MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 2/1991

Combinatorial Optimization

13.01. bis 19.01.1991

Die Tagung fand unter Leitung der Professoren Rainer E. Burkard (Technische Universität Graz) und Martin Grötschel (Universität Augsburg) statt.

Auf der Tagung waren 57 Teilnehmer aus 12 Ländern zugegen, die in 44 Vorträgen über neueste Forschungsergebnisse aus dem Bereich der Kombinatorischen Optimierung berichteten. Die Vorträge deckten ein breites Spektrum der Theorie, der Algorithmik und der Anwendungen der Kombinatorischen Optimierung ab. Neben den vier Vortragssitzungen, die täglich stattfanden, präsentierten acht Teilnehmer am Abend die von ihnen entwickelte Software. Computer für diese Softwaredemonstrationen wurden von den Teilnehmern nach Oberwolfach mitgebracht. Zum Teil wurde Software zur Lösung großer Praxisprobleme vorgeführt; ein Teil der Software hat Lehrcharakter und dient dem Einsatz in der Ausbildung von Studenten in algorithmischer diskreter Mathematik. Diese Demonstrationen fanden bei allen Teilnehmern großen Anklang.

Ein kleiner mathematischer Wettbewerb hat die Teilnehmer zu intensiver Arbeit in den Pausen herausgefordert. Die Aufgabe bestand darin, die kürzeste Rundreise für eine Bohrmaschine zu suchen, die 159 Löcher zu bohren hat. Von zwei Teilnehmern wurde in Teamarbeit (per Hand) erstaunlicherweise eine optimale Lösung dieses Travelling-Salesman-Problems gefunden (siehe Bild auf Seite 2). Insgesamt wurden überraschend gute Lösungen manuell bestimmt. Offensichtlich waren Experten am Werk! Die besten Lösungen wurden mit einem Travelling-Salesman-T-Shirt belohnt. Diese Preise wurden vom Center of Research in Parallel Computing, Rice University, Houston, Texas, gestiftet.

Die bewährte Konzeption des Hauses ermöglichte es allen anwesenden Wissenschaftlern, die vorgetragenen Gedanken in kleinen Arbeitsgruppen zu vertiefen, gegenseitig neue Ideen auszutauschen, sowie sich in geselliger Runde am Abend näher zu kommen. Damit konnten nicht nur die wissenschaftlichen Kontakte vertieft, sondern auch persönliche Beziehungen

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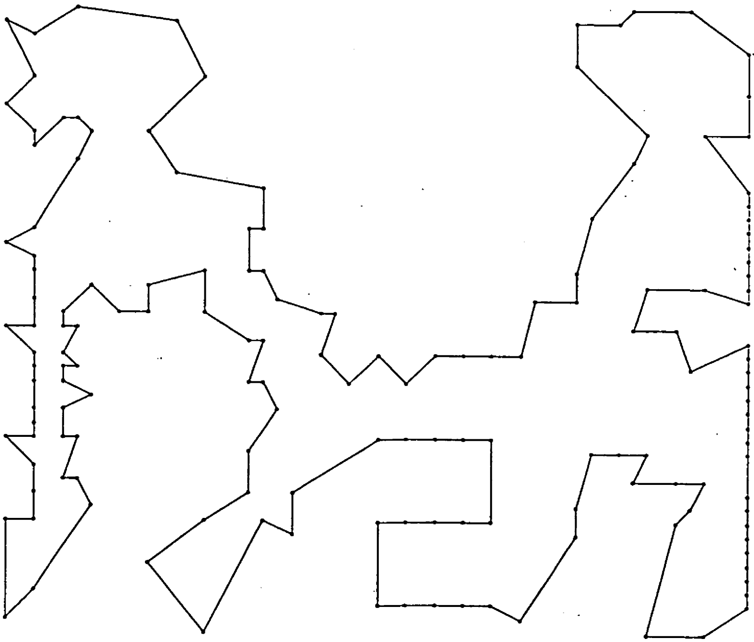
aufgebaut und gefestigt werden. Das Institut bot für alle Teilnehmer einen idealen Rahmen, um in freundschaftlichem Miteinander Forschung betreiben zu können.

Die Veranstalter sowie die Teilnehmer danken dem Haus und insbesondere dem Direktor des Instituts, Herrn Professor Barner, für die freundliche Aufnahme und hervorragende Betreuung während der Tagung.



Die folgenden Vortragszusammenfassungen geben einen Überblick über die in dieser Tagung behandelten Themen.

Vortragsauszüge

E. Balas

The traveling salesman problem with precedence constraints: some polyhedral results

In the TSP with precedence constraints the salesman has to visit certain cities before others. The problem can be formulated on a directed or undirected graph. In both versions, the model has wide industrial applications. We introduce several new classes of valid inequalities, establish the dimension of the polyhedron, and give conditions for some of the inequalities to be facet defining. The talk is based on joint work (in progress) with Matteo Fischetti and Bill Pulleyblank.

R. E. Bixby

The max-cut problem

Given a graph $G = (V, E)$ and a weight function $w \in \mathbf{R}^E$, the associated max-cut problem is to compute $max\{w(\delta(X)) : X \subseteq V\}$ where $\delta(X) = \{uv \in E : u \in X, v \notin X\}$. We present an algorithm for that problem based on an idea of F. Barahona. Computational results are given for the case when G is a toroidal grid with one additional vertex joined to all other vertices. The main idea of the algorithm is that for any cut K of G, if we define $\overline{w}_e = w_e$ for $e \notin K$ and $\overline{w}_e = -w_e$ for $e \in K$, then K is a max cut w. r. t. $w \iff \emptyset$ is a max cut w. r. t. $\overline{w}$. This observation transforms the given problem to one on a cone and simplifies greatly separation. The use of the correct initial LP formulation and a good primal heuristic are essential to the computational results. Problems on grids of size up to 70×70 are solved. This is joint work with S. Saigal.

K. H. Borgwardt

Saving effects in enumerative methods for solving random knapsack problems caused by dominance

In a usual knapsack problem, n items $O_1, \ldots, O_n$ are given with weights $a_1, \ldots, a_n$ and with values $c_1, \ldots, c_n$. We have to determine a subset of $\{O_1, \ldots, O_n\}$ such that the sum of weights of this subset does not exceed a capacity b and that - under this condition - the sum of values becomes minimal. It is clear that an optimal subset cannot contain an item O_i as long as a better O_j (with $a_j > a_i$ and $c_i < c_j$) is left out. This property could be exploited in the design of a simple enumeration method, where only such inversion-free packages are checked for feasibility and optimality. The crucial figure for the complexity of this method is the number of inversion-free packages. It is known that in case of complete anti-isotonity the number becomes $n+1$. We try to parametrize this observation in a stochastic model where $\mu \in (0, 1)$ describes the likelihood for the appearence of inversions in random problems. For a certain distribution of the permutations between $a-$ and $c-$ ranking we are successful in deriving $E_n(\mu)$, the expected number of inversion-free packages, for every

$\mu \in (0,1)$. This delivers also the expected complexity of our enumeration method as a function of μ.

R. P. Brucker

The complexity of one machine batching problems

Batching problems are combinations of sequencing and partitioning problems. For each job sequence JS there is a partition of JS into batches with optimal value $opt(JS)$ and one has to find a job sequence which minimizes this optimal value. We show that in many situations $opt(JS)$ is the solution of a shortest path problem in some network. An algorithm solving this special path problem in linear time with respect to the number of vertices is presented. Using this algorithm some new batching results are derived. Furthermore, it is shown that most of the batching problems which are known to be polynomially solvable turn into $\mathcal{NP}$-hard problems when modified slightly.

R. E. Burkard

Discrete optimization with a two-dimensional reverse convex constraint

In this joint work with R. T. Thanh (Hanoi) and W. Oettli (Mannheim) we deal with

$$min\{f(x)|\ x \in G \cap \mathbf{Z}^n, T(x) \notin int(D)\}, \qquad (P)$$

where f is lower semicontinuous, G a compact set in $\mathbf{R}^n, T : \mathbf{R}^n \rightarrow \mathbf{R}^2$ continuous and D a convex set in $\mathbf{R}^2$. Let w be a minimum of $f(x)$ on $G \cap \mathbf{Z}^n$. If $T(w) \notin int(D)$, w is an optimal solution. Otherwise the polar set E of $D - T(w)$ is compact and convex and $h(t) := min\{f(x)|\ x \in G \cap \mathbf{Z}^n, \langle t, T(x) - T(w)\rangle \geq 1\}$ defined on E is quasiconcave. Thus it can be shown that (P) is equivalent with $min\{h(t)|\ t \in E\}$. We describe a cutting plane approach for the solution of the latter problem. As special case the reverse convex constraint of the form $\langle c, x\rangle \cdot \langle d, x\rangle \leq 1$ will be discussed, where c and d are two linearly independant vectors of $\mathbf{R}^n_+$.

W. Cook

Implementing the Blossom algorithm

We describe a new implementation of Edmond's blossom algorithm for computing minimum cost perfect matchings. Combining this with specialized pricing techniques, we obtain a method for large-scale graphs. We report on the solution of a set of geometric test problems (complete graphs, described as points in the plane), the largest having 202888 nodes. This talk is based on joint work with David Applegate.

G. Cornuejols
Balanced 0/1- matrices

A 0/1- matrix is balanced if it contains no square submatrix of odd order with two ones per row and per column. We propose decomposition results with the goal of getting a polynomial recognition algorithm for balanced matrices. We introduce the notion of 2-joined bicliques and show how this concept can be used to generalize known results about strongly balanced and totally balanced matrices.

V. G. Deineko
Solvable cases of the traveling salesman problem and heuristics

The well known tree algorithm for the travelling salesman problem (TSP) may be presented as follows: Find a spanning tree T, duplicate each edge in T and find a eulerian cycle Z on the resulting graph. Extract a tour from Z by deleting node repetitions.

An algorithm that allows to find an optimal tour among all ones constructed by the tree algorithm is proposed. Connection between the algorithm and well known solvable cases of the TSP are discussed. Computational results are presented.

W. Deuber
A diameter problem for the Lee-metric

Let $\mathbf{Z}_m^n = \{0, \ldots, m-1\}^n$ with the Lee-metric (toroidal metric)

$$d(x', y') = \sum \min\{| x_i - y_i |, m- | x_i - y_i |\}.$$

The problem of finding sets $A \subset \mathbf{Z}_m^n$ of maximal cardinality and given diameter d is discussed. Results were obtained by Deuber and Koppenrade as well as Bollobas and Leader: If miseven then balls are maximal, but not the unique solutions. For m, d odd balls are not maximal.

J. Edmonds
Convex Combinations

We give a practical polynomial time reduction of a general b-matching problem to one small 1-matching problem and one small min cost flow problem. We can also give a corresponding graphtheoretically interesting reduction of the dual to the duals, but the main point we want to make is the following result: there is a practical polynomial time algorithm using no optimization algorithm other than binary search which, using any oracle for obtaining a well described optimum solution for input consisting of a polyhedral feasibility set from a class $\mathcal{P}$ and any well described linear objective c, will solve the problem of finding a dual optimum solution using facet inducing inequalities for input consisting of a member of $\mathcal{P}$ and a c. Similarly there is a good algorithm, using a separation oracle, for finding, for input x and $P \in \mathcal{P}$, an expression of x by generators of P.

R. Euler

On balanced matrices and the set covering polytope

A 0/1- matrix is said to be balanced if it does not contain any submatrix of odd order with exactly two ones in each row and each column. A well known necessary (but not sufficient) condition for a 0/1- matrix A to be balanced is that the polytope associated with the linear programming relaxation of the set covering problem associated with A has only integral vertices.

In this paper we characterize a class of 0/1- matrices A for which the above condition is also sufficient for A to be balanced. This provides at the same time a new class of facet defining inequalities for the general set covering polytope, where the coefficients can be arbitrary elements in $\{0, 1, \ldots, p\}$, the p being a specified positive integer. Some applications to the K_i-cover problem and K_i-perfect graphs are also discussed. This is joint work with A. R. Mahjoub.

M. Fischetti

Facets of the asymmetric traveling salesman polytope

New results on the facial structure of the Asymmetric Traveling Salesman polytope are presented. These include:

- a new class of facet-inducing inequalities, called SD-inequalities, generalizing several known classes from the literature;

- two simple facet-lifting procedures, called clique-lifting and facet-merging, with examples of application.

B. Fleischmann

Optimizing cyclic schedules in a public transit network

We consider a public urban transit network (e.g. subway, buses, trains) consisting of several intercrossing lines operating according to a cyclic schedule. The departure times of each line within the common cycle are to be determined so as to minimize the total waiting time of the transfer passengers. This problem can be formulated as a mixed integer program (MIP). We present an exact solution method using special cutting planes and standard MIP software as well as a fast heuristic. We report on results for test problems and for a real-life case.

A. Frank

Augmentations problems

A directed graph is called k−edge-connected if every cut contains at least k edges in both directions (or equivalently, by Menger, if for every ordered pair (u, v) of nodes there are k edge disjoint paths from u to v). We want to make a prescribed digraph k-edge-connected by adding a minimum number of edges. What is this minimum?

Theorem: A digraph $G = (V, E)$ can be made k-edge-connected by adding at most r edges if and only if $\sum(k - \gamma(X_i)) \leq r$ and $\sum(k - \delta(X_i)) \leq r$ for every family $\{X_1, X_2, \ldots, X_t\}$ of disjoint non-empty subsets of V where $\gamma(X)$ [resp. $\delta(X)$] denotes the number of edges entering [resp. leaving] X.
Regrettably, the following more general problem is $\mathcal{NP}$−complete even for $k = 1$: Given a digraph $G = (V, E)$ and a subset $I \subset V$, what is the minimum number of new edges to be added to G so that there are k edge-disjoint paths from u to v for every $u, v \in T$.
An analogous prblem can be solved for undirected graphs in the more general case when local edge-connectivity is prescribed for every pair of nodes (where "solution" means a min-max theorem and a polynomial time algorithm).

A. M. H. Gerards

On Tutte's characterization of graphic matroids - a graphic proof

In this paper we present a relatively simple proof of Tutte's characterization of graphic matroids. The proof uses the notion of signed graphs and it is graphic in the sense that it can be presented almost entirely by drawing (signed) graphs.

A. Goldberg

Tight bounds on the number of minimum mean cycle cancellations

We improve the bound on the number of iterations of the minimum mean cycle canceling algorithm for the minimum cost flow problem to $O(\min(nm^2, nm\log(nC))$. We also show an $\Omega(\min(nm^2, nm\log(C))$ lower bound. Our bounds are tight for $C = \Omega(n)$. This is joint work with T. Radzik.

P. Gritzmann

The width of point sets: computation, approximation and some applications

Let S be a subset of some Minkowski space $\mathbf{M}$ - some R^n equipped with a norm - and let $\mathbf{B}$ denots $\mathbf{M}$'s unit ball. The width $w(S)$ of S is the infimum of all positive ρ such that there is a hyperplane H with $S \subset H + \frac{1}{2}\rho\mathbf{B}$. (Hence $\frac{1}{2}w(S)$ is the error of a minimax approximation of S by hyperplanes.)
Motivation for the computation of the width of polytopes (given as the convex hull of a finite point set or as the intersection of finitely many halfspaces) or of convex bodies (given by some oracle) has arisen from problems in mathematical programming, statistics and pattern recognition.
We outline some of these applications, determine the compuational complexity of the width problem for the most relevant norms and study the error of polynomial-time approximations. This is joint work with Victor Klee.

M. Grötschel

Modelling and optimization discrete dynamic systems

The problem area I have in mind arises, for instances, in flexible manufacturing. E. g. , there is a huge complicated (almost) automatic production line that can manufacture, in a certain range, a number of different goods. The mix of goods to be produced varies considerably from day to day. How should the goods be sequenced so that the production can be performed in shortest possible time, in other words, how can one achieve a maximum production level? If, moreover, certain components of the system fail to work (for certain, initially unknown periods of time), how should the system react in order to maintain a reasonable production level. It is not clear how to model such questions realistically. There are competing mathematical approaches. I will outline here combinatorial models and discuss the results of two case studies for complex production systems in electronics industry.

H. Hamacher

Efficient algorithms for some restricted facility location problems in the plane

Frequently, facility location problems in the plane are subject to constraints. We consider as restriction the exclusion of the interior of a convex region, as it is used, for instance, in the assembly of printed circuit boards. We show that the contour line approach which is recommended in the literature to solve these problems can be replaced by some efficient combinatorial algorithms. For several examples of distance functions polynomially bounded procedures are developed.

M. Hartmann

Max balanced flows in oriented matroids

Let M be a matroid on the ground set E, and let (M, O) be an oriented matroid. A real-valued vector x defined on E is a max-balanced flow for (M, O) if for every signed cocircuit $y \in O^{\perp}$, we have $\max_{e \in Y^+} x_e = \max_{e \in Y^-} x_e$. We extend the addmissibility theorem of Hamacher from regular to general oriented matroids in the case of max-balanced flows, which gives necessary and sufficient conditions for the existence of a max-balanced flow x satisfying $l \leq x \leq u$. We further investigate the semilattice of such flows under the usual coordinate partial order, and obtain structural results for the minimal elements. We also give necessary and sufficient conditions for the existence of such a flow when we are allowed to reverse the signs on a subset $F \subseteq E$. The proofs of both this result and the admissibility theorem are constructive, and yield polynomial algorithms in case (M, O) is coordinatized by a rational matrix A. In this setting, we describe a polynomial algorithm which for a given vector w defined on E either finds the unique potential $y = pA$ such that $w + y$ is max-balanced or certificates that (M, O) has no max-balanced flow.

W. Hochstättler

A lattice theoretical characterization of oriented matroids

Let L be the lattice of the signed cocircuit span of an oriented matroid. If we map the cocircuits in the complements of their support, we derive a cover-preserving, order-reversing surjection $\Phi : L \to \mathrm{L}$ onto the geometric lattice of the underlying (unoriented) matroid. We give two sufficient conditions for such a map to come from the lattice of an oriented matroid.

P. Kleinschmidt

A strongly polynomial algorithm for the transportation problem

Balinski's signature method for the assignment problem is a dual algorithm which is guided by the deficit and surplus of the target nodes in a flow on a dual feasible tree.

I will present a strongly polynomial extension of that algorithm for the transportation problem. The complexity proof uses a scaling approach similar to one found by Orlin. This is joint work with H. Schannath.

M. Laurent

The cut cone: On the role of triangle facets

The cut polytope P_n is the convex hull of the incidence vectors of the cuts (i.e. complete bipartite subgraphs) of the complete graph on n nodes. A well known class of facets of P_n arises from the triangle inequalities: $x_{ij} + x_{ik} + x_{jk} \leq 2$ and $x_{ij} - x_{ik} - x_{jk} \leq 0$ for $1 \leq i, j, k \leq n$. Hence, the metric polytope M_n, defined as the solution set of the triangle inequalities, is a relaxation of P_n. We consider several properties of geometric type for P_n, in particular, concerning its position within M_n. Strengthening the known fact that P_n has diameter 1, we show that any set of k cuts, $k \leq \log_2(n)$, satisfying some additional assumption, determines a simplicial face of M_n and thus, also, of P_n. In particular, the collection of low dimension faces of P_n is contained in that of M_n. Among a large subclass of the facets of P_n, the triangle facets are the closest ones to the barycentrum of P_n and we conjecture that this result holds in general. The lattice generated by all even cuts (corresponding to bipartitions of the nodes into sets of even cardinality) is characterized and some additional questions on the links between general facets of P_n and its triangle facets are mentioned. This is joint work with M. Deza and S. Poljak.

J. K. Lenstra

Local search for constrained routing problems

We investigate the adaption of local search algorithms for the traveling salesman problem to satisfy side constraints that occur in real-world distribution situations. In particular, we consider the single-depot pickup-and-deliver problem, which is a TSP with time window, capacity and precedence constraints. Classical arc-exchange methods, applying 2-exchanges and Or-exchanges, can be implemented to handle these constraints

without an increase in their running time order. This does not seem to be the case for the variable-depth search algorithm, which has enough structure to allow us to keep track of the constraints using the available efficient techniques.
Our implementation consists of two phases. The first phase tries to find an initial feasible solution, using variable-depth search with a certain measure of infeasibility as objective function. The second phase applies iterative improvements to this solution, using the proper variable-depth search algorithm. We finally discuss possible refinements of the method.
This is joint work with Lambert van der Bruggen, Martin Savelsbergh and Peter Schuur.

T. M. Libura

Sensitivity analysis for the minimum weight base of a matroid

A number of discrete optimization problems can be formulated as finding a minimum weight base of an appropriate matroid. The presentation adresses some postoptimality analysis questions for this problem. Given the minimum weight base a method of computing elements tolerances, defined as maximum increase and decrease of the weight of each matroid element which preserves the optimality of this base, is described. Some other postoptimality analysis problems, which can be solved when the tolerances of elements are known, are discussed.

T. M. Liebling

Disjoint euclidean paths problem (DEPP)

DEPP consists in finding paths of minimum total length between N given pairs of terminals on the plane that can be made disjoint by a continuous $\epsilon-$deformation or equivalently, given a graph and sites on the plane for its nodes, find a minimum total length embedding that can be made planar by such a deformation. This continuous version of a VLSI routing problem is a combinatorial problem, as its solutions are chain families on the complete rectilinear graph induced by terminal sites and is likely to be $\mathcal{NP}-$ hard. Bounds for the optimal solution are discussed and three types of heuristics are presented. For terminal sites randomly generated on the unit square, the optimal solution is a.s. asymptotically in $\Omega(N\sqrt{2N})$. The heuristics construct the paths sequentially, either using Dijkstra's algorithm on a spanning graph that is appropriately modified during the process to prevent subsequent paths from crossing the ones previously constructed, or wrapping around a spanning walk and then shortcutting useless detours in a given order. All heuristics yield results behaving like $cN\sqrt{2N}$. While Dijkstra type heuristics yield the best results for appropriately chosen order of construction ($c \cong .08$), they are very slow, the wrapping heuristics can be implemented using $O(NlogN)$, resp. $O(N^2)$ time and yield c values 0.16 resp. 0.12. Backfitting does not seem to produce significant improvements. This talk is based on on going work with A. Prodon, F. Margot and L. Stauffer.

L. Lovász

Approximating the stability number and interactive proof systems

If EXPTIME $\neq$ NEXPTIME then there is no polynomial time algorithm to approximate the stability number of a graph with a relative error of $O(2^{\log n^{0.99}})$. This result, joint with V. Feige, S. Goldwasser and S. Safran, is proved using the recent important result of Babai, Fortnow and Lund, asserting that every language in NEXPTIME has 2-prover polynomial time interactive proofs. The main construction associates an (exponential size) graph with every instance of the problem, whose stability number is proportional to the success probability of the provers.

A. Martin

Routing in VLSI-Design by cutting planes

From a graphtheoretical point of view the routing problem in VLSI-Design can be viewed as the problem of packing Steiner-trees in special graphs. We study this problem from a polyhedral point of view and define, for a given instance, a polyhedron P whose vertices are in one to one correspondence to the feasible packings of Steiner-trees for that instance. We describe some classes of valid inequalities for P, which define facets of P if the underlying graph is complete and the terminal sets are disjoint. We also study the separation problem for two of the introduced classes of facets. Preliminary results obtained from a cutting plane algorithm are shown. This is joint work with M. Grötschel and R. Weismantel.

R. H. Möhring

Combinatorial algorithms for evaluating stochastic project networks

This is joint work with R. Müller. We present software and new results for evaluating a project network (= acyclic directed digraph) N whose activities (= edges of N) have random, possibly dependent, processing times with the aim to obtain information about the random shortest project duration PD (= longest path length of N). It is known (Hagström 88) that calculating the distribution function of PD at one point is $\#\mathcal{P}$-complete. This motivates - besides simulation - the construction of stochastic upper and lower bounds for the distribution of PD. We discuss existing approaches, elaborate on their relationship with combinatorial optimization (e. g. modifying N into series-parallel networks, time-cost tradeoff problems, k-longest paths), and demonstrate a software package with these approaches. In theoretical respect, we unify and generalize several known bounds for independent processing times (e. g. Kleindorfer 71, Spalde 76, Dodin 85) by a new minor construction for networks and their path clutters. We also show that the evaluation problem at one point remains weakly $\mathcal{NP}-$hard even for series-parallel networks with discrete processing time distributions, while it becomes polynomial in the number of values of the project duration.

C. Monma

Euclidean minimum spanning tree: topology, stability and embedding

Consider a minimum spanning tree on a fixed set of points S in d-dimensional euclidean space and a variable point x, denoted by $\text{MST}(S,x)$. The key questions we adress are as follows:

(1) How many topologically distinct MST's are possible as x varies? We show a lower bound of $D(n^d)$ and an upper bound of $D(n^{2d})$; For $d = 2$ we show a tight bound of $O(n^2)$.

(2) We compute subdivisions of E^d into maximal cells C, so that for all $x \in C$ $\text{MST}(S,x)$ are topologically equivalent. This requires $O(n^{2d} \log n)$ time; for $d = 2$ it requires $O(n^2 \log n)$ time.

(3) Given a tree T on $S + x$, check if there is a point $p \in E^d$ so that $\text{MST}(S,p) = T$. If so, we construct the optimality zone for T in $O(n\lceil\frac{d+1}{2}\rceil)$ time; for $d = 2$ this requires $O(n \log n)$ time. This zone is made up of the intersection of hulls, their complements and half-spaces.

(4) For $d = 2$, we compute the stability measure of S, which is the largest distance by which points in S can be moved without changing their MST.

(5) We show that any tree T with maximum degree five or less, can be realized as a MST for points embeded in E^2.

This is joint work with S. Suri (Bellcore).

D. Naddef

Heuristics for some real life vehicle routing problems

We describe characteristics of some real life vehicle routing problems. In the case when the number of customers that will be assigned to any vehicle remains small enough for the TSP part of the vehicle routing problem to be easy, we show that Tabu search is a reasonable heuristic to consider. This heuristic, together with a 2-interchange heuristic, is implemented in the software CHROME of which a demonstration will be done.

G. Nemhauser

Trying to make integer programming work: a case study

We present a large-scale distribution problem formulated as a mixed-integer linear program. This model which contains more than 50000 real variables, 8000 0/1-variables and 17000 constraints could not be solved by commercial codes even for a feasible solution. We deformulate the problem in such a way, that the possibility of solving it is greatly enhanced.

W. Pulleyblank

Railway meet/pass planning

The meet/pass problem is to optimally schedule trains travelling in both directions over a segment of track which has sidings located at certain locations. (A siding permits a train to leave the main track and wait for another to pass.) We describe a mathematical formulation of the problem and heuristic methods which produce good solutions. We also discuss some of the practical considerations involved in creating a computer system for the operational version of this problem. This is joint work with Denis Naddef and Bruce Shepherd.

M. Queyranne

A projective approach to travelling salesman polytopes

The Hamiltonian Path approach has recently proved very successful for studying the facial structure of symmetric and asymmetric Travelling Salesman Polytopes (TSP). A Hamiltonian Path Polytope is the convex hull of the characteristic vectors of all Hamiltonian paths (with free endnodes) in the complete graph with n nodes. This polytope is isomorphic to the Travelling Salesman Polytope on $n+1$ nodes, and it is of near-full dimension (full minus one). These properties hold both for the directed and undirected cases. Combined with the greater ease in working with Hamiltonian paths instead of cycles, these properties led to significant advances in identifying new classes of TSP facets; proving general node-cloning and node-lifting results for symmetric TSP facets; and developing composition methods for large classes of TSP facets.

This talk describes the major results obtained by applying this approach to symmetric TSPs, and to symmetric facets of asymmetric TSPs. This is joint work with Y. Wang.

G. Rote

Cluster analysis in the plane and coloring algorithms for graphs of large distances

Given a set of n points in the plane, we want to partition them into $K = 3$ clusters such that the maximum of the k diameters (i.e., the largest distance between points in the same custer) is minimized. The fastest algorithm for this problem that is known so far takes $O(n^5 \log n)$ time. If we want to test whether a 3-clustering with diameter less than a given threshold exists we can draw the graph on the point set, where we join pairs of points whose distance is at least d, and test this graph for 3-colourability. Every 3-clustering with diameter at most d corresponds to a 3-coloring of this "graph of large distances" and vice versa. This leads naturally to investigations regarding this class of graphs, to questions like characterizing them. We investigate 3-colourable graphs that are critical with respect to removal in the class of graphs of large distances and we conjecture that a single "no choice" coloring algorithm can be used to test colorability. This would reduce the complexity of the 3-clustering problem to $O(n^3)$.

G. Ruhe

Intervall scheduling using network flows

A generalization of the Fixed Job Scheduling problem is considered where both the set of machines and the set of jobs are divided into different classes. A Boolean matrix describes which job class may be performed by which machine class.

Two questions are investigated:
(i) For given numbers of machines find a subset of (scheduled) jobs of maximum weight.
(ii) Find a minimum cost combination of machines able to realize all the jobs.
Both questions are equivalently formulated as minimum-cost flow problem with additional constraints and integrality demand. Different solution methods to compute upper and lower bounds are presented and computationally tested. This is joint work with L. Kroon.

A. Schrijver

Tait's flyping conjecture for well-connected links

Let K be an alternating link diagram. We call K well-connected, if it is 4-edge connected and the only 4-edge cuts are the stars. We show that if two links are equivalent (i. e., isotopic) and their diagrams are well-connected, then their diagrams are the same (up to rerouting edges through the unbounded face and up to turning the diagram upside down). This is Tait's flyping conjecture for well-connected links. For general (not necessarily well-connected) links Tait conjectures that one should add a further operation on diagrams: that of flyping.

E. Tardos

Finding approximate packings and coverings

We consider the problem to find $x \in P$ such that $Ax \leq b$ for a well-solved convex set P and a matrix $A \geq 0$. We give a fast polynomial approximation scheme that for a fixed $\epsilon > 0$ either finds $x \in P$ such that $Ax \leq (1+\epsilon)b$ or concludes that the system has no feasible solution. Such a system was known to be solvable in polynomial time e.g. by the ellipsoid method. Our algorithm is not based on a polynomial time LP algorithm and does not use matrix inversions. It is faster if ϵ is large (constant), the optimization over P ist fast and max $(\frac{a_i x}{b_i} : x \in P)$ is small for every row $a_i x \leq b_i$ of $Ax \leq b$. Examples of such problems include the multicommodity flow problem, the LP relaxation of scheduling independent parallel machines and the subtour elimination relaxation of the TSP. The talk is based on joint work with Serge Plotkin and David Shmoys.

G. Tinhofer

Lower bounds for the makespan of a single machine scheduling problem with release dates and postprocessing times

Consider a single machine scheduling problem $(r(i), p(i), q(i) \mid i \in I = \{1, \ldots, n\})$ where each job i has a release date $r(i)$, a processing time $p(i)$ and a postprocessing time $q(i)$. We need a schedule $t(i) \geq r(i), i \in I$, such that the makespan $LV(I) = \max\{t(i) + p(i) + q(i) \mid i \in I\}$ is minimum. For every subset $J \subset I$ there is a corresponding lower bound for the optimal makespan $\min LV(I)$, namely

$$chb(J) = \min\{r(i) \mid i \in J\} + \sum_{i \in J} p(i) + \min\{q(i) \mid i \in J\}.$$

It is known that $maxchb(I) = \max\{chb(J) \mid J \subset I\}$ equals the optimal makespan of the relaxed scheduling problem where job splitting is allowed. Hence, this bound is computable in time $O(n \log n)$. We introduce and discuss a new bound $bound(J) \leq \min LV(I)$ for each $J \subset I$. We show that $maxbound(I) = \max\{bound(J) \mid J \subset I\}$
(a) is uniformly at least as good as $maxchb(I)$
(b) is computable in $O(n^2)$
(c) is a remarkable improvement compared with $maxchb(I)$ for small job numbers.

L. Trotter

Hilbert covers and partitions for polyhedral cones

We discuss several canonical theorems of finite convexity and their discrete analogues, i.e. analogues in the integers. Examples considered are: Minkowski's theorem for polyhedral cones and Gordan's existence result for Hilbert bases; Weyl's theorem on finitely generated cones and the discrete linear analogue provided by homogenous totally dual integral systems and results of Blair-Jeroslaw and Ryan establishing a duality between finitely generated integral monoids and finite families of Chvátal restrictions; Helly's theorem for linear inequalities and its Doignon, Bell-Scarf integral analogue; Radon's theorem on point partitions and its discrete counterpart due to S. Onn; the Carathéodory theorem for cones and integral analogues due to Cook-Fonlupt-Schrijver and Sebö.
The discrete Carathéodory property is implied by the existence of a "Hilbert partition" (cover) of a polyhedral cone by unimodular cones, each with generators drawn from a fixed Hilbert basis. We show, in particular, that the pointed polyhedral cone generated by $a^1, \ldots, a^m \in \mathbf{Z}^n$ has a Hibert partition for the Hilbert basis $\{x \in \mathbf{Z}^n : x = \sum_{i=1}^m \lambda_i a^i; 0 \leq \lambda_i < d^{\log_2(3)}, \forall i\}$, where $d = \max \mid det(a^{i_1}, \ldots, a^{i_n}) \mid$.

K. Truemper

Minimal forbidden subsystems of easily solved logic problems

We define a matrix to be central if it has certain easily recognized properties. Central matrices encode several problem classes of easily solved logic problems such as 2-SAT or renamable Horn systems. In that talk we provide two characterizations of central matrices. One of them is in terms of Boolean minors, and the other one in terms of regions, which are obtained by submatrices taking and replacement of nonzeros by zeros.

D. Wagner

Channel routing in the knock-knee mode

Channel routing is a basic problem in the design of VLSI-circuits and has recieved considerable attention in the past. We consider the two terminal channel routing in the knock-knee mode: Given is a rectilinear grid (channel) and a collection of pairs of terminals (called nets), where the input-terminal lies on the upper boundary of the channel. The layout consists of edge disjoint paths (called wires) through the channel connecting the input- and the exit-terminals. To avoid physical contacts between the wires the edges of the paths are assigned to the different layers such that no two wires share a grid point in the same layer (called wiring). Connections between distinct layers (called vias) are placed on grid points. For the design of algorithms solving the layout, repectively, wiring problem the following criteria are of central importance:
The area of the layout, the length of the wires, the number of layers, the number of vias and the complexity of the algorithm.
We present new algorithms that guarantee provably good or optimal results for these problems.

R. Weismantel

Simultaneous placement in the sea of gates layout style

A VLSI-chip in the sea of gates layout style consists of a regular array of basecells. Any cell to be placed on the chip covers a defined area according to its width and height. The placement problem consists of finding an assignment of the cells to non-overlapping sets of basecells such that certain conditions are met. We present a new hierchical approach to the simultaneous placement by modelling the problem as a quadratic 0/1- optimization problem subject to linear constraints. Since there do not exist provably good algorithms for the solution of the problem, the involved optimization problems are solved by heuristics exploiting the special structure of the data. This is joint work with M. Jünger, A. Martin and G. Reinelt.

D. de Werra

An open shop scheduling problem with resource constraints

For a preemptive open shop scheduling problem with a renewable resource (PROS) a graph-theoretical formulation consists in finding in a bipartite multigraph $G = (P, J, E)$ an edge coloring $(M_1, \ldots, M_q)$ with $| M_i | \leq h_i \quad (i = 1, \ldots, q)$ where $| M_i |$ is the cardinality of matching M_i and $h_1, \ldots, h_q$ are given positive integers. PROS is $\mathcal{NP}-$ complete (even when the maximum degree $\Delta(G)$ is 3). We consider the associated problem (PNOS) where the resource is non renewable; the constraints are $\sum_{p=1}^{i} \mid M_p \mid \leq \sum_{p=1}^{i} h_p \quad (i = 1, \ldots, q)$. $\mathcal{NP}-$completeness of PNOS is shown and polynomially solvable cases are studied (the graph G is a caterpillar; there are at most 4 processors or at most 4 jobs; all nodes in P (or in J) have maximum degree; etc). Cases are studied where the condition $h_1 + \ldots + h_i + \nu_{q-i} \geq \mid E \mid$ is necessary and sufficient (ν_k is the maximum cardinality of a $k-$matching). The talk is based on joint work with J. Blazewicz, F. Glover and E. A. Silver.

H. Wolkowicz

New bounds for the graph partitioning problem

Let $G = (N, E)$ be a given undirected graph. We present several new techniques for partitioning the node set N into k disjoint subsets of specified sizes. These techniques involve eigenvalue bounds and tools from continuous optimization. Comparisons with examples taken from the literature show these techniques to be very successful.

L. Wolsey

A forgotten variant of a convex hull proof technique

Lovász has given a proof of the matching polytope based on the following observations: "Given X and $P = \{x \in \mathbf{R}^n : Ax \leq b\} \supseteq X$, if for all $c \in \mathbf{R}^n$ there exists $i = i(c)$ such that arg $\max_x\{cx : x \in X\} \subseteq \{x : a^i x = b_i\}$, then $P = conv(X)$". We show a couple of examples where existing proofs are simplified significantly, and use it to provide a partial characterization of the facets of a constant batch lot sizing problem arising as a subproblem in a class of network design problems. The latter is joint work with Yves Pochet.

Berichterstatter: A. Martin, R. Weismantel

SOFTWAREDEMONSTRATIONEN

Während der Tagung wurde abends von einigen Teilnehmern Computersoftware vorgeführt. Es handelte sich um selbstentwickelte Codes zur Lösung verschiedener Kombinatorischer Optimierungsprobleme. Einige der Codes wurden für den praktischen Einsatz bei Anwendungen programmiert; andere haben Lehrcharakter. Sie sind aufgrund komfortabler Oberflächen und Graphikmöglichkeiten sehr gut zu Unterrichtszwecken geeignet. Diese abendlichen Softwaredemonstrationen haben bei den Tagungsteilnehmern großen Anklang gefunden, zeigen sie doch, daß große Teile der Theorie bereits in effiziente Software umgesetzt werden. Die folgenden Softwarevorführungen fanden statt:

A. Bachem
Solving vehicle routing problems based on digital road maps — hierarchical shortest path and parallel insertion algorithms

W. J. Cook
The BINKY demo

R. H. Möhring
Combinatorial algorithms for evaluating stochastic project networks

G. Nemhauser
The MINTO show

G. Reinelt
The TSP challenge

G. Rote
Realizing planar graphs by disk packings

K. Truemper
The Leibniz logic programming system

D. Wagner
CRP-Algorithms for the channel routing problem

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