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T. Hanne, S. Nickel

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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

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

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

Abstract

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.

1 Introduction

Today, software industry is facing increasing requirements for the quality of their products. At the same time, controlling the costs and keeping the deadlines of software development (SD) projects have become increasingly important issues.

*Corresponding author

Up to now there are quite few formal approaches in practical use for supporting project managers, e.g. by the simulation and optimization of SD processes. Since a couple of years, simulation models have been developed for supporting the understanding and planning of SD processes. Mostly, these models (see Kellner, Madachy, and Raffo (1999) for a survey) are based on the system dynamics approach which is particularly useful for modelling feedback loops on a macro level but does hardly support a detailed representation of the considered system. For that purpose, a discrete-event simulation approach is better suited and allows for an individual representation of objects such as persons and items produced in an SD process (design documents, source code modules, etc.).

Within two larger research projects we developed a discrete-event simulation model for supporting project managers in the software industry (see Neu et al. (2002), Münch et al. (2002)). In that model, the assignment of tasks to persons (e.g. items to be coded, items to be inspected) is done in an arbitrary way, thus in a first come-first serve (FCFS) fashion. This means that items are treated in a given arbitrary order and the developers being next available become their authors. The assignment of coding and other SD tasks to people is relevant since the duration of the project, i.e. the makespan in scheduling terminology (see Pinedo (1995) or Brucker (1998) for some introduction to scheduling), depends on this assignment and, in general, the time required for performing a task depends on a person's productivity which is, for instance, influenced by their experience. For these reasons, we have reformulated the assignment problem as a problem to be solved externally by some tools for optimization.

Our model focuses on the planning of inspections as a key technology for finding defects and, thus, for ensuring the quality of a software product (see Basili and Boehm (2001)). Questions to be answered are, e.g., whether inspections should be applied, which documents should be inspected and by how many persons. The relationships between the inspection team size and the inspection technique on the one hand and the inspection effectiveness on the other hand has been analyzed during many experiments and in real-life settings, see, e.g. Briand et al. (1997). It is generally assumed that finding defects (at an early stage) in inspections is more effective (i.e. lower costs per found defect) than at a later stage, i.e. during testing, and that some inspection techniques seem to be superior to others. More differentiated results in combination with the planning of a specific SD project are, however, not available. Besides inspections also coding activities, rework, and testing are represented in the model. Other activities such as those in the requirement and design phases are neglected at the moment.

For the model, it is assumed that a source code item of a length known in advance is coded first. Then it is to be inspected and, after that, subject to rework. After that, an item is going to be tested and is then again subject to rework. During coding, defects are produced some of them which are detected during inspection and test, and removed during rework. For doing so, a person has to be assigned to an item as its author who performs the coding. For the inspection, several persons have to be assigned as inspectors. These persons must not be the same as the author. Also for the testing, one person (not the same as the author) has to be assigned. The rework of a document is done again by its author. Details on the organization of such a process can, for instance, be found in Ebenau and Strauss (1994) and Humphrey (1989).

In below we discuss the usage of an evolutionary algorithm (EA) approach for planning inspections and scheduling staff. Evolutionary algorithms such as genetic algorithms (Holland (1975)) or evolution strategies (Schwefel (1983), Bäck, Hoffmeister, and Schwefel (1991)) have shown to be robust approaches applicable to a wide range of optimization problems. Applications in the area of scheduling can, for instance, be found in Wang and Uzsoy (2002), Della Croce, Tadei, and Volta (1995), and Yun (2002).

Since about 15 years, evolutionary algorithms are also increasingly being developed and used for multiobjective optimization problems. Surveys on such multiobjective evolutionary algorithms (MOEAs) are given by Fonseca and Fleming (1995), Horn (1997), and Tamaki, Kita, and Kobayashi (1996). More recent research results are included in the proceedings of the First International Conference on Evolutionary Multi-Criterion Optimization edited by Zitzler et al. (2001)). Results on applying MOEAs to specific scheduling problems can be found, for instance, in Celano et al. (1999), Cochran, Horng, and Fowler (2002), or Esquivel et al. (2002). General results on multicriteria scheduling problems are presented in T'kindt and Billaut (2002).

The subsequent paper is organized as follows: In Section 2 we present our model for the planning of inspections and the scheduling of staff. In Section 3, the MOEA for solving the corresponding multiobjective optimization problem is outlined. Section 4 presents results of applying the MOEA to the multiobjective SD planning problem. The paper ends with some conclusions and an outlook to future work.

2 A Multiobjective Software Inspection Problem

The basic assumption of our software process model is that a given number of n source code items has to be produced. The size of each item and a measure of its complexity are known in advance.[1] The coding tasks are done by a team of m developers such that each item is coded by one person called its author. After coding, an item may be subject to an inspection. This means that one or several persons from the team read the item and try to find defects. After the inspection, the item is subject to some rework for eliminating the found defects. After that, a document may be subject to some testing (and subsequent rework) which also serves the purpose of finding defects. We assume all these tasks to be done by a team of m persons, each of them being able to perform any task.

Unlike the other tasks, inspections are assumed to be done in a preempting way such that persons involved in coding or testing (i.e. processes with a lower priority) may interrupt their tasks and read the documents to be inspected in between. Inspections themselves are assumed to be non-preemptive. Similar problems in scheduling with priorities specific to the task occur in real-time operating systems (see, e.g., Lamie (1997) and Mäki-Turja, Fohler, and Sandström (1999)).

[1] This and similar simplifications are necessary in order to make the problem treatable. In subsequent research it is planned to analyze a stochastic version of this problem which should allow a better representation of the situations in reality.

2.1 Assignment of Tasks (Decision Variables)

According to our general assumptions each item has to be coded by exactly one person. Therefore, we consider the assignment of persons to coding tasks by an n-dimensional vector *author* with

$$author_i \in \{1, ..., m\} \tag{2.1}$$

for $i \in \{1, ..., n\}$.

For the inspection team size, $no\_inspectors_i$, we assume

$$no\_inspectors_i \in \{0, ..., no\_inspectors_{max}\} \text{ for all } i \in \{1, ..., n\} \tag{2.2}$$

with a 0-component indicating that the corresponding item is not subject to inspection and considering a maximum team size $no\_inspectors_{max} \leq m - 1$.

For $i \in \{1, ..., n\}, k \in \{1, ..., no\_inspectors_i\}$ let

$$inspector_{ik} \in \{1, ..., m\} \tag{2.3}$$

indicate which persons are assigned to the inspection of item i. The restrictions

$$inspector_{ik} \neq author_i \text{ for all } i, k, \tag{2.4}$$

indicate that the author of a document is not allowed to be an inspector of the same document and, of course, the inspectors must be pairwise different, i.e.

$$inspector_{ik} \neq inspector_{il} \text{ for } k \neq l \text{ and } i \in \{1, ..., n\}. \tag{2.5}$$

In a similar way, persons are assigned for testing an item, i.e.

$$tester_i \in \{1, ..., m\} \tag{2.6}$$

with

$$tester_i \neq author_i \text{ for all } i \in \{1, ..., n\}. \tag{2.7}$$

Unlike for the other activities which duration genuinely depends on item and person attributes (see below) and which are endogenously determined within the model, the test time is exogenously given as a decision variable. The reason is that more and more testing increases the number of found defects (although) with a decreasing rate). Thus, test times are determined, for instance by using a pre-specified test intensity, ti, used as a multiplicative factor, i.e.

$$tt_i = ti \cdot cplx_i \cdot size_i, \tag{2.8}$$

thus defining the test times as proportional to the size of an item wheighted by its complexity. In reality it may be the case that the test time is not pre-specified but depends on the number of defects found per time unit, e.g. with the motivation to reach a desired quality of the source code. This case is considered in the simulation model but will be neglected here for simplicity.

For determining the temporal sequence for scheduling tasks, we use priority values for the coding and testing activities,

$$priority\_c_i \in [0, 1], \tag{2.9}$$

$$priority\_t_i \in [0, 1], \tag{2.10}$$

for $i \in \{1, ..., n\}$. A higher priority value indicates that the corresponding task should be scheduled before a task with a lower value, if possible. For the inspections such priority information is not required since we assume them to be done immediately after the coding of the item. In general, we assume that developers perform all their coding tasks within a project before starting the first testing activities.

In the discrete-event simulation model constructed with the simulation tool Extend, the above decision variables are set implicitly by some kind of first-come first-serve (FCFS) logic. This means that at the start of a simulation run, items are batched with persons according to a given order (determined by item and person numbers) as long as persons are available. Later on, items waiting for their next processing steps are batched with the person becoming next available. While determining an FCFS solution, for all the above decision variables values being consistent with that solution are determined. Within our optimization model such an FCFS solution can be reproduced and serves as a benchmark solution for judging the quality of solutions generated by the MOEA.

2.2 Working Times and Effectiveness of Work

For the processing times, we assume that these depend on the jobs to be processed, i.e. the sizes of the items, their complexities and their domains, and the programmers assigned to, i.e. their experiences, skills, and other human factors. Since not all of these factors can be modelled explicitly (especially because of a lack of data) we consider only skills as determining factors for the individual productivities. For each developer $k \in \{1, ..., m\}$ skill values are considered for the different activities, i.e. coding (coding productivity skill, cps_k) and inspection (inspection productivity skill, ips_k). The skills are assumed to be measured on the $[0, 1]$ interval. Multiplied by given values for maximum productivities (corresponding to skill values of 1), i.e. a maximum coding productivity, mcp, and a maximum inspection productivity, mip, the productivities of developers for the various tasks can be determined. Multiplied by the size of an item, $size_i$, and considering an adjusting factor for the complexity of the item, $cplx_i$, the specific working times can be calculated as follows:

Coding times:

$$ct_i = size_i \cdot cplx_i/(mcp \cdot cps_k) \tag{2.11}$$

Inspection times:

$$it_{ik} = size_i \cdot cplx_i/(mip \cdot ips_k) \tag{2.12}$$

The rework times depend on the one hand on the number of defects to be reworked, on the other hand on the skills of the person doing the rework. Since the rework activities are closely connected to the coding activities, the same skill values are also used for determining the rework times, rt_i. This is done by using a factor expressing the relationship between rework productivity (number of defects per hour) and coding productivity (number of lines of code per hour), the average defect size, ads.

$$rt_i := fd_i \cdot cplx_i/(ads \cdot mcp \cdot cps_k) \tag{2.13}$$

In this way, we calculate the times for rework after inspection, rt_i^1, and after testing, rt_i^2, depending on the found defects fd_i^1 and fd_i^2, respectively.

As for the working times, the quality of work measured by the number of defects produced, found, and removed during the various activities depends on attributes of an item, i.e. its size and complexity, and attributes of the person assigned to the task. As for the times, we assume specific skill attributes for the persons measuring the quality of work on a $[0, 1]$-scale. The number of defects produced when an item i is coded by author k is assumed to be

$$pd_i = size_i \cdot cplx_i \cdot mdd/cqs_k \tag{2.14}$$

where cqs_k is the coding quality skill of k and mdd denotes the minimum defect density, i.e. the defect density of a highly skilled developer.

For an individual inspector k, it is assumed that the probability of finding a defect is a result of his or her defect detection skill, $dds_k \in [0, 1]$, multiplied by a factor, *itf*, expressing the effectiveness of the inspection technique and the influence of other organizational factors. Thus, inspector k's individual probability of overlooking a defect is $1 - itf \cdot dds_k$. For the inspection team, the effect of double counting found defects is considered by using the team probability of overlooking a defect (which is the product of the individual probabilities) for calculating the number of found defects:

$$fd_i^1 = pd_i \cdot (1 - \prod_{k=1}^{no\_inspectors_i} (1 - itf \cdot dds_k)) \tag{2.15}$$

For the rework, it is assumed that all found defects are removed but some of them not correctly, or that new defects are produced in a proportional relationship to the correctly removed ones:

$$rd_i = rdf \cdot fd_i \tag{2.17}$$

with *rdf* being a rework defects factor with $rdf < 1$. For the defects found during test, we assume that these are as follows in an exponential relationship to the testing time:

$$fd_i^2 = d_i \cdot (1 - e^{-dfr \cdot tqs_k \cdot tt_i}) \tag{2.18}$$

where d_i are the defects remaining after coding, inspection, and rework. tqs_k is the testing quality skill of k and *dfr* is a defect find rate.

In the discrete-event simulation model, the skill values are dynamically varied, especially by employing a learning model. These effects are neglected in the simplified model used for optimization.

In general, the result of an activity (e.g. number of defects produced during coding, found during an inspection) as well as the time needed for performing it can be considered as random since many human effects cannot be predicted with a sufficiently high accuracy. In the discrete-event simulation model (see Neu et al. (2002)) these influences are represented by stochastic distributions. For the model considered here we, however, apply a deterministic approach based on expected values. It is, of course, easily possible to consider a "security span" in these deterministic values.

2.3 Objectives

From a practical point of view (see, e.g., Abdel-Hamid and Madnick (1991)), the following three objectives are frequently considered for software development processes: a) the quality of the product measured by the eventual overall number of defects of the documents produced during a project, b) the duration of the project (its makespan), and c) the costs or total effort of the project. Based on the model above, the corresponding objective functions can be formalized as follows for the optimization:

a) The total number of defects, td, at the end of the project is a simple and effective measure for the quality of a software project. td is simply calculated by

$$td = \sum_i d_i. \tag{2.19}$$

where

$$d_i = pd_i - fd_i^1 + rd_i^1 - fd_i^2 + rd_i^2 \tag{2.20}$$

is the total number of defects in item i at the end of the process.

b) Assuming that there are no specific dependencies among the coding tasks and that inspections tasks are done in an "interrupt fashion", waiting times do not occur prior to the testing of items. Interrupts for the inspection of other author's documents are done in between where it is assumed that associated inspectors are immediately available when an item is finished with coding. This assumption can be justified because inspection times are comparably small and, in practice, people usually have some alternative tasks for filling "waiting times".

For a person assigned to the testing of an item he or she has to wait until the item is finished with coding, inspection, and rework. An item can therefore not be tested until it is ready for testing and its tester is available. The specific times of each task are calculated by constructing a schedule for all tasks to be done. Based on this, the project duration, du, can simply be calculated by the maximum finishing time of the tasks.

c) The project costs can be assumed to be proportional to the project effort which is the total time spent by the team members for accomplishing all tasks of the project.

$$tc = c \cdot \sum_i (ct_i + \sum_k it_{ik} + rt_i^1 + tt_i + rt_i^2) \tag{2.21}$$

where c are the unit costs of effort [EUR/h]. Thus, in case of waiting times, we assume that the persons can do some tasks outside the considered project, i.e. that these times are not lost.

The considered multiobjective optimization problem can then be formulated as

$$\text{“}min\text{”}(td(x), du(x), tc(x)) \tag{2.22}$$

for the decision variables

$$x = (author, no\_inspectors, inspector, tester, tt, priority\_c, priority\_t) \tag{2.23}$$

subject to the above constraints (2.1) - (2.21).

"*min*" means that each of the objectives should be minimized. Usually, the objectives can be considered to be conflicting such that there exists no solution which optimizes all objectives at the same time. As a solution in the mathematical sense, generally the set of efficient solutions is considered. An efficient solution is an alternatives for which there does not exist another one which is better in at least one objective without being weaker in any other objective, or formally: A multiobjective optimization problem is defined by

$$\text{“}min\text{”} f(x) \tag{2.24}$$

with $x \in A$ (set of feasible solutions) and $f : R^n \rightarrow R^q$ being a vector-valued objective function. Using the Pareto relation " $\leq$ " defined by

$$x \leq y :<=> x_i \leq y_i \ \forall i \in \{1, ..., q\} \text{ and } x_i < y_i \ \exists i \in \{1, ..., q\} \tag{2.25}$$

for all $x, y \in R^q$, the set of efficient (or Pareto-optimal) alternatives is defined by:

$$E(A, f) := \{x \in A : \nexists y \in A : f(y) \leq f(x)\}. \tag{2.26}$$

See Gal (1986) for more details on efficient sets.

When the efficient set is determined, or a number of (almost) efficient solutions is calculated, then further methods may be applied to elicit preference information from the decision maker (the project manager) and for calculating some kind of compromise solution (see Zeleny (1982), Steuer, (1986), Vincke (1992), Hanne (2001a)). For instance, some interactive decision support may be applied for that purpose. Below, a multicriteria approach based on the calculation of the (approximately) efficient set is presented.

3 A Multiobjective Evolutionary Algorithm for Scheduling SD Jobs

3.1 General Framework

In the following, we sketch a new multiobjective evolutionary algorithm suitable for approximating the efficient set of the considered multiobjective SD scheduling problem.

The basic idea of EAs is that from a set of intermediary solutions (population) a subsequent set of solutions is generated by imitating concepts of natural evolution such as mutation, recombination, and selection. From a set of 'parent solutions' (denoted by M^t) in generation $t \in N$, a set of 'offspring solutions' (denoted by N^t) is generated using some kind of variation. From the offspring set (or the offspring set united with the parent set) a subsequent solution set (the parents of the next generation) is selected. Note that the described algorithm is based on the more abstract MOEA outlined in Hanne (1999, 2000, 2001b). In these works there also a more technical treatment is given as well as theoretical results such as an analysis of convergence.

Fig. 1 illustrates the general framework of the evolutionary algorithm. Aspects of adapting an EA to the given problem and for considering its multiobjective nature are treated below. The following sections also serve a discussion of the single steps of the algorithm in more details.

3.2 Data Structures

One of the most important issues in applying evolutionary algorithms to specific types of problems is their problem-specific adaptation (Michalewicz (1998)). This concerns the choice of data types for representing instances of solutions to the given problem and the tailoring of the evolutionary operators to the data types and the considered class of problems. One of the main reasons for this is that, in this way, the search space can be represented adequately without losing to much search effort and time in exploring "uninteresting" regions or for "repairing" infeasible solutions.

For the given problem, an essential amount of data is required to define a specific instance of the problem. This concerns the characterization of items by their attributes, e.g. their sizes, complexities, and domains, the characterization of persons by attributes such as their skills, and other global parameters relevant for a specific SD project, e.g. maximum inspection team sizes. A solution instance to the problem (i.e. a feasible alternative) is defined by those data specified in (2.23). Discrete variables are represented by integer numbers, real variables by floating point numbers.

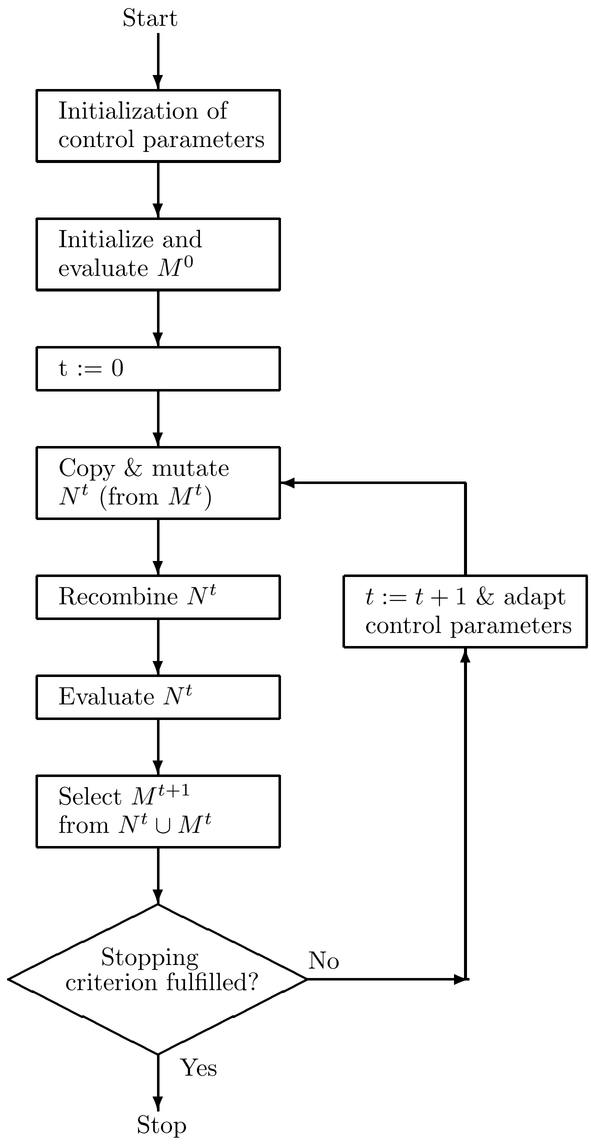

Figure 1: General framework of the MOEA

3.3 The Starting Population

For the starting population we require $\mu^0 \geq 1$ feasible solutions to the given project. In our implementation, we generate these solutions as random solutions. This is done by assigning a random author to each item, i.e.

$$author_i := uniform(1, ..., m) \, \text{for} \, i \in \{1, ..., n\}, \tag{3.1}$$

where $uniform(1, ..., m)$ denotes a random number according to the discrete uniform distribution on $\{1, ..., m\}$.

The inspection team size for each item is set to a default value, e.g. 3. For each item the inspectors and testers are assigned in the same fashion as the author but assuring that author and inspectors are not the same and that inspectors are mutually different for one item.

The priority values for tasks are assigned by

$$priority\_c_i := uniform[0, 1], \tag{3.2}$$

$$priority\_t_i := uniform[0, 1] \tag{3.3}$$

with $uniform[0, 1]$ denoting a random variable according to the continuous distribution on the interval $[0, 1]$.

In our MOEA software it is also possible to generate FCFS solutions (see above) similar to those used in the simulation model. Experiments have shown that these FCFS solutions are usually much better, esp. with respect to the makespan, than the random solutions. Unfortunately, these solutions turned out to be bad as starting solutions for the MOEA. However, just after a small number of generations the MOEA started with random solutions as above has generated better solutions than FCFS solutions.

3.4 Mutation

For each item $i \in \{1, ..., n\}$ do with probability p_m the following re-assignment: The persons responsible for each of the tasks related to that item are re-assigned according to the mechanism (3.1) used in creating a random starting solution.

The inspection team size is varied by mutations which are distributed around the previous inspection team size. This is done by normally distributed mutations similar to those used in evolution strategies, i.e.

$$no\_inspectors_i := no\_inspectors_j + round(normal(0, \sigma)) \tag{3.4}$$

where $normal(0, \sigma)$ denotes a random variable according to the normal distribution with expected value 0 and variance σ. For the new inspection team size, the restriction (2.2) has to be observed. This is done by delimiting the value for $no\_inspectors_i$ at the interval borders 0 and $no\_inspectors_{max}$. So in case of an increased inspection team size, additional inspectors have to be determined randomly.

All these re-assignments of decision variables are done ensuring that the restrictions (2.1)–(2.22) are kept. In the case of infeasible values, new random values are calculated.

3.5 Recombination

For performing the recombination of solutions, all offspring entities are randomly grouped into pairs. For each such pair of solutions, say a and b, perform a recombination of data with probability p_{reco1}. If a recombination is going to be performed, then for each item $i, i \in \{1, ..., n\}$, with a probability of p_{reco2} the assigned authors, inspectors, testers, testing times, and priorities of tasks are exchanged. This always leads to new feasible solutions.

3.6 Evaluation

In contrast to many other applications of evolutionary algorithms, the considered SD scheduling software requires complex procedures for the evaluation of an alternative (i.e. the calculation of the objective values) specified by data as in (2.23). While the calculation of the total number of defects, $td(x)$, and the total costs, $tc(x)$, is rather trivial for an alternative x, the calculation of the project duration, $du(x)$, requires the construction of a specific schedule. This proceeding necessitates the consideration of restrictions concerning the precedence of tasks (the sequence of the phases coding – inspection – rework – test – rework) and their preemption (see above).

The high-level procedure for calculating a schedule is as follows: All the tasks of one phase are planned before those of a subsequent phase. So first all coding tasks are scheduled. Then all inspections tasks are planned. It is assumed that inspections should take place as soon as possible after finishing the coding of an item. Since inspection tasks have a higher priority than other tasks it is assumed that they interrupt a coding activity of an inspector which leads a prolongation of this task and a corresponding postponing of the subsequent coding tasks. Rework and test are scheduled after that without allowing interrupts of other tasks.

For the (non-preemptive) scheduling of the tasks of one type, there are two basic approaches implemented. Method 1 is based on observing the given assignment of persons to tasks and scheduling the tasks for one person according to the priorities, *priority_c* for coding and rework, *priority_t* for tests. Method 2 is based on the FCFS logic discussed above. This means that ignoring pre-specified assignments and priorities, tasks are scheduled according in the sequence of their first possible starting times being assigned to the earliest available person.

Computational experiments with these scheduling methods have shown that the MOEA has difficulties in finding solutions being scheduled by method 1 which are better with respect to the project duration compared with a complete FCFS solution. While an FCFS solution works economically by avoiding waiting times, these are a significant problems in the case of pre-speficified assignments and priorities. Here, the MOEA has difficulties in finding good solutions in the high-dimensional search space. On the other hand, a pure FCFS solution may lead to unnecessarily long project durations, for instance, because of starting longsome tasks to late. Trying out combinations of methods 1 and 2 (and other variants of these methods) has shown that using method 1 for scheduling coding and rework and method 2 for testing leads to superior results. So the comparably long lasting coding tasks in the beginning are scheduled by optimized assignments and priorities while the later testing tasks are scheduled in an FCFS fashion which allows the filling of waiting time gaps. This concept of constructing a schedule has been employed for the numerical results described in Section 4.

3.7 Selection

The selection step of the MOEA is the only one which requires a special consideration of the multiobjective nature of the optimization problem. For ordinary, scalar optimization problems the objective value of each alternative is used for evaluating its fitness and for determining whether or in which way an alternative contributes to the subsequent generation. For instance, in canonical genetic algorithms, the probability for an alternative to reproduce is proportional to its fitness and in evolution strategies, only the best alternatives are selected as parents for the next generation (elitist selection).

For multiobjective optimization problems, several criteria are to be considered for judging an alternative's fitness. A simple traditional approach to this problem is to find some mapping of the q criteria to a single one. This can, for instance, be done by weighting the objective values or applying a different kind of scalarization to them. A common disadvantage to this approach is that it does not lead to a representative calculation of efficient solutions. Instead, solutions may concentrate in a specific region of the efficient set (genetic drift). Especially, in many cases not all efficient solutions are solutions to the scalar substitute problem (Fonseca and Fleming (1993, 1995)).

Therefore, various approaches have been developed for a more sophisticated multiobjective selection. One of them is the straightforward idea just to use information included in the dominance (Pareto) relation. For instance, the dominance grade (see Hanne (1999, 2001b)) of an alternative $a \in A$ is defined by the number of alternatives which dominate it, i.e.:

$$domgrade(a) := |\{b \in M^t \cup N^t : f(b) \geq f(a)\}|. \tag{3.5}$$

If several alternatives have the same dominance grade, those from the parent population are preferred to ensure certain conservative properties required for the convergence analysis of the MOEA (see Hanne (1999)). It may, however, be the case that other selection rules not satisfying these properties show a faster progress towards the efficient frontier. These issues are still open questions in the research of MOEAs

4 Results

4.1 Test Problems and Settings of the MOEA

For performing numerical tests we have implemented the above MOEA and procedures related to the handling of SD projects within MATLAB.

For testing the evolutionary algorithm, it was necessary to generate test problems. The following technical parameters with respect to problem size etc. have been chosen:

1. number of items: $n = 100$
2. number of staff members: $m = 20$
3. maximum coding productivity: $mcp = 25$ [loc/h]
4. minimum defect density: $mdd = 0.02$ [defects/loc]
5. maximum inspection productivity: $mip = 175$ [loc/h]
6. inspection technique factor: $itf = 0.45$
7. test intensity: $ti = 0.05$
8. defect find rate: $dfr = 0.1$
9. rework defects factor $rdf = 0.1$
10. average defect size: $ads = 8$ [loc]
11. unit costs: $c = 150$ [EUR/h]

Item and person attributes were initialized with random values for defining a test problem instance. For the skill attributes, a normal distribution with an expected value 0.5 and a variance of 0.1 is assumed (but ensuring that the values are in $[0, 1]$). This means that the person on the average reach 50 % of the optimum skill values. For the item size, a lognormal distribution with expected value 300 [loc] and variance 120 is applied. For the item complexity, a normal distribution with expected value 1 and variance 0.1 is assumed.

For the applied evolutionary algorithm, the following parameters have been chosen:

1. no. of generations: $t_{max} = 1000$
2. population size (no. of parent solutions): $\mu = 30$
3. no. of offspring solutions: $\lambda = 30$
4. strategy type = + (consider parents and offspring for selection)
5. mutation probability: $p_{mut} = 0.15$
6. recombination probabilities: $p_{reco1} = 0.45$
7. $p_{reco2} = 0.15$

The above probability values for the MOEA are determined by choosing the best parameters from a series of systematic experiments based on varying them over an interval in equidistant steps. Altogether, 74 runs of the MOEA have been performed for finding good parameter values. As a criterion for judging the performance of an MOEA the average relative improvement (compared with respect to the FCFS solution) for the maximum improvement (over the population) in the 3 objective values and for 3 stochastic repetitions of the MOEA run have been chosen. Because of running time reasons, for these experiments a smaller population size ($\mu = 10, \lambda = 10$) and a smaller number of generations $t_{max} = 20$.) than above have been used. Another approach for determining parameter values for an EA based on the idea of applying another (meta) EA is outlined in Hanne (2001a). A more refined analysis of these parameter values did not seem to be necessary since their effect on the MOEA was not that high according to Tab. 1. Thus, the MOEA works rather robust with respect to these parameters.

Table 1: Some sorted results from the systematic variation of MOEA control parameters.

p_{mut}	p_{reco}	p_{reco2}	*avg. rel. improvement*
0.15	0.45	0.15	8.30
0.25	0.05	0.05	8.25
0.15	0.25	0.45	8.16
0.15	0.15	0.35	7.94
0.05	0.25	0.05	7.82
0.15	0.35	0.15	7.76
0.05	0.45	0.35	7.76
0.25	0.35	0.45	7.53
0.25	0.35	0.35	7.36
0.05	0.45	0.25	7.32

4.2 Numerical Results of the MOEA

In Fig. 2-7 the basic results of applying an MOEA with the above properties to a given test problem are shown. In Fig. 2-4, the results with respect to one of the 3 objective functions are shown. The distributions of respective objective values within the populations is visualized for some of the generations by using box plots. Especially, the box plots show the maximum, median, and minimum values. In Fig. 5-7, for the populations of some selected generations the values for 2 objective functions are represented in the 2-dimensional space for each combination of 2 objectives.

The box plots show that the most significant improvements with respect to the best values for the objectives costs and duration take place within the first 200 generations of the MOEA (Fig. 2-3). With respect to the number of defects, there are enhancements until about generation 500. But even after that generation, there is no steady state of the populations. For instance, worst and median objective values for the duration can be improved without impairing the other objectives. In general, the bandwidth of objective values does not decrease beyond a specific level during the evolution. This reflects the fact that the objectives are conflicting. Therefore, an approximation of the efficient set consists of a diverse set of solutions.

This results becomes also evident by considering the 2-dimensional projections of the populations for several generations (Fig. 5-7). As can be seen there

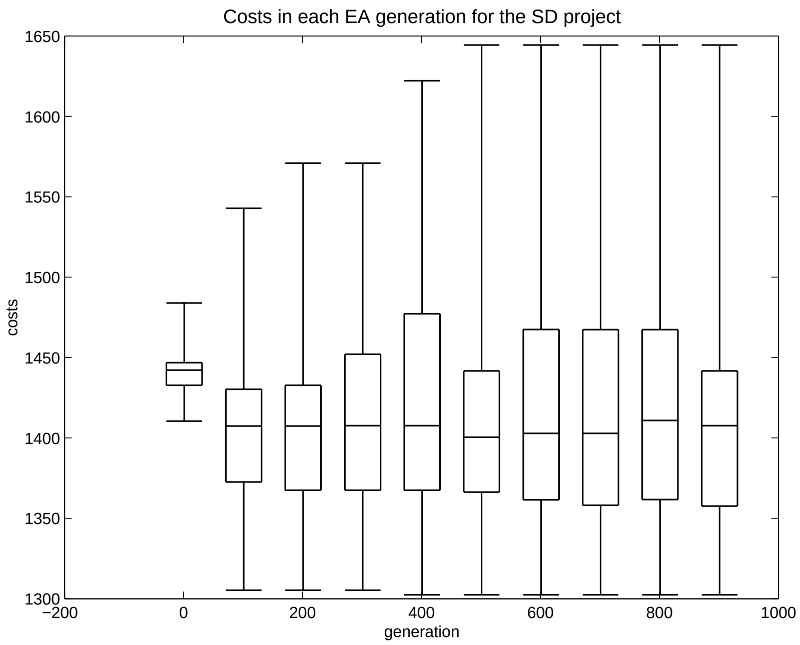

Figure 2: Costs of solutions depending on the generation no.

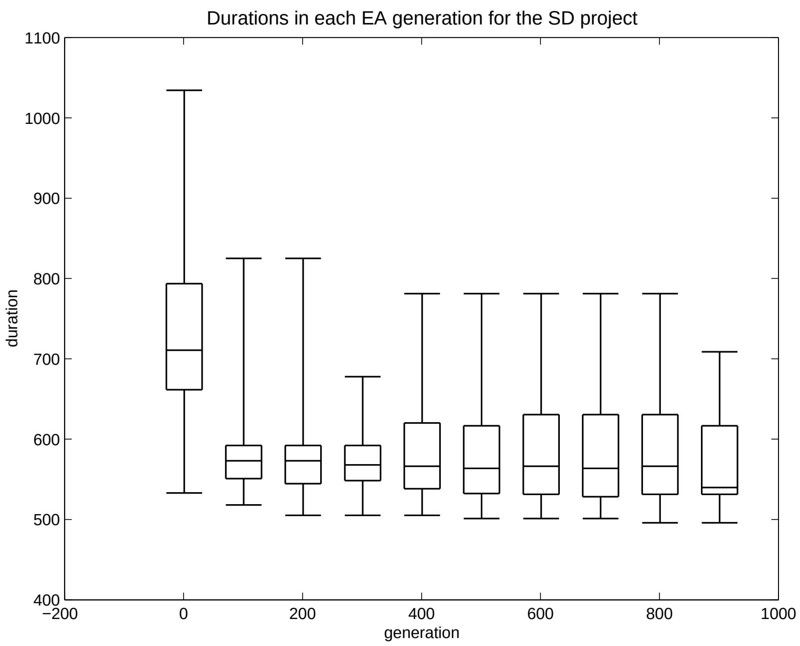

Figure 3: Duration (makespan) of solutions depending on the generation no.

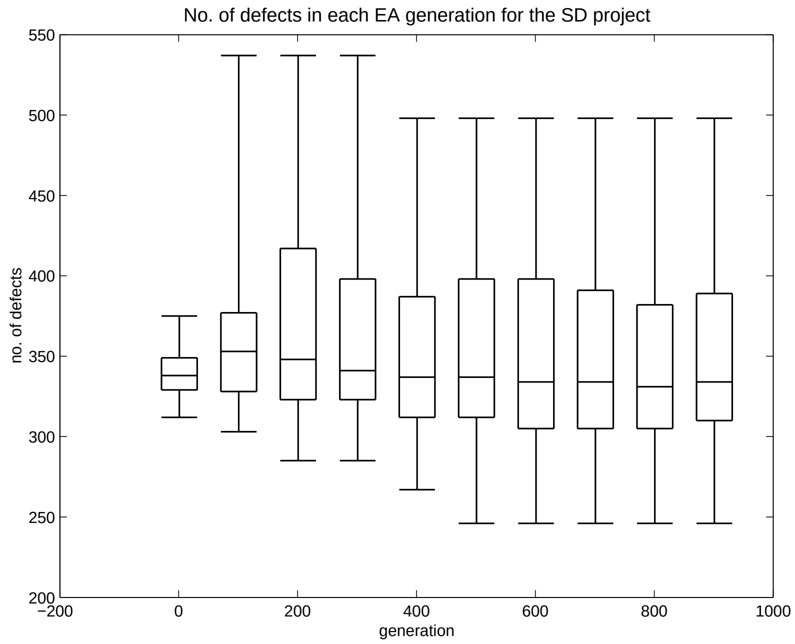

Figure 4: Defects of solutions depending on the generation no.

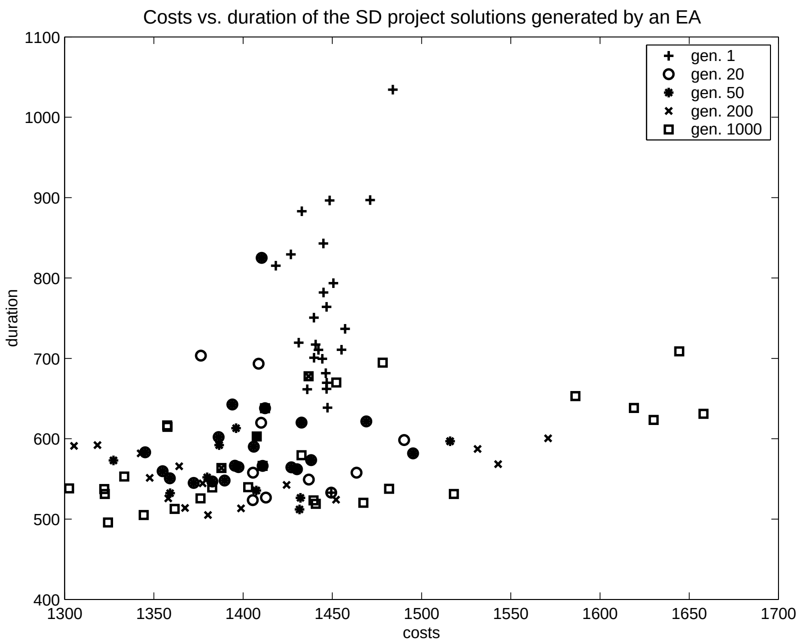

Figure 5: Costs and durations in solutions of several generations

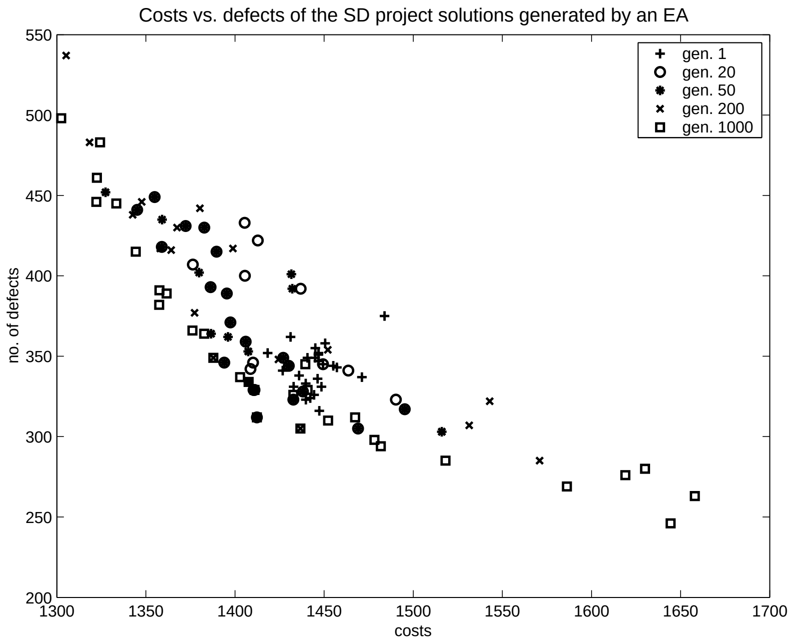

Figure 6: Costs and defects in solutions of several generations

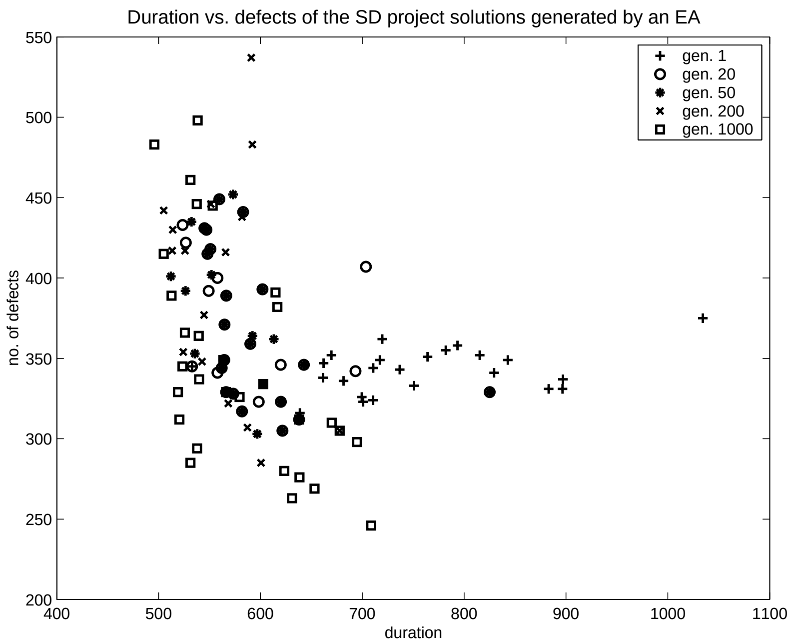

Figure 7: Durations and defects in solutions of several generations

is a continuing progress towards the minimization of the objectives and the diversity of the solutions. For instance, considering the population of generation 1000 in Fig. 5, there are several solutions which are better with respect to the duration and the costs although there is no significant progress with respect to the best values in these objectives. Fig. 6 and 7 show for generation 1000 significant progress in the no. of defects (compared with generation 200) leading to a more diverse population. For some part, this is only possible by decreasing other objective values, e.g. by allowing higher costs. Altogether, a more diverse population provides a better fundament for decision making. Of course, it is always possible (if desired) to decrease this scope, e.g. by applying aspiration levels for some or all of the objectives. On the other hand, it is possible to get a denser representation of the efficient set by increasing the population size which, however, increases to computational effort.

Even for a population size of 30 and an evolution of 1000 generations, the computational requirements of the MATLAB code are quite high. After performing some improvements of the algorithm by profiling it, the running times are still about 6 hours on an 850MHz computer for a 1000 generation MOEA with the above parameters. About 90% of the running time is required for evaluating the fitness function, i.e. calculating project schedules. An analysis of the MATLAB code has shown that major parts of the running time are used for operations which can be significantly sped up by using more specific data structures. Therefore, porting the code to C/C++ and replacing inefficient data structures will be an issue of our future work.

In Tab. 2, results from 10 stochastic repetitions of the MOEA with a given problem instance are shown. The average, minimum, and maximum percental improvements (rows of the table) in each criterion, and for the unweighted average of all criteria (columns of the table) are listed. The results indicate a sufficient robustness of the MOEA for producing improved solutions.

Table 2: Results for the MOEA compared with an FCFS solution.

	td	du	tc	avg
avg	7.13	6.87	10.87	8.29
min	4.98	5.30	5.99	6.47
max	9.15	8.27	20.36	11.04

5 Summary and Conclusions

In this paper, we have presented a novel model of the software development process comprising the phases coding, inspection, test, and rework. For this model, originally developed as an discrete-event simulation model, there are various variables to be fixed corresponding to process parameters, task assignment, and scheduling. With respect to the usually important aspects quality, costs, and projects duration, we have formulated the model as a multiobjective optimization problem. For solving it, an evolutionary algorithm has been designed based in part on some additional scheduling heuristics. The application of the algorithm to test instances of the problem has shown significant improvement with respect to all of the objectives compared to a first-come first-serve solution implicitly used within the original simulation model. The populations generated by the MOEA are broadly distributed with respect to the approximation of the efficient set such that a decision maker may revert to clearly distinguishable alternatives for planning a software development project.

For the future development of our basic model, a number of extensions are planned. On the one hand, the behavioural model of the developers is going to be refined, especially by considering human effects such as learning or fatigue. On the other hand, we aim at a better consideration of the stochastic nature of SD processes. To some extend, these extensions are already considered in the discrete-event simulation model but not in the optimization model for keeping it simple.

Up to now, the optimization model is working as a stand-alone tool. This will be changed by coupling it with the simulation software such that solutions calculated by the optimization model may serve as solutions to be used for the simulation model. In this way, the inefficient FCFS solutions can be replaced by better ones.

Both the discrete-event simulation model as well as the optimization model are going to be validated and/or adapted to a specific industrial setting by the usage of real-life data on processes in software development. Moreover, it is planned to equip the model with a user-friendly interface to facilitate its application into practice.

6 Acknowledgements

The authors gratefully acknowledge the support of this research done in connection with the SEV project and the ProSim project by the German Bundesministerium für Bildung und Forschung (SEV) and the Stiftung Rheinland-Pfalz für Innovation (ProSim, project no.: 559).

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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 Uncapacita*ted 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 Î 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 cannot 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)

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