Graduate Programs

Computational Discrete Mathematics

Combinatorics, Geometry, and Computation

infos – schedules – reports

summer 2001

Contents

1 Introduction

The participating institutions are the three universities in Berlin - Free University, Humboldt University, Technical University - and the Konrad Zuse Center for Scientific Computing.

Discrete Mathematics comprises both classical domains, such as combinatorics and graph theory, as well as algorithmic aspects of problems. Computational discrete mathematics has substantially contributed to applications in coding theory and data encryption, in computational geometry and robotics, in network design and various other topics related to design and analysis of algorithms. The graduate program aims to improve the capability of the students to model and analyze discrete problems as well as to improve their ability to develop efficient algorithms to solve such problems. By the cooperation of mathematicians, working in the fields of combinatorics, graph theory, and geometry, with computer scientists and specialists in operations research, the students of the program can participate in comprehensive research and diverse lectures.

“Computational Discrete Mathematics”

Because this program finished September 30, 2000 there are only 2 Ph.D. students remaining.

They will present the progress in their work in their semester reports in this booklet.

“Combinatorics, Geometry, and Computation”

This European graduate program, which exists since January 2000, has basically the same faculty like the old one and is a joint initiative with scientists from the Departments of Computer Science and Mathematics at ETH Zurich, Switzerland. The existing cooperation between the main partners “Berlin” and “Zurich” will be extended by other partner institutes in Belgium, Great Britain, the Netherlands, Poland, the Czech Republic, and Hungary.

The duration of the program is planned for nine years. Currently, financial support for the first three-year period has been granted by Deutsche Forschungsgesellschaft (DFG). Presently the program supports 7 Ph.D. students and one postdoctoral fellowship. Eventually, the complete program will concurrently provide scholarships for 10 Ph.D. students and 2 postdoctorands. The partner program in Zurich has about the same size.

Discrete mathematics and theoretical computer science are the main research fields in the new program. In addition, geometrical aspects will play an important role. The major scientific goal of the program is to intensify the cooperation and interaction between discrete mathematics, algorithmics, and application areas. Therefore, especially at the partner institute in Zurich, faculty members working in application areas like geographic information systems, computer graphics, computer vision, and operations research, are participating. The program is subdivided into four basic research areas: combinatorics, geometry, optimization, and algorithms and computation. In each of these areas at least one of the partners in the program is an internationally renowned center of expertise.

In the new program we will continue to offer the weekly "Monday-lectures" and special schools once or twice per year. The lectures are held by our own faculty or guest professors in blocks consisting of one up to three meetings. They provide a state of the art survey of new developments in one of the subjects represented in the graduate program. In the colloquium new research results are reported. The Monday meetings take place alternately at the participating institutions in Berlin.

One of the essential ideas of the program is to let students not only study the immediate scientific area of their dissertation but benefit from the combined expertise of the scientists involved. For this purpose the partners will offer special advanced block courses in their area of specialization. Doctorands are required to participate in at least one block course within each of the four basic research areas. In addition, each student in the program will spend 6 and 12 months as a guest at the partner university. In return the partners will send their students to Berlin for the same amount of time. There will be one general workshop annually, bringing together all students and faculty involved in the program.

This exchange program is designed to give the students the unique chance to obtain insight into each of the research areas mentioned and therefore, in their scientific work, see possibilities that remain unknown to their peers staying with only one research group during their doctoral studies.

Contact and Information

You may obtain additional information from the coordinator of the program Monday to Thursday 10 a.m. – 1 p.m.. If you are interested in announcements of the program via e-mail you may send an e-mail to the coordinator who will place your name on a mailing list.

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2 Faculty of the Program and their Fields of Research

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- discrete geometry, computational combinatorics
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3 Partner Universities

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Prof. Dr. Jürg Nievergelt (Dept. Informatik)
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Prof. Dr. Bernt Schiele (Dept. Informatik)
Prof. Dr. Luc van Gool (Institut für Kommunikationstechnik)
Prof. Dr. Thomas Erlebach (Institut für Technische Informatik und Kommunikationsnetze)

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Prof. Dr. Ervin Győri

Technical University Eindhoven

Prof. Dr. Jan Karel Lenstra

Adam Mickiewicz University Poznań

Prof. Dr. Michal Karónski

University of Oxford

Prof. Dr. Colin McDiarmid
Prof. Dr. Dominic J.A. Welsh

Catholic University Louvain-la-Neuve

Prof. Dr. Michel Goemans
Prof. Dr. Laurence Wolsey

University of the Saarland

Prof. Dr. Kurt Mehlhorn
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Students who left the program in the last semester

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Schedule of the Semesters

summer semester 2001

start:	April 17, 2001
end:	July 21, 2001
break:	May 1, 2001
	May 24, 2001 (Himmelfahrt)
	June 04, 2001 (Pfingsten)

winter semester 2001/02

start:	October 15, 2001
end:	February 16, 2002
break:	December 24, 2001 – January 05, 2002

Workshop on Combinatorics, Geometry, and Computation

Monte Verità, Centro Stefano Franscini,

Ascona, Ticino, Switzerland

May 13-15, 2001

This is the first joint workshop of the graduate program Combinatorics, Geometry, and Computation (CGC) which is carried by the three Berlin Universities, ETH Zurich, and a number of partner institutions. The program started January 1, 2000. It offers scholarships for a Pre-Doc and a Graduate program, and for Post-Docs. Several advanced block courses, schools and colloquia are organized.

The workshop gives an overview of the research performed in the program, and promotes interaction between the participating sites. Several talks by students and faculty currently participating in the program are presented.

5 Lectures and Colloquia

The programs offer weekly "Monday-lectures" which are held by guests or faculty members. Usually, the first lecture gives an introduction to some special topic from the main research fields of the graduate programs. In the following colloquium new research results are reported by the students. You may find the schedule for the week at each participating university (memo boards of the working groups of the faculty members and next to the office of the program Takustr. 9, room 111 at FU Berlin). In addition we send out announcements via e-mail one week in advance. People or groups who are interested in getting information may ask Bettina Felsner (`bfelsner@inf.fu-berlin.de`) to place their names on a mailing list.

Schedule for the Current Semester

date	*lecture 14–16*	*coll. 16–17*	*location*
23.4.	D. Hochbaum, Berkley	M. Uetz, TU	TU
7.5.	J. Buchmann, Darmstadt	B. Broser, FU	FU
21.5.	A. Scott, London	Shi L., HU	HU
28.5.	M. Smid, Magdeburg	I. Streinu, Northhampton	FU
11.6.	C. Stein, Dartmouth	V. Kääb, TU	TU
18.6.	V. Strassen, Konstanz	L. Fleischer, Pittsburgh	TU
25.6.	G. Kalai, Jerusalem	J. Richter-Gebert, Zurich	TU
2.7.	L. Stougie, Eindhoven	D. Poensgen, ZIB	ZIB
9.7.	J. Blömer, Paderborn	O. Cheong, Utrecht	FU
16.7.	J.H. Kim, Seattle	M. Thimm, HU	HU

The lectures and colloquia take place regularly on Mondays, 14:15 - 15:45 and 16:00 - 17:00, respectively alternating at the participating institutions in Berlin. The locations are:

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Takustr. 9, room 005;

(HU) Humboldt–Universität zu Berlin, Institut für Informatik,
Rudower Chaussee 5, Raum 3.101;

(TU) Technische Universität Berlin, Fachbereich Mathematik,
Str. des 17. Juni 136, room MA 042;

(ZIB) Konrad–Zuse–Zentrum Berlin, Takustr. 7, lecture hall (room 2005)

The Lectures (in detail)

Monday, April 23, 2001 [FU]
DORIT HOCHBAUM, UNIVERSITY OF CALIFORNIA
The Pseudoflow Algorithm for the Maximum Flow Problem

We introduce an algorithm that solves the maximum flow problem without generating flows explicitly. The algorithm solves directly a problem we call the maximum s-excess problem. That problem is equivalent to the minimum cut problem, and is a direct extension of the maximum closure problem. A new certificate of optimality and a novel solution approach were influenced by the work of Lerchs and Grossmann, 1964, on the maximum closure problem. The concepts used also lead to a new parametric analysis algorithm generating all breakpoints in the amount of time of a single run.

The complexities of the pseudoflow algorithm, and the parametric analysis pseudoflow algorithm are $O(mn \log n)$ on a graph with n nodes and m arcs. The amount of time required for the generation of maximum flow, once the maximum s-excess solution is available, is $O(m \log n)$.

The pseudoflow algorithm leads to a pseudoflow-simplex algorithm that solves the maximum s-excess problem and has the best complexity known for parametric analysis using simplex. It can be used to solved the minimum cost network flow problem and several other related problems as well.

The pseudoflow algorithm is flexible and can start from any initial solution. This makes it particularly useful as a "warm start" algorithm for sensitivity analysis or within Lagrangean relaxation or branch and bound procedures applied to integer programming problems.

Monday, May 7, 2001 [FU]
JOHANNES BUCHMANN, UNIVERSITÄT DARMSTADT
How Secure is Public Key Cryptography?

The security of public key cryptosystems is based on the difficulty of solving computational problems in number theory. In this lecture I explain which computational problems are particularly relevant in public key cryptography and I discuss the difficulty of those problems.

Monday, May 21, 2001 [FU]
Alexander Scott, University College London
Reconstructing Subsets of the Plane

The k-deck of a set S in the plane is the collection of all its subsets of size k, given up to rigid motion. For instance, the 2-deck can be thought of as the set of distances (with multiplicity) determined by the set. We discuss the problem of when a finite subset of the plane is determined (up to rigid motion) by its k-deck. We also give some results for infinite subsets of the plane.

Monday, May 28, 2001 [FU]
Michiel Smid, Universität Magdeburg
Translating a Planar Object to Maximize Point Containment: Exact and Approximation Algorithms

Let C be a closed and bounded set in the plane and let S be a set of n points in the plane. We consider the problem of computing a translate of C that contains the maximum number of points of S. We start by giving two basic algorithms for this problem whose running times are roughly quadratic in n. Then we show how random sampling can be used to transform any deterministic algorithm for this optimal-placement problem into a Monte Carlo approximation algorithm. For sets C that satisfy a certain fatness condition, we use a simple bucketing technique to transform any algorithm for the optimal-placement problem into an algorithm that solves the same problem. The bucketing transformation can be implemented in the algebraic computation-tree model, or in a more powerful model using hashing. Applying the random-sampling and bucketing transformations to the two basic algorithms, we obtain a variety of results. For example, if C is a convex polygon with m vertices, we can solve the optimal-placement problem in the algebraic computation-tree model in $O(n \log n + mn \log(mk^*) + nk^*)$ time, where k^* is the number of points in an optimal placement of C. Also, for any constants $\epsilon, c > 0$, we can compute a placement of C that contains at least $(1-\epsilon)k^*$ points in $O(m + n\log(mn))$ time with error probability at most $e^{-c\sqrt{k^*}}$. Employing hashing techniques, we can implement this algorithm so that its running time is bounded by $O(m + n \log m)$. (This is joint work with Torben Hagerup and Rahul Ray.)

Monday, June 11, 2001 [FU]
CLIFFORD STEIN, DARTMOUTH COLLEGE
Scheduling to Simultaneously Optimize Two Criteria

Scheduling algorithms are designed to optimize many optimality criteria in a wide variety of scheduling models. To design an algorithm that is specialized to one paricular problem/object is well-motivated and justified, as an algorithm that works well for one scheduling problem/objective may perform poorly on a different scheduling problem/objective.

We give very general results about the existence of schedules which simultaneously minimize two criteria. We will focus mainly on results that apply to almost any scheduling environment, and apply to all pairs of metrics in which the first metric is one of maximum flow time, makespan, or maximum lateness and the second metric is one of average flow time, average completion time, average lateness, or number of on-time jobs. We will show that for almost all such pairs of metrics there exist schedules which are simultaneously close to optimal for both metrics.

We will also discuss algorithms for simultaneously optimizing two metrics.

Monday, June 18, 2001 [FU]
VOLKER STRASSEN, UNIVERSITÄT KONSTANZ
Degeneration of Linear and Bilinear Maps

Classification problems of linear algebra, such as those leading to the Jordan and Kronecker normal forms, find their natural place in the representation theory of quivers, dating from the early seventies. Degeneration of a hyperbola to a pair of straight lines is an instance of a principle that plays an important role in modern geometry. We will give an introduction to representations of quivers and their degeneration, then shift to an asymptotic point of view and resort to the asymptotic spectrum, a data structure that unifies geometry and computational complexity of bilinear maps, in particular of matrix multiplication.

Monday, June 25, 2001 [FU]
GIL KALAI, JERUSALEM
tba

Monday, July 2, 2001 [FU]

LEEN STOUGIE, TECHNISCHE UNIVERSITEIT EINDHOVEN

Approximation and Exact Algorithms for the Minimum Test Set Problem

The *minimum test set problem* is a problem that arises from practical problems in which tests have to be executed in order to investigate the effect of application of measures or drugs on a number of diseases. In fact the motivation for this research came from a request from the Agricultural University of Wageningen in The Netherlands concerning studies of potato diseases. Each potato race is vulnerable for a number of diseases. In order to investigate the effect of special treatments on the diseases a selection of potato races had to be made such that any pair of diseases could be distinguished from one another.

Presented more formally, in the minimum test set problem a set of items and a set of tests are given. Each test is a subset of the items, and is said to differentiate the items in the test from the items not in the test. The objective is to find a smallest subset of tests such that every pair of items is differentiated.

Algorithms for minimum test set problems are studied. For the general problem we define branch and bound algorithms, which we tested empirically, and appeared to be working remarkably well. We also analyse a greedy approximation algorithm for this problem from a worst-case point of view.

Finally, we pay attention to the special case in which each test contains exactly two items. This problem can be formulated as the optimization problem of packing paths of length two in a graph. The relation to this packing problem is exploited to show that this special minimum test set problem is NP-hard, contradicting a claim in [Garey & Johnson 1979], and in deriving performance guarantees for a series of local improvement heuristics. The latter are some of the first results on performance guarantees of local search heuristics in the literature.

The results presented are joint work with C.A.H. Hurkens, J.K. Lenstra, K. De Bontridder, Technische Universiteit Eindhoven, J.B. Orlin, Massachusetts Institute of Technology (MIT).

Monday, July 9, 2001 [FU]

JOHANNES BLÖMER, UNIVERSITÄT PADERBORN

Grids and Cryptography

Grids and cryptography are connected in two ways. On the one hand grid problems can be used to design cryptographic methods. On the other hand the LLL-algorithm for computing the shortest vector in a grid is one of the most important tools in the cryptoanalysis of many cryptographic methods. In the talk we will elaborate on both aspects. We will consider the complexity of computing the successive minima of a grid. This problem is the basis of an encryption method suggested by Ajtai some years ago. The average complexity of Ajtai's method corresponds to the worst-case complexity of computing the last successive minimum of a grid. In the second part of the lecture we will explain how the LLL-algorithm can be used to crack certain variants of the RSA-algorithm.

Monday, July 16, 2001 [FU]
Jeong Han Kim, Microsoft Research Seattle
Survey on the Nibble Method

Probabilistic methods have recently become a very powerful tool in extremal graph theory. The methods are useful in proving existence of combinatorial structures satisfying certain properties. Typically, one constructs an appropriate probability space and proves that a randomly chosen object (in the probability space) satisfies the desired properties with positive probability.

The nibble (or semi-random) method comprises one approach that has attracted much attention for its flexibility of construction. While the random greedy method usually constructs the desired object (independent set, matching, coloring, etc.) one by one, the nibble method constructs it in small random increments, which makes analysis easier. The method has been used to settle nice extremal graph theory problems related to partial Steiner systems, hypergraph matchings and colorings, chromatic numbers of triangle-free graphs, and Ramsey number $R(3, t)$. In this talk, which will be self-contained, we will describe the method and its application to the extremal graph theory problems.

The Colloquia (in detail)

Monday, April 23, 2001 [FU]
MARC UETZ, TECHNISCHE UNIVERSITÄT BERLIN
Project Scheduling and Minimum Cuts

This talk addresses a Lagrangian relaxation approach to a very general class of scheduling problems. The Lagrangian relaxation is a scheduling problem with start-time dependent costs, and it turns out that this problem reduces to a minimum cut problem in a directed graph.

To compute lower bounds on the optimum objective value of precedence- and resource-constrained scheduling problems via Lagrangian relaxation, a standard subgradient optimization can be used. In its core, this algorithm repeatedly solves minimum cut problems on the same graph with varying arc capacities.

In fact, this approach provides reasonable strong lower bounds in moderate computation times, and its efficiency is strongly correlated to the used minimum cut algorithm. In addition to the lower bound computation, the dual information from solutions of the Lagrangian relaxations can be used to obtain feasible solutions as well.

(Based on joint work with R. H. Möhring, A. S. Schulz, and F. Stork)

Monday, May 7, 2001 [FU]
BRITTA BROSER, FREIE UNIVERSITÄT BERLIN
Time Series Analysis

It is possible to draw conclusions about a (e.g. physical) system only from a series of measured values of this system. In general we have no further concrete information about it. Takens has proved an important theorem concerning this problem.

In practice this way of analysing systems might be the only one for getting some information about complicated systems. For its realisation we need a mathematical model, a procedure for solving the problem and an implementation.

In this talk we focus on an experiment with a magneto-elastic ribbon which is located in an oscillating magnetic field. We want to show that the motion of the ribbon is chaotic. For this we use a model based on the theorem of Takens. We construct a multivalued map which describes the dynamics of the system and is representable on a computer. For extracting some of the information we use index pairs. These are the basic concept of Conley index theory.

Monday, May 21, 2001 [FU]

Shi Lingshen, Humboldt-Universität zu Berlin

Cube Ramsey Numbers are Polynomial

Given a graph G, the Ramsey number $R(G)$ is the least integer p such that for all colorings of the edges of complete graph of order p, at least one of the monochromatic subgraphs contains a copy of G. In 1973, Burr and Erdős asked whether there is a constant c such that $R(Q_n) \leq c2^n$ where Q_n is an n-cube i.e. $R(Q_n)$ is linear in the order of Q_n. Though we are unable to settle this question, we can deduce a polynomial bound $R(Q_n) < 2^{(3+\sqrt{5})n/2+o(n)}$ by showing that for any positive constant c and bipartite graph $G = (U, V; E)$ of order n where the maximum degree of vertices in U is at most $c \log n$, $R(G) < n^{1+(c+\sqrt{c^2+4c})/2+o(1)}$. The proof is based on an idea of Kostochka and Rödl.

Monday, May 28, 2001 [FU]

Ileana Streinu, Smith College Northampton

Pseudo-Triangulations, Rigidity Theory and Efficiently Planning Non-Colliding Robot Arm Motions

Is it always possible to convexify a simple planar polygon with a continuous motion that rotates the fixed-length edges around the vertices, stays in the plane and avoids self-intersections? If so, then one can move continuously from any configuration of a simple fixed-edge-length polygon (or planar robot arm) to any other and maintain simplicity throughout. A positive answer to this long standing open question was given recently by Connelly, Demaine and Rote.

In this talk I describe an extension of this result to an effective, efficient and surprisingly simple combinatorial approach for planning the motion. It is based on a novel class of embedded minimally rigid planar graphs called pseudo triangulations, which possess rich combinatorial properties and can be characterized in many equivalent ways. I will discuss the rigidity-theoretical properties of pseudo triangulations and several algorithms for constructing and using them in the convexifying motion.

Monday, June 11, 2001 [FU]
Vanessa Kääb, Technische Universität Berlin
Critical Sets in AND/OR-Networks

An instance of the resource-constrained project scheduling problem can be represented by a set V of jobs, with integral processing times, a precedence digraph $D = (V, A)$, and a set $\mathcal{F} = \{F_1, \ldots, F_k\}$ of minimal forbidden sets, representing various resource constraints. Every such minimal forbidden set $F \in \mathcal{F}$ is a set of precedence-unrelated jobs that cannot be scheduled simultaneously but every proper subset can. The objective is to minimize the makespan, i.e. the latest completion time of any job.

To resolve the resource conflicts, we select a waiting job $j \in F$ for every minimal forbidden set. Such a selection $s = (j_1, \ldots, j_k)$ can be represented by a so-called AND/OR-network N, which contains the precedence digraph D as a subgraph. If the selection s is feasible it induces a well defined schedule, which can be computed efficiently in the network N.

Ignoring the resource conflicts, the problem reduces to finding the makespan subject to the precedence constraints represented by D. In an acyclic digraph the makespan is determined by at least one "longest path" in the graph. The jobs on such a path are often called critical. These critical jobs have the property that any increase in the processing time of one of them results in an increase of the makespan. Unfortunately one cannot identify a simple longest path or a single critical job in an AND/OR-network in general. However it is possible to detect critical sets of jobs. We will present three different definitions of "criticality" and show the connections between them. It turns out that two of these definitions form a blocking pair of clutters.

Monday, June 18, 2001 [FU]
Lisa Fleischer, Carnegie Mellon University, Pittsburgh
Approximating Minimum Cost Vertex Connectivity

In reliable network design, it is desired to build efficiently a network that stays connected even under a specified number of node or link failures. A natural formulation of this problem includes the Steiner tree problem as a special case, so is not only NP-hard, but is also hard to approximate to within an arbitrarily small constant factor of optimal. We develop factor 2 approximation algorithms for some non-trivial special cases: the survivable network design problem studied by Monma and Shallcross, and Grötschel, Monma, Stoer in which all connectivity requirements are in the set $0, 1, 2$; and the element connectivity problem introduced by Jain, et al. in which only links and Steiner nodes may fail. This improves on previous approximation guarantees of 3 and $\log |V|$ respectively, and match the best known approximation guarantees for the easier problem when only links may fail. We will also discuss the possibility of extending our techniques to more general vertex connectivity problems.

Monday, June 25, 2001 [FU]
Jürgen Richter-Gebert, ETH Zürich
Pappos Theorem — Ten Proofs and Three Variations

The main topic of this talk is to show how inspection of algebraic equations can be used to generalize proofs of geometric theorems. We take the well known Theorem of Pappos about nine points and nine lines in the projective plane as a starting point for our investigation. Starting from there we will look at several different ways of proving this theorem. Each way of proving leads to different kinds of generalization. By this we will obtain a large collection of geometric incidence theorems including many well known theorems in euclidean and projective geometry. In particular we will see, that the structure of cycles in geometric simplicial complexes is responsible for the algebraic cancelation patterns that arise in many proofs of geometric theorems.

Monday, July 2, 2001 [FU]
Diana Poensgen, Konrad-Zuse-Zentrum Berlin
Online Call Admission in Optical Networks

In optical telecommunication networks, data is sent via glass fibers as optical signals of a certain wavelength without converting them into electronical form at intermediate nodes. A connection is implemented by one or several *lightpaths*, where each lightpath is a combination of a path and a wavelength.

In the problem of Online Call Admission in Optical Networks, we are given a graph together with a set of wavelengths. *Connection requests*, also referred to as *calls*, arrive in an online fashion, i.e., an online algorithm learns the next call only after having processed the previous one. A call specifies a pair (s, t) of nodes to be connected and its *demand*, that is, the number b of lightpaths needed. The task of an online algorithm is to decide which calls to accept and which to reject. If a call is accepted, a valid routing has to be provided, i.e., b paths connecting nodes s and t, each together with a wavelength, have to be implemented. The crucial restriction is that on every edge, each wavelength can be used by at most one lightpath (*wavelength conflict constraint*). Consequently, previously accepted calls restrict the availability of wavelengths for the implementation of further lightpaths. When a call with demand b is accepted, it contributes b to the overall profit. The objective is to maximize the profit.

After giving a short introduction to the area of online optimization and competitive analysis, we review an online algorithm for the special case of the problem where all demands equal 1, proposed by Awerbuch, Azar, Fiat, Leonardi and Rosén. We then present a competitive online algorithm for the general case in which calls may request up to χ wavelengths, where χ is the number of eligible wavelengths on any edge. This is the first competitive algorithm for the general case.

Monday, July 9, 2001 [FU]

OTFRIED CHEONG, UNIVERSITEIT UTRECHT

Paths with bounded curvature

Motion planning with non-holonomic constraints, such as the restriction on the radius of curvature natural for car-like robots, is of considerable practical interest, but even simple theoretical questions turn out to be quite hard. We discuss some fundamental results on bounded curvature paths that can be applied to robot motion planning. In particular, we characterize the region of all points inside a convex polygon that can be reached by a bounded-curvature robot from a given starting configuration. We also show that no robot can effectively visit a sequence of points that are given on-line (that is, one by one) using a bounded curvature path, while giving an algorithm to compute a short path if the whole sequence is given in advance.

(Joint work with Hee-kap Ahn, Kyung-Yong Chwa, Jae-Ha Lee, Jiri Matousek, Woo-Cheol Kwon, Sung-Yong Shin, and Antoine Vigneron)

Monday, July 16, 2001 [FU]

MARTIN THIMM, HUMBOLDT–UNIVERSITÄT ZU BERLIN

On the Approximability of the Steiner Tree Problem

Suppose that we are given a graph, a metric given by edge weights and a set T of required vertices called *terminals*. The *minimum Steiner tree problem* consists of finding a tree of minimum weight that spans all vertices in T.

We show that it is NP-hard to approximate the minimum Steiner tree problem within $\frac{136}{135}$. This improves the currently best known lower bound by a factor of three.

The reduction is from Håstad's nonapproximability result for maximum satisfiability of linear equations modulo 2. The improvement on the nonapproximability ratio is mainly based on the fact that our reduction does not use variable gadgets. This idea was introduced by Papadimitriou an Vempala.

On the occasion of the 85. Birthday of

Prof. Dr. Dr. h.c. Hanfried Lenz

the department of Mathematics and Computer Science of the Free University Berlin is organizing a colloquium on

Saturday, May 5, 2001.

LOCATION: Free University Berlin, Institut für Informatik,
Takustr. 9, 14195 Berlin, Lecture Hall

INVITED TALKS:

PETER GRUBER (TU Wien):
Große Persönlichkeiten der Konvexgeometrie des 20. Jahrhunderts

FRED PIPER (Royal Holloway College, London):
From Lenz–Barlotti to Chryptography

DIRK HACHENBERGER (Univ. Augsburg):
Algebraische Methoden in der Ganzzahligen Optimierung

PETER GRITZMANN (TU München):
Über einige geometrische Probleme und ihre Anwendungen

INFORMATION: R.–H. Schulz (schulz@math.fu-berlin.de)

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http://www.math.fu-berlin.de/user/schulz/lenz.html

6 Applicable Courses of the Participating Universities, Summer 2001 (in German)

6.1 Freie Universität Berlin

Algorithmen für Fortgeschrittene [Vorlesung]

Dozent: Alt; Vorlesungszeit: Di, Do 10-12 Uhr, 4-stündig;
Veranstaltungsort: Takustraße 9, SR 055 (17.04.).
Übungen: n.V., 2-stündig;

INHALT: weiterführende Themen aus der Algorithmentheorie, insbesondere Approximationsalgorithmen für NP-schwere Probleme, arithmetische Algorithmen für ggT, Multiplikation und Primzahltest mit Anwendungen in der Kryptographie, RSA-Kryptosystem, probabilistische Algorithmen

Literatur: T H. Cormen, C. E. Leiserson und R. L. Rivest. Introduction to Algorithms. MIT Press/McGraw-Hill, 1990 und Originalarbeiten.

Dynamische Geometrie [Vorlesung]

Dozent: Kortenkamp; Vorlesungszeit: Di 10-12 Uhr, 2-stündig;
Veranstaltungsort: Takustraße 9, SR 037.
Übungen: n.V., 2-stündig;

INHALT: In der Vorlesung werden die mathematischen und informatischen Grundlagen dynamischer Geometriesoftware (siehe z.B. Cinderella, `http://www.cinderella.de`) vermittelt und durch eigene Programmierübungen vertieft.

Parallele Algorithmen in der Bioinformatik [Vorlesung]

Dozent: Reinefeld, Steinke; Vorlesungszeit: n.V., 4-stündig;
Veranstaltungsort: Takustraße 9.
Übungen: n.V.;

INHALT: Nach einem kurzen Überblick über die Bioinformatik werden die wichtigsten molekularbiologischen Grundlagen behandelt und eine Einführung in paralleles Programmieren gegeben. Der Schwerpunkt der Vorlesung liegt auf der Vorstellung von Algorithmen für das Sequenz-Alignment (global alignment, multiple alignment) und deren parallelen Varianten. Weitere Themen in Stichpunkten: phylogenetische Bäume, parallele Threadingverfahren, Erzeugung von 3D-Strukturen, Datenrepräsentationen, Nutzung von Web-Portalen. In den Übungen werden Algorithmen parallelisiert und auf einer Cray T3E bzw. einem Cluster erprobt.

Offene Probleme der diskreten Geometrie [Vorlesung]

Dozent: Braß; Vorlesungszeit: Di 16-18 Uhr, 4-stündig;
Veranstaltungsort: Takustraße 9, SR 055.

Inhalt: In dieser Veranstaltung werde ich eine Reihe offener Probleme im Bereich der Diskreten Geometrie vorstellen, die unter anderem Polygone, Polyeder, Zellzerlegungen, Packungen, Überdeckungen, Gitterpunkte und ähnliche Objekte betreffen. Falls Interesse besteht, werde ich auch eine Arbeitsgruppe anbieten, in der wir gemeinsam an einigen dieser Probleme arbeiten werden. Damit wird exemplarisch eine Einführung in die wissenschaftliche Arbeit gegeben.

Geometrische Approximationsalgorithmen [Vorlesung]

Dozent: Hoffmann; Vorlesungszeit: Mi 10-12 Uhr, 4-stündig;
Veranstaltungsort: Takustraße 9, SR 039 (18.04.).
Übungen: Fr 10-12 Takustraße 9, SR 037 (20.04.), 2-stündig;

Inhalt: Die Vorlesung bietet einen Überblick über den Entwurf und die Analyse von Approximationsalgorithmen für geometrische Optimierungsprobleme. Viele dieser auch aus Anwendersicht interessanten Probleme sind algorithmisch schwer (NP-schwer), so dass man nicht auf effiziente algorithmische Lösungen hoffen kann. Ausweg sind dann meistens heuristische Verfahren oder aber Approximationslösungen. Der Vorteil von letzteren ist, dass sie für alle Eingabeinstanzen Lösungen mit nachweisbarem Gütefaktor liefern. Im Mittelpunkt werden neuere Approximationsergebnisse für geometrische Tourenprobleme (wie das bekannte euklidische Travelling Salesman Problem) stehen, an denen auch klar wird, wie algorithmischer “Fortschritt” von neuen Einsichten über die zu Grunde liegenden geometrischen Strukturen abhängt.

Literatur: D. Hochbaum (ed.), Approximation Problems for NP-Complete Problems PWS Publishing Company, 1997.

Seminar über Kryptographie [Seminar]

Dozent: Aigner; Veranstaltungszeit: Di 14 - 16 Uhr, 2-stündig;
Veranstaltungsort: Arnimallee 3, SR 119.

Seminar für Diplomanden und Doktoranden [Seminar]

Dozent: Aigner; Veranstaltungszeit: Di 16 - 18 Uhr, 2-stündig;
Veranstaltungsort: Arnimallee 2, Villa.

Ausgewählte Kapitel aus Diskreter und Algorithmischer Geometrie [Seminar]

Dozent: Felsner; Veranstaltungszeit: n.V., 2-stündig;
Veranstaltungsort: Takustraße 9, SR 051.

Inhalt: Im Seminar werden klassische und neuere Arbeiten aus dem Bereich der geometrischen Graphen und der Geradenarrangements behandelt. Geometrische Graphen sind Graphen die mit einer nicht notwendig kreuzungsfreien Zeichnung in der Ebene gegeben sind. Ausgehend von der klassischen Extremaltheorie für Graphen werden die in den letzten Jahren entwickelten Grundzüge einer Extremaltheorie für geometrische Graphen nachvollzogen. Und Anwendungen der Theorie bei Untersuchungen von Geradenanordnungen besprochen.

Rekonstruktion und Vereinfachung von Oberflächen [Seminar]

Dozent: Rote; Veranstaltungszeit: n.V., 2-stündig;
Veranstaltungsort: Takustraße 9.

Inhalt: Bei der Aufnahme von dreidimensionalen Objekten durch Laserscanner oder ähnliche Geräte entsteht zunächst als Rohdaten ein Punkthaufen oder eine Serie von Punkthaufen. Die ersten Schritte vor der Weiterverarbeitung dieser Daten ist die Rekonstruktion einer Fläche, die durch die Punkte verläuft, sowie gegebenfalls die Vereinfachung und Reduktion der Datenmenge auf ein vernünftiges Maß. Für diese Aufgaben sind verschiedene Verfahren vorgeschlagen worden, die wir in diesem Seminar kennenlernen wollen.

Literatur: Originalarbeiten.

Algorithmen für das World Wide Web [Seminar]

Dozent: Alt, Knauer; Veranstaltungszeit: Di 16-18 Uhr, 2-stündig;
Veranstaltungsort: Takustraße 9, SR 039.

Inhalt: Das Internet und insbesondere das WWW wirft eine Vielzahl von neuen algorithmischen Fragen auf. Wir wollen uns in diesem Seminar einigen davon zuwenden und einen Einblick in aktuelle Forschungsarbeiten in diesem Umfeld gewinnen. Im Einzelnen sollen folgende Themen angesprochen werden:

- Datenstrukturen für Suchmaschinen
- Qualitätsbeurteilung für Webseiten
- Datenkompression
- Sicherheit im Internet
- Der WWW-Graph und seine Eigenschaften
- Routing- und Schedulingprobleme im Internet

Literatur: Originalarbeiten.

Diplomanden- und Doktorandenseminar - Theoretische Informatik [Seminar]

Dozent: Alt, Braß, Felsner, Kriegel, Rote; Veranstaltungszeit: Di, Do 12-13 Uhr, 3-stündig;
Veranstaltungsort: Takustraße 9, SR 055.

Inhalt: Vorträge über eigene Forschung und Originalarbeiten aus der Theoretischen Informatik, insbesondere Algorithmen. Die Ankündigungen werden jeweils gesondert gegenüber Raum 111 in der Takustraße 9 ausgehängt. Siehe auch Semesterheft zum Studienschwerpunkt Effiziente Algorithmen.

Programmieren mit Java [Kurs]

Dozent: Kortenkamp; Veranstaltungszeit: 2.-13.4.01
Veranstaltungsort: Takustraße 9, HS / Übungsräume.

Inhalt: Einführung in die imperative und objektorientierte Programmierung mit Java und Vermittlung von grundlegenden Programmierkenntnissen. Praktische Rechneraufgaben in den Übungen.

6.2 Humboldt–Universität zu Berlin

Graphen und Algorithmen [Vorlesung]

Dozent: Hougardy; Vorlesungszeit: Mo, Mi 11-13 Uhr, 4-stündig;
Veranstaltungsort: Rudower Chaussee 25, Raum 3.101
Übungen: Hougardy, Mi 13-15 Uhr, 2-stündig; Ort wie VL;

Inhalt: Die VL setzt den im WS 2000/2001 abgehaltenen Teil 1 fort. Es werden anspruchsvollere Prinzipien der Graphenalgorithmen, insbesondere für

NP-schwere Probleme betrachtet, u.a. Approximationsalgorithmen und randomisierte Verfahren. Die VL wird durch Übungen begleitet. Kenntnis des ersten Teils der VL ist wünschenswert, aber nicht notwendig.

Kombinatorische Optimierung [Vorlesung]

Dozent: Proksch; Vorlesungszeit: Fr 11-13 Uhr, 2-stündig;
Veranstaltungsort: Rudower Chaussee 25, Raum 4.110

Inhalt: Diese VL setzt den im Wintersemester begonnenen Halbkurs fort und widmet sich linearen Optimierungsproblemen und deren Lösungsverfahren wie Simplexalgorithmus oder Ellipsoidmethode. Im begleitenden Praktikum sollen die lokalen Suchverfahren aus dem Wintersemester für einfache Anwendungen implementiert werden.

Färbungsalgorithmen [Vorlesung]

Dozent: Taraz; Vorlesungszeit: Do 11-13 Uhr, 2-stündig;
Veranstaltungsort: Rudower Chaussee 25, Raum 4.110

Inhalt: Wir untersuchen Verfahren, die den Knoten eines Graphen Farben zuweisen, so dass benachbarte Knoten nicht die gleiche Farbe erhalten, und dabei mögichst wenig Farben verwenden. Diese Problemstellung findet Anwendung in vielen unterschiedlichen Bereichen, wie beispielsweise bei der Register- oder Frequenzzuweisung.

Bioinformatik [Vorlesung]

Dozent: Gröpl, Thimm; Veranstaltungszeit: Di 9-11 Uhr, 2-stündig;
Veranstaltungsort: Rudower Chaussee 25, Raum 4.111

Inhalt: Im Seminar werden Algorithmen und Datenstrukturen behandelt, die in der Bioinformatik zum Einsatz kommen. Nach einer Einführung in die Grundlagen betrachten wir ausgewählte Themen wie Sequenzierung und Sequenzvergleich, phylogenetische Bäume, genome rearrangements und Proteinstruktur.

Algorithmen und Kombinatorik [Seminar]

Dozent: Osthus, Proksch; Veranstaltungszeit: Mi 8-10 Uhr, 2-stündig;
Veranstaltungsort: Dorotheenstraße 24, Raum 213

Inhalt: Viele in der Praxis auftretende Aufgaben lassen sich als kombinatorische Optimierungsprobleme oder als graphentheoretische Fragestellungen modellieren. Von Sortieren bis kürzesten Wegen, von Matching bis zum 5-Farben-Theorem; in diesem Proseminar wollen wir einige der grundlegenden Verfahren und Algorithmen kennenlernen, die zur Lösung dieser Probleme und ihrem Verständnis beitragen.

6.3 Technische Universität Berlin

Graphen- und Netzwerkalgorithmen [Vorlesung]

Dozent: Möhring; Vorlesungszeit: Di, Mi 16-18 Uhr, 4-stündig;
Veranstaltungsort: Mathematikgebäude TU Berlin, Di/Mi: MA 043/MA 041

INHALT: Viele praxisrelevante Fragestellungen führen auf Optimierungsprobleme in Graphen oder Netzwerken. Beispiele sind kürzeste Wege in Verkehrsnetzen, Optimierung von Verkehrsflüssen, ausfallsichere Telekommunikationsnetze, Steuerung von Produktionsabläufen u.v.a. Die Vorlesung behandelt grundlegende Graphen- und Netzwerkalgorithmen (kürzeste Wege, maximale und kostenminimale Flüsse, Zuordnungsprobleme ...) und die dazu benötigten mathematischen Grundlagen der Graphentheorie, Komplexitätstheorie und Optimierung. Insbesondere werden auch Problemklassen gemäß ihrer Komplexität klassifiziert (effizient lösbar, NP-schwer) und Techniken zur Lösung NP-schwerer Probleme (zu denen die meisten Praxisprobleme gehören) behandelt.

Literatur: B. Korte, J. Vygen: Combinatorial Optimization: Theory and Algorithms, Springer, 2000

Weitere Informationen zu dieser Lehrveranstaltung finden Sie unter: `http://www.math.tu-berlin.de/Vorlesungen/SoSe01/GuNA/`

Theorie und Praxis der Kombinatorischen Optimierung [Vorlesung]

Dozent: Grötschel; Vorlesungszeit: Di, Mi 14-16 Uhr, 4-stündig;
Veranstaltungsort: Mathematikgebäude TU Berlin, Di/Mi: MA 366/MA 367.

INHALT: Behandelt werden u. a. Schnittebenenverfahren, Polyedrische Kombinatorik, Branch&Bound, Branch&Cut, Heuristiken für schwere Probleme, lineare und nichtlineare Relaxierungen. Bei dieser Vorlesung handelt es sich um eine der Vorlesungen im Studienschwerpunkt Algorithmische Diskrete Mathematik, die als Algorithmische Diskrete Mathematik III gewählt werden können.

Insbesondere werden einige Themenbereiche der Vorlesungen ADM I und II vertieft.

Weitere Informationen zu dieser Lehrveranstaltung finden Sie unter: `http://www.math.TU-Berlin.de/Vorlesungen/SS01/TheoPraxKombOpt/`

Graphentheorie [Seminar]

Dozent: Jung; Veranstaltungszeit: n.V., 4-stündig;
Veranstaltungsort: Mathematikgebäude TU Berlin.

Doktoranden- und Diplomanden-Seminar [Seminar]

Dozent: Möhring ; Veranstaltungszeit: Do 10-12 Uhr, 4-stündig;
Veranstaltungsort: Mathematikgebäude TU Berlin, MA 645.

Inhalt: Vorträge von Doktoranden, Diplomanden und Mitarbeitern zu aktuellen Forschungsthemen in der kombinatorischen Optimierung und algorithmischen Graphentheorie

Grundlegende Algorithmen der Optimierung [Seminar]

Dozent: Grötschel, Lutz; Veranstaltungszeit: Das Seminar wird als Blockseminar am Wochenende 22.-24. Juni im Konrad-Zuse-Zentrum durchgeführt. 4-stündig;

Inhalt: Es werden Originalartikel und entsprechende Kapitel aus einschlägigen Lehrbüchern behandelt, die einen Überblick verschaffen über algorithmische Ideen, die sich in der Optimierung als wichtig erwiesen haben.

Kombinatorische Geometrie: Polytope [Seminar]

Dozent: Joswig; Vorlesungszeit: Mi 14 -16 Uhr, 2-stündig;
Veranstaltungsort: Mathematikgebäude TU Berlin, MA 645.

Inhalt: Im Sommersemester 2001 biete ich ein Seminar über Polytope im Rahmen des Studienschwerpunktes "Kombinatorische Geometrie" an. Zielgruppe sind Studierende aller Mathematik-Studiengänge im Hauptstudium. Im Rahmen des Seminars tragen die Teilnehmer über neuere (überwiegend englischsprachige) mathematische Originalarbeiten vor. Außer der Teilnahme am Seminar (2 Semesterwochenstunden) besteht die wesentliche Aufgabe darin, sich über die Semesterferien in die Materie einzuarbeiten.

Weitere Informationen zu dieser Lehrveranstaltung finden Sie unter:
`http://www.math.tu-berlin.de/ joswig/lectures/poly01VL`

7 Reports of the Students for the Winter Semester 2000/2001

Dr. Hendricus van der Holst

Supervisor:	Prof. Dr. Martin Aigner
Field of Research:	Graph Theory
Topic	Topological Graph Theory and the Colin de Verdière invariant
Postdoc Student	at the Program “CGC” since November 2000

Field of Research

The Colin de Verdière invariant $\mu(G)$ of a graph G, introduced by Y. Colin de Verdière in [1], is defined as the maximum corank of any matrix $M \in O_G$ with exactly one negative eigenvalue and such that it fulfills a certain transversality condition. Here O_G denotes the set of a symmetric matrices $M = (m_{i,j})$ with $m_{i,j} < 0$ if ij is an edge of G and $m_{i,j} = 0$ if $i \neq j$ and ij is a not an edge.

This invariant has the intriguing property that planar and flat graphs are described by it as those graphs G with $\mu(G) \leq 3$ and $\mu(G) \leq 4$, respectively. The open problem is to describe, if possible in topological terms, the graphs for which $\mu(G) \leq 5$. Here two possible candidates comes to mind.

The first candidate is called the class of 4-flat graphs. This class is defined as those graphs such that its 2-closure can be embedded into 4-space. The 2-closure of a graph G is defined as the regular 2-cell complex obtained from G by attaching to each circuit C of G a 2-disc with boundary C. It has been shown [5] that $\lambda(G) \leq 4$ if G is 4-flat. Here $\lambda(G)$ is a graph invariant [4] which seems to lay close to $\mu(G)$ (it is known that $\mu(G) - \lambda(G) \leq 2$ [6], but there is no bound known for $\lambda(G) - \mu(G)$). The graphs that can be obtained by applying ΔY- and $Y\Delta$-transformations from K_7 and $K_{3,3,1,1}$ have $\mu(G) = 6$ and it is shown [3] by using the Van Kampen obstruction (see [8]) that these graphs are not 4-flat.

The second candidate is the class of graphs that can be embedded into 3-space such that no circuit forms a nontrivial knot. Conway and Gordan [2] showed that K_7 does not belong to this class and Pendavingh [7] improved this result by showing that the graphs that can be obtained from $K_{3,3,1,1}$ by applying ΔY- and $Y\Delta$-transformations and the graphs that can be obtained from K_7 by applying ΔY-transformations cannot be embedded knotlessly in 3-space. Because the collection of graphs that can be obtained from K_7 by applying ΔY- and $Y\Delta$-transformations is really larger than the collection of graphs that can be obtained by applying only ΔY-transformation, the open problem here is whether the remaining graphs cannot be embedded knotlessly in 3-space.

Addition to Field of Research

Before I came to Berlin, I had a stay in Brazil, where I worked with the Combinatorics Research Group at São Paolo on problems in approximation theory. We obtained two results and these will be written down.

References

[1] Y. Colin de Verdière. On a new graph invariant and a criterion of planarity. In N. Robertson and P. Seymour, editors, *Graph Structure Theory*, volume 147 of *Contemporary Mathematics*, pages 137–147. American Mathematical Society, Providence, Rhode Island, 1993.

[2] J. H. Conway, and C. McA. Gordan. Knots and Links in Spatial Graphs. *Journal of Graph Theory*, 7:445–453, 1983.

[3] H. van der Holst. In preparation.

[4] H. van der Holst, M. Laurent, and A. Schrijver. On a minor-monotone graph invariant. *J. Comb. Theory, Ser. B.*, 65:291–304, 1995.

[5] H. van der Holst, and R. Pendavingh. In preparation.

[6] R. Pendavingh. On the relation between two minor-monotone graph parameters. *Combinatorica*, 18(2):281–292, 1998.

[7] R. Pendavingh. Knots in spatially embedded graphs. manuscript

[8] D. Repovš, and A. B. Skopenkov. Embeddability and Isotopy of Polyhedra in Euclidean Spaces. *Proceed. of the Steklov Institute of Math.*, 212:163–178,1996.

Laura Heinrich-Litan

Supervisor:	Prof. Dr. Helmut Alt
Field of Research:	Nearest Neighbor Search
Topic	Exact Nearest Neighbor Search in High Dimensions
PhD Student	at the Program "CDM" since April 1999

Field of Research

The *nearest neighbor problem* is the problem of constructing an efficient data structure storing a set P of n points in $\mathbb{R}^d$ for answering *nearest neighbor queries*. In a nearest neighbor query some point $q \in \mathbb{R}^d$ is specified and the (some) point in P closest to q has to be determined.

In many applications, the dimension d of the search space is quite high and can reach several hundreds or even several thousands. Therefore, running times and storage requirements exponential in d are prohibitive in these cases. All query algorithms are in fact competing with the *brute-force* method which requires no preprocessing, storage only the set P, and has a query time of $O(nd)$ for all L_p-distances, $1 \leq p \leq \infty$.

Results

My work concentrates on exact nearest neighbor search with respect to the L_∞-distance. The first algorithms (they are called *cube-methods*, for more details see reports in the previous semester booklets) I have considered require no preprocessing and storage only for the point set P. Their average runtime assuming that the set P of n points is drawn randomly from the unit cube $[0,1]^d$ under uniform distribution is essentially $\Theta(nd/ln\ n)$ thereby improving the brute-force method by a factor of $\Theta(1/ln\ n)$. I generalized the methods and their analysis to other "well-behaved" probability distributions and to the important problem of finding the k nearest neighbors to a query point. The k nearest neighbors from P to some query point $q \in [0,1]^d$ can be found with an expected asymptotic runtime of $O\left(\frac{nd}{\ln(n/k)} + n + dk + d\log d\right)$ if the points of P are independently drawn at random from $[0,1]^d$ under uniform distribution. The results are summarized in [1].

In order to improve the query time of the algorithms I looked for preprocessing methods. The idea is to partition the point set into few classes such that for each class orthogonal range searching can be done efficiently. I directed my attention to monotone sequences in $\mathbb{R}^d$. It is easy to see that for a monotone sequence of length r in $\mathbb{R}^d$ orthogonal range searching can be done efficiently in time $O(d \log r)$. I have also proven that the nearest neighbor to a query q in a set which is a monotone sequence of length r in $\mathbb{R}^d$ can be computed by binary search in time $O(d \log r)$. In order to get a small partition into monotone subsequences long longest monotone subsequences are needed. A trivial lower bound for the length of the longest monotone subsequence is $\lceil n^{\frac{1}{2^{d-1}}} \rceil$. I have shown in [4] that there exists a set of n points in $\mathbb{R}^d$ which has no monotone subsequences of length larger then $\lceil n^{\frac{1}{2^{d-1}}} \rceil$. This implies that the size of partition may be too large. To overcome this I look for a partition into subsequences which are monotone only with respect to some of the variables. For the analysis I used the fact (see [2]) that that for d'-dimensional n points, independent und uniformly distributed on $[0,1]^{d'}$, the length of a longest subsequence which is monotone with respect to the *dominance order* converges to $c_{d'} \cdot \sqrt[d']{n}$ with increasing n, where $c_{d'}$ is a constant depending on d' with $\lim_{d' \to \infty} c_{d'} = e$. In some special cases the expected query time is $O(\frac{dn^{1-\frac{1}{\sqrt{d}}}}{\ln n} + n^{1-\frac{1}{\sqrt{d}}})$ providing a speedup factor of $\Omega(n^{\frac{1}{\sqrt{d}}})$ with respect to the *cube-methods*. The complete analysis is under investigation.

Furthermore this semester I completed the analysis of a method which provides tradeoffs between the space complexity of the data structure and the time complexity of the query algorithm. The average runtime of the query algorithm assuming that the set P is drawn randomly from the unit cube $[0,1]^d$ under uniform distribution is essentially $\Theta(d \cdot (1 + \frac{\sqrt[d]{n}}{m})^d)$ where $m \geq 2$ is a parameter. The expected storage required by the data structure is $\Theta(d(m + \sqrt[d]{n})^d)$. The results are summarized in [4].

Activities

- I took part at the course *Auswählen und Entscheiden*, held by Peter Brass.
- I took part at the practical course *Algorithmische Softwarebibliotheken*, held by Helmut Alt and Christian Knauer.
- Participation at the lectures and colloquia of the graduate program.
- Preparation of the papers [1], [3] and [4].

Preview

- Talk in the colloquim of the graduate program on January 29, 2001.
- Participation at ADIMMO 2001, March 15-16, 2001, Trier.
- Participation and talk at the Dagstuhl Seminar on Computational Geometry, March 18-23, 2001.
- Participation and talk at the 17th European Workshop on Computational Geometry, March 26-28, 2001, Berlin.
- Participation and talk at Workshop on Combinatorics, Geometry, and Computation, May 13-15, 2001, Ascona.
- Participation and talk at the 17th ACM Symposium on Computational Geometry, June 2001, Medford.

References

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Vanessa Kääb

Supervisor:	Prof. Dr. Rolf H. Möhring
Field of Research:	Scheduling
Topic:	Local Search Algorithms
PhD Student	at the Program "CGC" since March 2000

Field of Research

In the last issue of the semester booklets I have written about the field of my research. Therefore I will concentrate on the specific topic I am at the moment working at. In resource-constrained project scheduling, a set $V = \{1, 2, \dots, n\}$ of jobs has to be scheduled subject to precedence and resource constraints in order to minimize a given objective function. An instance of a resource-constrained project scheduling problem, or short RCPSP, in general is given as follows. With every job $j \in V$ an integral processing time p_j and integral resource consumptions for the different resources are associated. A limited total amount of every resource is available. Precedence constraints are given as an acyclic directed graph $D = (V, A)$, where $(i, j) \in A$ if j cannot be started before i has been completed. The resource constraints can be represented by a set $\mathcal{F} = \{F_1, F_2, \dots, F_{|\mathcal{F}|}\}$ of so-called minimal forbidden sets. A subset $F \subseteq V$ of jobs is called *forbidden* if the jobs in F are an anti-chain of the partial order defined by the precedence digraph D, and the total resource consumption of the jobs in F exceeds the resource availability for some resource. F is called *minimal forbidden* if any proper subset can be scheduled simultaneously. The number $|\mathcal{F}|$ of minimal forbidden sets obviously can be exponential in n, the number of jobs. For a parallel machine scheduling problem with m machines, for example, the minimal forbidden sets are exactly the anti-chains of cardinality $m + 1$. For more details about forbidden sets in scheduling see [Radermacher85], [Schäffter97], or [StorkUetz00], for example.

A Schedule S for a problem instance is a set of start times $\{S_1, S_2, \dots, S_n\}$, where S_j is the start time of job j, $j = 1, 2, \dots, n$. It is called *time-feasible* if $S_i + p_i \leq S_j$ for all precedence relations $(i, j) \in A$. S is *resource feasible*, if the sum of the resource consumptions of all jobs in process at any time t doesn't exceed the resource availability. If S is both, resource- and time-feasible, S is said to be *feasible*. The makespan of a schedule S, $C_{max}(S) = \max_{j \in V}\{S_j + p_j\}$, is the latest completion time of any job. We restrict our research to the objective of finding a schedule S^* with minimal makespan, $C_{max}(S^*) = \min\{C_{max}(S) \mid S \text{ feasible schedule}\}$.

The described problem is NP-hard and therefore it is unlikely to construct a fast algorithm computing an optimal schedule. Nevertheless there are different ways to find a feasible schedule. To resolve the resource conflicts we select for every forbidden set $F_i \in \mathcal{F}$ a waiting job $j_i \in F_i$, $i = 1, 2, \ldots, |\mathcal{F}|$. Such a selection $s = \{j_1, j_2, \ldots, j_{|\mathcal{F}|}\}$ can be represented by a so-called AND/OR-network N, which contains the precedence digraph D as a subgraph. In [Möhring00] some more details are given. If the selection s and therefore the respective AND/OR-network is feasible one can easily compute an earliest-start schedule $ES(s)$, i.e. a schedule where every job is started as early as possible with respect to all given constraints. The earliest-start schedule is an optimal schedule for a given selection. In order to get the optimal schedule S^* for our RCPSP, we have to find a selection s such that the earliest-start schedule $ES(s)$ is optimal among the earliest-start schedules $ES(s')$ of all feasible selections s'.

Results

A canonical way of searching an optimal solution from a given solution is local search. As I have mentioned before, a selection s determines a well-defined schedule, the earliest-start schedule. We therefore define a neighboring relation on the set of all possible selections for a given instance of the RCPSP. Let s be a selection, then s' is defined to be a neighbor of s, if they differ in the selected waiting job for exactly one forbidden set. Obviously the size of this neighborhood roughly is $|F_1| + |F_2| + \cdots + |F_{|\mathcal{F}|}$, which is, as $\mathcal{F}$ is part of the input, polynomial in the input size. For the set of feasible selections among all possible selection I have shown that it is connected under this neighborhood relation. Thus it is possible to find the optimal selection from any given feasible selection by a series of neighborhood moves considering only feasible selections.

In ordinary precedence digraphs D the makespan is determined by the longest chain in D, the so-called critical path. The starting times of the jobs on the critical path cannot be moved without prolonging the makespan or violating some precedence constraints. These ideas can also be applied to AND/OR-networks although the classical notion of a critical path fails as soon as resource constraints are involved, see [Wiest63] for example. For a given selection s and the corresponding earliest-start schedule ES, I have defined a special latest-start schedule LS. This latest-start schedule differs slightly from the intuitive latest-start notion. In return it is well-defined which is not the case for the classical latest-start schedule in resource-constrained problems. With the earliest- and latest-start schedules it is now possible to define slack-values for the nodes. The slack $slack(v) = LS(v) - ES(v)$ of node v is just the amount of time it can be scheduled later than its earliest-start without increasing the makespan. We call nodes v with $slack(v) = 0$ critical. The subnetwork induced by the critical nodes will be called the critical path, although in general it will not be a path.

Recall that in AND/OR-networks there are also nodes representing forbidden sets. In our aspired neighborhood search we are looking for a forbidden set such that the exchange of its waiting job will result in a shorter makespan. One canonical way to reach this goal is to look at all possible neighbors, compute the corresponding earliest start schedules and compare the makespans. This policy requires the evaluation of roughly $|F_1| + |F_2| + \cdots + |F_{|\mathcal{F}|}|$ AND/OR-networks. I am currently investigating the possibility of determining a forbidden set in the actual AND/OR-network and a waiting job for it, such that the resulting neighbor will have a shorter makespan. The critical forbidden sets and jobs are the most promising candidates. It is still open whether one can find a forbidden set and a waiting job for it with the required properties without evaluating all possibilities.

Activities

- Lectures and Colloquia of the Graduate Program
- Lecture *"Complexity Theory and Approximation"* by Martin Skutella
- Block-Seminar *"Linear Optimization"* by Prof. Möhring, 14. – 16. July, 2000
- Euroconference *"Discrete and Algorithmic Geometry"* on Crete, 19. – 25. August 2000
- Summer School on *"Shape in Computer Vision and Graphics"* in Zürich, 6. – 8. September 2000
- 8th Workshop *"Resource-Constrained Project Scheduling"* in Sehlendorf, 27. – 29. September 2000
- 3rd Siemens Workshop *"Applied Discrete Optimization"*, Würzburg, 22. – 24. October 2000.
  Given Talk: *Dualität von Suchstrategien auf planaren Graphen*

- Support of a student's talk in the seminar *"Scheduling and Combinatorial Optimization"* by Prof. Möhring

Preview

- Block-Course *"Connectivity Problems of Networks: Structures and Algorithms"* at FU Berlin, 1. – 12. April 2001
- 9th Workshop *"Resource-Constrained Project Scheduling"* in Berlin, 2. – 4. April 2001
- CGC Workshop in Ascona, 13. – 15. May 2001

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Carsten Lange

Supervisor:	Prof. Dr. Günter M. Ziegler
Field of Research:	Discrete and Combinatorial geometry
Topic:	Combinatorial Curvatures and Weitzenböck Formulae
PhD Student	at the Program "CGC" since January 2000

Field of Research and Results

Robin Forman's Ricci curvature is still in the centre of my interest, see [For99] for a survey and [For00] for a detailed account of his approach and results. The fundamental idea is to postulate a decomposition of the Hodge-Laplacian of a CW-complex, consider this decomposition as a combinatorial analogue of the classical differential geometer's Weitzenböck formula, and obtain by this "smooth-to-discrete" analogy a definition of Ricci curvature. This notion of curvature led to combinatorial versions of the classical theorems of Myers and Bochner which indicates the relevance of this ad-hoc definition.

As I mentioned in last term's report, I was able define a combinatorial difference operator that might be viewed as a discrete counterpart of the covariant derivative in differential geometry. By imitating constructions used in differential geometry, I succeeded in deriving the decomposition Forman postulated in the same way the classical Weitzenböck formula is derived. For these computations, the space of p-chains was considered as an inner product space where the set of p-cells form an orthonormal basis.

The natural question arises whether a decomposition of Weitzenböck type holds in case of a more general class of inner product spaces or not. I investigated the case of inner products where the p-cells are orthogonal, and after adjusting the difference operator, I was able to generalise Forman's decomposition to this class of inner products. This "weighted" combinatorial Weitzenböck formula coincides with Forman's in case of weights under his consideration, but differs in general. This more general version is of particular interest, because it implies for a certain choice of weights induced by the combinatorics of a closed cellular surface, i.e. certain CW-complexes of dimension two, a combinatorial version of the classical theorem of Gauß and Bonnet, as shown by Forman.

Before I worked on this generalization, I had five exciting weeks at ETH in Zurich, where Komei Fukuda, Jürgen Richter-Gebert, and Emo Welzl taught me in an excellent and condensed way many aspects of oriented matroids and randomised algorithms.

Activities

- Lectures and Colloquia of the graduate program, including a talk in the colloquium on December 4, 2000, titled *Differential Geometric Methods In Combinatorics?*
- Block courses of CGC's PreDoc program on *Randomised Algorithms* by Emo Welzl and *Combinatorial Geometry* by Komei Fukuda and Jürgen Richter-Gebert (October 23, 2000 - November 24, 2000)
- *Oberseminar Diskrete Geometrie* at TU Berlin, including a talk on February 2, 2001, titled *Gewichtete kombinatorische Weitzenböckformeln und eine kombintorische Version des Satzes von Gauß-Bonnet*
- *Mittagsseminar* of Emo Welzl's research group *Theory of Combinatorial Algorithms* during my stay at ETH Zurich, including a talk on November 16, 2000, titled *Curvatures in Combinatorics? - A New Approach by Robin Forman*
- Talk on October 10, 2000, at *Forschungsseminar Spinoren und Lorentz-Geometrie*, HU Berlin, titled *Diskrete Weitzenböckformeln*
- Lecture *Topological Combinatorics* by Günter M. Ziegler at TU Berlin
- Berliner Algorithmen-Tag (February 16, 2001)

Perspectives

At the end of March, I shall attend the Combinatexas 2001. Robin Forman will give a lecture there and I am looking forward discussing the subject with him personally. In April I shall be in Berkeley and Minneapolis, where fruitful discussions will hopefully continue!

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Katharina Langkau

Supervisor:	Prof. Dr. Rolf H. Möhring
Field of Research:	Combinatorial optimization
Topic:	Traffic networks and dynamic flows
PhD Student	at the Program “CGC” since October 2000

Field of Research

My work is part of a project that is concerned with questions arising in the area of traffic routing. More and more cars get equipped with route guidance systems, which guide the driver to the destination entered at the beginning of the journey. These systems are comparatively simple from an algorithmic point of view since they only compute shortest paths to the destination. Simulations predict that the benefits of such systems will be lost once the number of equipped vehicles exceeds a certain threshhold.

Within this project a *static* approach has been developped [1] that models the problem as a *nonlinear multicommodity flow problem*. Instead of discrete vehicles static flows are routed through a network with arc travel time depending nonlinearly on arc usage. The objective is to minimize total travel time. Further constraints ensure that the path assigned to a vehicle is “acceptable” meaning that its geographical lenght does not exceed a given upper bound.

In order to have a more realistic model in the future, it will be necessary to consider *dynamic flows*, which take into account that pulks of cars move through the network as time progresses. An inherent difficulty in all dynamic models is that the path computations depend on arc travel times, which in turn depend on traffic on these paths. A satisfactory model which covers the full-dynamic case has not been found yet. In a first step we are thinking of a *semidynamic model*, where travel times are allowed to change over time, but are independent of the flow on that link. When we assume discrete time steps, it turns out that the methods used to solve the static problem are also applicable in the semidynamic case. One idea is an iterative procedure that updates travel times according to the flow computed in the last iteration [2]. We do not know under what assumption such a procedure converges.

Another interesting task arising in the area of traffic routing is to look at different variations of the objective function. So far we only considered the so-called *system optimum*, where one minimizes total travel time under the constraint that the assigned paths are not too long. Another common approach is to route drivers along the paths of a *user equilibrium*. In such an equilibrium a driver cannot reduce his travel time by changing his route. One question is how much these two equilibria differ. Recent work answers this question in the static case [3]. It is shown that in special cases (linear travel times) these two equilibria are not far apart. It would be nice to have similar results if additional constraints, for example the restriction only to use paths that are not too long, are added to the nonlinear problem. Further we would like to compare system optimum and user equilibrium in the dynamic version of the problem.

Activities

- Lectures and colloquium of the graduate program
- Lecture *Complexity Theory and Approximation* by Martin Skutella
- Fall school on *Bioinformatics* in Neuseddin, Germany, November 6 - 11, 2000

Preview

- Adimmo workshop in Trier, Germany, March 15 - 16, 2001
- Aracne Spring school on *Approximation Algorithms for Scheduling and Telecommunications* in Kiel, Germany, March 26 - 30, 2001
- Block course *Connectivity Problems of Networks: Structures and Algorithms* in Berlin, Germany, April 1 - 12, 2001
- CGC workshop in Ticino, Switzerland, May 13 - 15, 2001

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Michael Naatz

Supervisor:	Prof. Dr. Rolf H. Möhring
Field of Research:	Order theory and orientations of graphs
Topic:	Acyclic and strong orientations of graphs
PhD Student	at the Program "CDM" since October 1998

Field of Research

The primal focus of my work is on acyclic orientations of mixed graphs (i.e., graphs in which some edges may have a direction). These objects are closely related to extensions of partially ordered sets; just think of the case that the directed edges of our mixed graph form a transitive digraph. I am especially interested in the graph $G_{ac}(G)$ of acyclic orientations of a mixed graph G. $G_{ac}(G)$ has as vertices the acyclic orientations of G, and two of these are adjacent if they differ only in the direction of a single arc. This graph is a valuable tool in the investigation of questions coming from graph theory, order theory, and other fields. More recently, it turned out that the methods developed for the study of this graph sometimes also apply when we replace acyclic by strongly connected orientations. A digraph is strongly connected (or just strong) if, for any two vertices v and w, there is a directed path from v to w.

Results

Among other topics, I worked on a certain notion of convexity in graphs during the last semester. We call a set of vertices of a graph convex if it contains all shortest paths between any two of its vertices. This notion has already been studied by several authors (e.g., [1, 3, 5, 6, 7]), especially during the eighties. Generalizing results by Feldman Högaasen [4] (rediscovered later by Björner and Wachs [2] and by Reuter [8]), I could prove that this notion of convexity has a very beautiful interpretation in graphs of acyclic as well as graphs of strong orientations. It turns out that convex sets of vertices in such a graph correspond in a canonical way to the different possibilities of prescribing directions of arcs in such an orientation. This was known before only for linear extensions of posets.

Activities

- Lecture and colloquium of the graduate program
- "Doktoranden- und Diplomandenseminar" of Prof. Möhring's group
- Talk at the International Conference on Graph Theory (ICGT 2000), August 28th – September 1st, Marseille
- Talk at the Conference on "Optimal Discrete Structures and Algorithms" (ODSA 2000) in Rostock
- started compiling my doctoral thesis

Preview

I will be (and I already am) quite busy finishing my thesis.

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Dr. Deryk Osthus

Supervisor:	Prof. Dr. Hans Jürgen Prömel
Field of Research:	Random discrete structures, probabilistic methods
Postdoctoral member	of the program since Oktober 2000

Results

Induced subdivisions of graphs

A classical theorem of Mader states that for every graph H there exists $d = d(H)$ such that every graph G of average degree at least d contains a subdivision of H. (A *subdivision* of a graph H is obtained by replacing the edges of H by internally disjoint paths of arbitrary length). Obviously, the result becomes false if we ask for an *induced* subdivision of H. Together with Daniela Kühn, I proved that this stronger assertion holds if G is 'locally sparse' in the sense that it fails to contain some complete bipartite graph $K_{s,s}$ [3]:

For every graph H and every $s \in \mathbb{N}$ there exists $d = d(H, s)$ such that every graph G of average degree at least d contains either a $K_{s,s}$ as a subgraph or an induced subdivision of H.

Of course, one cannot replace 'subdivision' by 'subgraph', as for example there exist graphs which have both arbitrarily large average degree and arbitrarily large girth. On the other hand, Kierstead and Penrice [2] proved that if H is a tree then one can indeed find it as an induced subgraph in any $K_{s,s}$-free graph of sufficiently large average degree. They used this result to prove a special case of the conjecture of Gyárfás and Sumner that given a tree T and $s \in \mathbb{N}$, every K_s-free graph of sufficiently large chromatic number contains an induced copy of T. Scott [6] proved that this conjecture becomes true if we only require an induced subdivision of T. Motivated by this result, he proposed a conjecture which is analogous to our result—replacing 'average degree' by 'chromatic number' and $K_{s,s}$ by K_s.

At several stages, our proof makes use of probabilistic arguments. In [4], we also give a short proof of the case when H is a cycle. However, the analogous conjecture about induced cycles in K_s-free graphs of high chromatic number (which in this case is already due to Gjárfás) is still open.

Random planar graphs

Compared to the wealth of knowledge one has about random graphs in general, rather little is known about the likely properties of a random planar graph on n vertices—not even the expected number of edges. Together with Hans Jürgen Prömel and Anusch Taraz [5], I considered the following uniform model: let $\mathcal{P}_n$ be the set of labelled planar graphs on n vertices. A random planar graph P_n is chosen uniformly at random from $\mathcal{P}_n$. This should not be confused with a random planar map, since a planar map is defined as a connected graph which is embedded in the plane and may have multiple edges, whereas a planar graph may have several embeddings.

Random planar graphs were first investigated by Denise, Vasconcellos and Welsh [1], who (amongst others) gave bounds on $|\mathcal{P}_n|$ and proved that the expected number of edges of P_n is at least $3n/2$. They also introduced a Markov chain whose stationary distribution is the uniform measure on $\mathcal{P}_n$. This Markov chain was investigated in much more detail by McDiarmid, who showed that almost surely P_n has at least $13n/7$ edges and that the limiting probability that P_n is connected is neither zero nor one.

Using a different approach, we showed that $|\mathcal{P}_n| \geq n!\,(10\sqrt{2})^{n+o(n)}$. Combined with a result of Tutte on the number of planar triangulations, this implies that almost surely a random planar graph on n vertices has at most $2.92n$

edges. We also proved that the number of triangulations of any planar graph is at least exponential in the number of edges which need to be added in order to triangulate it. This implies an improved upper bound for the total number of planar graphs on n vertices.

Activities

- Workshop on cycles, Vancouver, 3.-13.7.2000 (with a talk "On a conjecture of Thomassen")
- Workshop on random structures, Poznań, 13.-14.10.2000 (with a talk on "Some random graph models for the world wide web")
- Kolloquium über Kombinatorik, Braunschweig, 17.-18.11.2000 (with a talk on "Constrained evolution of random graphs")
- Joint organization of the seminar "Randomisierte Algorithmen für Routing und Hashing Probleme"
- Referee for the journal "Random Structures & Algorithms"
- "Forschungsseminar Algorithmen und Komplexität" at the HU (with talks on "Induced subdivisions" and "The Kim-Vu polynomial concentration inequality")
- attendance of the lectures and the colloquium of the graduate school (with a talk on "Subgraphs with large average degree and high girth")

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Julian Pfeifle

Supervisor:	Prof. Dr. Günter M. Ziegler
Field of Research:	Discrete and Combinatorial Geometry
Topic:	Triangulated Complexes
PhD Student	at the Program "CGC" since March 2000

Field of Research and Results

In this semester, I focused on some exciting work of Kalai on "many" triangulated spheres. The motivation for this goes back at least to the paper [2] of Goodman and Pollack with the revealing title, *"There are asymptotically far fewer polytopes than we thought"*, in which they proved the upper bound

$$\log c(d,n) \leq d(d+1)n \log n \tag{1}$$

for the number $c(d,n)$ of combinatorial types of simplicial d-polytopes with n labeled vertices. This was very surprising in view of the only previously known upper bound of $\log c(d,n) = O(n^{\lfloor d/2 \rfloor} \log n)$ for fixed d, which derives from the *Upper Bound Theorem* for simplicial polytopes.

In contrast to this, Kalai built a large number of simplicial spheres by giving a rule to produce quite many different lists of facets that assemble to distinct triangulated spheres. He arrived at this rule by modifying an ingenious construction by Billera and Lee [1], which they had used to prove the sufficiency part of a conjectured characterization of f-vectors of simplicial polytopes by McMullen.

If $s(d,n)$ denotes the number of simplicial $(d-1)$-spheres with n labeled vertices, Kalai's "squeezed spheres" establish the lower bound

$$\log s(d,n) = \Omega(n^{\lfloor (d+1)/2 \rfloor - 1}) \quad \text{for fixed } d. \tag{2}$$

The bounds (1) and (2) together reveal that for $d \geq 5$, there are many more simplicial $(d-1)$-spheres than simplicial d-polytopes. This means that for $d \geq 5$, most of KALAI's spheres cannot be polytopal—there are simply too many of them. However, we cannot draw this conclusion for $d = 4$, because the number of squeezed 3-spheres is strictly less than the bound in (1) for the number of simplicial 4-polytopes, for all $n \geq 5$.

By further adapting the procedure of BILLERA and LEE, I can now show that KALAI's 3-spheres are in fact polytopal by realizing them as boundary complexes of 4-polytopes. The main idea is to realize a cyclic 5-polytope C in just the right way, and then to pick a point v outside of C that sees exactly the facets in KALAI's list. The 3-sphere we want to realize is then the boundary of the vertex figure at v of $\operatorname{conv}(C \cup \{v\})$.

In a different vein, I also continued work on the construction of secondary polytopes for the EG-MODELS archive [5], which have now been officially released, and on the further integration of my software into the `polymake` framework [6].

But where I definitely learned the most exciting new mathematics in the shortest time this semester was in the excellent 5-week block courses on Randomized Algorithms and Combinatorial Geometry at ETH Zurich.

Activities

- Attendance of the lectures and colloquia of the CGC
- Lecture *Topological Combinatorics* by Günter M. Ziegler
- Talk in the CGC colloquium on January 22, 2001, with the title *Kalai's squeezed 3-spheres are polytopal*
- Attendance of the *Oberseminar* of the Discrete Geometry group at TU Berlin
- Attendance of the CGC PreDoc Block Courses, *Randomized Algorithms* by EMO WELZL and *Combinatorial Geometry* by KOMEI FUKUDA and JÜRGEN RICHTER-GEBERT, 23.10.–24.11.2000, at ETH Zürich

Preview

A number of issues related to the KALAI construction remain open, for example how to prove that there are really many more 3-spheres than 4-polytopes (which is just what Kalai's spheres fail to do), or whether one can build an even larger number of nonshellable spheres [4].

As always, Günter Ziegler keeps on providing inspiration and any number of open problems to try one's hand on. In particular, I plan to continue to work on counting lattice triangulations.

During my planned stay at ETH Zurich next semester, I will also try to resolve the general case of deciding the existence of neighborly centrally symmetric fans with tools from Discrepancy Theory.

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Shi Lingsheng

Supervisor:	Prof. Dr. Hans Jürgen Prömel
Field of Research:	Discrete Mathematics
Topic:	Ramsey Theory
PhD Student	at the Program "CGC" since July 2000

Field of Research

There is a vast literature on Ramsey type problems starting in 1930 with the original paper of Ramsey [4]. There are many results regarding to asymptotic bounds for various types of Ramsey numbers (see the survey paper [2]), but the progress on evaluating the basic numbers themselves has been very unsatisfactory for a long time. In the last decade, however, considerable progress has been obtained in this area, mostly by employing computer algorithms. The few known exact values and several bounds for different numbers are scattered among many technical papers (see [3]). The numbers $R(k,l)$ are known for $k = 3$ and $l = 3$ to 9 as well as $k = 4$ and $l = 4,\ 5$. These are all known exact values for nontrivial classical graph Ramsey numbers.

Results

The Ramsey number $R(G_1, G_2, ..., G_n)$ is the least integer p such that for any n-edge coloring $(E_1, E_2, ..., E_n)$ of K_p, $K_p[E_i]$ contains G_i for some i, G_i as a subgraph in $K_p[E_i]$. The existence of $R(G_1, G_2, ..., G_n)$ was shown by Ramsey in his original paper [4]. In [6] we obtained the following inequality by counting the number of small subgraphs of Ramsey partition.

$$R(G_1, G_2, ..., G_n) \leq \sum_{i=1}^{n} R(G_1, ..., G_{i-1}, G_i^{'}, G_{i+1}, ..., G_n) - n + 2$$

whenever we can express G_i as either the disjoint union or the join of a vertex and a graph $G_i^{'}$. This generalizes the classical Ramsey inequality,

$$R(m_1, m_2, ..., m_n) \leq \sum_{i=1}^{n} R(m_1, ..., m_{i-1}, m_i - 1, m_{i+1}, ..., m_n) - n + 2.$$

which applies to complete graphs of order m_i.

In [5] I proved several related but more complicated upper bound formulas. From these bounds I was able to deduce some improved bounds for small Ramsey numbers. For example, we have

$R(9,9) \leq 6588,\ R(9,10) \leq 12677,\ R(10,10) \leq 23556,$
$R(K_5 - e, K_7) \leq 88,\ R(K_6 - e, K_6) \leq 119,\ R(K_6 - e, K_7) \leq 204,$
$R(K_6, K_7 - e) \leq 205$ and $R(K_7 - e, K_7 - e) \leq 251$ etc.

Preview

Among the most interesting problems in graph Ramsey theory are the linear bounds for graphs with certain upper bound constraints on the average degree. A set of graphs has linear Ramsey numbers if there exists a constant c so that whenever we two-color the edges of a complete graph of order cn, we find a monochromatic copy of any graph of order n in this set. In 1973, Burr and Erdös proposed the following conjecture [1].

Any set of graphs whose all subgraphs having bounded average degree has linear Ramsey numbers.

Some weakened versions of this conjecture were obtained in the last two decades. In 1983, Chvátal, Rödl, Szemerédi, and Trotter showed that any set of graphs with bounded maximal degree has linear Ramsey numbers. In 1993, Chen and Schelp extended the result of Chvátal et al. by replacing the bounded maximal degree condition by the following weaker one. A graph of order n is p-arrangeable if its vertices can be ordered as $v_1, v_2, ..., v_n$ such that $|N_{L_i}(N_{R_i}(v_i))| \leq p$ for all i, where $L_i = \{v_1, v_2, ..., v_i\}$, $R_i = \{v_{i+1}, v_{i+2}, ..., v_n\}$, and $N_A(B)$ denotes the neighbors of B lying in A. They proved that any set of p-arrangeable graphs has linear Ramsey numbers. They also showed that a planar graph is 761-arrangeable, which was later improved to 10-arrangeable by Kierstead and Trotter. Thus their results imply that the set of planar graphs has linear Ramsey numbers. Recently, Rödl and Thomas proved that any set of graphs without the subdivision of a fixed complete graph has linear Ramsey numbers.

At this moment I am trying to find further set of graphs having linear Ramsey numbers.

Activities

- Workshop on October 13 and 14, 2000, in Poznan

- Fall School on Bioinformatics from November 6 to 11, 2000, in Neuseddin
- Seminar "Algorithm and Complexity" at the HU (with talk about "A sequence of formulas for Ramsey numbers" and "New lower bounds for the Ramsey numbers of a 4-cycle"
- Lecture and colloquium of the European graduate program

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Martin Thimm

Supervisior	Prof. Dr. Hans Jürgen Prömel
Field of research	Approximation algorithms and nonapproximability
Topic:	Expander graphs
PhD Student	at the Program “CDM” since April 1999

Fields of research

I mainly work on approximation algorithms and nonapproximability. Expander graphs, “sparse” graphs with “high” connectivity, have various applications in these areas. They can be used for both lower bound proofs (e.g. [5, 7]) and also upper bounds (e.g. [1]). The existence of the desired expanders can be shown by probabilistic arguments (e.g.[9]), but very little is known about how to construct them deterministically [6, 8, 12].

Results

One example for the use of expanders are nonapproximability results. We improved the best known lower bound for the Steiner Tree Problem – this follows from a nonapproximability result for $VERTEX-COVER$ in graphs of bounded degree [5] – by a factor of 3.

Suppose that we are given a graph $G = (V, E)$, a metric given by edge weights $c : E \to \mathbb{R}$, and a set of required vertices $T \subset V$, the terminals. The Steiner Tree Problem consists of finding a subtree of G that spans all vertices of T.

Our reduction is quite similar to that of Papadimitriou and Vempala [7]. They prove a very strong nonapproximability result for the traveling salesman problem. Similar to their approach we do not use “variable gadgets” to assure correct assignments to each literal and its opposite (in the reduction to MAX-$E3$-LIN-2), like in most reductions of this kind. This is implicitly done by the construction.

Bipartite, linear, d-regular expanders are an important ingredient for the reduction. We prove their existence by counting arguments as well as a formula connecting the degree d and the expansion coefficent x. It is now possible to calculate the nonapproximability ratio as a function of d and x. This directly improves the result if better expanders are found [11].

What makes a graph a good expander? How difficult is it to approximately calculate the expansion properties of a graph?

These are the questions I'm working on. It is known to be hard to calculate expansion of a given graph exactly [4]. One (only) knows that expansion is closely related to the second largest eigenvalue of the adjacency matrix of the graph [2, 3, 10]. The expanders constructed in [8] have an optimal second largest eigenvalue, but probabilistic arguments prove that there exist constructions with an even better expansion.

I implemented a simple but empirically very useful heuristic to test expansion properties of graphs. It searches for subsets of small expansion. In many cases it helped to find structural properties of graphs leading to bad expansion. On the other hand one can learn from the existing known examples together with new ideas and the empirical test which structural properties we need.

Activities

- Lectures and Colloquium of the CGC program
- Research seminar "Algorithms and Complexity" at HU with talks "Zig–Zag–graph product, expanders and extractors" and "Expander graphs II"
- Fall school of the CGC program on bioinformatics in Neuseddin (6. - 11.11. 2000).
- Review for STACS2001

Preview

By the above mentioned process, iterated severel times, we finally found one class of graphs which look like very good candidates for expanders. It remains to prove this claim. First partial results seem to point into the right direction.

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