Mathematisches Forschungsinstitut Oberwolfach

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Geometric Convex Combinatorics

June 16th – June 22nd, 2002

The meeting was organized by Bert Gerards (Amsterdam), András Sebö (Grenoble), and Robert Weismantel (Magdeburg). The goal of the conference was to bring together the communities of different, but related fields of mathematics: Combinatorial Optimization, Discrete and Convex Geometry, and Graph Theory. The meeting was attended by more than 40 participants from various countries.

The scientific program was started on Monday by László Lovász, who gave a tutorial on lattices. Twenty-eight talks were given during the eight morning and afternoon sessions.

A highlight of the conference was the purported proof of the Strong Perfect Graph Conjecture by Paul Seymour and his group. It was the topic of three regular talks and an extra, informal session on Thursday evening. There also was a special session with three talks on the topic of Path Matching on Thursday morning.

On Wednesday evening, a problem session was held. A. Frank, L. Lovász, P. Seymour, S. Onn, M. Laurent, and A. Schrijver presented interesting problems from their current research and some of their favourite conjectures.

The abstracts of the talks are given below (in alphabetical order).

Abstracts

Knapsacks, the Frobenius number, and Lattices

Karen Aardal

(joint work with Arjen K. Lenstra)

We consider the following integer feasibility problem: "Given positive integer numbers $a_0, a_1, \ldots, a_n$, with $\gcd(a_1, \ldots, a_n) = 1$ and $a = (a_1, \ldots, a_n)$, does there exist a vector $x \in \mathbf{Z}^n_{\geq 0}$ satisfying $ax = a_0$?" Some instances of this type have been found to be extremely hard to solve by standard methods such as branch-and-bound, even if the number of variables is as small as ten. We observe that not only the sizes of the numbers $a_0,\ a_1, \ldots, a_n$, but also their structure, have a large impact on the difficulty of the instances. This particular structure enables us to derive a strong lower bound on the Frobenius number for these instances. Moreover, we demonstrate that the characteristics that make the instances so difficult to solve by branch-and-bound make the solution of a certain reformulation of the problem almost trivial. We accompany our results by a small computational study.

The minimum area convex lattice n-gon

Imre Bárány

(joint work with Norihide Tokushige)

Let $A(n)$ be the minimum area of convex lattice n-gons. (Here lattice is the usual lattice of integer points in $\mathbf{R}^2$.) G. E. Andrews proved in 1963 that $A(n) > cn^3$ for a suitable positive c. We show here that $\lim A(n)/n^3$ exists. Our computations suggest that the value of the limit is very close to $0.0185067\ldots$. It turns out further that the convex lattice n-gon P_n with area $A(n)$ has elongated shape: After a suitable lattice preserving affine transformation P_n is very close to the ellipsoid $x^2/A^2 + y^2/B^2 = 1$ with $A = 0.00357n^2$ and $B = 1.656n$.

Robust Discrete Optimization

Dimitris Bertsimas

(joint work with Melvyn Sim)

We propose an approach to address data uncertainty for discrete optimization problems that allows controlling the degree of conservatism of the solution, and is computationally tractable both practically and theoretically. In particular, when both the cost coefficients and the data in the constraints of a mixed integer programming problem are subject to uncertainty, we propose a robust mixed IP of moderately larger size that allows to control the degree of conservatism of the solution in terms of probabilistic bounds on constraint violation. When only the cost coefficients are subject to uncertainty and the problem is a $0/1$ IP on n variables, then we solve the robust counterpart by solving $n+1$ instances of the original problem with different objective functions. Thus, the robust counterpart of a polynomially solvable $0/1$ IP remains polynomially solvable. In particular, robust matching, spanning tree, shortest path, matroid intersection, etc. are polynomially solvable. Moreover, we show that the robust counterpart of an $\mathcal{NP}$-hard α-approximable $0/1$ IP remains α-approximable.

Path-Matchings and Even Factors

Bill Cunningham
(joint work with Jim Geelen)

An even factor of a digraph is the edge-set of a collection of vertex-disjoint dipaths and even dicircuits. The problem of finding a maximum size even factor is $\mathcal{NP}$-hard in general, but solvable in polynomial time when the digraph is weakly symmetric, meaning that every strong component is symmetric. We show this result, and also solvability results for a weighted version, and a version in which matroid structure is imposed on the end vertices of the dipaths. These problems generalize corresponding problems in path-matchings, and thus generalize (weighted) matching and (weighted) matroid intersection. Main tools are the Tutte matrix of the digraph, a generalization of Geelen's matching algorithm, and Murota's valuated matroid intersection algorithm.

On the stable $\mathfrak{b}$-matching polytope

Tamás Fleiner

We characterize the bipartite stable $\mathfrak{b}$-matching polytope in terms of linear constraints. The stable $\mathfrak{b}$-matching polytope is the convex hull of the characteristic vectors of stable $\mathfrak{b}$-matchings, that is, of stable assignments of a two-sided multiple partner matching model. Our proof uses the comparability theorem of Roth and Sotomayor and follows a similar line as Rothblum did for the stable matching polytope.

On the geometric rank of relaxations

Peter Gritzmann
(joint work with Andreas Brieden)

We introduce the *geometric rank* as a measure for the quality of relaxations of certain combinatorial optimization problems in the realm of polyhedral combinatorics. This notion leads in particular to sharp inapproximability bounds for largely restricted classes of the general *polynomial programming* problem. We also relate the geometric rank of a relaxation of the stable set polytope to the question whether the separation problem for the relaxation can be solved in polynomial time.

Packing T-joins and edge colouring

Bertrand Guenin

Let (G,T) be a planar graft for which there exists a T-cut with at most 5 edges and where all T-cuts have the same parity. We show that in that case the cardinality of the minimum T-cut equals the maximum number of pairwise disjoint T-joins. As a corollary we obtain that k-regular planar graphs G (where $k \leq 5$) have chromatic index k iff $\forall X \subseteq V(G)$, $|\delta(X)| \geq k$ when $|X|$ odd. The case $k = 4$ was conjectured by Seymour in 1979, it is a strict generalization of the 4-colour theorem.

Representation of polyhedra by polynomial inequalities

Martin Henk

(joint work with Martin Grötschel)

A beautiful result of Bröcker and Scheiderer on the stability index of basic closed semi-algebraic sets implies, as a very special case, that every n-dimensional polyhedron admits a representation as the set of solutions of at most $n(n+1)/2$ polynomial inequalities. Even in this polyhedral case, however, no constructive proof is known, even if the quadratic upper bound is replaced by any bound depending only on the dimension.

Here we give, for simple polytopes, an explicit construction of polynomials describing such a polytope. The number of used polynomials is exponential in the dimension, but in the 2- and 3-dimensional case we get the expected number $n(n+1)/2$.

Hilbert Bases, Gomory Integer Programs and Supernormal Vector Configurations

Serkan Hoşten

We study the hierarchy of normal configurations (those configurations of vectors which form a Hilbert basis of the cone they generate) from the point of view of covering properties of the monoid of lattice points in the cone that the configuration defines, as well as from the integer programming point of view. We introduce 2 new classes of configuration namely Δ_c-normal configurations and supernormal configurations. These are generalizations of configurations with unimodular triangulations and unimodular configurations, respectively.

A Faster Scaling Algorithm for Minimizing Submodular Functions

Satoru Iwata

A set function f on a finite set V is submodular if it satisfies

$$f(X) + f(Y) \geq f(X \cap Y) + f(X \cup Y), \qquad \forall X, Y \subseteq V.$$

Submodular functions are discrete analogues of convex functions.

Recently, combinatorial strongly polynomial algorithms for minimizing submodular functions have been developed by Iwata, Fleischer, and Fujishige (IFF) and by Schrijver. The IFF algorithm employs a scaling scheme for submodular functions, whereas Schrijver achieves a strongly polynomial bound by introducing a novel subroutine in a lexicographic augmentation framework. Subsequently, Fleischer and Iwata have been described a push/relabel framework that uses this subroutine to improve the running time bound.

In this talk, we combine these two streams of techniques to yield a faster combinatorial algorithm for submodular function minimization. The resulting algorithm improves over the previously best known bound by an almost linear factor in the size of the underlying ground set.

Primal (Mixed) Integer Programming

Matthias Köppe
(joint work with Utz-Uwe Haus and Robert Weismantel)

We review the "classic" primal Integer Programming algorithms by R. D. Young and others. The known weaknesses of these methods and the lack of an algorithm of this type for mixed integer programs provide the motivation for the study of new primal-type algorithms that are based on "linear reformulations", rather than integer pivoting. We present such an algorithm, the Integral Basis Method, for which we present computational results both on proving optimality of given optimal solutions and augmenting suboptimal points, for hard 0/1 integer programs from the MIPLIB. Finally we present a recent extension of our algorithm to mixed integer programs.

Bases, Reorientations and Linear Programming in Graphs, Hyperplane Arrangements, and Oriented Matroids

Michel Las Vergnas
(joint work with Emeric Gioan)

The present work pursues a series of results originating in a theorem of R. Stanley (1973) on the number of acyclic orientations of a graph. First generalizations of this result are given by theorems of T. Zaslavsky (1975) on the number of regions of an hyperplane arrangement, and of M. Las Vergnas (1975) on the number of acyclic reorientations of an oriented matroid, or equivalently, the number of regions of its topological representation. A further generalization is a state model for the Tutte polynomial of an oriented matroid on a linearly ordered set in terms of orientation activities (M. Las Vergnas 1982). Comparing the classical state model of the Tutte polynomial in terms of basis activities (W.T. Tutte 1954) to the state model in terms of orientation activities yields a remarkable relation between the numbers of bases and reorientations with given activities in an oriented matroid – namely $2^{i+j} b_{ij} = o_{ij}$. We present here a bijective proof of this relation. Our construction consists in first decomposing activities, then establishing a bijection between bases and reorientations by means of two dual algorithms. The resulting active correspondence, which preserves active partitions, is closely related to oriented matroid programming.

Semidefinite relaxation for 0/1 polytopes Application to Max-Cut

Monique Laurent

Several methods for constructing linear and/or semidefinite relaxations of 0/1 polytopes have been proposed; in particular, the lift-and-project method (Balas, Ceria and Cornuéjols), the iterative matrix-cut method (Lovász and Schrijver), the RLT method (Sherali and Adams), and some algebraic methods based on representations of polynomials as sums of squares and the dual theory of moments (Lasserre, Parrilo, Shor). We show that the tightest relaxations are obtained when applying the algebraic construction and give a simple combinatorial interpretation in the 0/1 case.

We study in detail the application to the maximum cut problem. Several results are presented, including a linear lower bound on the number of iterations needed for finding the cut polytope, and a geometric result on the set of moment matrices.

Multi-index Transportation Polytopes

Jesús Antonio de Loera

A *d-way table of size* $(n_1, \ldots, n_d)$ is an array $v = v_{i_1,\ldots,i_d}$ of nonnegative integers with $1 \leq i_j \leq n_j$. For $0 \leq m < d$, an *m-marginal* of $v_{i_1,\ldots,i_d}$ is any of the $\binom{d}{m}$ possible m-tables obtained by summing the entries of $v_{i_1,\ldots,i_d}$ over all but m indices. For instance, if $v_{i,j,k}$ is a 3-table of size (n, n, n) then its 0-marginal is $v_{+,+,+} = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n} v_{i,j,k}$, its 1-marginals are $v_{i,+,+} = \sum_{j=1}^{n}\sum_{k=1}^{n} v_{i,j,k}$. A *multi-index transportation polytope* associated to some marginals is the set of tables whose marginals are exactly as those specified. Such polytopes appear often in Statistical analysis. Two theorems were presented about these polytopes:

- In joint work with S. Onn, we provided an integer preserving affine isomorphism between transportation polytopes of 3-tables with given 1-marginals *and* upper bounds on entries on one hand, transportation polytopes of 3-tables with given 2-marginals (and no upper bounds) on the other hand. It can be used to systematically obtain "empty" transportation polytopes – that are rationally nonempty yet contain no integer lattice point.
- In joint work with M. Ahmed and R. Hemmecke, we use a new implementation of Barvinok's algorithm for counting lattice points to derive explicit formulae for the Ehrhart quasi-polynomials of several transportation of 3-tables.

Harmonic and analytic functions on graphs

László Lovász

(joint work with Itai Benjamini)

Harmonic and analytic functions have natural discrete analogues. Harmonic functions can be defined on every graph, while analytic functions (or, more precisely, holomorphic forms) can be defined on graphs embedded in orientable surfaces. Many important properties of the "true" harmonic and analytic functions can be carried over to the discrete setting. We prove that a nonzero analytic function can vanish only on a very small connected piece.

As an application, we describe a simple local random process on embedded graphs, which have the property that observing them in a small neighborhood of a node through a polynomial time, we can infer the genus of the surface.

Discrete Convex Functions

Kazuo Murota

Discrete convex analysis is a theory of M-convex and L-convex functions, aiming at a discrete analogue of convex analysis for nonlinear discrete optimization. Technically it is a nonlinear generalizations of matroid/submodular function theory. This talk consists of two parts. The first part points out a connection of discrete convex analysis to the results of D. Gale and T. Politof (Substitutes and complements in network flow problems, Discrete Applied Mathematics, Vol. 3 (1981), pp. 175–186). The submodularity of the maximum cost with respect to weights and capacities on parallel arcs is a consequence of the following fact: The maximum cost of a feasible circulation is $\mathrm{L}^\natural$-convex as a function in weights on parallel arcs, and is $\mathrm{M}^\natural$-concave as a function in capacities on parallel arcs. The second part of the talk explains fundamental results in discrete convex analysis, with emphasis on conjugacy and duality.

A Polynomial Time Algorithm for Universal Gröbner Bases

Shmuel Onn

We provide a polynomial time algorithm for computing the universal Gröbner basis of any polynomial ideal having a finite set of common zeros in fixed number of variables. One ingredient of our algorithm is an effective construction of the state polyhedron of any member of the Hilbert scheme of n-long d-variate ideals, enabled by introducing the Hilbert zonotope and showing that it simultaneously refines all state polyhedra of ideals on the Hilbert scheme.

Lower Bounds for Covering Codes

Alain Plagne
(joint work with Laurent Habsieger)

My talk was about covering codes. The context is the following: we are given q and n two integers and study the ambiant space F_q^n, the n-th power of the finite alphabet with q elements, which is equipped with the usual Hamming distance. Given an integer R we define $K_q(n, R)$ to be the smallest possible number of balls with radius R which are needed to cover the whole space. In the talk, we did show how to derive good lower bounds for $K_q(n, R)$. The method is partly algorithmic and related with integer programming.

S-paths

Alexander Schrijver

An S-path is a path in a graph having two distinct end vertices in S. We explain a short proof of Mader's min-max relation for the maximum number of openly disjoint S-paths, and give relations to matroid theory, including a new representation in terms of matroid matching. We pose as problems to derive a direct, polynomial-time algorithm to find a maximum number of openly disjoint S-paths, and to characterize the Mader matroids in relation to linear matroids and gammoids.

Strong Perfect Graph Theorem

Paul Seymour and Maria Chudnovsky
(joint work with Neil Robertson and Robin Thomas)

Claude Berge proposed the conjecture in 1960 that, in every graph with no odd hole or odd antihole, the number of colours needed to properly colour the graph equals the size of the largest complete subgraph. (A "hole" means an induced subgraph which is a cycle of length ≥ 4, and an "antihole" is the same in the complement graph.) This has become one of the most well-known and popular open problems in graph theory. Most attempts on it have been based on linear programming methods, studying the properties of a minimal counterexample; they go a long way, but appear eventually to get stuck. Recently, however, a new approach was initiated by Conforti and Cornuéjols, an attempt to actually find explicit constructions for all the graphs not containing odd holes or antiholes, and checking directly that they satisfy Berge's conjecture. I am happy to report that this works. In joint work with Maria Chudnovsky, Neil Robertson and Robin Thomas, we have been able to carry out the Conforti–Cornuéjols program, and thereby prove Berge's conjecture. (We hope! – we only finished the proof in May, and there are two years worth of details to check, but so far it stands up.)

A Combinatorial Algorithm for the Independent Path-Matching Problem

Bianca Spille
(joint work with Robert Weismantel)

The independent path-matching problem is a common generalization of the matching problem and the matroid intersection problem. Cunningham and Geelen proved that this problem is solvable in polynomial time via the ellipsoid method. We present a polynomial-time combinatorial algorithm for its unweighted version that generalizes the known combinatorial algorithms for the cardinality matching problem and the matroid intersection problem.

Path-Matching and Even Factors

László Szegő
(joint work with Andras Frank, Bianca Spille, and Gyula Pap)

Cunningham and Geelen introduced the notion of path-matchings as a common generalization of maximum weight matchings and maximum weight matroid intersections. They proved that this problem can be solved in polynomial time. Here we show a simlified min-max formula for the maximum value of a path-matching along with a combinatorial proof (joint work with Andras Frank) and a Gallai-Edmonds-type structure theorem on the maximum valued path-matchings (joint work with Bianca Spille).

Cunningham and Geelen generalized path-matchings further, they defined the even factor problem. This problem turned out to be $\mathcal{NP}$-complete in general but in weakly symmetric graphs it is polynomial as Cunningham and Geelen showed. We give a simplified min-max formula for the maximum cardinality of an even factor in weakly symmetric graphs together with a structure theorem (joint work with Gyula Pap).

Valid Inequalities for MIP, Superadditivity and Submodularity

Lawrence Wolsey

We consider the question of which "hard" mixed integer programming sets should be studied so as to improve cutting plane algorithms. This leads us to reconsider the liftings of valid inequalities. We derive general conditions for lifting sets of variables subject to arbitrary constraints, with superadditivities playing a crucial role. Several questions are raised concerning superadditive functions on $\mathbb{R}^n$, $\mathbb{R}^1_+$, $\mathbb{R}^1_-$, etc. especially related to single node flow sets; and the structure of the corresponding lifting functions.

The second set considered is a multi-constraint extension of the single node flow model, arising in capacitated lot-sizing. Here simultaneous lifting results are known even though the lifting functions are not superadditive. However here the submodularity of certain fixed charge network flows provides a different validation of the simultaneous lifting property.

Edited by Matthias Köppe and Utz-Uwe Haus

Participants

Prof. Dr. Karen Aardal
aardal@math.uu.nl
aardal@iye.gatech.edu
aardal@isye.gatech.edu
Mathematisch Instituut
Universiteit Utrecht
Budapestlaan 6, de Uithof
P. O. Box 80.010
NL-3508 TA Utrecht

Prof. Dr. Imre Barany
barany@renyi.hu
barany@math.ucl.ac.uk
Alfred Renyi Institute of
Mathematics
Hungarian Academy of Sciences
P.O.Box 127
H-1364 Budapest

Prof. Dr. Dimitris J. Bertsimas
dbertsim@mit.edu
Sloan School of Management
Mass. Inst. of Technology
50 Memorial Drive, E 53-363
Cambridge, MA 02139 - USA

Maria Chudnovsky
mchudnov@Math.Princeton.EDU
Department of Mathematics
Princeton University
Fine Hall
Washington Road
Princeton, NJ 08544-1000 - USA

Prof. Dr. Jose Coelho de Pina
coelho@ime.usp.br
Instituto de Matematica e
Estatistica
Universidade de Sao Paulo
rua do Matao 1010
Sao Paulo 05508-900 - SP - Brazil

Prof. Dr. Michelangelo Conforti
conforti@math.unipd.it
Dipartimento di Matematica Pura
ed Applicata
Universita di Padova
Via Belzoni, 7
I-35131 Padova

Prof. Dr. William H. Cunningham
whcunnin@uwaterloo.ca
Dept. of Combinatorics and
Optimization
University of Waterloo
Waterloo, Ontario N2L 3G1 - Canada

Dr. Friedrich Eisenbrand
eisen@mpi-sb.mpg.de
Max-Planck-Institut
für Informatik
Stuhlsatzenhausweg 85
D–66123 Saarbrücken

Dr. Tamas Fleiner
fleiner@renyi.hu
Alfred Renyi Institute of
Mathematics
Hungarian Academy of Sciences
P.O.Box 127
H-1364 Budapest

Prof. Dr. Andras Frank
frank@cs.elte.hu
Department of Operations Research
Eötvös Lorand University
ELTE TTK
Pazmany Peter setany 1/C
H-1117 Budapest

Dr. Bert Gerards
bert.gerards@cwi.nl
CWI - Centrum voor Wiskunde en
Informatica
Postbus 94079
NL-1090 GB Amsterdam

Drs. Dion Gijswijt
gijswijt@science.uva.nl
Dept. of Mathematics
University of Amsterdam
Plantage Muidergracht 24
NL-1018 TV Amsterdam

Prof. Dr. Peter Gritzmann
gritzmann@ma.tum.de
gritzman@mathematik.tu-muenchen.de
Zentrum Mathematik
TU München
80290 München

Prof. Dr. Bertrand Guenin
bguenin@math.uwaterloo.ca
Dept. of Combinatorics and
Optimization
University of Waterloo
Waterloo, Ontario N2L 3G1 - Canada

Dr. Utz Uwe Haus
haus@mail.math.uni-magdeburg.de
Institut für Mathematische
Optimierung
Universität Magdeburg
Postfach 4120
D–39016 Magdeburg

Dr. Martin Henk
henk@tuwien.ac.at
Abteilung für Analysis
Technische Universität Wien
Wiedner Hauptstr. 8-10
A-1040 Wien

Prof. Dr. Serkan Hosten
serkan@math.sfsu.edu
Dept. of Mathematics
San Francisco State University
1600 Holloway Avenue
San Francisco, CA 94132 - USA

Prof. Dr. Cor Hurkens
wscor@win.tue.nl
Dept. of Mathematics and
Computer Science
Eindhoven University of Technology
Postbus 513
NL-5600 MB Eindhoven

Prof. Dr. Satoru Iwata
iwata@sr3.t.u-tokyo.ac.jp
Dept. of Math. Eng. and Inf. Physic
Grad. School of Engineering
University of Tokyo
7-31, Hongo, Bunkyo-ku
Tokyo 113-8656 - Japan

Prof. Dr. Tibor Jordan
jordan@cs.elte.hu
Department of Operations Research
Eötvös Lorand University
ELTE TTK
Pazmany Peter setany 1/C
H-1117 Budapest

Dr. Matthias Köppe
mkoeppe@mail.math.uni-magdeburg.de
Institut für Mathematische
Optimierung
Universität Magdeburg
Universitätsplatz 2
D–39106 Magdeburg

Prof. Michel Las Vergnas
mlv@ccr.jussieu.fr
Université Pierre et Marie Curie
Case 189 - Combinatoire
4, Place Jussieu
F-75252 Paris Cedex 05

Dr. Monique Laurent
monique@cwi.nl
Centrum voor Wiskunde en
Informatica
P.O. Box 94079
NL-1090 GB Amsterdam

Prof. Dr. Jesus de Loera
deloera@math.ucdavis.edu
Department of Mathematics
University of California, Davis
One Shields Avenue
Davis CA 95616-8633 - USA

Prof. Dr. Laszlo Lovasz
lovasz@cs.yale.edu
lovasz@microsoft.com
Microsoft Research
One Microsoft Way
Redmond, WA 98052-6399 - USA

Frédéric Maffray
Frederic.Maffray@imag.fr
Laboratoire LEIBNIZ-IMAG
46 avenue Felix Viallet
F-38031 Grenoble Cedex

Gabor Maroti
G.Maroti@cwi.nl
G.Maroti@Reizigers.ns.nl
Centrum voor Wiskunde en
Informatica
P.O. Box 94079
NL-1090 GB Amsterdam

Prof. Dr. Alexander Martin
martin@mathematik.tu-darmstadt.de
FB Mathematik, AG 7
TU Darmstadt
Schlossgartenstr. 7
D–64289 Darmstadt

Prof. Dr. Kazuo Murota
murota@mist.i.u-tokyo.ac.jp
Dept. of Mathematical Informatics
Grad. School of Inform. Sci.& Tech.
University of Tokyo
7-3-1 Hongo, Bunkyo-ku
Tokyo 113-8656 - Japan

Prof. Dr. Shmuel Onn
onn@ie.technion.ac.il
Industrial Engineering - Management
Science - Technion
Israel Institute of Technology
Haifa 32000 - Israel

Dr. Rudi Pendavingh
rudi@win.tue.nl
Dept. of Mathematics and
Computer Science
Eindhoven University of Technology
Postbus 513
NL-5600 MB Eindhoven

Prof. Dr. Alain Plagne
plagne@lix.polytechnique.fr
Laboratoire d'Informatique (Lix)
Ecole Polytechnique
F-91128 Palaiseau Cedex

Prof. Dr. Alexander Schrijver
lex.schrijver@cwi.nl
CWI
Postbus 94079
NL-1090 GB Amsterdam

Prof. Dr. Andras Sebö
andras.sebo@imag.fr
Laboratoire LEIBNIZ-IMAG
46 avenue Felix Viallet
F-38031 Grenoble Cedex

Dr. Paul Seymour
pds@math.princeton.edu
Department of Mathematics
Princeton University
609 Fine Hall
Washington Road
Princeton, NJ 08544 - USA

Prof. Dr. Frederick Bruce Shepherd
bshep@research.bell-labs.com
Bell Labs
Room 2C-381
600 Mountain Avenue
Murray Hill, NJ 07974 - USA

Dr. Bianca Spille
spille@imo.math.uni-magdeburg.de
Fakultät für Mathematik
Otto-von-Guericke-Universität
Magdeburg
Universitätsplatz 2
D–39106 Magdeburg

Prof. Dr. Laszlo Szego
szego@cs.elte.hu
Department of Operations Research
Eötvös Lorand University
ELTE TTK
Pazmany Peter setany 1/C
H-1117 Budapest

Prof. Dr. Zoltan Szigeti
szigeti@ecp6.jussieu.fr
Equipe Combinatoire
Universite Pierre et Marie Curie
175, Rue du Chevaleret
F-75013 Paris

Nicolas Trotignon
Nicolas.Trotignon@imag.fr
Laboratoire LEIBNIZ-IMAG
46 avenue Felix Viallet
F-38031 Grenoble Cedex

Prof. Dr. Robert Weismantel
weismantel@imo.math.uni-magdeburg.de
Fakultät für Mathematik
Otto-von-Guericke-Universität
Magdeburg
Universitätsplatz 2
D–39106 Magdeburg

Prof. Dr. Laurence A. Wolsey
wolsey@core.ucl.ac.be
Center for Operations Research and
Econometrics
Universite de Louvain
34 Voie du Roman Pays
B-1348 Louvain-la-Neuve