ESPRIT Working Group: 21726
Randomized Algorithms (RAND2)

Annual Progress Report

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1 RAND2 Research Sites

The research sites of RAND2 Working Group are:

- University of Bonn,
- University of Edinburgh,
- University of Leeds,
- University of Lund,
- University of Oxford,
- University of Paris-Sud,

  and
- The Weizman Institute, Rehovot

2 Overview of Research Activities

The research within the project RAND2 has concentrated on the following research areas (see Section 3, Research Papers):

(1) Design of efficient (both sequential and parallel) randomized algorithms for selected combinatorial, algebraic, and geometric problems (Bonn, Edinburgh, Leeds, Lund, Oxford, Paris, Rehovot)

(2) Foundations of randomized complexity of computational problems (Bonn, Oxford, Paris, Rehovot)

(3) Randomized approximation problems (Bonn, Edinburgh, Leeds, Oxford, Rehovot)

(4) Computation with limited randomness resources (de-randomization methods) (Bonn, Edinburgh, Lund, Oxford, Paris, Rehovot)

(5) Computational learning theory, theory of Neural Networks, and Applications (Bonn, Edinburgh, Paris)

(6) Quantum Computation (Bonn, Edinburgh, Oxford, Paris)

3 Research Papers – Publications

1. F. Ablayev and M. Karpinski.
   A Lower Bound for Interger Multiplication on Randomized Read-Once Branching Programs, Research Report No. 85184-CS, University of Bonn, 1997.

2. C. Aldridge, J.Chapman, R. Gower, R. Leese, C.J.H. McDiarmid, M. Shepherd, H. Tuenter, H. Wilson and A. Zinober.)
   Pattern reduction in paper cutting, Report of the 29th European Study Group with Industry, University of Oxford, March 1996.

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   Edge-disjoint cycles in regular directed graphs, J. Graph Theory **22** (1996) 231-237.

4. A. Ambainis, K. Aprits, C. Calude, R. Freivalds, M. Karpinski, T. Larfeldt and I. Sala.
   Effects of Kolmogorov Complexity Present in Inductive Inference, Proc. 8th Workshop on Algorithmic Learning Theory, ALT'97.

5. A. Ambainis, R. Freivalds, and M. Karpinski.
   Weak and Strong Recognition by 2-Way Randomized Auotmata, Proc. 1st Symp. on Randomization and Approximation Techniques in Computer Science, RANDOM'97, Bologna, Lecture Notes in Computer Science Vol. 1269, Springer Verlag, pp. 175 - 185.

6. A. Andersson. *Faster deterministic sorting and searching in linear space.* Proc. IEEE FOCS, 1996.

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8. A. Andersson and O. Peterson. On-line approximate list indexing with applications. To appear in Journal of Algorithms.

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12. A. Andersson. *Which flavor of balanced tree? Plain vanilla!* DIMACS Implementation challenge, 1996.

13. A. Andersson and M. Thorup. *Implementing monotone priority queues.* DIMACS Implementation challenge, 1996.

14. R.A. Bailey and D.J.A. Welsh.
Approximate counting. Invited lecture to the 16th British Combinatorial Conference (1997), Surveys in Combinatorics, London Mathematical Society Lecture Note Series **241** (1997), 287–323.

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Diffusion Approximation for Random Allocations, Technical Report, LRI, (1997), (http://www.lri.fr/~boucheron/PUB/dara97.ps), submitted.

16. J.E. Bartels.
On randomised approximations of computationally hard graph and matroid invariants, D.Phil. thesis, Oxford, submitted September 1997.

17. J.E. Bartels and D.J.A. Welsh.
The polytope of win vectors. *Annals of Combinatorics* **1** (1997) 1–15.

18. C. Bazgan, H.Li, M. Wozniak.
On the Loebl-Komlos-Sos conjecture, Technical Report No. 1094, LRI, (1997).

19. C. Bazgan, A. Harkat-Benhamdine, H. Li, and M. Wozniak.
On the vertex-distinguishing proper edge-colorings of graphs, Technical Report No. 1129, LRI, (1997).

20. C. Bazgan, A. Harkat-Benhamdine, H. Li and M. Wozniak.
Partitionning vertices of 1-tough graphs into paths, Technical Report No. 1136, LRI, (1997).

21. C. Bazgan and M. Santha and Z Tuza.
On Approximation of Finding Another Hamiltonian Cycle in Cubic Hamiltonian Graphs, Proceedings of 15th STACS, LNCS, (1998), Springer-Verlag.

22. L.W. Beineke, C.J.H. McDiarmid and R.J. Wilson.
Probability, Graph Connections, Oxford Lecture Notes in Mathematics and its Applications 5, OUP, 1997.

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On-Line Load Balancing for Related Machines, Proc. WADS'97.

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On the Complexity of Pattern Matching for Highly Compressed Two-Dimensional Texts, Proc. CPM'97.

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On Approximation Intractability of the Bandwidth Problems, Research Report No. 85182-CS, 1997.

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Information Theoretical Aspects of Priority Encoding Transmission, Technical Report, LRI, (1997), (http://www.lri.fr/~boucheron/PUB/pet6.ps), submitted.

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Path coupling: a technique for proving rapid mixing in Markov chains, Proceedings of the Thirty Eighth Symposium on Foundations of Computer Science, IEEE Computer Press, 1997, pp 223–231.

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Randomised approximation of the number of bases, Contemporary Mathematics **197** (1996), 371-376.

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Polynomial Time Algorithms for Modules over Finite Dimensional Algebras, Proc. ACM Symp. ISSAC'97.

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Critical sets in direct products of back circulant latin squares, Utilitas Mathematica, **50** (1996), 127–162.

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On total colouring of hypergraphs, D.Phil. thesis, Oxford, February 1997.

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The random planar graph, Congressus Numerantium 13 (1996), 61-79.

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Fast Algorithms for Complete Link Clustering. Accepted for publication in Discrete and Computational Geometry.

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A Near-Optimal Heuristic for Minimum Weight Triangulation of Convex Polygons. Proc. ACM-SIAM Symposium on Discrete Algorithms (SODA'97), pp. 518-527, New Orleans, Louisiana, January 1997.

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4 Research Reports/Activities

1997 RAND2 Report - Bonn

The main emphasis was in studying (1) efficient approximation algorithms, (2) lower approximation bounds as well as (3) general upper and lower randomized bounds. In the first category the highlights were the papers (sections 3) [66], [81], [89], [90] and [91], in second, the papers [24], [27], [88] and [85], and the third [1], [4], [51], [52], [65], [71], [73] and [87].

1997 RAND2 Report - Lund

Research results

Computational Geometry

Voronoi diagrams and related structures. We have designed a linear-time randomized algorithm for the so called bounded Voronoi diagram of a simple polygon. In the diagram the edges of the input figure act as visibility barriers for the vertex sites. Further, we have generalized Chew's randomized linear-time algorithm for the Voronoi diagram of a convex polygon to include certain convex hulls in 3D and sequences of monotone line segments in the plane. We have also obtained a linear-time randomized algorithm for the so called skeleton of a simple polygon, i.e., the Voronoi diagram of the edges of the input polygon. As for parallel geometric algorithms, we have presented the first nearly work-optimal randomized NC algorithm for the Voronoi diagram of vertices (or, edges) of a convex polygon. The parallel versions of our approximation heuristics for optimal covering of polygons with rectangles rely on parallel randomized algorithms for polygon skeletons.

Data structures We have designed new efficient data structures for sorting and searching. Randomness is used in two ways, by analyzing algorithms in terms of random input and by employing randomization in the algorithms.

Random input. It is natural to let an algorithm take advantage of the input distribution under the assumption of random input. Such algorithms often prove very fast in practical applications. We have presented improved algorithms for dynamic interpolation search. Our new method for trie compression, level-compressed tries, combines simplicity with efficiency.

Randomization. We have improved the complexity of the sorting problem dramatically, showing that n integers can be sorted in $O(n \log \log n)$ time. The algorithm is based on a combination of *range reduction* and *packed sorting*. Both parts are deterministic, but randomization (universal hashing) is used to decrease the space requirement to linear. Another integer sorting algorithm, signature sort, uses a randomized range reduction technique. This algorithm can sort in $O(n)$ time, provided that the wordlength is $\Omega(\log^{2+\epsilon} n)$, $\epsilon > 0$. Our recent tight lower and upper bounds on the time for answering static dictionary queries rely also on randomization techniques. In the circuit RAM model, our lower bound holds even for Monte Carlo Schemes.

Graph Algorithms

Parallel graph algorithms. An f-matching is a subset of the edge set of a graph such that for each vertex v at most $f(v)$ incident edges are in the subset. We have shown the problem of finding a maximum cardinality f-matching to be in the randomized NC class. Further, we have provided a randomized NC algorithm for constructing a maximal f-matching which is more efficient that our earlier deterministic NC algorithm for this problem. An f-dependent set is a subset of the set of vertices of a graph such that for each vertex v in the subset at most $f(v)$ other vertices in the subset are adjacent to v. We have provided several deterministic results on the f-dependent set problem, e.g., we have shown that the problem of finding a maximal f-dependent set problem admits an NC algorithm if f is poly-log bounded. It is an open problem whether for unbounded f one could get a randomized or deterministic NC solution here. Surprisingly we have found the latter problem to be essentially equivalent to the major open problem of whether a maximal independent set of a hypergraph can be constructed by a randomized or deterministic NC algorithm (when hyperedge size is constantly bounded a randomized NC solution is known). For the hypergraph problem we have provided an NC solution in the bounded arboricity case.

Computational Biology. We have recently started research on evolutionary trees in computational biology. One of our heuristics for the local consensus tree problem relies on randomized subroutine for minimum cut. We have also found simple randomization techniques useful in the design of efficient algorithms for constructing evolutionary trees from experiments.

1997 RAND2 Report–Leeds Site

This year has been very successful with respect to RAND2 research. The main emphasis has been on studying rapidly mixing Markov chains. These arise in counting/sampling applications in Statistics and Statistical Physics, as well as being of fundamental importance in problems of theoretical computer science.

We have been working mainly on the *coupling* approach, and have recently developed at Leeds a new technique in this area, which we have termed *path coupling*. The basic expository paper appeared in the 1997 IEEE Foundations of Computer Science conference, but five other papers have been written and are currently submitted for conference or journal publication.

The ideas will also form the basis of Russ Bubley's PhD thesis, which will appear soon. The Leeds team now comprises Martin Dyer and Catherine Greenhill, since Bubley has very recently left to take up a post in mathematical finance with a bank in the City of London. However, we hope to augment this with a new PhD student this coming year.

Visits this year under the auspices of RAND2 include Dagstuhl and Oberwolfach meetings (Dyer), on approximation algoeithms and probabilistic methods respectively, the FOCS conference mentioned above (Miami, Bubley). Artur Czumaj, of the University of Paderborn, Germany, visited Leeds in the summer to work with Dyer in connection with applications of Markov chain methods in parallel computation. Dyer was a plenary speaker at the 1997 Random Structures and Algorithms conference in Poznan, Poland. Leeds also hosted the September workshop of RAND2. This was held over a weekend. The format proved highly successful, and may be repeated.

1997 RAND2 Report - Oxford Site (Dominic Welsh)

Apart from the activities listed above we have had close cooperation on specific problems with Mark Jerrum (Edinburgh) who spent Michaelmas Term 1995 as a Visiting Research Fellow in Oxford. Steve Homer (Boston) and Stu Whittington (Toronto) were visitors in Michaelmas term 1996 and Bruce Reed (Paris) has visited Oxford on several occasions, Paco Santos (Santander) spent 9 months in the department, and there was considerable interaction with the group led by Hans Jürgen Prömel at the Humboldt Univesity of Berlin. There has been a lot of activity on the Channel Assignment Problem, with 4 members of the group participating in the Spectrum Workshop at Cumberland Lodge in February and Robert Leese organising a meeting on the topic in Oxford in the week beginning April 8th 1997.

Two members (McDiarmid and Welsh) participated in the RAND workshop in Leeds, September 1997, while McDiarmid and Welsh were invited speakers at the European Science Foundation Research Conference near Barcelona, September–October 1997.

Three students (Bartels, Cowling, Noble) have completed their doctoral theses this year. Two new research students, Steffi Gerke (Berlin) and Malwina

Luczak (Torun) have joined the group as research students and Uli Ruhrmeir (Munich) is doing an M.Sc. in Mathematics and Foundations of Computer Science.

Dr Jaime Caro from the University of the Phillippines has joined the group as a postdoctoral visitor for the year beginning October 1, 1997.

5 Seminars, Conferences, Workshops and Research Stays

J.E. Bartels (Oxford)

- How to generate a random independent set of a regular matroid, Humboldt-Universität, Berlin, 10 June 1996.

C. Bazgan (Paris)

- On Approximation of Finding Another Hamiltonian Cycle in Cubic Hamiltonian Graphs, Universtiy of Leeds, RAND2 Workshop, September 1997.

S. Boucheron (Paris)

- Information Theoretical Aspects of Priority Encoding Transmission, Universtiy of Leeds, RAND2 Workshop, September 1997.

Anders Dessmark (Lund)

- Research and work on fast randomized graph algorithms, Univ. of Bonn, July 1997.

C. Dorgerloh (Bonn)

- Fast Randomized and Parallel Algorithms for Finding Simple Cycles in Graphs, Lund, 02. - 08.03.97.

- Faster Finding of Simple Cycles in Planer Graphs on a Randomized EREW-PRAM, 11th International Parallel Processing Symposium, Genf, 31.03. - 05.04.97.

R. Gower (Oxford)

- Channel Assignment: how should we specify the constraints? Electronics Department. York University, UK, February 10th 1997.
- The sensitivity of Channel Assignment to constraint specification EMC–Zurich, 1997, Feburary 18th 1997.
- , Directions of current and further work in mathematical aspects of Radio Channel Assignment, Institut fur Informatik, Humboldt-Universitat zu Berlin June 12th 1997.
- Radio Channel Assignment for directional antenna. 16th British Combinatorial Conference, QMW, London, July 8th 1997.

Joachim Gudmudsson and Andrzej Lingas (Lund)

- ICALP'97 and RANDOM'97 in Bologna (see the enclosed report). Joachim Gudmudsson presented his paper (joint with C. Levcopoulos) *Approximation Algorithms for Covering Polygons with Squares and Similar Problems* at RANDOM'97.

Report on RANDOM and ICALP by Joachim Gudmudsson and Andrzej Lingas

This year ICALP'97 (24th International Colloquium on Automata, Languages and Programming) and RANDOM'97 (1st Symposium on Randomization and Approximation Techniques in Computer Science) were co-located in Bologna, Italy. The venue of the conference and the workshop was the magnificent Aula Magna of Santa Lucia in the center of Bologna.

The ICALP in Bologna was a reformed one. For the first time, there were parallel sessions and numerous associated workshops either preceding or following this conference. Also, the change of the submission deadline from that common with STOC in November to the middle of January seems to help ICALP to catch large number of very good papers. In this way ICALP reassured its position as the most important conference and meeting event in theoretical computer science in Europe worthy to attend for everybody working in this field. Several of the ICALP papers relied on randomized techniques. Some of papers addressed the problems of randomness and derandomization directly (Andreev, Clementi, Rolim), some other studied randomized versus nondeterministic program classes (Ablayev). Those of ICALP participants interested in randomness and randomized algorithms were also eager to attend the RANDOM'97 workshop.

RANDOM focuses on algorithmic and complexity aspects arising in the development of efficient randomized solutions to computationally difficult problems. The scientific program of RANDOM'97 consisted of four sessions, namely, Approximation, Randomness, Algorithms, and Complexity. Fourteen papers was presented at the conference, and they were selected from totally 37 submitted papers. Many of these were of very high standard. Even if it is hard to grade the presentations we should mention two that were very interesting. The first was an invited talk by Marek Karpinski, University of Bonn, that presented an overview about the latest results for polynomial approximation schemes for some dense instances of NP-hard optimization problems. The second talk was a presentation by A.S. Schulz and M. Skutella, University of Berlin, that described randomized approximation algorithms for scheduling.

At RANDOM'97 our paper "Approximation Algorithms for Covering Polygons with Squares and Similar Problems" was presented. The paper concerns geometrical covering problems with applications to the fabrication of VLSI chips, and it is written together with Christos Levcopoulos. The parallel version of the algorithm presented in the paper heavily rely on randomized techniques.

C. Günzel (Bonn)

- RAND2 Workshop on Randomized Approximation Algorithm, Leeds, 19. - 23.09.97.

Jesper Jansson and Anna Östlin (Lund)

- COCOON'97 where they presented their paper (joint with A. Lingas) *On the Complexity of Computing Evolutionary Trees* (see the enclosed report by Anna Östlin).

Report on COCOON'97 by Anna Östlin (Lund)

The 1997 COCOON conference, the Third Annual International Computing and Combinatorics Conference, took place in Shanghai, China, on 20-22 august. 53

papers were presented at the conference, and they were selected from totally 106 submitted papers. The conference was really nice, and I had the opportunity to meet some researchers who are, like I am, interested in problems within computational biology. Eight of the papers at Cocoon was dealing with this kind of problems, and five of them concerned evolutionary trees, including our paper.

At COCOON'97 our paper "On the complexity of computing evolutionary trees" was presented. The paper concerns tree-problems, with applications in evolutionary biology, and is written together with Andrzej Lingas, Jesper Jansson and Leszek Gasieniec. It deals mainly with two problems; the maximum inferred consensus tree problem, MICT for short, and the maximum homeomorphic subtree problem, MHT. These problems ask for trees that are consistent with an as large part of the given data as possible. The given data represent known (or probable) relationships between species. The tree constructed is a likely evolutionary tree for the species. Some of our approximation heuristics for the aforementioned problems rely on randomized subroutines (e.g., for max-cut).

The other talks were about work from a wide range of areas including graph algorithms, cryptography, parallel computing, logic and distributed computing. In several of the talks interesting randomized techniques were presented.

M. Karpinski (Bonn)

- Randomized Lower Bounds for Algebraic Decision Trees, Conference on Computational Complexity, Oberwolfach, 10. - 16.11.96.
- Towards Polynomial Bounds for VC Dimension of Pfaffian Formulas and Some Neural Networks Appoications, Banach Center in Warsaw, 08. - .11.12.96.
- Theory Seminar on Randomized Approximation Schemes for Hard Counting Problems, ICSI Berkeley und UC Berkeley, 4. - 19.03.97.
- Research on Randomized Approximation Algorithms, Univ. of Princeton, 14. - 18.03.97.
- Approximation Algorithms for some hard counting problems in finite fields, Seminar, Oberwolfach, 19. - 23.01.97.
- Workshop in Computer Aided Design and Test: Decision Diagrams-Concept and Applications, Dagstuhl, 26. - 27.01.97.
- Research on Randomized Algorithms, University of Latavia, Riga, 18. - 22.05.97.
- Polynomial Time Approximation Schemes for Some Dense Instances of NP-Hard Optimization Problems, ICALP'97, Bologna, 09. - 13.07.97.

- An Approximation Algorithm for the Bandwidth Problem on Dense Graphs, Workshop on Approximation Algorithms, Dagstuhl, 17. - 22.08.97.
- Fundamental of Computation Theory - Conference, Cracow, 31.08. - 06.09.97.
- Research on Randomized Approximation Algorithms, ICSI Berkeley and UC Berkeley, 07. - 16.09.97.
- RAND2 Workshop on Randomized Approximation Algorithm, Leeds, 19. - 23.09.97
- Polynomial Time Approximation Schemes for some Dense Instances of NP-Hard Optimization Problems, Workshop on Random Graphs and Combinatorial Structures in Oberwolfach, 28.09. - 02.10.97
- Randomized Complexity of Linear Arrangements,
  - Randomized Complexity of Integer Programming and Knapsack,
  - Fast Randomized Decision Trees for the MAX Problem,
  School and Workshop on Randomized Algorithms in Sequential, Parallel and Distributed Computing - RALCOM'97, Santorini, 05. - 10.10.97.

R. Leese (Oxford)

- Methods and algorithms for radio channel assignment, Oxford 8th-10th April 1997, workshop organised under the EPSRC Mathfit scheme.
- The efficient use of radio spectrum for mobile communications, invited talk at 3rd annual ACM/IEEE international conference on mobile computing and netowrking (1997), Budapest.

C.J.H. McDiarmid (Oxford)

- DIMACS Workshop on Probabilistic Methods in Discrete Mathematics, Rutgers, 14-18 October 1996, invited talk.
- Seminar at Carnegie Mellon University, Pittsburgh 'Non-interfering flows', 21 October 1996.
- Paris VI, seminar 'Non-interfering flows', 5 December 1996.
- Conference on Radio Channel Assignment, University of Oxford, 8–10 April 1997, invited speaker.

- Combinatorics Research Students Conference, Royal Holloway College, 18 April 1997, invited talk.
- DIMACS workshop on Probabilistic Analysis of Algorithms, Princeton University, NJ, USA, 11–14 May 1997, invited talk.
- One-day Combinatorics Colloquium, University of Reading, 21 May 1997, invited talk.
- European Science Foundation Research Conference on Algebra and Discrete Mathematics, San Feliu de Guixols, Spain, 27 September to 2 October 1997, invited talk.

C. Merino-Lopez (Oxford)

- 16th British Combinatorial Conference, QMW, London, July 8th 1997, Tutte polynomials and the chip firing problem.
- University of Seville, 19 September 1997. Playing with dollars in graphs.
- European Science Foundation Research Conference on Algebra and Discrete Mathematics, San Feliu de Guixols, Spain, 27 September to 2 October 1997, poster contribution.

M. Mosca (Oxford)

- Clemson University, Mathematics and Algebra Seminar, October 1996, Discrete Logarithms in Finite Fields.
- ISI Workshop on Quantum Computation, Torino, July 1997, Quantum Algorithms Revisited.
- T-6 Division Lunch Seminar, Los Alamos National Lab, September 12 1997, Quantum Computer Algorithms Revisited.
- University of New Mexico Information Physics Seminar, September 22 1997, Albuquerque, Quantum Computer Algorithms.

M. Santha (Paris)

- September 1997, Universtiy of Leeds, RAND2 Workshop, invited talk.

I. Sarmiento (Oxford)

- 2 June 1997, Mathematical Seminar, Lulea University of Technology (Sweden), Dowling lattaices.
- 10 July 1997, 16th British Combinatorial Conference, QMW, London, A characterisation of jointless Dowling geometries.

M. Shepherd (Oxford)

- July 1997, 16th British Combinatorial Conference, QMW, London, Scaling a graph colouring problem.

W. Fernandez de la Vega (Paris)

- Polynomial Time Approximation Schemes for Dense Instances of Weighted Max Cut, Universtiy of Leeds, RAND2 Workshop, September 1997.

D.J.A. Welsh (Oxford)

- 13 November 1996: Seminar University College London: Approximate counting of colourings flows and lattice points.
- 20 March 1997: Seminar, Department of Mathematics, Princeton University.
- 23 March 1997–27 March 1997: Institute of Advanced Study, Princeton and DIMACS CORE Building Rutgers Workshop on Statistical Physics methods in Discrete Probability, Combinatorics and Theoretical Computer Science. Invited lecture: Computational complexity of the Tutte polynomial.
- 7 May 1997: Invited lecture: Workshop on Geometry and Complexity, Fields Institute Toronto. Complexity of some geometric Tutte invariants.
- 23 May 1997: Main lecture at Berliner Algorithmen-Tag: Generating structures uniformly at random.
- 10 July 1997: Invited lecture: British Combinatorial Conference: Approximate counting.

- 27 September 1997: Invited lecture European Science Foundation Research Conference in Algebra and Discrete Mathematics, San Feliu de Guixols, Spain: Knots, graphs and polynomials.

J. Wirtgen (Bonn)

- An Approximation Algorithm for the Bandwidth Problem on Dense Graphs, RAND2 Workshop on Randomized Approximation Algorithm, Leeds, 19. - 23.09.97.
- An Approximation Algorithm for the Bandwidth Problem on Dense Graphs, Workshop on Randomized Algorithms in Sequential, Parallel and Distributed Computing - RALCOM'97, Santorini, 05. - 10.10.97.
- Faster Finding of Simple Cycles in Planer Graphs on a Randomized EREW-PRAM, 11th International parallel Processing Symposium, Genf, 31.03. - 05.04.97.