Mathematisches Forschungsinstitut Oberwolfach

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Graph Theory

January 12th – January 18th, 2003

The meeting was organized by Reinhard Diestel (Hamburg), Alexander Schrijver (Amsterdam) and Paul D. Seymour (Princeton). Almost 40 scientists from more than 10 countries took part to the happening and more than 30 participants could stay in Oberwolfach for the whole workshop. Important new results were presented and directions for further research were discussed and considered. The organizers and participants thank the "Mathematisches Forschungsinstitut Oberwolfach" for providing a comfortable and inspiring setting for this conference. The pleasant atmosphere in Oberwolfach contributed to the overall success of the meeting.

In the following we include the abstracts in alphabetical order.

Abstracts

Independent systems of representatives

Ron Aharoni (Technion, Haifa)

Given a graph G and disjoint subsets $V_1, \dots, V_n$ of $V(G)$ an "independent system of representatives" (ISR) is a choice of independent (in G) vertices $v_1 \in V_1, \dots, v_n \in V_n$. Denote by $\mathcal{I}(G)$ the complex of independent sets in G, and by $\eta(G)$ the connectivity (in the homological sense) of $\mathcal{I}(G)$.

Theorem: If $\eta(G[\cup_{i\in I} V_i]) \geq |I|$ for every $I \subseteq \{1, \dots, n\}$, then there exists an ISR.

The function η can be bounded below by various domination parameters of the graph. Plugging these bounds into the theorem yields combinatorial versions of it.

Polynomial Recognition Algorithm for Perfect Graphs

Maria Chudnovsky (Princeton)
(joint work with Paul Seymour (Princeton))

A graph is perfect if for every induced subgraph of it, the chromatic number equals the clique number. A graph is Berge if it contains no odd cycle of length greater than 3 and no complement of such cycle. The recent proof of the Strong Perfect Graph Theorem reduced the long standing open question of the existence of a poly time recognition algorithm for perfect graphs to finding a poly time recognition algorithm for Berge graphs. We present such an algorithm with complexity $O(|V(G)|^9)$. The algorithm is independent of the proof of the Strong Perfect Graph Theorem and tests directly for the presence of an odd hole in a graph.

Restricted t-matchings in bipartite graphs

Andràs Frank (Eötvös University, Budapest)

Let $G = (S, T; E)$ be a bipartite graph. By a bi-clique, we mean a complete bipartite graph with at least one edge. Given integer $t \geq 2$, a bi-clique is called large if it has more than t vertices. A *t-covering* is a subset of edges intersecting every large bi-clique of G. It can be shown rather easily that a t-cover actually intersects each large bi-clique H in at least $|V(H)| - t$ edges.

Theorem: The cardinality of a minimum t-covering is equal to the maximum of $\sum_i (|V(H_i)| - t)$ where $H_1, \dots, H_l$ are edge-disjoint large bi-cliques.

By a *t-matching* we mean a subgraph of G in which every degree is at most t. $K_{t,t}$ denotes a bi-clique on $t + t$ nodes.

Theorem: The maximum cardinality of a $K_{t,t}$-free t-matching in a bipartite graph $G = (S, T; E)$ is equal to:

$$\min_{Z \subseteq S \cup T} \{t|Z| + i(G - Z) - c_t(Z)\},$$

where $i(x)$ denotes the number of edges induced by X, and $c_t(Z)$ denotes the number of $K_{t,t}$-components of $G - Z$.

This result was proved for $t = 2$ by Z. Király, who sharpened an earlier result of D. Hartvigsen.

[to appear in Discrete Applied Mathematics, 2003, guest editor S. Fujishige]

Excluding a planar graph from binary Matroids

Jim Geelen (University of Waterloo)
(joint work with Bert Gerards (CWI) and Geoff Whittle (Victoria University))

We prove that a binary matroid with huge branch-width contains the cycle matroid of a large grid as a minor. More generally, this holds for matroids representable over any finite field.

On the excluded minors for the matroids with branch-width k

Bert Gerards (CWI, Amsterdam)
(joint work with Jim Geelen, Neil Robertson (Ohio State University) and Geoff Whittle)

We prove that there are only finitely many excluded minors for branch-width at most k (for each fixed k). Actually, we prove that each such excluded minor has at most $\frac{6^k-1}{5}$ elements. Main ingredient in the proof is the result that each excluded minor for branch-width k is "well-connected" in the sense that each l separation with $l \leq k$ has a side with at most $\frac{6^{l-1}-1}{5}$ elements.

Many edge-disjoint circuits through prescribed vertices

Luis Goddyn (Simon Fraser University, Canada)
(joint work with Laco Stacho)

One standard theme of "classical" graph theory considers circumstances under which a graph is guaranteed to posses a long circuit. The degree condition of Ore is a pioneering example. Another theme regards the packing of edge-disjoint circuits, usually Hamilton circuits into a graph. Connectivity conditions typically arise here. This result is a common generalization of strong recent results from the theme.

Question: Given a set W of vertices in a graph G, and an integer k, do there exist k pairwise edge disjoint circuits in G, each circuit containing all vertices in W (and possibly more)?

Theorem: Such circuits exist, provided that

a) the subgraph induced by W is $2k$-connected;

b) any two vertices $u, v \in W$ at distance two in the subgraph induced by W satisfy the following "fan type" degree condition

$$\max\{deg_G u; deg_G v\} \geq \frac{n}{2} + 2(k-1),$$

where $n = |V(G)|$.

The case $k = 1$ was proved by Bollobás and Brightwell in 1993. The case $W = V(G)$ was proved by G. Li in 2000. Conditions (a) and (b) are, in a sense, best possible.

Edge colouring in plane multigraph

Bertrand Guenin (University of Waterloo)

We show that a 4 regular planar multigraph has chromatic index 4 if and only if for every odd subset of its vertices X, there are at least 4 edges with exactly one end in X. The result was conjectured by Seymour in 79 and it implies the four colour theorem. The corresponding result for 5 regular graphs also holds.

Transversals in Graphs

Penny Haxell (University of Waterloo)

Let G be a graph and $V_1 \cup \ldots V_n$ be a partition of the vertex set of G. An *independent transversal* $\{v_1, \ldots, v_n\}$ is an independent set of vertices in G such that $v_i \in V_i$ for each i. We give various conditions on G and the partition that guarantee the existence of an independent transversal. Applications of these results to other combinatorial problems will also be given such as list colouring, hypergraphs matching and strong chromatic number.

How to construct railway-routes

Andreas Huck (Deutsche Bahn AG)

We have a set of areas and for each pair (a, b) of areas, we have the average number of daily travellers from a to b no matter what kind of transportation they use. The aim is a good set of railway routes where each route is defined by a path in the graph representing the railway net, a train type, and the departure and arrival times at each stop. "Good" means that the profit for the railway company should be as large as possible. On the one hand, the route set must be attractive so that a lot of travellers will choose the railway (low number of changes, small travel time, large number of train connections between the areas etc.) but on the other hand, the route set must be economical, i.e. it must not contain too much routes.

At the moment, the Deutsche Bahn AG is experimenting with a Greedy concept for constructing good route sets which I developed and a concept based on meta heuristics (simulated annealing, genetic algorithms etc.) developed by Frank Wagner, the Intranetz company in Berlin, and the TU Berlin.

Zero Distribution in Flow Polynomials of Cubic Graphs

Bill Jackson (Queen Mary College, London, UK)

A graph is near cubic if it has at most one vertex of degree other than three. The talk describes several results on the zero distribution of flow polynomials of near cubic graphs which imply that the only zeros of the flow polynomial of a cubic graph in $(-\infty, \alpha)$ are the integer zeros at 1 and 2, where $\alpha \approx 2.54$ is the zero of the flow polynomial of the cube in $(2, 3)$.

Dense minors in graphs of large girth

Daniela Kühn (Universität von Hamburg)
(joint work with Deryk Osthus (Humboldt-Universität zu Berlin))

Thomassen observed that if a graph of minimum degree at least 3 has large girth, then it contains a large clique as minor. We obtained the following more detailed picture:

Theorem. For each odd integer g there exists a constant c such that every graph G of minimum degree at least r and girth at least g contains some graph H as a minor whose minimum degree is at least $c(r-1)^{\frac{g+1}{4}}$.

If $g = 4k + 3$ for some integer k then in fact c does not depend on g and thus every graph of minimum degree at least 3 and girth at least $4 \log_2 r + o(\log r)$ contains K_r as a minor. Assuming the truth of a well-known conjecture, the bound in the theorem would be best possible up to the value of the constant c.

Forbidden distances in the reals

I. Leader (Cambridge)
(joint work with N. Hindman, D. Strauss)

We show that there is a partition of the reals into finitely many classes with 'many forbidden distances', in the following sense: for every positive x, there is a positive integer n such that no two points in the same class are at distance x/n.

This problem arises naturally from some questions in Ramsey theory. The proof appears to depend in a fundamental way on CH, but in fact it turns out that the result still holds without CH.

Graph decomposition and topological quantum field theory

Làszlò Lovàsz (Microsoft Research)
(joint work with Mike Friedman, Kevin Walker and Dominic Welsh)

Topological quantum field theory leads to a number of very combinatorial questions about planar curves and graphs. This talk surveys some of these, based on joint work with Mike Friedman, Kevin Walker and Dominic Welsh. It turns out that the occurrence of the golden ratio in Tutte's work on the chromatic polynomial and in some studies in quantum field theory have a common root. These studies also motivate some questions about graphs that are interesting on their own right, like rank-connectivity and physicalness of a graph parameter.

High connectivity keeping sets in graphs and digraphs

W. Mader (Hannover University)

The following theorem was proved.

Theorem: For all positive integers n, k, there is an integer $g(n,k)$ so that every finite n-connected graph G with at least $g(n,k)$ vertices contains a vertex set A with $|A| = k$ such that $G - A$ is still $(n-2)$-connected.

This result does not remain true for $n-1$ instead of $n-2$ or if the condition $G(A)$ connected is added. In the last case, $(n-3)$-connected would be best possible, but I could prove this only for $k = 4$. A corresponding result for digraphs is conjectured and proved in the last case.

Strongly 2-connected digraphs

William McCuaig (Burnaby, Canada)

A digraph D is strongly 2-connected if $D \neq \emptyset$ and for every vertex $x \in V(D)$ the digraph $D - x$ is strongly connected. A digraph D is strongly connected if $|V(D)| \geq 2$ and for every $u, v \in V(D)$ there exists a u, v-dipath. We give a method for generating strongly 2-connected digraphs. Starting with a base set consisting of 4 families, all strongly 2-connected digraphs can be constructed using 2 local operations.

Circular chromatic number of edge-weighted graphs

Bojan Mohar Mohar (University of Ljubljana, Slovenia)

The notion of circular colourings of edge-weighted graphs was introduced. This notion generalizes the notion of circular colourings of graphs, the channel assignment problem, and several other optimization problems. For instance, its restriction to colourings of weighted complete graphs corresponds to the travelling salesman problem (metric case). It also gives rise to a new definition of the chromatic number of directed graphs. Various basic results about the circular chromatic number of edge-weighted graphs were presented.

Subdivisions and Minors in locally Sparse Graphs

Deryk Osthus (HU Berlin)
(joint work with Daniela Kühn (Hamburg University))

Mader proved that for every positive integer r there exists a positive integer $g(r)$ such that every graph of minimum degree at least r and girth at least $g(r)$ contains a subdivision of TK_{r+1} of a complete graph K_{r+1}. We proved that a girth of 200 will do (or a girth of 15 if r is large). If the girth is at least 5, we still obtain a TK_p, where p is almost linear in the minimum degree.

Similarly, a graph of large girth (or even a $K_{s,s}$ free one) contains a large complete minor. For example, our results imply that Hadwiger's conjecture is true for all $K_{s,s}$-free graphs whose chromatic number is sufficiently large compared to s. Also, they can be applied to linkage problems.

The structure of 3-separations of a 3-connected matroid

JAMES OXLEY (LOUISIANA STATE UNIVERSITY)
(joint work with Charles Semple and Geoff Whittle)

More than twenty years ago, Cunningham and Edmonds showed that every 2-connected matroid M has a tree decomposition that enables one

(i) to canonically reconstruct M; and
(ii) to describe all 2-separations of M.

In particular, the 2-separations coincide with partitions induced by edges or special vertices of the tree. It is not possible to canonically reconstruct all 3-connected matroids from their 3-separations. However, every 3-connected matroid has an associated tree that displays all 3-separations, up to a certain natural equivalence. As with 2-connected matroids, these 3-separations are displayed either by edges or by special vertices of the associated tree.

Knots in spatially embedded graphs

RUDI PENDAVINGH (EINDHOVEN UNIVERSITY, THE NETHERLANDS)

Conway and Gordon show in a 1983 paper that K_7 is knotted in the sense that for each tame embedding $f : K_7 \hookrightarrow \mathbb{R}^3$ there is some circuit C of K_7 such that $f[C]$ is a nontrivial knot. Specifically, they show that

$$\sum_{C \in \mathcal{H}(K_7)} \alpha(f[C]) \text{ is odd, for all } f : K_7 \hookrightarrow \mathbb{R}^3,$$

where $\mathcal{H}(K_7)$ is the set of Hamiltonian circuits of K_7 and $\alpha(K)$ is the Arf invariant. Knottedness follows since $\alpha(\text{unknot}) = 0$. To similarly show that another graph G is knotted, we need a set of circuits $\mathcal{C}(G)$ to tale the role of $\mathcal{H}(K_7)$. Our main theorem is a characterization of such $\mathcal{C}(G)$ by an explicit list of parity constraints. It follows that all graphs obtained from $K_{1,1,3,3}$ by both ΔY- and $Y\Delta$-exchanges are knotted (there are 58 such graphs). In the set of 20 graphs obtained from K_7 by ΔY's and $Y\Delta$'s, only the 14 graphs gotten by only ΔY's are shown to be knotted. Since it is easy to see that ΔY's preserve knottedness, this means that the latter already follows from Conway and Gordon's Theorem. The second result is that each graph that has an embedding in the Klein bottle has a knotless embedding.

A-Path Packing Structure of Graphs

ANDRÁS SEBÖ (LEIBNIZ-IMAG, GRENOBLE)
(joint work with László Szegö (Egerváry Research Group, Budapest))

I stated and sketched the proof of Gallai-Edmonds type structure theorems for Mader's edge- and vertex-disjoint paths. I have also spent much time explaining what Gallai-Edmonds type structure theorem is and what are the possible applications. Our main motivations are algorithmic.

Graph capacity and graph entropy

Gábor Simonyi (Alfred Renyi Mathematical Institute, Budapest)

Asymptotic growth rates of graph invariants like the clique chromatic number and the chromatic number lead to well-investigated graph parameters as Shannon capacity and the fractional chromatic number. Sperner capacity is a generalization of the former to digraphs. Its extremal values over all orientations of an undirected graph lead to several open questions that are summarized in the talk. A probabilistic refinement of the latter (i.e. of the fractional chromatic number) leads to the notion of graph entropy and shows its relation to Gerde and McDiarmid's recent notion of imperfection ratio that is expressed by the following theorem.
Theorem. $\log imp(G) = \max_P\{H(G,p) + H(\overline{G},p) - H(p)\}$.
Where $imp(G)$ stand for the imperfection ratio and $H(G,p)$ is the entropy of graph G with respect to probability distribution p given on its vertices. $H(p)$ is the Shannon entropy of p, i.e., $-\sum_i p_i \log p_i$.

The Strong Perfect Graph Theorem

Robin Thomas (Georgia Tech)
(joint work with M. Chudnovsky, N. Robertson and P.D. Seymour)

A graph is *perfect* if for every induced subgraph the chromatic number is equal to the cardinality of a maximum complete subgraph. Berge conjectured in 1960 that a graph is perfect if and only if it has no induced subgraph isomorphic to a cycle of odd length, or the complement of such cycle. In the talk we briefly survey the history and relevance of perfect graphs, and then outline a proof of Berge's conjecture, found in joint work with M. Chudnovsky, N. Robertson and P.D. Seymour.

Extremal results for incomplete minors

Andrew Thomason (University of Cambridge)
(joint work with Joseph Myers)

We describe how the extremal function (that is, the average degree needed) for forcing a minor isomorphic to the graph H depends on the structure of H. For graphs H of order t the extremal function is in fact determined by the parameter

$$\gamma(H) = \min_w \frac{1}{t} \sum_{u \in H} w(u) \qquad \text{such that} \qquad \sum_{uv \in E(H)} t^{-w(u)w(v)} \le t\,,$$

where the minimum is over all assignments $w : V(H) \to \mathbf{R}^+$ of non-negative weights to the vertices of H.

The principal reason for the significance of this parameter is a threshold result, stating that H is a minor of almost no graphs of density lower than the threshold but H is minor of all (not just almost all) graphs of higher density. The threshold can be evaluated in terms of $\gamma(H)$.

The parameter $\gamma(H)$ itself is probably difficult to evaluate but ways are discussed in which it can be estimated more or less exactly for nearly all H.

k-color-critical graphs of girth q on a fixed surface

Carsten Thomassen (Tech. University Denmark)

Are there infinitely many $(k+1)$-colour-critical graphs of girth q on a fixed surface? This question has been answered in the literature except for one case: $k = 3$, $q = 5$. I have recently proved that in this case, the number of critical graphs is finite. As a consequence, there exists a polynomial time algorithm for finding the chromatic number of a graph of girth 5 on any fixed surface.

A polynomial algorithm for recognizing perfect graphs

Kristina Vuskovic (University of Leeds, UK)
(joint work with Gérard Cornuéjols, Wy and Xiuming Lin)

A hole is a chordless cycle of length at least 4. A hole is odd if it contains an odd number of edges, and otherwise it is even. A graph G contains a graph H if H is isomorphic to an induced subgraph of G. A graph is H-free if it does not contain H. By the Strong Perfect Graph theorem, recently proved by Chudnovsky, Robertson, Seymour and Thomas, a graph G is perfect if and only if neither G nor $\overline{G}$ contains an odd hole. In this talk I present an algorithm that tests whether G and $\overline{G}$ are odd hole free. The algorithm consists of 2 parts. In the first part, given an input graph G, a clean graph G' is produced or it is concluded that G or $\overline{G}$ is not odd-hole-free. And the second part tests whether G' contains an odd hole. The first part of the algorithm is done in joint work with Chudnovsky, Cornúejols, Lin and Seymour. The second part is done in 2 different ways, one way produced by Chudnovsky and Seymour, and the other by our team. Our approach uses the decomposition method. We use the decomposition theorem for odd-hole free graphs, obtained in joint work with Conforti and Cornuéjols, that states that an odd-hole-free graph is either basic (bipartite graphs, line graph of a bipartite graph or their complements) or it has a double star cutset or a 2-join.

Recent Progress in Matroid Representation Theory

Geoff Whittle (Victoria University, Wellington, New Zealand)

The basic questions of matroid representation theory have proved to be very persistent and difficult to resolve. However, there has been some progress in recent years using techniques inspired by the Graph Minors project of Robertson and Seymour. In the talk, I outlined recent results and discussed prospects for further progress.

K_p-minor in p-connected graphs

Cun-Quan Zhang (West Virginia University)
(joint work with K. Kawarabayashi, R. Luo, J. Niu)

Let G be a $(k+2)$-connected graph where $k \geq 5$. We proved that if G contains three complete graphs of order k, say L_1, L_2, L_3 such that $|L_1 \cup L_2 \cup L_3| \geq 3k-3$, then G contains a K_{k+2}-minor. This result generalizes some early results by Robertson, Seymour and Thomas (Combinatorica, 1993) for $k = 4$, and Kawarabayashi and Toft for $k = 5$.

Edited by Romeo Rizzi

Participants

Prof. Dr. Ron Aharoni
ra@techunix.technion.ac.il
Department of Mathematics
Technion
Israel Institute of Technology
Haifa 32000 – Israel

Prof. Dr. Martin Aigner
aigner@math.fu-berlin.de
Institut für Mathematik II (WE2)
Freie Universität Berlin
Arnimallee 3
D–14195 Berlin

Dr. Thomas Böhme
tboehme@theoinf.tu-ilmenau.de
Institut f. Mathematik
Technische Universität Ilmenau
Weimarer Str. 25
D–98693 Ilmenau

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

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. Matthew J. DeVos
matdevos@math.princeton.edu
Department of Mathematics
Princeton University
Fine Hall
Washington Road
Princeton, NJ 08544-1000 – USA

Prof. Dr. Reinhard Diestel
diestel@math.uni-hamburg.de
Mathematisches Seminar
Universität Hamburg
Bundesstr. 55
D–20146 Hamburg

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

Prof. Dr. Jim Geelen
jfgeelen@math.uwaterloo.ca
Dept. of Combinatorics and
Optimization
University of Waterloo
Waterloo, Ontario N2L 3G1 – Canada

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

Prof. Dr. Luis Goddyn
goddyn@math.sfu.ca
Dept. of Mathematics & Statistics
Simon Fraser University
Burnaby, B.C. V5A 1S6 – Canada

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

Prof. Dr. Penny Haxell
pehaxell@math.uwaterloo.ca
Department of Combinatorics and Optimization
University of Waterloo
Waterloo, Ont. N2L 3G1 – Canada

Prof. Dr. Hein van der Holst
Hein.van.der.Holst@cwi.nl
hvdholst@math.fu-berlin.de
Dennenlaan 1
NL-6711 RA Ede (Gld)

Andreas Huck
huck@math.uni-hannover.de
Voltmerstr. 41
D–30165 Hannover

Prof. Dr. Bill Jackson
w.jackson@gold.ac.uk
Dept. of Mathematical Sciences
Goldsmiths' College
New Cross
GB-London, SE14 6NW

Dr. Ken-ichi Kawarabayashi
k_keniti@math.keio.ac.jp
k_keniti@math.princeton.edu
Mathematics Department
Princeton University
Fine Hall
Washington Road
Princeton N.J. 08544-1000 – USA

Prof. Dr. Martin Kochol
kaifkoch@savba.sk
Mathematical Institute
Slovak Academy of Sciences
Stefanikova 49
814 73 Bratislava 1 – Slovakia

Prof. Dr. Alexandr V. Kostochka
sasha@math.nsc.ru
kostochk@math.uiuc.edu
Department of Mathematics
University of Illinois
234 Illini Hall, MC 382
1409 W. Green Street
Urbana, IL 61801-2975 – USA

Dr. Matthias Kriesell
kriesell@math.uni-hannover.de
Institut für Mathematik (A)
Universität Hannover
Welfengarten 1
D–30167 Hannover

Dr. Daniela Kühn
daniela.kuehn@math.uni-hamburg.de
Mathematisches Seminar
Universität Hamburg
Bundesstr. 55
D–20146 Hamburg

Dr. Imre Leader
i.leader@dpmms.cam.ac.uk
Dept. of Pure Mathematics and Mathematical Statistics
Center for Mathematical Sciences
Wilberforce Road
GB-Cambridge CB3 OWB

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

Prof. Dr. Wolfgang Mader
mader@math.uni-hannover.de
Institut für Mathematik
Universität Hannover
Welfengarten 1
D–30167 Hannover

Prof. Dr. Bill McCuaig
wmccuaig@netcom.ca
5268 Eglinton St.
Burnaby, B.C. V5G 2B2 – Canada

Prof. Dr. Bojan Mohar
bojan.mohar@uni-lj.si
FMF - Matematika
University of Ljubljana
Jadranska 19
1111 Ljubljana – Slovenia

Dr. Deryk Osthus
osthus@informatik.hu-berlin.de
Institut für Informatik
Humboldt-Universität zu Berlin
Unter den Linden 6
D–10044 Berlin

Prof. Dr. James Oxley
oxley@math.lsu.edu
Dept. of Mathematics
Louisiana State University
Baton Rouge, LA 70803-4918 – USA

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

Dr. Erich Prisner
Eppendorfer Weg 203
20253 Hamburg

Prof. Dr. Bruce Reed
breed@cs.mcgill.ca
School of Computer Science
McGill University
3480 University Street
Montreal Quebec H3A 2A7 – Canada

Prof. Dr. Bruce Richter
brichter@uwaterloo.ca
Department of Combinatorics and
Optimization
University of Waterloo
Waterloo, Ont. N2L 3G1 – Canada

Prof. Dr. Romeo Rizzi
romeo@science.unitn.it
Dip. di Informatica e
Telecommunicazioni
I-38100 Trento

Prof. Dr. Neil Robertson
robertso@math.ohio-state.edu
Department of Mathematics
Ohio State University
231 West 18th Avenue
Columbus, OH 43210-1174 – USA

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

Prof. Dr. Alex Scott
scott@math.ucl.ac.uk
Department of Mathematics
University College London
Gower Street
GB-London WC1E 6BT

Prof. Dr. Andras Sebö
Andras.Sebo@imag.fr
Laboratoire LEIBNIZ-IMAG
46, Avenue Felix Viallet
F-38031 Grenoble Cedex 1

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

Prof. Dr. Gabor Simonyi
simonyi@math-inst.hu
simonyi@renyi.hu
Alfred Renyi Mathematical Institute
of the Hungarian Academy of Science
Realtanoda u. 13-15
P.O.Box 127
H-1053 Budapest

Prof. Dr. Michael Stiebitz
stiebitz@mathematik.tu-ilmenau.de
Institut f. Mathematik
Technische Universität Ilmenau
Weimarer Str. 25
D–98693 Ilmenau

Prof. Dr. Zoltan Szigeti
szigeti@ecp6.jussieu.fr
Institut Mathématiques de Jussieu
Université Pierre et Marie Curie
175, Rue du Chevaleret
F-75013 Paris

Prof. Dr. Robin Thomas
thomas@math.gatech.edu
School of Mathematics
Georgia Institute of Technology
Atlanta, GA 30332-0160 – USA

Dr. Andrew Thomason
A.G.Thomason@dpmms.cam.ac.uk
Dept. of Pure Mathematics and
Mathematical Statistics
University of Cambridge
Wilberforce Road
GB-Cambridge CB3 OWB

Prof. Dr. Stephan Thomasse
Stephan.Thomasse@univ-lyon1.fr
Département de Mathématiques
Université Claude Bernard de Lyon I
LaPCS Bat. 101
43, Bd. du 11 Novembre 1918
F-69622 Villeurbanne Cedex

Prof. Dr. Carsten Thomassen
c.thomassen@mat.dtu.dk
Matematisk Institut
Danmarks Tekniske Universitet
Bygning 303
DK-2800 Lyngby

Prof. Dr. Kristina Vuskovic
vuskovi@comp.leeds.ac.uk
The School of Computing
University of Leeds
GB-Leeds LS2 9JT

Prof. Dr. Dominic J. A. Welsh
dwelsh@maths.ox.ac.uk
Mathematical Institute
Oxford University
24 - 29, St. Giles
GB-Oxford OX1 3LB

Prof. Dr. Geoff Whittle
Geoff.Whittle@vuw.ac.nz
School of Mathematical & Computing
Sciences
Victoria University of Wellington
PO Box 600
Wellington – New Zealand

Prof. Dr. Cun Quan Zhang
cqzhang@math.wvu.edu
Department of Mathematics
West Virginia University
Morgantown, WV 26506-6310 – USA