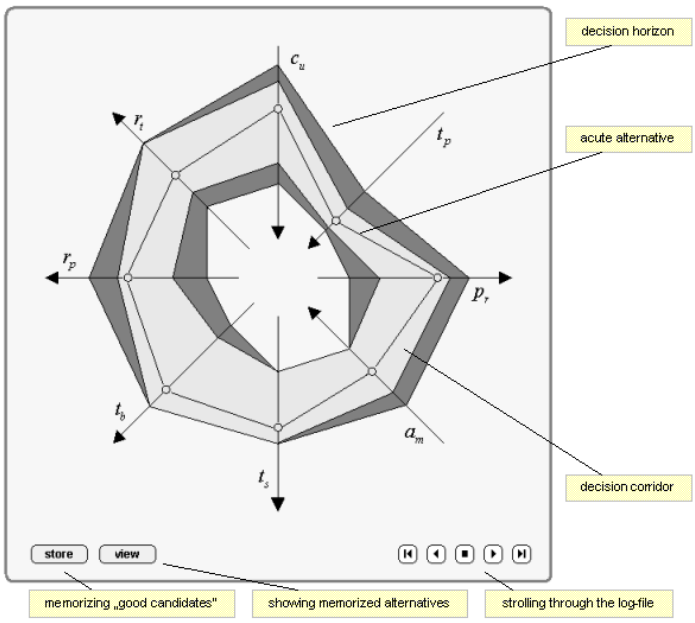


Figure 12: knowCube Navigator.

Popup-windows serve to show attached information, as for instance in Figure 13, the (exaggerated) torsion under a certain force (big picture), and the material stress visualized by colorings of distinguished profile details (small pictures).

Now, a last time back to the visualization of the "vision" in Figure 1: The `knowCube Navigator` supports the decision maker (easily identified at the bottom of the sketch) by offering to him/her a number of decision horizons, which are organized corresponding to the specific needs of the concrete application. So, in some cases, one horizon could contain only dependent criteria, and the decision maker were examining the outcomes, as shown on the right side of the sketch. Another horizon could handle independent criteria, and the decision maker were working with these, like on the left side of the sketch, e.g. also by acoustic or even tactile interaction, what could make sense especially for handicapped persons.

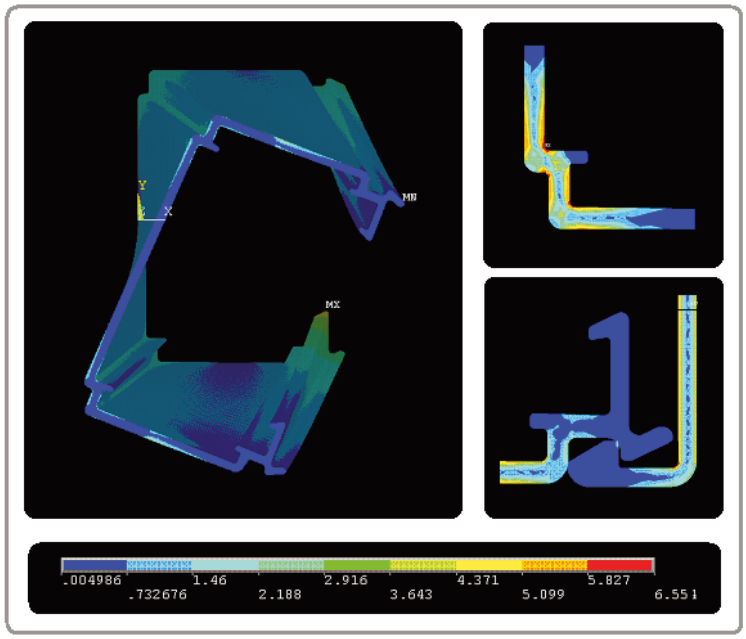


Figure 13: Design of Trunking Devices – Information Attachment.

For further illustration of the manifold applicability of `knowCube` and its `Navigator`, another real-life case will be presented, belonging to a completely different domain, and which is – not only from a mathematical point of view – much more complex than the technical design task just discussed. This medical application illustrates the "power" of `knowCube` very well. It is especially a well-fitting instance for demonstrating parallel utilization and visualization of hierarchically aggregated attachment information in a transparent way.

6 An Interactive Decision Support System for Intensity Modulated Radiation Therapy

"What is the ideal radiation therapy plan for a patient?"

Within the complete, time consuming workflow process of intensity modulated radiation therapy (IMRT), two topics are of main interest for the optimization task: First, the segmentation of the CT (computer tomography) or MR (magnetic resonance) slides, i.e. adding curves onto the slides, describing the boundaries of the tumor and the R organs at risk – which in most cases must be done manually, at least today. Second, the dose calculation, i.e. computing the dose contributions to each voxel (volume element inside the body) of

interest, coming from corresponding bixels at the beamheads (beamhead pixels) of a linear accelerator, used for the radiation treatment.

Some output of these two steps is taken as input for the knowledge data base: General information concerning the patient to be treated, his/her CT or MR slides, the segmentation contours, and the dose matrix.

A slide is a 256 x 256 or 512 x 512 grey-value pixel image, and because up to 40 parallel slides in 3 different orientations – transversal, frontal, sagittal – are needed, CT or MR slides means "fat data". The same holds for the dose matrix, up to one million entries are not unusual. Segmentation contours, on the other hand, means "slim data", that takes merely some kB.

Now the optimization procedure, done within the module `knowOpt`, may start, taking about four hours on a high-end PC. It generates up to 1000 distinct Pareto optimal 3D-solutions, "covering" the planning horizon with a grid of planning alternatives for the patient. In this specific case, a solution assigns a real number to each bixel, representing the amount of radiation emitted from there. The superposition of all bixel contributions sums up to a radiation distribution in the volume of interest, containing the tumor and neighboring organs at risk. Each of these objects obtains a set of "notes" – as e.g. numbers, functions, and point sets – by which the decision maker will be able to estimate their "qualities". More details on radiation therapy planning are presented in Bortfeld (1995), and Hamacher and Küfer (1999).

All calculations mentioned above happen automatically, they may be done overnight as a batch job, and stored in the data base `knowBas`. The next day, the results may be transferred to a notebook, such that the physician (and even his/her patient) may look for the optimal plan interactively.

But then – how to manage this enormous quantity of data to find out the "best" plan with reasonable effort?

This works

- by real-time accesses on the pre-calculated and pre-processed data base mentioned above – which in particular contains various data aggregations in a cascading manner,
- by simultaneous visualizations of dose distributions – in the shape of well known (for a physician, at least) dose-volume-histograms and colored isodose lines ("slim data"), superimposed on the patient's grey-value CTs or MRs ("fat data"), and, on top of that,
- by our tricky exploration tool `knowCube Navigator`, which supports and controls the interactive, goal oriented tour through the huge variety of planning solutions – leading towards the patient's optimal radiation therapy plan within some minutes.

Some details will be explained now by a typical navigation session:

The physician starts the program, types in his/her identification and the patient's name, and gets a planning screen, which contains some information objects similar to Figure 14.

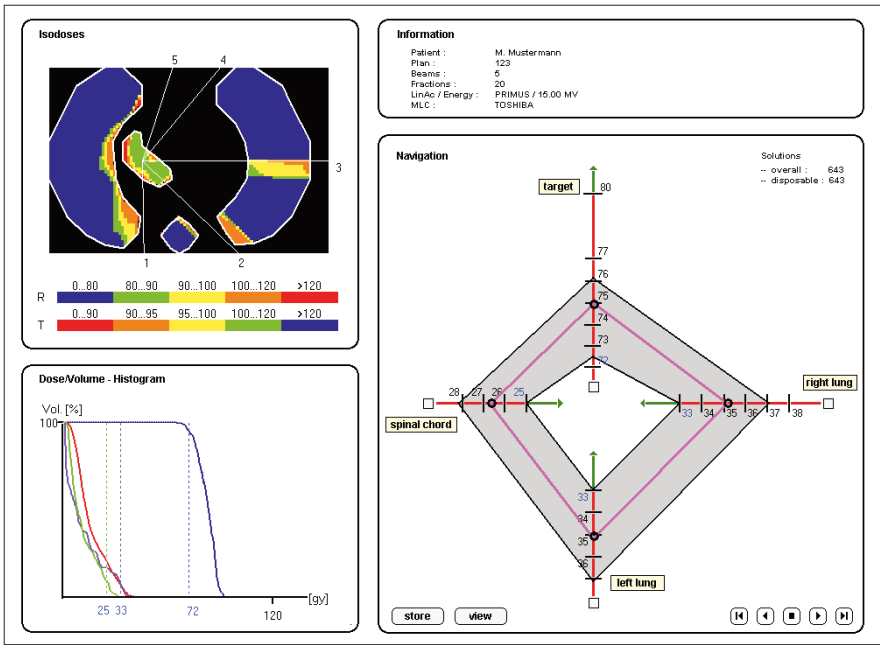


Figure 14: GUI for IMRT.

One part of the graphical user interface (GUI) shows static information, concerning the patient of interest and the physical setup, that was given – or selected, e.g. from a data base – before the optimization computations were started. The other parts of the GUI contain dynamic information: With the beginning of the planning session, the main pointer of the database references on the solution of least common tolerance – a kind of "average solution", that balances "notes" of conflicting criteria.

Information objects, corresponding to the respective, acute solution, are presented by the GUI in a decreasing degree of fineness:

- "Richest" information is given by CTs or MRs, through the isocenter of the tumor (transversal, frontal, and sagittal), superimposed by in advance calculated isolines. (Of course, it is possible to skim through these three stacks of slides, continually getting the immediate isolines, and so gaining maximum detail knowledge.)

- "Medium" information content is aggregated in the dose-volume histogram, where each curve shows the accumulated Gray contribution per organ at risk or tumor. (Gray is the physical unit for radiation energy.)
- The "coarsest" information is delivered by the navigation object of the GUI: All radiation energy absorbed by an organ at risk – or by the tumor – is summarized in just one number, thus getting $R + 1$ numbers (R risks, as already mentioned before) specifying the radiation plan. These numbers are inscribed as pull points (i.e. grip points) on the organs' or tumor's acceptance intervals (i.e. decision ranges), that are arranged in a star-shaped sketch. Linking these grip points by line segments results in a solution polygon (i.e. navigation polygon), characterizing the whole planning solution from a top point of view, well-suited for a first, quick estimate of the solution's relevance.

To recapitulate: The starting point, the so-called solution of least common tolerance, is visualized by various graphical objects, culminating in its solution polygon.

But `knowCube` yields much more – and for that reason again let us look somewhat closer on the details:

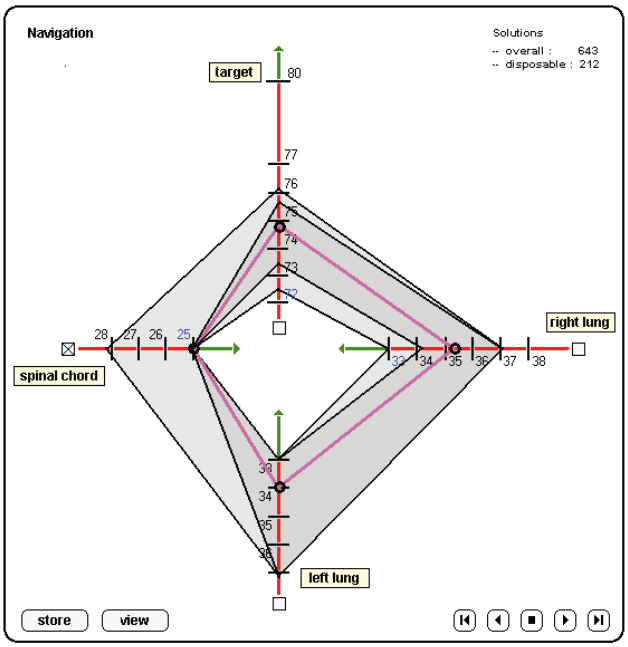


Figure 15: `knowCube Navigator` for Intensity Modulated Radiation Therapy.

Each precalculated solution, that has been accepted to be a member of the data base, provides for each risk, respectively for the tumor, an entry on the corresponding acceptance interval. So all solutions together define the ranges of the acceptance intervals. Connecting their smallest respectively largest endpoints delimits the shaded area, called planning horizon (i.e. decision range).

Why? It permits at any time an overview on all solutions in the data base. The physician not only gets a general view of a solution visualized by its polygon, but he/she also may estimate its significance with respect to all other solutions, recognizing which planning goals really are achievable and which are not.

So now the action may start with the solution of least common tolerance: The physician e.g. wants to reduce the total radiation given to a certain risk. To achieve this, he/she clicks with the mouse on the corresponding pull point and moves it towards smaller Gray values. The data base, with an index family for modified lexicographic ordering strategies, is scanned simultaneously, such that isolines and dose-volume curves of "neighboring solutions" are updated on the screen at the same time. As soon as the mouse-click is released, the "moving polygon" stops in its new position.

This first kind of action: pull, may be repeated again and again to explore the planning horizon – with the same organ at risk or any other, and with the tumor too, of course. Just one remark to keep an eye on: Moving a pull point towards smaller/higher risk/tumor values results in a new solution-polygon, where at least one other pull point shows a higher/smaller risk/tumor value – in accordance with the Pareto optimality of the data base.

In the meantime the physician may have found a solution fulfilling his/her first priority, e.g. a total Gray value for a specified risk that is less than a fixed amount. Only solutions which are not worse with respect to this are of interest furthermore. Therefore, the second kind of action: lock, is getting importance. The physician clicks in the corresponding lock box, and the planning horizon immediately is divided into two parts (shaded differently), a locked area and an active area. Now active navigation is restricted – a filter selects the accessible objects in the data base.

It should be superfluous to mention, that this locking action naturally may be applied to more than one acceptance interval, and that unlocking, pulling, and any combination of them is possible as well.

Some more actions are integrated in the software to facilitate the work of the physician: storing of favored solutions, viewing of stored solutions, and skimming through already regarded solutions, by using well known recorder button functionalities. All of them support: Navigating in a planning horizon – towards an optimal solution!

7 Summary, Conclusions, and Outlook

We have introduced `knowCube`, a novel interactive multicriteria decision support system, which integrates various tools for knowledge organization, generation, and navigation.

The main guideline for designing `knowCube` was to have a user-friendly visual interface, and to utilize interactivity in terms which are familiar to a non-expert decision maker (in particular for an "intuitive surfing through data bases of alternatives") – according to the statement of Stanley Zionts, already cited in the introduction: "I strongly believe that what is needed is a spreadsheet type of method that will allow ordinary people to use MCDM methods for ordinary decisions." We hope, that `knowCube` may point towards this direction, and our experiences won by the two application examples already realized in practise strongly are confirming this hope.

This paper was dealing only with quantitative criteria – to keep it simple, to introduce the main concepts of `knowCube`, as a first step, and to have place for explaining the basics by examples.

To work also with other types of criteria – like qualitative, objective or subjective, rational or irrational, active or passive, dependent or independent, deterministic or statistic, hard or soft, timely, ..., and all mixed together – the topics introduced so far must be extended. This will happen in a paper to follow. And again, the main new ideas therein will be motivated, guided and demonstrated by real-life applications.

8 Acknowledgements

Thanks a lot to our colleagues Heiko Andrä, Karl-Heinz Küfer, and Juliana Matei for many valuable discussions, thanks to the Tehalit GmbH, in Heltersberg, Germany, for setting and funding the trunk device optimization task, and thanks to Thomas Bortfeld at Massachusetts General Hospital, Boston, USA, for the cooperation in intensity modulated radiation therapy.

9 References

Belton, V., Vickers, S. (1993): Demystifying DEA – A Visual Interactive Approach Based on Multiple Criteria Analysis. Research Paper No. 1993/9

Bortfeld, T. (1995): Dosiskonformation in der Tumortherapie mit externer ionisierender Strahlung. Habilitationsschrift, Universität Heidelberg.

Eberl, M., Jacobsen, J. (2000): Macromedia Director 7 Insider. Markt&Technik Verlag, München.

Geoffrion, A.M., Dyer, J.S., Feinberg, A. (1972): An Interactive Approach for Multi-Criterion Optimization, with an Application to the Operation of an Academic Department. Management Science, 19(4):357-368.

Hamacher, H.W., Küfer, K.-H. (1999): Inverse Radiation Therapy Planning - a Multiple Objective Optimisation Approach. Berichte des ITWM, Nummer 12.

Hanne, T. (2001): Intelligent Strategies for Meta Multiple Criteria Decision Making. Kluwer Academic Publishers, Boston/Dordrecht/London.

Korhonen, P. (1988): A Visual Reference Direction Approach to Solving Discrete Multiple Criteria Problems. European Journal of Operational Research, 34(2):152-159.

Korhonen, P. (1987): VIG – A visual interactive support system for multiple criteria decision making. JORBEL, 27(1):4-15.

Korhonen, P., Laakso, J. (1986): A Visual Interactive Method for Solving the Multiple Criteria Problem. European Journal of Operational Research, 24(2):277-287.

Korhonen, P., Laakso, J. (1986): Solving generalised goal programming problems using a visual interactive approach. European Journal of Operational Research, 26(3):355-363.

Korhonen, P., Wallenius, J. (1988): A Pareto Race. Naval Research Logistics, 35(6):615-623.

Larkin, J., Simon, H. (1987): Why a Diagram Is (Sometimes) Worth 10 000 Words. Cognitive Science, 4, 317-345.

Rosemeier, H.P. (1975): Medizinische Psychologie. Ferdinand Enke Verlag, Stuttgart.

Simon, H.A. 1957. Models of Man. Macmillan, New York.

Schnetger, J. (1998): Kautschukverarbeitung. Vogel Buchverlag, Würzburg.

Steuer, R.E. (1986): Multiple Criteria Optimization: Theory, Computation, and Application, John Wiley & Sons, New York.

Tversky, A. (1972a): Choice by elimination. Journal of Mathematical Psychology, 9:341-367.

Tversky, A. (1972b): Elimination by aspects: A theory of choice. Psychological Review 79:281-299.

Vincke, P. (1992): Multicriteria Decision-Aid, Wiley, Chichester.

v. Hornbostel, E.M. (1922): Über optische Inversion. Psychol. Forsch., 1, 130-156.

Wertheimer, M. (1923): Untersuchungen zur Lehre von der Gestalt, II. Psychologische Forschung, 4, 301-350

Wickelgren, W.A. (1979): Cognitive Psychology, Prentice-Hall, Englewood Cliffs.

Wierzbicki, A.P. (1998): Reference Point Methods in Vector Optimization and Decision Support. IIASA Interim Report IR-98-017.

Zeleny, M. (1982): Multiple Criteria Decision Making, McGraw-Hill, New York.

Zionts, S. (1999): Foreword. in Gal, T., Stewart, T.J., Hanne, T. (eds.): Multicriteria Decision Making – Advances in MCDM Models, Algorithms, Theory, and Applications. Kluwer Academic Publishers, Boston/Dordrecht/London.

10 Appendix – To Convince the "Sceptical"

... as already mentioned in Section 1, we present five simple tests, make our observations and find some conclusions:

Test 1: Tim is taller than Ted, Sally is smaller than Sam, Sam is taller than Sally, Tina is taller than Ted and smaller than Sam, who is smaller than Sue and taller than Ted and Sally. Is Ted taller or smaller than Tina?

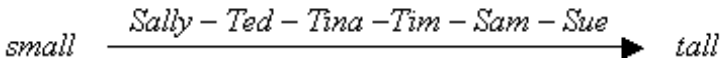
Observation: The human cognitive system has two most important constraints:

• Its "working memory" has limited capacity, only 1 to 4 pieces of information can be mentally manipulated at the same time.

• Its"processor" works strictly serially, in complex environments this process is slow.

Conclusion: Reading text information or listening to a speaker is not sufficient to generate knowledge for solving problems or making decisions!

Test 2: Translate Test 1 into ...



Observation: Little graphics helps a lot!

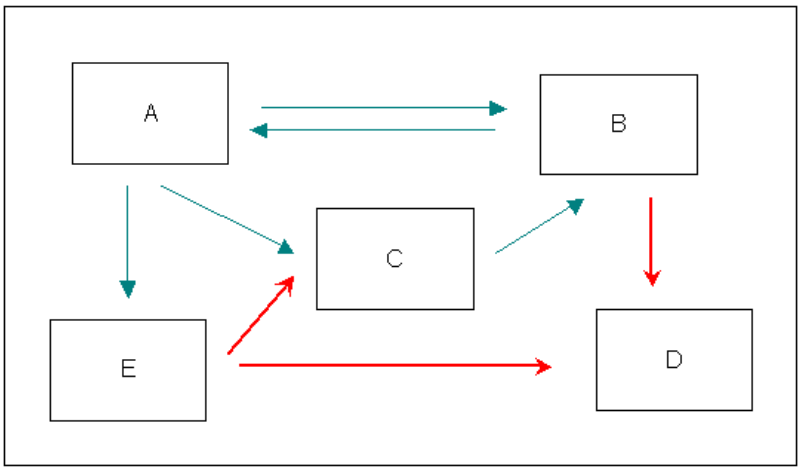
Test 3: Let A, B, C, D, E be natural persons, sections in business enterprises, departments of universities, states, ...

- A is positively affected by B and affects B, C and E positively.
- B is affected by A and C positively and affects D negatively and A positively.
- C is positively affected by A, negatively affected by E, and affects B positively.
- B and E negatively affect D.
- E affects C and D negatively and is positively affected by A.

What's going on?

Observation: No chance to find out!

Test 4: Translate Test 3 into ...



Observation: Again – little graphics helps a lot!

Conclusion: The human visual system has a highly efficient information processing architecture. It allows inferences to be drawn based on visual spatial relationships – extremely fast, with hardly any demands on "working capacity"!

Test 5: Let R be a reader of this paper, and let a spider S crawl across the room's white wall.

Observation: R becomes aware of S, though R was not prepared for S – biological evolution helps a lot!

Conclusion: The human visual system is also highly sensitive for moving objects and changing shapes.

Summary: Tools for MCDM should appeal to the human visual system, transforming complex situations into time-animated, spatial presentations.

Published reports of the Fraunhofer ITWM

The PDF-files of the following reports are available under:
www.itwm.fraunhofer.de/rd/presse/berichte

1. D. Hietel, K. Steiner, J. Struckmeier

A Finite - Volume Particle Method for Compressible Flows

We derive a new class of particle methods for conservation laws, which are based on numerical flux functions to model the interactions between moving particles. The derivation is similar to that of classical Finite-Volume methods; except that the fixed grid structure in the Finite-Volume method is substituted by so-called mass packets of particles. We give some numerical results on a shock wave solution for Burgers equation as well as the well-known one-dimensional shock tube problem.
(19 pages, 1998)

2. M. Feldmann, S. Seibold

Damage Diagnosis of Rotors: Application of Hilbert Transform and Multi-Hypothesis Testing

In this paper, a combined approach to damage diagnosis of rotors is proposed. The intention is to employ signal-based as well as model-based procedures for an improved detection of size and location of the damage. In a first step, Hilbert transform signal processing techniques allow for a computation of the signal envelope and the instantaneous frequency, so that various types of non-linearities due to a damage may be identified and classified based on measured response data. In a second step, a multi-hypothesis bank of Kalman Filters is employed for the detection of the size and location of the damage based on the information of the type of damage provided by the results of the Hilbert transform.
Keywords: Hilbert transform, damage diagnosis, Kalman filtering, non-linear dynamics
(23 pages, 1998)

3. Y. Ben-Haim, S. Seibold

Robust Reliability of Diagnostic Multi-Hypothesis Algorithms: Application to Rotating Machinery

Damage diagnosis based on a bank of Kalman filters, each one conditioned on a specific hypothesized system condition, is a well recognized and powerful diagnostic tool. This multi-hypothesis approach can be applied to a wide range of damage conditions. In this paper, we will focus on the diagnosis of cracks in rotating machinery. The question we address is: how to optimize the multi-hypothesis algorithm with respect to the uncertainty of the spatial form and location of cracks and their resulting dynamic effects. First, we formulate a measure of the reliability of the diagnostic algorithm, and then we discuss modifications of the diagnostic algorithm for the maximization of the reliability. The reliability of a diagnostic algorithm is measured by the amount of uncertainty consistent with no-failure of the diagnosis. Uncertainty is quantitatively represented with convex models.
Keywords: Robust reliability, convex models, Kalman filtering, multi-hypothesis diagnosis, rotating machinery, crack diagnosis
(24 pages, 1998)

4. F.-Th. Lentes, N. Siedow

Three-dimensional Radiative Heat Transfer in Glass Cooling Processes

For the numerical simulation of 3D radiative heat transfer in glasses and glass melts, practically applicable mathematical methods are needed to handle such problems optimal using workstation class computers. Since the exact solution would require super-computer capabilities we concentrate on approximate solutions with a high degree of accuracy. The following approaches are studied: 3D diffusion approximations and 3D ray-tracing methods.
(23 pages, 1998)

5. A. Klar, R. Wegener

A hierarchy of models for multilane vehicular traffic
Part I: Modeling

In the present paper multilane models for vehicular traffic are considered. A microscopic multilane model based on reaction thresholds is developed. Based on this model an Enskog like kinetic model is developed. In particular, care is taken to incorporate the correlations between the vehicles. From the kinetic model a fluid dynamic model is derived. The macroscopic coefficients are deduced from the underlying kinetic model. Numerical simulations are presented for all three levels of description in [10]. Moreover, a comparison of the results is given there.
(23 pages, 1998)

Part II: Numerical and stochastic investigations

In this paper the work presented in [6] is continued. The present paper contains detailed numerical investigations of the models developed there. A numerical method to treat the kinetic equations obtained in [6] are presented and results of the simulations are shown. Moreover, the stochastic correlation model used in [6] is described and investigated in more detail.
(17 pages, 1998)

6. A. Klar, N. Siedow

Boundary Layers and Domain Decomposition for Radiative Heat Transfer and Diffusion Equations: Applications to Glass Manufacturing Processes

In this paper domain decomposition methods for radiative transfer problems including conductive heat transfer are treated. The paper focuses on semi-transparent materials, like glass, and the associated conditions at the interface between the materials. Using asymptotic analysis we derive conditions for the coupling of the radiative transfer equations and a diffusion approximation. Several test cases are treated and a problem appearing in glass manufacturing processes is computed. The results clearly show the advantages of a domain decomposition approach. Accuracy equivalent to the solution of the global radiative transfer solution is achieved, whereas computation time is strongly reduced.
(24 pages, 1998)

7. I. Choquet

Heterogeneous catalysis modelling and numerical simulation in rarified gas flows Part I: Coverage locally at equilibrium

A new approach is proposed to model and simulate numerically heterogeneous catalysis in rarefied gas flows. It is developed to satisfy all together the following points:
1) describe the gas phase at the microscopic scale, as required in rarefied flows,
2) describe the wall at the macroscopic scale, to avoid prohibitive computational costs and consider not only crystalline but also amorphous surfaces,
3) reproduce on average macroscopic laws correlated with experimental results and
4) derive analytic models in a systematic and exact way. The problem is stated in the general framework of a non static flow in the vicinity of a catalytic and non porous surface (without aging). It is shown that the exact and systematic resolution method based on the Laplace transform, introduced previously by the author to model collisions in the gas phase, can be extended to the present problem. The proposed approach is applied to the modelling of the EleyRideal and LangmuirHinshelwood recombinations, assuming that the coverage is locally at equilibrium. The models are developed considering one atomic species and extended to the general case of several atomic species. Numerical calculations show that the models derived in this way reproduce with accuracy behaviors observed experimentally.
(24 pages, 1998)

8. J. Ohser, B. Steinbach, C. Lang

Efficient Texture Analysis of Binary Images

A new method of determining some characteristics of binary images is proposed based on a special linear filtering. This technique enables the estimation of the area fraction, the specific line length, and the specific integral of curvature. Furthermore, the specific length of the total projection is obtained, which gives detailed information about the texture of the image. The influence of lateral and directional resolution depending on the size of the applied filter mask is discussed in detail. The technique includes a method of increasing directional resolution for texture analysis while keeping lateral resolution as high as possible.
(17 pages, 1998)

9. J. Orlik

Homogenization for viscoelasticity of the integral type with aging and shrinkage

A multiphase composite with periodic distributed inclusions with a smooth boundary is considered in this contribution. The composite component materials are supposed to be linear viscoelastic and aging (of the nonconvolution integral type, for which the Laplace transform with respect to time is not effectively applicable) and are subjected to isotropic shrinkage. The free shrinkage deformation can be considered as a fictitious temperature deformation in the behavior law. The procedure presented in this paper proposes a way to determine average (effective homogenized) viscoelastic and shrinkage (temperature) composite properties and the homogenized stressfield from known properties of the components. This is done by the extension of the asymptotic homogenization technique known for pure elastic nonhomogeneous bodies to the nonhomogeneous thermoviscoelasticity of the integral noncon-

volution type. Up to now, the homogenization theory has not covered viscoelasticity of the integral type. SanchezPalencia (1980), Francfort & Suquet (1987) (see [2], [9]) have considered homogenization for viscoelasticity of the differential form and only up to the first derivative order. The integralmodeled viscoelasticity is more general then the differential one and includes almost all known differential models. The homogenization procedure is based on the construction of an asymptotic solution with respect to a period of the composite structure. This reduces the original problem to some auxiliary boundary value problems of elasticity and viscoelasticity on the unit periodic cell, of the same type as the original non-homogeneous problem. The existence and uniqueness results for such problems were obtained for kernels satisfying some constrain conditions. This is done by the extension of the Volterra integral operator theory to the Volterra operators with respect to the time, whose 1 kernels are space linear operators for any fixed time variables. Some ideas of such approach were proposed in [11] and [12], where the Volterra operators with kernels depending additionally on parameter were considered. This manuscript delivers results of the same nature for the case of the spaceoperator kernels.
(20 pages, 1998)

10. J. Mohring

Helmholtz Resonators with Large Aperture

The lowest resonant frequency of a cavity resonator is usually approximated by the classical Helmholtz formula. However, if the opening is rather large and the front wall is narrow this formula is no longer valid. Here we present a correction which is of third order in the ratio of the diameters of aperture and cavity. In addition to the high accuracy it allows to estimate the damping due to radiation. The result is found by applying the method of matched asymptotic expansions. The correction contains form factors describing the shapes of opening and cavity. They are computed for a number of standard geometries. Results are compared with numerical computations.
(21 pages, 1998)

11. H. W. Hamacher, A. Schöbel

On Center Cycles in Grid Graphs

Finding "good" cycles in graphs is a problem of great interest in graph theory as well as in locational analysis. We show that the center and median problems are NP hard in general graphs. This result holds both for the variable cardinality case (i.e. all cycles of the graph are considered) and the fixed cardinality case (i.e. only cycles with a given cardinality p are feasible). Hence it is of interest to investigate special cases where the problem is solvable in polynomial time. In grid graphs, the variable cardinality case is, for instance, trivially solvable if the shape of the cycle can be chosen freely. If the shape is fixed to be a rectangle one can analyze rectangles in grid graphs with, in sequence, fixed dimension, fixed cardinality, and variable cardinality. In all cases a complete characterization of the optimal cycles and closed form expressions of the optimal objective values are given, yielding polynomial time algorithms for all cases of center rectangle problems. Finally, it is shown that center cycles can be chosen as rectangles for small cardinalities such that the center cycle problem in grid graphs is in these cases completely solved.
(15 pages, 1998)

12. H. W. Hamacher, K.-H. Küfer

Inverse radiation therapy planning - a multiple objective optimisation approach

For some decades radiation therapy has been proved successful in cancer treatment. It is the major task of clinical radiation treatment planning to realize on the one hand a high level dose of radiation in the cancer tissue in order to obtain maximum tumor control. On the other hand it is obvious that it is absolutely necessary to keep in the tissue outside the tumor, particularly in organs at risk, the unavoidable radiation as low as possible.
No doubt, these two objectives of treatment planning - high level dose in the tumor, low radiation outside the tumor - have a basically contradictory nature. Therefore, it is no surprise that inverse mathematical models with dose distribution bounds tend to be infeasible in most cases. Thus, there is need for approximations compromising between overdosing the organs at risk and underdosing the target volume.
Differing from the currently used time consuming iterative approach, which measures deviation from an ideal (non-achievable) treatment plan using recursively trial-and-error weights for the organs of interest, we go a new way trying to avoid a priori weight choices and consider the treatment planning problem as a multiple objective linear programming problem: with each organ of interest, target tissue as well as organs at risk, we associate an objective function measuring the maximal deviation from the prescribed doses.
We build up a data base of relatively few efficient solutions representing and approximating the variety of Pareto solutions of the multiple objective linear programming problem. This data base can be easily scanned by physicians looking for an adequate treatment plan with the aid of an appropriate online tool.
(14 pages, 1999)

13. C. Lang, J. Ohser, R. Hilfer

On the Analysis of Spatial Binary Images

This paper deals with the characterization of microscopically heterogeneous, but macroscopically homogeneous spatial structures. A new method is presented which is strictly based on integral-geometric formulae such as Crofton's intersection formulae and Hadwiger's recursive definition of the Euler number. The corresponding algorithms have clear advantages over other techniques. As an example of application we consider the analysis of spatial digital images produced by means of Computer Assisted Tomography.
(20 pages, 1999)

14. M. Junk

On the Construction of Discrete Equilibrium Distributions for Kinetic Schemes

A general approach to the construction of discrete equilibrium distributions is presented. Such distribution functions can be used to set up Kinetic Schemes as well as Lattice Boltzmann methods. The general principles are also applied to the construction of Chapman Enskog distributions which are used in Kinetic Schemes for compressible Navier-Stokes equations.
(24 pages, 1999)

15. M. Junk, S. V. Raghurame Rao

A new discrete velocity method for Navier-Stokes equations

The relation between the Lattice Boltzmann Method, which has recently become popular, and the Kinetic Schemes, which are routinely used in Computational Fluid Dynamics, is explored. A new discrete velocity model for the numerical solution of Navier-Stokes equations for incompressible fluid flow is presented by combining both the approaches. The new scheme can be interpreted as a pseudo-compressibility method and, for a particular choice of parameters, this interpretation carries over to the Lattice Boltzmann Method.
(20 pages, 1999)

16. H. Neunzert

Mathematics as a Key to Key Technologies

The main part of this paper will consist of examples, how mathematics really helps to solve industrial problems; these examples are taken from our Institute for Industrial Mathematics, from research in the Technomathematics group at my university, but also from ECMI groups and a company called TecMath, which originated 10 years ago from my university group and has already a very successful history.
(39 pages (4 PDF-Files), 1999)

17. J. Ohser, K. Sandau

Considerations about the Estimation of the Size Distribution in Wicksell's Corpuscle Problem

Wicksell's corpuscle problem deals with the estimation of the size distribution of a population of particles, all having the same shape, using a lower dimensional sampling probe. This problem was originary formulated for particle systems occurring in life sciences but its solution is of actual and increasing interest in materials science. From a mathematical point of view, Wicksell's problem is an inverse problem where the interesting size distribution is the unknown part of a Volterra equation. The problem is often regarded ill-posed, because the structure of the integrand implies unstable numerical solutions. The accuracy of the numerical solutions is considered here using the condition number, which allows to compare different numerical methods with different (equidistant) class sizes and which indicates, as one result, that a finite section thickness of the probe reduces the numerical problems. Furthermore, the relative error of estimation is computed which can be split into two parts. One part consists of the relative discretization error that increases for increasing class size, and the second part is related to the relative statistical error which increases with decreasing class size. For both parts, upper bounds can be given and the sum of them indicates an optimal class width depending on some specific constants.
(18 pages, 1999)

18. E. Carrizosa, H. W. Hamacher, R. Klein, S. Nickel

Solving nonconvex planar location problems by finite dominating sets

It is well-known that some of the classical location problems with polyhedral gauges can be solved in polynomial time by finding a finite dominating set, i.e. a finite set of candidates guaranteed to contain at least one optimal location.
In this paper it is first established that this result holds

for a much larger class of problems than currently considered in the literature. The model for which this result can be proven includes, for instance, location problems with attraction and repulsion, and location-allocation problems.
Next, it is shown that the approximation of general gauges by polyhedral ones in the objective function of our general model can be analyzed with regard to the subsequent error in the optimal objective value. For the approximation problem two different approaches are described, the sandwich procedure and the greedy algorithm. Both of these approaches lead - for fixed epsilon - to polynomial approximation algorithms with accuracy epsilon for solving the general model considered in this paper.
Keywords: Continuous Location, Polyhedral Gauges, Finite Dominating Sets, Approximation, Sandwich Algorithm, Greedy Algorithm
(19 pages, 2000)

19. A. Becker

A Review on Image Distortion Measures

Within this paper we review image distortion measures. A distortion measure is a criterion that assigns a "quality number" to an image. We distinguish between mathematical distortion measures and those distortion measures in-cooperating a priori knowledge about the imaging devices (e. g. satellite images), image processing algorithms or the human physiology. We will consider representative examples of different kinds of distortion measures and are going to discuss them.
Keywords: Distortion measure, human visual system
(26 pages, 2000)

20. H. W. Hamacher, M. Labbé, S. Nickel, T. Sonneborn

Polyhedral Properties of the Uncapacitated Multiple Allocation Hub Location Problem

We examine the feasibility polyhedron of the uncapacitated hub location problem (UHL) with multiple allocation, which has applications in the fields of air passenger and cargo transportation, telecommunication and postal delivery services. In particular we determine the dimension and derive some classes of facets of this polyhedron. We develop some general rules about lifting facets from the uncapacitated facility location (UFL) for UHL and projecting facets from UHL to UFL. By applying these rules we get a new class of facets for UHL which dominates the inequalities in the original formulation. Thus we get a new formulation of UHL whose constraints are all facet–defining. We show its superior computational performance by benchmarking it on a well known data set.
Keywords: integer programming, hub location, facility location, valid inequalities, facets, branch and cut
(21 pages, 2000)

21. H. W. Hamacher, A. Schöbel

Design of Zone Tariff Systems in Public Transportation

Given a public transportation system represented by its stops and direct connections between stops, we consider two problems dealing with the prices for the customers: The fare problem in which subsets of stops are already aggregated to zones and "good" tariffs have to be found in the existing zone system. Closed form solutions for the fare problem are presented for three objective functions. In the zone problem the design of the zones is part of the problem. This problem is NP hard and we therefore propose three heuristics which prove to be very successful in the redesign of one of Germany's transportation systems.
(30 pages, 2001)

22. D. Hietel, M. Junk, R. Keck, D. Teleaga:

The Finite-Volume-Particle Method for Conservation Laws

In the Finite-Volume-Particle Method (FVPM), the weak formulation of a hyperbolic conservation law is discretized by restricting it to a discrete set of test functions. In contrast to the usual Finite-Volume approach, the test functions are not taken as characteristic functions of the control volumes in a spatial grid, but are chosen from a partition of unity with smooth and overlapping partition functions (the particles), which can even move along pre- scribed velocity fields. The information exchange between particles is based on standard numerical flux functions. Geometrical information, similar to the surface area of the cell faces in the Finite-Volume Method and the corresponding normal directions are given as integral quantities of the partition functions. After a brief derivation of the Finite-Volume-Particle Method, this work focuses on the role of the geometric coefficients in the scheme.
(16 pages, 2001)

23. T. Bender, H. Hennes, J. Kalcsics, M. T. Melo, S. Nickel

Location Software and Interface with GIS and Supply Chain Management

The objective of this paper is to bridge the gap between location theory and practice. To meet this objective focus is given to the development of software capable of addressing the different needs of a wide group of users. There is a very active community on location theory encompassing many research fields such as operations research, computer science, mathematics, engineering, geography, economics and marketing. As a result, people working on facility location problems have a very diverse background and also different needs regarding the software to solve these problems. For those interested in non-commercial applications (e. g. students and researchers), the library of location algorithms (LoLA can be of considerable assistance. LoLA contains a collection of efficient algorithms for solving planar, network and discrete facility location problems. In this paper, a detailed description of the functionality of LoLA is presented. In the fields of geography and marketing, for instance, solving facility location problems requires using large amounts of demographic data. Hence, members of these groups (e. g. urban planners and sales managers) often work with geographical information too s. To address the specific needs of these users, LoLA was inked to a geographical information system (GIS) and the details of the combined functionality are described in the paper. Finally, there is a wide group of practitioners who need to solve large problems and require special purpose software with a good data interface. Many of such users can be found, for example, in the area of supply chain management (SCM). Logistics activities involved in strategic SCM include, among others, facility location planning. In this paper, the development of a commercial location software tool is also described. The too is embedded in the Advanced Planner and Optimizer SCM software developed by SAP AG, Walldorf, Germany. The paper ends with some conclusions and an outlook to future activities.
Keywords: facility location, software development, geographical information systems, supply chain management.
(48 pages, 2001)

24. H. W. Hamacher, S. A. Tjandra

Mathematical Modelling of Evacuation Problems: A State of Art

This paper details models and algorithms which can be applied to evacuation problems. While it concentrates on building evacuation many of the results are applicable also to regional evacuation. All models consider the time as main parameter, where the travel time between components of the building is part of the input and the overall evacuation time is the output. The paper distinguishes between macroscopic and microscopic evacuation models both of which are able to capture the evacuees' movement over time.
Macroscopic models are mainly used to produce good lower bounds for the evacuation time and do not consider any individual behavior during the emergency situation. These bounds can be used to analyze existing buildings or help in the design phase of planning a building. Macroscopic approaches which are based on dynamic network flow models (minimum cost dynamic flow, maximum dynamic flow, universal maximum flow, quickest path and quickest flow) are described. A special feature of the presented approach is the fact, that travel times of evacuees are not restricted to be constant, but may be density dependent. Using multicriteria optimization priority regions and blockage due to fire or smoke may be considered. It is shown how the modelling can be done using time parameter either as discrete or continuous parameter.
Microscopic models are able to model the individual evacuee's characteristics and the interaction among evacuees which influence their movement. Due to the corresponding huge amount of data one uses simulation approaches. Some probabilistic laws for individual evacuee's movement are presented. Moreover ideas to model the evacuee's movement using cellular automata (CA) and resulting software are presented. In this paper we will focus on macroscopic models and only summarize some of the results of the microscopic approach. While most of the results are applicable to general evacuation situations, we concentrate on building evacuation.
(44 pages, 2001)

25. J. Kuhnert, S. Tiwari

Grid free method for solving the Poisson equation

A Grid free method for solving the Poisson equation is presented. This is an iterative method. The method is based on the weighted least squares approximation in which the Poisson equation is enforced to be satisfied in every iterations. The boundary conditions can also be enforced in the iteration process. This is a local approximation procedure. The Dirichlet, Neumann and mixed boundary value problems on a unit square are presented and the analytical solutions are compared with the exact solutions. Both solutions matched perfectly.
Keywords: Poisson equation, Least squares method, Grid free method
(19 pages, 2001)

26. T. Götz, H. Rave, D. Reinel-Bitzer, K. Steiner, H. Tiemeier

Simulation of the fiber spinning process

To simulate the influence of process parameters to the melt spinning process a fiber model is used and coupled with CFD calculations of the quench air flow. In the fiber model energy, momentum and mass balance are solved for the polymer mass flow. To calculate the quench air the Lattice Boltzmann method is used. Simulations and experiments for different process parameters and hole configurations are compared and show a good agreement.

Keywords: Melt spinning, fiber model, Lattice Boltzmann, CFD

(19 pages, 2001)

27. A. Zemitis

On interaction of a liquid film with an obstacle

In this paper mathematical models for liquid films generated by impinging jets are discussed. Attention is stressed to the interaction of the liquid film with some obstacle. S. G. Taylor [Proc. R. Soc. London Ser. A 253, 313 (1959)] found that the liquid film generated by impinging jets is very sensitive to properties of the wire which was used as an obstacle. The aim of this presentation is to propose a modification of the Taylor's model, which allows to simulate the film shape in cases, when the angle between jets is different from 180°. Numerical results obtained by discussed models give two different shapes of the liquid film similar as in Taylors experiments. These two shapes depend on the regime: either droplets are produced close to the obstacle or not. The difference between two regimes becomes larger if the angle between jets decreases. Existence of such two regimes can be very essential for some applications of impinging jets, if the generated liquid film can have a contact with obstacles.

Keywords: impinging jets, liquid film, models, numerical solution, shape

(22 pages, 2001)

28. I. Ginzburg, K. Steiner

Free surface lattice-Boltzmann method to model the filling of expanding cavities by Bingham Fluids

The filling process of viscoplastic metal alloys and plastics in expanding cavities is modelled using the lattice Boltzmann method in two and three dimensions. These models combine the regularized Bingham model for viscoplastic with a free-interface algorithm. The latter is based on a modified immiscible lattice Boltzmann model in which one species is the fluid and the other one is considered as vacuum. The boundary conditions at the curved liquid-vacuum interface are met without any geometrical front reconstruction from a first-order Chapman-Enskog expansion. The numerical results obtained with these models are found in good agreement with available theoretical and numerical analysis.

Keywords: Generalized LBE, free-surface phenomena, interface boundary conditions, filling processes, Bingham viscoplastic model, regularized models

(22 pages, 2001)

29. H. Neunzert

»Denn nichts ist für den Menschen als Menschen etwas wert, was er nicht mit Leidenschaft tun kann«

Vortrag anlässlich der Verleihung des Akademiepreises des Landes Rheinland-Pfalz am 21.11.2001

Was macht einen guten Hochschullehrer aus? Auf diese Frage gibt es sicher viele verschiedene, fachbezogene Antworten, aber auch ein paar allgemeine Gesichtspunkte: es bedarf der »Leidenschaft« für die Forschung (Max Weber), aus der dann auch die Begeisterung für die Lehre erwächst. Forschung und Lehre gehören zusammen, um die Wissenschaft als lebendiges Tun vermitteln zu können. Der Vortrag gibt Beispiele dafür, wie in angewandter Mathematik Forschungsaufgaben aus praktischen Alltagsproblemstellungen erwachsen, die in die Lehre auf verschiedenen Stufen (Gymnasium bis Graduiertenkolleg) einfließen; er leitet damit auch zu einem aktuellen Forschungsgebiet, der Mehrskalenanalyse mit ihren vielfältigen Anwendungen in Bildverarbeitung, Materialentwicklung und Strömungsmechanik über, was aber nur kurz gestreift wird. Mathematik erscheint hier als eine moderne Schlüsseltechnologie, die aber auch enge Beziehungen zu den Geistes- und Sozialwissenschaften hat.

Keywords: Lehre, Forschung, angewandte Mathematik, Mehrskalenanalyse, Strömungsmechanik

(18 pages, 2001)

30. J. Kuhnert, S. Tiwari

Finite pointset method based on the projection method for simulations of the incompressible Navier-Stokes equations

A Lagrangian particle scheme is applied to the projection method for the incompressible Navier-Stokes equations. The approximation of spatial derivatives is obtained by the weighted least squares method. The pressure Poisson equation is solved by a local iterative procedure with the help of the least squares method. Numerical tests are performed for two dimensional cases. The Couette flow, Poiseuelle flow, decaying shear flow and the driven cavity flow are presented. The numerical solutions are obtained for stationary as well as instationary cases and are compared with the analytical solutions for channel flows. Finally, the driven cavity in a unit square is considered and the stationary solution obtained from this scheme is compared with that from the finite element method.

Keywords: Incompressible Navier-Stokes equations, Meshfree method, Projection method, Particle scheme, Least squares approximation

AMS subject classification: 76D05, 76M28

(25 pages, 2001)

31. R. Korn, M. Krekel

Optimal Portfolios with Fixed Consumption or Income Streams

We consider some portfolio optimisation problems where either the investor has a desire for an a priori specified consumption stream or/and follows a deterministic pay in scheme while also trying to maximize expected utility from final wealth. We derive explicit closed form solutions for continuous and discrete monetary streams. The mathematical method used is classical stochastic control theory.

Keywords: Portfolio optimisation, stochastic control, HJB equation, discretisation of control problems.

(23 pages, 2002)

32. M. Krekel

Optimal portfolios with a loan dependent credit spread

If an investor borrows money he generally has to pay higher interest rates than he would have received, if he had put his funds on a savings account. The classical model of continuous time portfolio optimisation ignores this effect. Since there is obviously a connection between the default probability and the total percentage of wealth, which the investor is in debt, we study portfolio optimisation with a control dependent interest rate. Assuming a logarithmic and a power utility function, respectively, we prove explicit formulae of the optimal control.

Keywords: Portfolio optimisation, stochastic control, HJB equation, credit spread, log utility, power utility, non-linear wealth dynamics

(25 pages, 2002)

33. J. Ohser, W. Nagel, K. Schladitz

The Euler number of discretized sets - on the choice of adjacency in homogeneous lattices

Two approaches for determining the Euler-Poincaré characteristic of a set observed on lattice points are considered in the context of image analysis { the integral geometric and the polyhedral approach. Information about the set is assumed to be available on lattice points only. In order to retain properties of the Euler number and to provide a good approximation of the true Euler number of the original set in the Euclidean space, the appropriate choice of adjacency in the lattice for the set and its background is crucial. Adjacencies are defined using tessellations of the whole space into polyhedrons. In R 3 , two new 14 adjacencies are introduced additionally to the well known 6 and 26 adjacencies. For the Euler number of a set and its complement, a consistency relation holds. Each of the pairs of adjacencies (14:1; 14:1), (14:2; 14:2), (6; 26), and (26; 6) is shown to be a pair of complementary adjacencies with respect to this relation. That is, the approximations of the Euler numbers are consistent if the set and its background (complement) are equipped with this pair of adjacencies. Furthermore, sufficient conditions for the correctness of the approximations of the Euler number are given. The analysis of selected microstructures and a simulation study illustrate how the estimated Euler number depends on the chosen adjacency. It also shows that there is not a uniquely best pair of adjacencies with respect to the estimation of the Euler number of a set in Euclidean space.

Keywords: image analysis, Euler number, neighborhod relationships, cuboidal lattice

(32 pages, 2002)

34. I. Ginzburg, K. Steiner

Lattice Boltzmann Model for Free-Surface flow and Its Application to Filling Process in Casting

A generalized lattice Boltzmann model to simulate free-surface is constructed in both two and three dimensions. The proposed model satisfies the interfacial boundary conditions accurately. A distinctive feature of the model is that the collision processes is carried out only on the points occupied partially or fully by the fluid. To maintain a sharp interfacial front, the method includes an anti-diffusion algorithm. The unknown distribution functions at the interfacial region are constructed according to the first order Chapman-Enskog analysis. The interfacial boundary conditions are satis-

fied exactly by the coefficients in the Chapman-Enskog expansion. The distribution functions are naturally expressed in the local interfacial coordinates. The macroscopic quantities at the interface are extracted from the least-square solutions of a locally linearized system obtained from the known distribution functions. The proposed method does not require any geometric front construction and is robust for any interfacial topology. Simulation results of realistic filling process are presented: rectangular cavity in two dimensions and Hammer box, Campbell box, Sheffield box, and Motorblock in three dimensions. To enhance the stability at high Reynolds numbers, various upwind-type schemes are developed. Free-slip and no-slip boundary conditions are also discussed.
Keywords: Lattice Boltzmann models; free-surface phenomena; interface boundary conditions; filling processes; injection molding; volume of fluid method; interface boundary conditions; advection-schemes; upwind-schemes
(54 pages, 2002)

35. M. Günther, A. Klar, T. Materne, R. Wegener

Multivalued fundamental diagrams and stop and go waves for continuum traffic equations

In the present paper a kinetic model for vehicular traffic leading to multivalued fundamental diagrams is developed and investigated in detail. For this model phase transitions can appear depending on the local density and velocity of the flow. A derivation of associated macroscopic traffic equations from the kinetic equation is given. Moreover, numerical experiments show the appearance of stop and go waves for highway traffic with a bottleneck.
Keywords: traffic flow, macroscopic equations, kinetic derivation, multivalued fundamental diagram, stop and go waves, phase transitions
(25 pages, 2002)

36. S. Feldmann, P. Lang, D. Prätzel-Wolters

Parameter influence on the zeros of network determinants

To a network N(q) with determinant D(s;q) depending on a parameter vector $q \hat{I} R^r$ via identification of some of its vertices, a network N^ (q) is assigned. The paper deals with procedures to find N^ (q), such that its determinant D^ (s;q) admits a factorization in the determinants of appropriate subnetworks, and with the estimation of the deviation of the zeros of D^ from the zeros of D. To solve the estimation problem state space methods are applied.
Keywords: Networks, Equicofactor matrix polynomials, Realization theory, Matrix perturbation theory
(30 pages, 2002)

37. K. Koch, J. Ohser, K. Schladitz

Spectral theory for random closed sets and estimating the covariance via frequency space

A spectral theory for stationary random closed sets is developed and provided with a sound mathematical basis. Definition and proof of existence of the Bartlett spectrum of a stationary random closed set as well as the proof of a Wiener-Khintchine theorem for the power spectrum are used to two ends: First, well known second order characteristics like the covariance can be estimated faster than usual via frequency space. Second, the Bartlett spectrum and the power spectrum can be used as second order characteristics in frequency space. Examples show, that in some cases information about the random closed set is easier to obtain from these characteristics in frequency space than from their real world counterparts.
Keywords: Random set, Bartlett spectrum, fast Fourier transform, power spectrum
(28 pages, 2002)

38. D. d'Humières, I. Ginzburg

Multi-reflection boundary conditions for lattice Boltzmann models

We present a unified approach of several boundary conditions for lattice Boltzmann models. Its general framework is a generalization of previously introduced schemes such as the bounce-back rule, linear or quadratic interpolations, etc. The objectives are two fold: first to give theoretical tools to study the existing boundary conditions and their corresponding accuracy; secondly to design formally third- order accurate boundary conditions for general flows. Using these boundary conditions, Couette and Poiseuille flows are exact solution of the lattice Boltzmann models for a Reynolds number $Re = 0$ (Stokes limit).
Numerical comparisons are given for Stokes flows in periodic arrays of spheres and cylinders, linear periodic array of cylinders between moving plates and for Navier-Stokes flows in periodic arrays of cylinders for $Re < 200$. These results show a significant improvement of the overall accuracy when using the linear interpolations instead of the bounce-back reflection (up to an order of magnitude on the hydrodynamics fields). Further improvement is achieved with the new multi-reflection boundary conditions, reaching a level of accuracy close to the quasi-analytical reference solutions, even for rather modest grid resolutions and few points in the narrowest channels. More important, the pressure and velocity fields in the vicinity of the obstacles are much smoother with multi-reflection than with the other boundary conditions.
Finally the good stability of these schemes is highlighted by some simulations of moving obstacles: a cylinder between flat walls and a sphere in a cylinder.
Keywords: lattice Boltzmann equation, boudary condistions, bounce-back rule, Navier-Stokes equation
(72 pages, 2002)

39. R. Korn

Elementare Finanzmathematik

Im Rahmen dieser Arbeit soll eine elementar gehaltene Einführung in die Aufgabenstellungen und Prinzipien der modernen Finanzmathematik gegeben werden. Insbesondere werden die Grundlagen der Modellierung von Aktienkursen, der Bewertung von Optionen und der Portfolio-Optimierung vorgestellt. Natürlich können die verwendeten Methoden und die entwickelte Theorie nicht in voller Allgemeinheit für den Schulunterricht verwendet werden, doch sollen einzelne Prinzipien so heraus gearbeitet werden, dass sie auch an einfachen Beispielen verstanden werden können.
Keywords: Finanzmathematik, Aktien, Optionen, Portfolio-Optimierung, Börse, Lehrerweiterbildung, Mathematikunterricht
(98 pages, 2002)

40. J. Kallrath, M. C. Müller, S. Nickel

Batch Presorting Problems: Models and Complexity Results

In this paper we consider short term storage systems. We analyze presorting strategies to improve the effiency of these storage systems. The presorting task is called Batch PreSorting Problem (BPSP). The BPSP is a variation of an assigment problem, i. e., it has an assigment problem kernel and some additional constraints. We present different types of these presorting problems, introduce mathematical programming formulations and prove the NP-completeness for one type of the BPSP. Experiments are carried out in order to compare the different model formulations and to investigate the behavior of these models.
Keywords: Complexity theory, Integer programming, Assigment, Logistics
(19 pages, 2002)

41. J. Linn

On the frame-invariant description of the phase space of the Folgar-Tucker equation

The Folgar-Tucker equation is used in flow simulations of fiber suspensions to predict fiber orientation depending on the local flow. In this paper, a complete, frame-invariant description of the phase space of this differential equation is presented for the first time.
Key words: fiber orientation, Folgar-Tucker equation, injection molding
(5 pages, 2003)

42. T. Hanne, S. Nickel

A Multi-Objective Evolutionary Algorithm for Scheduling and Inspection Planning in Software Development Projects

In this article, we consider the problem of planning inspections and other tasks within a software development (SD) project with respect to the objectives quality (no. of defects), project duration, and costs. Based on a discrete-event simulation model of SD processes comprising the phases coding, inspection, test, and rework, we present a simplified formulation of the problem as a multiobjective optimization problem. For solving the problem (i. e. finding an approximation of the efficient set) we develop a multiobjective evolutionary algorithm. Details of the algorithm are discussed as well as results of its application to sample problems.
Key words: multiple objective programming, project management and scheduling, software development, evolutionary algorithms, efficient set
(29 pages, 2003)

43. T. Bortfeld , K.-H. Küfer, M. Monz, A. Scherrer, C. Thieke, H. Trinkaus

Intensity-Modulated Radiotherapy - A Large Scale Multi-Criteria Programming Problem -

Radiation therapy planning is always a tight rope walk between dangerous insufficient dose in the target volume and life threatening overdosing of organs at risk. Finding ideal balances between these inherently contradictory goals challenges dosimetrists and physicians in their daily practice. Today's planning systems are typically based on a single evaluation function that measures the quality of a radiation treatment plan. Unfortunately, such a one dimensional approach can-

not satisfactorily map the different backgrounds of physicians and the patient dependent necessities. So, too often a time consuming iteration process between evaluation of dose distribution and redefinition of the evaluation function is needed.
In this paper we propose a generic multi-criteria approach based on Pareto's solution concept. For each entity of interest - target volume or organ at risk a structure dependent evaluation function is defined measuring deviations from ideal doses that are calculated from statistical functions. A reasonable bunch of clinically meaningful Pareto optimal solutions are stored in a data base, which can be interactively searched by physicians. The system guarantees dynamical planning as well as the discussion of tradeoffs between different entities.
Mathematically, we model the upcoming inverse problem as a multi-criteria linear programming problem. Because of the large scale nature of the problem it is not possible to solve the problem in a 3D-setting without adaptive reduction by appropriate approximation schemes.
Our approach is twofold: First, the discretization of the continuous problem is based on an adaptive hierarchical clustering process which is used for a local refinement of constraints during the optimization procedure. Second, the set of Pareto optimal solutions is approximated by an adaptive grid of representatives that are found by a hybrid process of calculating extreme compromises and interpolation methods.
Keywords: multiple criteria optimization, representative systems of Pareto solutions, adaptive triangulation, clustering and disaggregation techniques, visualization of Pareto solutions, medical physics, external beam radiotherapy planning, intensity modulated radiotherapy
(31 pages, 2003)

44. T. Halfmann, T. Wichmann

Overview of Symbolic Methods in Industrial Analog Circuit Design

Industrial analog circuits are usually designed using numerical simulation tools. To obtain a deeper circuit understanding, symbolic analysis techniques can additionally be applied. Approximation methods which reduce the complexity of symbolic expressions are needed in order to handle industrial-sized problems. This paper will give an overview to the field of symbolic analog circuit analysis. Starting with a motivation, the state-of-the-art simplification algorithms for linear as well as for nonlinear circuits are presented. The basic ideas behind the different techniques are described, whereas the technical details can be found in the cited references. Finally, the application of linear and nonlinear symbolic analysis will be shown on two example circuits.
Keywords: CAD, automated analog circuit design, symbolic analysis, computer algebra, behavioral modeling, system simulation, circuit sizing, macro modeling, differential-algebraic equations, index
(17 pages, 2003)

45. S. E. Mikhailov, J. Orlik

Asymptotic Homogenisation in Strength and Fatigue Durability Analysis of Composites

Asymptotic homogenisation technique and two-scale convergence is used for analysis of macro-strength and fatigue durability of composites with a periodic structure under cyclic loading. The linear damage accumulation rule is employed in the phenomenological micro-durability conditions (for each component of the composite) under varying cyclic loading. Both local and non-local strength and durability conditions are analysed. The strong convergence of the strength and fatigue damage measure as the structure period tends to zero is proved and their limiting values are estimated.
Keywords: multiscale structures, asymptotic homogenization, strength, fatigue, singularity, non-local conditions
(14 pages, 2003)

46. P. Domínguez-Marín, P. Hansen, N. Mladenović, S. Nickel

Heuristic Procedures for Solving the Discrete Ordered Median Problem

We present two heuristic methods for solving the Discrete Ordered Median Problem (DOMP), for which no such approaches have been developed so far. The DOMP generalizes classical discrete facility location problems, such as the p-median, p-center and Uncapacitated Facility Location problems. The first procedure proposed in this paper is based on a genetic algorithm developed by Moreno Vega [MV96] for p-median and p-center problems. Additionally, a second heuristic approach based on the Variable Neighborhood Search metaheuristic (VNS) proposed by Hansen & Mladenovic [HM97] for the p-median problem is described. An extensive numerical study is presented to show the efficiency of both heuristics and compare them.
Keywords: genetic algorithms, variable neighborhood search, discrete facility location
(31 pages, 2003)

47. N. Boland, P. Domínguez-Marín, S. Nickel, J. Puerto

Exact Procedures for Solving the Discrete Ordered Median Problem

The Discrete Ordered Median Problem (DOMP) generalizes classical discrete location problems, such as the N-median, N-center and Uncapacitated Facility Location problems. It was introduced by Nickel [16], who formulated it as both a nonlinear and a linear integer program. We propose an alternative integer linear programming formulation for the DOMP, discuss relationships between both integer linear programming formulations, and show how properties of optimal solutions can be used to strengthen these formulations. Moreover, we present a specific branch and bound procedure to solve the DOMP more efficiently. We test the integer linear programming formulations and this branch and bound method computationally on randomly generated test problems.
Keywords: discrete location, Integer programming
(41 pages, 2003)

48. S. Feldmann, P. Lang

Padé-like reduction of stable discrete linear systems preserving their stability

A new stability preserving model reduction algorithm for discrete linear SISO-systems based on their impulse response is proposed. Similar to the Padé approximation, an equation system for the Markov parameters involving the Hankel matrix is considered, that here however is chosen to be of very high dimension. Although this equation system therefore in general cannot be solved exactly, it is proved that the approximate solution, computed via the Moore-Penrose inverse, gives rise to a stability preserving reduction scheme, a property that cannot be guaranteed for the Padé approach. Furthermore, the proposed algorithm is compared to another stability preserving reduction approach, namely the balanced truncation method, showing comparable performance of the reduced systems. The balanced truncation method however starts from a state space description of the systems and in general is expected to be more computational demanding.
Keywords: Discrete linear systems, model reduction, stability, Hankel matrix, Stein equation
(16 pages, 2003)

49. J. Kallrath, S. Nickel

A Polynomial Case of the Batch Presorting Problem

This paper presents new theoretical results for a special case of the batch presorting problem (BPSP). We will show tht this case can be solved in polynomial time. Offline and online algorithms are presented for solving the BPSP. Competetive analysis is used for comparing the algorithms.
Keywords: batch presorting problem, online optimization, competetive analysis, polynomial algorithms, logistics
(17 pages, 2003)

50. T. Hanne, H. L. Trinkaus

knowCube for MCDM – Visual and Interactive Support for Multicriteria Decision Making

In this paper, we present a novel multicriteria decision support system (MCDSS), called knowCube, consisting of components for knowledge organization, generation, and navigation. Knowledge organization rests upon a database for managing qualitative and quantitative criteria, together with add-on information. Knowledge generation serves filling the database via e. g. identification, optimization, classification or simulation. For "finding needles in haycocks", the knowledge navigation component supports graphical database retrieval and interactive, goal-oriented problem solving. Navigation "helpers" are, for instance, cascading criteria aggregations, modifiable metrics, ergonomic interfaces, and customizable visualizations. Examples from real-life projects, e.g. in industrial engineering and in the life sciences, illustrate the application of our MCDSS.
Key words: Multicriteria decision making, knowledge management, decision support systems, visual interfaces, interactive navigation, real-life applications.
(26 pages, 2003)

Status quo: May 2003