MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 2/1989

Computational Aspects of Combinatorial Optimization

8.1. bis 14.1.1989

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

In 52 Vorträgen berichteten Teilnehmer aus 13 Ländern über neueste Ergebnisse im Zusammenhang mit der numerischen Behandlung von kombinatorischen Optimierungsaufgaben. Mehrere Teilnehmer führten darüber hinaus die von ihnen entwickelte Software am Computer vor, was großen Anklang fand. Neben den vier täglichen Vortragssitzungen und drei abendlichen Software-Demonstrationen gab es zahlreiche informelle Diskussionen und Arbeitsgruppen, die die anregende Atmosphäre des Hauses nutzten, um gegenseitig neue Ideen auszutauschen. Das einmalige Ambiente des Instituts bot wie gewohnt einen idealen Rahmen für den mathematischen Gedankenaustausch, der sich befruchtend für die weitere Forschung in der kombinatorischen Optimierung auswirken wird.

Die Veranstalter wie auch die Teilnehmer dieser Tagung danken dem Haus und insbesondere dem Direktor des Instituts, Herrn Professor Barner, für die freundliche Aufnahme.

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

VORTRAGSAUSZÜGE

Achim Bachem

Visualizing combinatorial algorithms

In this talk we present a software system for visualizing combinatorial algorithms. The idea of the system is to make the data structure as well as the underlying geometrical idea of the algorithms visible to the user and to use (interactively) heuristics as well as algorithms for a relaxation to give approximate solutions to NP-hard problems.
The system includes features such as interactively designing graphs, applying graph operations, and has been developed so far for shortest path, network flow, matching-, node-coloring-, face-coloring-, vehicle-routing-, job-shop-scheduling-, acyclic-subgraph- and chip-design- problems.

Egon Balas

Vertex packing algorithms using subgraphs with polynomial packing time

We discuss a class of branch and bound algorithms for finding a maximum weight clique in an arbitrary graph (a maximum weight vertex packing in the complement graph), whose branching rules guarantee that every subproblem created is solvable in polynomial time. The subproblems are defined on vertex- or edge-maximal triangulated subgraphs, subgraphs with a TR-formative edge-coloring, four-cycle-free subgraphs, subgraphs with a 4CF-formative edge coloring. Computational experience is discussed on graphs with up to 1,000 vertices and 150,000 edges.
The work is joint with J. Xue.

Daniel Bienstock

Generalized max-flow min-cut problems in the plane

Consider a plane graph G with selected vertices s,t; and a collection H of subsets of the plane, called *holes*, each homeomorphic to an open disk. The problem of interest is to compute the minimum number of holes whose removal from the plane disconnects s and t. This is a generalized min-cut problem (one hole for each edge). We show this problem is polynomially solvable, included directed and weighted versions. The combinatorial dual of this problem is a packing problem which generalizes max-flow: find the maximum number of s-t paths no two of which intersect a common hole. We show it is NP-complete to test whether ≥ 2 such paths exist, but that the cut and packing values are of the same order of magnitude.

Robert E. Bixby

The PLEXUS linear programming system

The PLEXUS linear programming system was described. It is simplex based, designed to be portable, usable by a wide range of users, and particularly convenient for use as a collection of subroutines callable by an integer programming application. Computational results were reported showing PLEXUS to be about equally fast with MPSX/370. The code is written in C. The numerical parts of the system were jointly designed with Andy Boyd.

Robert G. Bland

A production planning problem solvable by network flow.

We show how a lot-sizing problem that arises in production scheduling can be solved by a single network flow calculation in a directed graph of small size. The principal tool for recognizing and achieving the transformation is planar graph duality. It is shown that the linear programing dual of a cographic linear programming problem is graphic, and that, although most instances of the lot-sizing problem are not graphic, every instance is cographic.

Karl Heinz Borgwardt

On the quality of Greedy-algorithms for solving the subset-sum problem from a probabilistic point of view

We deal with heuristics for solving the problem: Given $a_1,\dots,a_n \in \mathbb{R}^+$

$$\text{maximize} \quad \sum_{i=1}^{n} a_i x_i$$

$$\text{subject to} \quad \sum_{i=1}^{n} a_i x_i \le b \,, \quad \text{where} \quad x_1,\dots,x_n \in \{0,1\} \,.$$

When such a heuristic yields a feasible combination, then the realized objective may differ (be less) from the optimal value. This "error" is bounded by the "gap", which is defined as the difference between b and the realized value.
Now we assume that $a_1,\dots,a_n,b$ are independent random variables, $a_1,\dots,a_n$ uniformly distributed on $[0,1]$ and b uniformly distributed on $[0,n]$.
Under this stochastic model we obtain information on the distribution and the expected gap (error) by evaluation of convolution-integrals for seven different Greedy-algorithms. Four of them are "on-line" algorithms with special $O(n)$, three require sorting and have speed $O(n \ln n)$.

Peter Brucker

Recent results in job-shop scheduling

It took nearly twentyfive years until Carlier and Perison proved optimality of a solution of a 10x10 job-shop scheduling problem given in a book by Muth and Tompson. To get this result they developped a clever branch and bound algorithm. It will be shown how this method can be combined with the block approach of Grabowski and a geometric method which reduces the problem to a shortest path problem with obstacles. Numerical results for different combinations of these three approaches are presented.

Rainer E. Burkard

Polynomially solvable special cases of bottleneck-TSPs

A bottleneck TSP asks for a tour for which the largest arc is as small as possible. Since this problem is NP-hard, special cases which can be handled by polynomial algorithms are of interest. We discuss two classes of such special cases. The first class concerns TSPs with symmetric cost matrix of circulant structure. Such TSPs can be solved in O(n log n)-time in the bottleneck case. No efficient algorithm for the corresponding sum TSP is known.
The second class contains TSPs the cost matrix of which fulfill special algebraic properties, for example

$$\max \{c_{tu}, c_{vs}, c_{sw}\} \le \max \{c_{ts}, c_{su}, c_{vw}\}$$

$$\text{for all} \quad 1 \le t,u,v < s < w \le n, \quad t \ne u, \quad t \ne v .$$

In this and similar cases there exists an optimal tour which is pyramidal and can therefore be determined in $O(n^2)$ steps.
(Joint work with W. Sandholzer.)

Gerard Cornuéjols and Farid Harche

Polyhedral study of the capacitated vehicle routing problem

Given (i) a road network and travel costs on each link, (ii) a fleet of identical vehicles with given capacity located at a central depot, and (iii) client demands and locations, the capacitated vehicle routing problem is to construct routes for the vehicles in order to meet the client demands at minimum travel cost while satisfying the vehicle capacity requirements. Two versions of the problem arise depending on whether clients can be on several routes or not. We study the associated integer polyhedra, relating them to the graphical traveling salesman polyhedron.

William H. Cunningham

Small TSP polytopes

We introduce a new class of valid inequalities for the symmetric travelling salesman polytope. These "bipartition inequalities" generalize the clique-tree inequalities of Grötschel and Pulleyblank. We also give a complete description of the polytope for six and seven cities. For the latter case, the bipartition inequalities are needed. These results are related to work of R.Z.Norman in the 1950's.
(Joint work with S.C.Boyd.)

Ulrich Derigs

Matching problems with side constraints

We give an outline of a procedure for solving the constrained matching problem (MPS)

(MPS) $\qquad \min \{c'x \mid x \text{ perfect matching}, \ Sx \le t\}$

and present computational results for a set of real-world problems where the additional constraints are so-called "generalized upper-bound"-constraints (GUB). These conditions can be interpreted as follows. Assume the set of edges E to be partitioned into k colors i.e. $E = K_1 \cup \ldots \cup K_k$ and let t_j, $j \doteq 1,\ldots,k$, the maximal allowable number of edges from class K_j , then we get the following problem:

(GUB-MP) $\min \{c'x \mid x \text{ perfect matching}, |X \cap K_j| \le t_j, \ j = 1,\ldots,k\}$.

Our approach for solving MPS resp. GUB-MP runs as follows:

(1) Solve the Lagrange dual/LP-relaxation.
(2) Use pairs of feasible/unfeasible matchings from phase 1 to construct better feasible matchings via a so-called knapsack heuristic.
(3) Close the gap between lower bound from phase 1 and upper bound by constructing the sequence of k-best matchings for the problem

$$\min \{c'x \ \bar{\lambda}(Sx-t) \mid x \text{ perfect matching}\} ,$$

where $\bar{\lambda}$ is the optimal Lagrange multiplier.

Laureano F. Escudero

Combinatorial aspects of production planning for flexible manufacturing systems (FMS).

Consider a FMS which produces parts of several types. The FMS consists of several groups of pooled, identical machines, a material handling system and other resources. A set of models and algorithms is presented which sequences and schedules the input of the parts in the FMS. It also gives the sequence in the execution of the operations for each part type and the processing route and schedule of the operations execution for each part, by considering constraints such as machine availabilities and other resources in the machine groups, the availability of the transport units, etc. A hierarchical set of goals is considered. The combinatorial aspects of the problem are emphasized, computational experience is reported and a real-life problem is described.

Reinhardt Euler

A new class of facet-defining inequalities for asymmetric traveling salesman polytopes.

We describe a class of (locally) facet-defining inequalities, which arises from digraphs whose intersection graphs are (nearly) odd K4's. We use lifting to obtain global such inequalities. Finally, we describe a generalization (which is based on odd CAT's as introduced by Egon Balas).

Gerd Finke

Complementary two-commodity flows: Formulations for TSPs and vehicle routing problems.

We describe several formulations for traveling salesman problems using different dimensions of the describing space, in particular one-, two-, and multicommodity flow versions. Especially the two-commodity formulation provides a very useful model. Extensions to non-dense graphs are possible. Precedence constraints can easily be formulated as linear constraints. Further simple modifications succeed to model multiple traveling salesman problems and vehicle routing problems with general capacities for the vehicles.

Bernhard Fleischmann

Single-machine lot-sizing and scheduling.

We consider the problem of scheduling several products on a single machine so as to meet the known dynamic demand and to minimize the sum of inventory and setup cost. The planning interval is phased into many short periods, e.g. shifts or days, and setups my occur only at the beginning of a period.
We present a branch-and-bound procedure using Lagrangean relaxation for determining both lower bounds and feasible solutions. The relaxed problems are solved by dynamic programming.
Computational results on a PC are reported for various examples from the literature with up to 12 products and 122 periods or 8 products and 423 periods.

Andrew Goldberg

Generalized cost scaling.

We describe a framework for designing minimum-cost flow algorithms based on using the maximum violation of complementary slackness conditions as a measure of quality of a circulation. This framework is based on better understanding of combinatorial structure of the problem and leads to good polynomial-time bounds as well as to strongly polynomial bounds. Namely, we obtain $O(nm \log \frac{n^2}{m} \min \{\log(nC), m \log n\})$ time bound, where n is the number of vertices, m is the number of arcs, and C is the biggest cost in the input problem.

Michael D. Grigoriadis

1. On the efficiency of the Goldberg-Tarjan preflow algorithm: A brief report.

We present results of computational experiments with three fundamentally different algorithms for the maximum flow problem: the steepest edge network simplex method, Dinic's method of blocking flows, and the more recent preflow algorithm of Goldberg and Tarjan. The set of problem instances used for the experiment are those generated by RMFGN (Grigoriadis 86) maximum- flow problem generator, of sizes up to about 150,000 vertices and 850,000 arcs. For these problems the preflow algorithm runs 4 to 15 times faster than the Dinic algorithm (DNS-B, Goldfarb and Grigoriadis 88). The steepest edge simplex algorithm (Goldfarb and Grigoriadis 88) runs faster for problems smaller than 4,000 vertices, but is slower than the other two methods.

2. An $O(n^{1.5} \log n)$-time approximation scheme for matching points in the plane.

The problem is to compute a minimum-weight perfect matching of 2n points in the plane, assuming Euclidean edge weights. It can be solved exactly in $O(\min\{n^3, n^{2.5}(\log n)^4\})$ time. A fully-polynomial approximation scheme runs in $O(n^{1.75}(\log n)^{2.75}\varepsilon^{-2})$ time to produce a matching whose weight is at most $1+\varepsilon$ times the optimal weight. Here we propose a polynomial-time approximation procedure which consists of the following three steps:
1) Compute the Delannay triangulation D of the given points,
2) Compute an optimal perfect path matching of D (an odd-degree spanning

forest F), and
3) traverse F to construct the required perfect matching.
The entire procedure can be implemented to run in $O(n^{1.5}\log n)$ time. It produces perfect matchings of weight at most about three or five times the optimal weight if D is computed in step 1 according to the L_1 or L_2 metrics, respectively. These error bounds are not tight. We present computational experiments for 120,000 instances of 8 to 1024 points uniformly distributed in the unit square. All perfect matchings produced by this procedure had extremely small errors compared to matchings computed by the exact algorithm.

Peter Gritzmann

Computational complexity of norm-maximization.

We discuss the problem of maximizing a norm for real n-space over a polytope that is presented as an intersection of m halfspaces. By work of Mangasarian and Shiau (1986) the maximization problem is known to be NP-hard for the classical p-norms. We establish NP-hardness for a considerably wider class of norms, roughly speaking, the norms for which the unit ball admits a strictly inscribed parallelotope. Further, we show that for p-norms norm-maximization is NP-hard even for parallelotopes. This in turn implies the NP-hardness of various other problems. We give two examples for such applications, one from pseudoboolean programming the other from computational convexity.
(Joint work with V. Klee.)

Martin Grötschel

Design of minimum-cost survivable networks: IP-models and polyhedral investigation.

In this talk we present a general integer linear programming model for the problem of designing minimum-cost survivable networks (introduced in the talk by C.Monma). We relate this model to concepts in graph theory and polyhedral combinatorics. In particular, we consider several interesting special cases of this general model including the minimum spanning tree problem, the Steiner tree problem, and the minimum cost k-edge connected and k-node connected network design problems. We study the integer polyhedra associated with these problems and identify some classes of facets of these polyhedra. We also address the separation problems with respect to these classes of facet-defining inequalities.

Peter L. Hammer

Roof duality revisited.

Together with Endre Boros we have re-examined the 1984 roof duality approach to quadratic 0-1 optimization, which provides a lower bound to the minimum, as well as a polynomial algorithm to decide whether this bound is equal to the minimum. The new results notice the determination of the roof duality bound to that of solving a max-flow problem in a network of O(n) vertices (if n is the number of variables) and establish a stronger "persisting" result (i.e. allow some of the 0-1 variables to be fixed in the optimal solution of the discrete problem to the same values as in an appropriately chosen continuous relaxation of the problem). On this basis very promising computational results are reported and it is conjectured that a constant k (≤ 2) exists so that $\rho \leq f_{min} \leq k\rho$, where ρ is the value of the roof dual of f.

Pierre Hansen

A variable elimination algorithm for bilevel linear programming.

Karla Hoffman

Solving large zero-one integer programming problems on distributed workstations.

Commercial workstations connected by an industry standard Ethernet network have been used to solve large-scale zero-one integer programming problems using a cutting-plane method based on the polyhedral structure of the zero-one polytope. These cutting planes are embedded in a tree-search strategy that uses logical implications, heuristics, reduced-cost fixing and facial cuts to tighten the bounds at every node. The parallel implementation generates a "pool" of facial cuts which are shared by all processors. Adaptive suspension and resumption of search nodes has been implemented. The largest problems are solved with super-linear speedup.

Michael Jünger

Euclidean matching, convex hulls, rural postman: A software demonstration.

We discuss and demonstrate three computer programs implementing the following algorithms:
- An O(n log n) heuristic for Euclidean perfect matching of n points in the Euclidean plane (jointly with W.R.Pulleyblank).
- An O(n) expected time algorithm for determining the convex hull of n uniformly distributed points in the unit circle (jointly with G.Reinelt).
- A rural postman heuristic applied to the problem of plotting marks for real world printed circuit boards (jointly with M.Grötschel and G.Reinelt).

Peter Kleinschmidt

A signature algorithm for the assignment problem and an application in the classification of chromosomes.

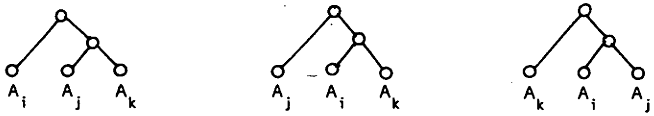
We present a new version of Balinski's signature algorithm for assignment problems which uses some ideas of Balinkski and Paparrizos. The algorithm proceeds by a dual pivoting strategy on forests with a special structure. Some computational experience and an application in the classification of human chromosomes are presented.

Eugene L. Lawler

Two problems in connection with rooted trees.

Problem 1:
A phylogenetic tree is a rooted binary tree where leaves are labelled with

"species" $A_1, A_2, \ldots, A_N$. The leaves of a subtree constitute a "phylum". Suppose, for each triple of species A_i, A_j, A_k, one can perform an experiment to determine which of the three relations holds:



How many experiments must be performed in order to determine the phylogenetic tree for N species? Answer: O(NlogN).

Problem 2:
The structure of a program in an Algol-like language is represented by a rooted tree in which each node represents a procedure. This tree may be augmented by two kinds of arcs:

(1) "blue" arcs extending from a node to one of its ancestors. These arcs represent references to variables.

(2) "red" arcs extending from a node to one of its ancestors, or to a child of one of its ancestors. These arcs represent procedure calls.

The problem is to "flatten" the tree, moving each node as close to the root as possible,while maintaining conditions (1) and (2). This can be done by an algorithm with $O(N+M\alpha(M,N))$ running time, where N is the number of nodes and M is the number of arcs.

Thomas Lengauer

Floor planning and global routing based on circuit partitioning.

We present a method for floor planning, i.e., placement of variable size blocks that are connected by wires. The cost measures to be minimized are area and wiring complexity. The method begins by constructing a cut-tree for the circuit. Subsequent phases process the cut-tree and transform it into a minimum-area floor plan. This floor plan is optimized w.r.t. wiring complexity by incorporating hierarchical routing.
The results presented analyse and extend methods proposed by Otten and others.
The work is joint with R.Müller and J.Heistemann.

Thomas M. Liebling

On partial order preserving injections.

Let $(V_1,<_1)$ and $(V_2,<_2)$ be two finite posets. An injection $f: V_1 \to V_2$ such that if i,j are in V_1 and $i<_1 j$, then $f(i)<_2 f(j)$, is said to be partial order preserving. The question whether such an injection exists is NP-complete. If real weights are attached to $V_1 \times V_2$, the problem of finding a minimum weight partial order preserving injection contains several well known combinatorial optimization problems as special cases. In particular one may cite several variants of machine scheduling problems under precedence constraints, network capacity expansion problems over time, the linear assignment problem, etc.
When $(V_1,<_1)$ is a totally ordered set, a polynomial algorithm solves the optimization problem and it is possible to give a complete linear characterization of the convex hull of the order preserving injections. On

the other hand, the problem remains NP-hard even if $(V_2,<_2)$ is a totally ordered set and $(V_1,<_1)$ is a disjoint union of chains.
Joint work with F.Margot and A.Prodon.

Laszlo Lovasz

Lifting polyhedra to higher dimensions.

Let P be a combinatorially described polytope (e.g. matching or travelling salesman), having an exponential number of facets. It has benn recognized that often more complete linear descriptions can be obtained at the cost of introducing new variables. During this meeting, Lex Schrijver and I discovered that if we allow non-polyhedral (but convex and computationally easy) descriptions of lifted polyhedron, then much larger classes of polyhedra become representable this way and thereby computationally tractable.* The method is to consider a system $Ax \le b$ and associate with it the set P' of matrices Y such that $AY \le b\bar{Y}^T$ and $Y - \bar{Y}'\bar{Y}^T$ is positive semidefinite (where $\bar{Y}$ denotes the diagonal of Y). Then one can optimize any linear objective function over P' and hence also over $P'' = \{\bar{Y}: Y \in P'\}$. P" satisfies $Ax \le b$ and contains all 0-1 solutions of $Ax \le b$. Moreover, if $Ax \le b$ defines the fractional vertex packing polytope of a graph G, then P" satisfies all the clique, odd cycle, and wheel constraints.

Tom L. Magnanti

Capacity expansion in local access telecommunication networks.

Telephone networks typically contain several components: a local area network that connects end users of the system, a switching network that connects a local geographical regim, and a backbone network that carries long distance traffic. We consider a large scale mixed integer program that models capacity expansion in a local area tree network. Using a dynamic programming algorithm to solve a special version of the problem as a subproblem for a Lagrangian relaxation decomposition method, we solve several problems arising in practice: two to optimality and one to within 2.3 % of optimality.
Joint work with A.Balakrishnan and R.Wong.

Kurt Mehlhorn

Randomized incremental construction of Voronoi diagrams.

Abstract Voronoi diagrams (R.Klein) are defined by a family of bisecting curves, one for each pair of sites. The bisecting curve J(p,q) splits the plane into two unbounded domains D(p,q) and D(q,p). The Voronoi region of p is given as $VR(p) = \bigcap_{q \in S-\{p\}} D(p,q)$. Under the assumption that Voronoi regions are connected, that the bisectors are computationally simple and that two bisectors intersect only finitely often it is shown that the abstract Voronoi diagram VD(S) can be constructed in time $O(n \log n)$, $n = |S|$, by a randomized algorithm. This extends work of R.Klein. The algorithm is based on the randomized incremental construction method recently introduced by Clarkson and Shor.
Joint work with St.Meiser and C.O'Dunlaig.

K. Merten

Combinatorial problems with complex VLSI chips in the IC-industry.

The presentation gives an overview about the design methods for VLSI circuits with modern CAD systems. In particular, we deal with place and route problems for very complex chips. On the base of practical examples designed in SIEMENS we discuss combinatorial problems concerning
- channelled gate arrays,
- channelless gate arrays,
- standard cell designs,
- macro cell designs

and appropriate solutions implemented in our own CAD software.

Rolf H. Möhring

On a class of perfect graphs and a channel routing problem.

We present a polynomial algorithm that solves a problem due to Dagan, Golumbic and Pinter [1988] about the complexity of recognizing trapezoid graphs. These graphs constitute a class of perfect graphs that naturally arise in VLSI-channel routing problems. The algorithm exploits the facts that trapezoid graphs are the incomparability graphs of partial orders of interval dimension two (i.e. the intersection of two interval orders) and that interval dimension is a comparability invariant (i.e. the same for all partial orders with the same comparability graph). It thus sufficies to test if a transitive orientation of the complement of the given graph (if it exists) has interval dimension two. This is done via substitution decomposition and PQ-trees.
Joint work with M.Habib.

Clyde L. Monma

Minimum cost survivable network design: Practical applications.

In this talk were describe certain practical problems arising in the design of fiber optic communication networks. These problems can be modelled as network design problems with costs on links subject to connectivity requirement. Tools based on graphics, user interaction and fast heuristics were used to problem design superior to manual approach currently used by network planners. Work on a polyhedral approach to these problems and computational results are also presented at this conference.

George L. Nemhauser

Solving an NP-hard edge coloring problem by linear programming.

We consider the problem of coloring the edges of a graph with a minimum number of colors so that any pair of edges incident to a common node have different colors. We formulate the edge coloring problem as a set covering problem of minimizing the number of matchings to cover the edges. The linear programming relaxation of this formulation can be solved efficiently since the pricing problem is a weighted matching problem. If the value of the LP solution is greater than Δ (the largest degree) then, by Vizing's theorem, $\Delta+1$ colors are required. When the value of the LP solution is Δ and the solution is fractional, we augment the LP with odd circuit cuts, which say that every odd circuit must be covered by at least 3 matchings. For 3-regular graphs we show how to solve the separation problem for the odd circuit constraints efficiently and we present computational results for random and difficult graphs. The time consuming part of the algorithm involves the solution of a constrained matching problem to accomplish the pricing.

Hartmut Noltemeier

Voronoi-trees and clustering problems.

A new data-structure - Voronoi trees - is introduced, which represents proximity properties in a general framework very efficiently. Structural properties are analyzed. Applications to the layout of flexible manufactoring systems as well as to some pattern recognition and image understanding problems are demonstrated and experimental results are reported.

Manfred W. Padberg

The Boolean quadratic polytope: Some characteristics, facets and relatives.

We study unconstrained quadratic zero-one programming problems having n variables from a polyhedral point of view by considering the Boolean quadratic polytope QP^n in $n(n+1)/2$ dimensions that results from the linearization of the quadratic form. We show that QP^n has a diameter of one, descriptively identify three families of facets of QP^n and show that QP^n is symmetric in the sense that all facets of QP^n can be obtained from those that contain the origin by way of a mapping. The naive linear programming relaxation QP^n_{LP} of QP^n is shown to possess the Trubin-property and its extreme points are shown to be $\{0,1/2,1\}$-valued. Furthermore, $O(n^3)$ facet-defining inequalities of QP^n suffice to cut off all fractional vertices of QP^n_{LP} whereas the family described by us has at least $O(3^n)$ members. Polynomially solvable problem instances are discussed and complete polyhedral characterization is given for the case where the underlying graph is series-parallel. The relationship to vertex-packing in graphs is discussed as well.

William R. Pulleyblank

A precedence constrained travelling salesman problem and helicopter routing.

The following version of the travelling salesman problem arises when scheduling helicopters between drilling platforms, in an off-shore field. We have certain platforms which must be visited and pickups and deliveries which must be made between certain platforms. We wish to find a route which satisfies these requirements and has minimum length.
We discuss the problem, describe a heuristic method which proves to be very good in practise, and present an integer programming formulation suitable for use in a cutting plane code.
Joint work with E.Balas and M.Tomlin.

Gerhard Reinelt

Fast heuristics for the symmetric traveling salesman problem.

Very often in practice it is the case that approximate solutions for large scale traveling salesman problems have to be computed very fast. In such cases the usually used heuristics cannot be applied directly because they are too CPU time consuming. We present several methods exploiting underlying geometric structure for constructing sparse subgraphs and show how heuristics for computation of upper and lower bounds can be adopted to run efficiently. We present computational results and give a software demonstration.

Franz Rendl

A new lower bound for the quadratic assignment problem (QAP).

The QAP is formulated as a matrix optimization problem on the set of permutation matrices. We relax the domain by minimizing over the intersection of orthogonal matrices with the set of matrices having row and column sums equal one. The corresponding relaxed problem can be solved by a spectral decomposition of the input matrices (which are assumed to be symmetric). Preliminary numerical results suggest that this bound is better than existing ones.
Joint work with H.Wolkowicz.

Celso Ribeiro

Simulated annealing and tabu search approaches to hyperbolic sum and clique partitioning.

We present computational results concerning the use of these heuristics in the resolution of two combinatorial optimization problems: hyperbolic sum and clique partitioning. The motivation for studying the hyperbolic sum problem in 0-1 variables comes from its application in the formulation of a query optimization problem in information retrival from classical data bases. The clique partitioning problem has some applications, e.g. in the aggregation of binary relations. The computational results illustrate the effectiveness of both approaches, in terms of the quality of the solution they obtain. Some conclusions are also presented concerning computational terms.
Joint work with P.Hansen, M.Poggi, J.P.Barthelemy.

Giovanni Rinaldi

Facets of the symmetric traveling salesman polytope.

We survey some results of a joint work with D.Naddef on the polyhedral structure of the symmetric traveling salesman polytope (STSP) and of the graphical traveling salesman polyhedron (GTSP). We use GTSP as a relaxation of STSP and describe some strong interconnections between the two polyhedrons. These interconnections are exploited to give a canonical form for the inequalities inducing facets of STSP and a technique to prove when an inequality induces a facet of STSP. The path inequalities are proved to be facet inducing and the crown inequalities are defined and proved to be facet inducing. The Path and the crown inequalities as well as the inequality defined by the Peterson graph are used as building blocks to construct more complex inequalities, by means of lifting and composition theorems. The family of inequalities obtained in this way contains practically all inequalities facet inducing for STSP known to date.

Günter Rothe

Speeding up parametric min-cost flow algorithms.

We consider the minimum cost flow problem, where the costs are linear functions of one parameter. The optimal cost curve is to be determined for a given interval of parameter values. The usual parametric simplex algorithm proceeds from left to right and determines critical values of the parameter by examining *all* arcs after each pivot. We can avoid the examination of the complete set of arcs by putting arcs which currently have high costs in "buckets" and examining them only some time later.
The results of some preliminary computational experiments are encouraging.

Catherine Roucairol

A supercomputer algorithm for the 0-1 multiknapsack problem.

The characteristics of parallel machines (vectorization, multiprocessing) are exploited in order to solve the 0-1 multiknapsack problem:

- in a first phase, a lot of tests are performed in parallel in order to reduce the size of the problem (fixation of variables, elimination of constraints),
- in a second phase, a parallel branch and bound algorithm allows to get an optimal solution.

Our parallel algorithm has been implemented on the asynchronous multiprocessor machine CRAY 2. Computational results are reported and compared with those obtained in a sequential approach.
Joint work with G.Plateau.

Günther Ruhe

Bicriterial minimum-cost flows: complexity and algorithms

The problem to determine efficient (Pareto-) minimal solutions for the bicriterial minimum-cost flow problem is considered. It is shown that the number of efficient extreme point solutions in the objective space may be exponential.
A subset $S \subset X$ of feasible solutions is called ε-optimal w.r.t. a vector valued function $f: X \to Y \subset \mathbb{R}^k$ if

$$\forall x \in X: \exists z_x \in S: f_k(z_x) \leq (1+\varepsilon) f_k(x); \quad k = 1,\dots,K .$$

For a given accuracy $\varepsilon > 0$, a $O(\varepsilon^1/\varepsilon \cdot T(m,n))$ time approximation algorithm using the lower approximation of the optimal value function is given. Therein, ε^1 is the accuracy at the first iteration, and $T(m,n)$ denotes the complexity to solve the minimum-cost flow problem.
Numerical results on NETGEN-generated examples are presented.

Alexander Schrijver

Routing in graphs.

We describe a polynomial-time algorithm for the following problem arising in the design of VLSI-circuits.
Given: a planar graph G=(V,E), faces $I_1,\ldots,I_p$ of G (inlcluding the unbounded face), and curves $C_1,\ldots,C_h$ in $\mathbb{R}^2\backslash(I_1\cup\ldots\cup I_p)$ with end points on the boundary of $I_1,\ldots,I_p$.
Find: pairwise vertex-disjoint simple paths $P_1,\ldots,P_h$ in G where P_i is homotopic to C_i in the space $\mathbb{R}^2\backslash(I_1\cup\ldots\cup I_p)$, for $i = 1,\ldots,n$.
The algorithm is based on a polynomial-time algorithm for finding an integer solution for a system $Ax \le b$ of linear inequalities, where A is an integer matrix satisfying

$$\sum_{j=1}^{n} |a_{ij}| \le 2 , \quad (i = 1,\ldots,m) .$$

We also describe an extension to finding disjoint trees connecting given sets of points.

David Shmoys

A polynomial approximation scheme for parallel machine scheduling with release and due dates.

We show that for any $\rho > 1$, there exists an algorithm that runs in polynomial time, and compute a schedule of length at most p times the optimum for the following problem: there are m identical machines on which n independent jobs are to be scheduled; each job j may scheduled only after its release time r_j and must be processed before p_j on one of the machines; there is a delivery time ρ_j (that plays the role of the due data) and if a job is completed at time c_j. it is deliverd at $c_j + \rho_j$, the objective is to minimize the maximum delivery time.

Mechthild Stoer

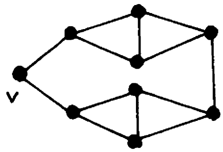
A cutting plane algorithm for the design of minimum cost survivable networks.

We designed a cutting plane algorithm for finding minimum cost "survivable" networks in a sparse graph, "survivable" meaning that the network has to satisfy certain connectivity constraints on the nodes (the maximal connectivity required is 2).
We study some valid inequalities (partition and "2-matching" inequalities) of the polytope associated with these networks. For the partition inequalities we devised a separation heuristic based on the Gomory method.
Problems can be reduced by decomposition if the underlying graph is sparse. Computational experience shows that this cutting plane algorithm provides good lower bounds. In some real world problems the optimum could be attained by adding cuts interactively.

Gottfried Tinhofer

Adjacency-coloring: The smallest partially hard-to-color graph.

Let $G = (V,E)$ be a simple undirected graph. An adjacency-coloring of G is a sequential coloring induced by some ordering $(v_1,\dots,v_n)$ of V for which all the subgraphs $G(\{v_1,\dots,v_i\})$, $1 \le i \le n$, are connected. A graph G is said to be hard-to-color from start-point $v \in V$ if all adjacency-colorings of G with start in v $(=v_1)$ need more than the chromatic number ch(G) of colors. In this context v is called a bad start-point. G is called partially hard-to-color (a phc-graph for short) if there exists at least one bad start-point. G is minimal with respect to this property if there is no phc-graph having less vertices than G.
Our main result is: There is no phc-graph on less than 10 vertices except the graph G in the figure below. This graph has a unique start-point v. Hence, G is the unique minimal phc-graph.



Paolo Toth

Computational results on exact algorithms for large size knapsack type problems.

Algorithms for determining the optimal solution of large size instances of single unidimensional knapsack type problems (0-1 knapsack problem, unbounded knapsack problem, subset-sum problem, change making problem) are considered. The algorithms are based on the definition of an approximate "core problem", its exact solution through effective implicit enumeration methods, the comparison of the corresponding approximate solution value with tight upper bounds, and the attempt to determine the optimal value of all the variables not considered in the core problem through fast reduction procedures. Extensive computational results for different classes of large size randomly generated test problems (considering up to one million variables) are presented.

Leslie E. Trotter

Node-packing problems with integer rounding properties.

We consider an integer programming formulation of the node-packing problem, $\max \{1\cdot x\colon Ax \le w,\ x \ge 0,\ x \text{ integral}\}$, and its linear programming relaxation, $\max \{1\cdot x\colon Ax \le w,\ x \ge 0\}$, where A is the edge-node incidence matrix of a graph G and w is a nonnegative integral vector. We give an excluded subgraph characterization quantifying the difference between the value of these two programs. One consequence of this characterization is an explicit description for the "integer rounding" case. Specifically, we characterize those graphs G with the property that for every subgraph of G and for any choice of w, the optimum objective function values of these two problems differ by less than unity.
Joint work with S.K.Tipnis.

Klaus Truemper

Minimal violators of centrality.

Let A be the clause/variable matrix of a system of propositional logic clauses in conjunctive normal form. That is, each row c of A corresponds to a clause, and each column x to a variable; A_{cx} is then = 1 if x occurs in c, = -1 if the complement of x occurs in c, and = 0 otherwise.
The matrix A is *nearly negative* if each row contains at most one +1, and is *central* if its columns can be scaled so that it becomes nearly negative.
If A is central, then satisfiability of the logic system can be decided in polynomial time. We identify the instances where A is not central.
We define the concept of *Boolean minor* of $\{0,\pm1\}$ matrices. With a complicated algorithm we then deduce the minimal violation minors of centrality. There are total of nine such minors. The result is useful for showing that satisfiability of logic system involving noncentral matrices can be decided in polynomial time when certain conditions are satisfied.

Jean-Pierre Uhry

Is combinatorial optimization practical?
Some combinatorial optimization problems in CAM systems with a software demonstration.

Dominique de Werra

Finding large independent sets in a graph with tabu search.

Recently tabu search has been applied to a huge variety of combinatorial problems. It is a general heuristic technique which finds iteratively good local optima. An application to the determination of large independent sets in a graph will be described and recent developments of these ideas will be outlined.

Laurence A. Wolsey

Time-indexed formulations of single-machine scheduling problems.

We consider the formulation of the non-preemptive single machine scheduling problem using time-indexed variables. Such formulations lead to very large formulations, but give better lower bounds than other mixed integer formulations. We derive a variety of valid inequalities, and show the role of aggregation and the knapsack problem with generalized upper bound constraints as a way of generating such inequalities. Computational experience on small problems with 20/30 jobs and various objectives are presented.
Joint work with J.Sousa.

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