# Contents

# 1 Executive Summary

DIMACS, the NSF Science and Technology Center for Discrete Mathematics and Theoretical Computer Science is a collaboration of four hosts: Rutgers University, Princeton University, BellCore and AT&T Bell Laboratories created to advance its sciences by promoting new research, supporting industry and technology through implementations and demonstrations of research advances, and developing educational programs. The advent of digital computing together with advances in discrete mathematics and awareness of discrete problems have made these fields central to advances in science and technology.

**Research at DIMACS**

DIMACS researchers have made major advances in algorithms, data structures, protocols, complexity, optimization, approximation, discrete and computational geometry, graph theory, coding theory, number theory, extremal set theory, probabilistic methods and a host of other areas central to computational science and discrete mathematics and DIMACS members are among the world leaders in the practical aspects of discrete scientific computation, holding many of the "world's records" in this area. DIMACS produces new results in discrete mathematics and theoretical computer science that ultimately find application in telecommunication, transportation, robotics, software , manufacturing, and other fields.

DIMACS is a major catalyst for research in the diverse areas which comprise discrete mathematics and theoretical computer science and their applications; it has become recognized as *the world center* for research in these areas. Unlike typical research centers, however, DIMACS does not support a permanent research staff. DIMACS' strategy is to create an environment that stimulates information exchange and collaboration among an extensive community of researchers and educators, including approximately 120 permanent members at the four sponsoring institutions each year, 12 long-term visitors, 9-12 postdoctoral fellows, and 9 graduate students, about 100 short term visitors and about 500 - 700 workshop participants. The combined strengths of the four participating institutions - coupled with the supporting role played by other area universities, centers and industries - are unmatched anywhere in the world and attract the world's leaders in research and education.

The activities of this wide collaboration of members with visitors, postdocs and students includes tutorials for researchers and educators, workshops and meetings with international participation, and extensive research collaborations. It is very broad in participation in both the sheer numbers involved but also in the varied backgrounds: graduate students, college faculty, university researchers and senior researchers from major laboratories. More important is the significance and impact of the work.

With the participation of permanent members on workshop and visitor committees DIMACS selects topics that are ripe for rapid development, increased attention, or high impact and stimulates tremendous activity - far more than conventional grants or centers for the same level of funding. Special years, workshops, and the results that grew out of them are described in sections following; lists of visitors, students, workshops, and seminars can be found in the appendices.

The special year in Mathematical Support for Molecular Biology illustrates the strength with which DIMACS can coordinate resources to apply to important scientific challenges. The year started August 1994 with training tutorials. The theme will be developed in 12 workshops. Participation will range from members, postdocs, visitors and graduate students at the four institutions including the Waksman Institute of Molecular Genetics at Rutgers and other bioscience departments at Rutgers, Princeton and elsewhere, to scientists from all over the world representing the disciplines. An *implementation challenge* on sequencing from shotgun sequence data, a proposed research-industry postdocs (joint with a bio-tech company), initiatives to encourage participation of NJ Bio-Tech companies, and a distinguished lecturer series will round out the focused efforts of the first year. The year after will continue postdoc training for longer projects and develop long-term programs with bioscientists and industry.

Topics for recent special years reported on in this proposal were Graph Theory and Algorithms, Combinatorial Optimization, and Massively Parallel Computation as well as results of other programs. Significant results from research programs and collaborations begun in prior years on Discrete and Computational Geometry and on Complexity Theory of Interactive Computing are also reported.

**Education, Training, Knowledge Transfer and Linkages at DIMACS**

DIMACS sponsors a variety of educational programs in addition to supported graduate students and postdocs. Programs for K-12 teachers and students are sponsored jointly with the Rutgers Center for Mathematics, Science and Computer Education (CMSCE). DIMACS main programs are:

*Teacher Leadership Program in Discrete Mathematics.* This successful program, operating since 1989, targets a community of K-12 teachers who develop, use and train other teachers to use discrete mathematics in the classroom. The program has a residential summer institute and four 1-day followups each year. Participating teachers contribute to *In Discrete Mathematics* a newsletter with short articles, bibliographies, and classroom activities circulated to 3300 readers; and to *Greatest Hits in Discrete Mathematics*, a forthcoming book of proven classroom activities.

*Young Scholars Program in Discrete Mathematics.* This is a four week residential program for 40 mathematically talented students (grades 11-12), with 4 additional 1-day meetings during the following year. Week long workshops are given by college and university faculty on topics ranging from number theory to fractals. The program is designed to excite and challenge the students, motivate them to continue the study of mathematics and computer science, and consider careers in the mathematical sciences.

*Research Experiences for Undergraduates (REU)* Mathematically talented undergraduates are matched with researchers in mathematics or computer science at DIMACS to work together for eight weeks during the summer. Projects often lead to new research results and are usually continued during the academic year.

*Bell Labs / BellCore / DIMACS Program for Under-Represented Groups.* DIMACS provides computing courses, mentoring, and career counseling for undergraduates in the Bell Labs and BellCore Summer Training Program for Women and Minority Students. The courses give students a strong start for summer projects and contacts with DIMACS researchers.

Through its alliance with CMSCE at Rutgers, DIMACS is forging strategic alliances to assure an impact well beyond direct training: we are working with the NJ-SSI and contributing to the NJ Mathematics Curriculum Framework to incorporate discrete mathematics throughout the state schools; we convene the annual Working Group in Discrete Mathematics that will develop national curriculum recommendations.

## 2 Introduction: DIMACS Mission and Goals

The Mission of the Center for Discrete Mathematics and Theoretical Computer Science (DIMACS) is to promote research, enhance education, and transfer knowledge to technology and industry sectors in the areas of discrete mathematics and theoretical computer science. The models, methods, data representations, and algorithms that comprise discrete mathematics and theoretical computer science increasingly drive progress in science, business and industry which DIMACS is uniquely positioned to stimulate.

Discrete mathematics and investigations of computing both have long histories but flowered in this century. Discrete mathematics grew as a pure and applied discipline with increased attention to graph theory, combinatorics, and optimization. The development of digital computers made it possible to implement what had been theoretical methods; simultaneously the design of computer hardware and software posed many discrete math type problems. Since the 1950's these disciplines have increasingly made important demands of each other as well as continued their rich traditions of science and applications. Interaction of the two fields include using data structures to implement optimization algorithms and using graph theory as a fundamental tool for analyzing parallel computer architectures, among many others. As external impacts, these areas have made it possible to solve discrete problems arising from practical problems of biology, chemistry, cryptanalysis, communication, transportation and decision sciences.

DIMACS origin was in efforts to stimulate further these developments, to disseminate the results more broadly and to undertake educational programs from pre-college to postdoctoral training that would develop the human resources to carry on research, teaching and application or core sciences. There was explicit recognition of the tremendous resources available in NJ that could be leveraged into a national resource and the potential benefits of greater contact among the disciplines and institutions. DIMACS pursues a highly integrated vision of its goals: research results enter education, postdoctoral training is both for research and knowledge transfer, and contacts with industry advise researchers and students of new research opportunities.

DIMACS builds on the existing strengths in discrete mathematics and theoretical computer science at its four sponsoring institutions: Rutgers, Princeton, AT&T Bell Laboratories, and BellCore. Approximately 120 research faculty and staff at the four institutions participate as permanent members. Faculty and researchers at other New Jersey, New York and Philadelphia institutions are frequent participants. In addition to being the principal engineering location for AT&T and BellCore, New Jersey is the location of hundreds of knowledge-based companies in telecommunications, computing, bio-technology, chemicals, etc. The Center for Mathematics, Science and Computer Education (CMSCE) at Rutgers already has programs for K-12 in other topics and alliances with mathematics reform leaders.

The criteria DIMACS look for in choosing research areas and educational activities are: to focus efforts where DIMACS can establish a national or world leadership role; to focus on topics and projects that will influence the directions of research and education for long term; to create new disciplinary links both among the discrete mathematics, computer science and operations research areas we directly cover and from these disciplines to other disciplines that can benefit from and influence the fundamental research and education of our core areas; to develop the human resources for further research, teaching and application of these disciplines;

to encourage and attract participation at all levels by women and under-represented minorities; to influence technology and industrial application by demonstrations and evaluations of the core science research; and to develop areas of research that will eventually become applicable science.

These goals and criteria are articulated at DIMACS in the following programs:

- Providing timely forums for scientific meetings that inform and enhance individual research programs, and nurturing collaborations that will extend beyond DIMACS and the four hosts to the national and internal community of scholars; specifically by hosting workshops, special years and visitor programs.

- Conducting tutorials for researchers and faculty that will bring new researchers to state of the art research subjects and invigorate educational programs at other institutions.

- Sponsoring implementation challenges for leading edge algorithmic problems that will drive theoretical investigations and be technology demonstrations and evaluations.

- Conducting direct education activities by permanent members at the four hosts such as research experiences for undergraduates (REU), graduate training and postdoctoral supervision that also yield research.

- Publishing a tech report series and refereed volumes of selected workshops; and serving as a national internet information resource for our core science areas.

- Conducting programs for 6-12 and undergraduate students in discrete mathematics and for K-12 teachers and teacher trainers who will develop and publish new curriculum materials in discrete math and computing.

- Contributing significantly to the current national effort in improving mathematics and science education, building on links to CMSCE and the NJ Statewide Systemic Initiative, and serving as a state, regional and national resource and center for those developing policy, curriculum, software, and other materials related to discrete mathematics and computer science in K-16 education.

- Linking research and education by affirming the importance of improving mathematics and computer science education locally and nationally, and by encouraging, supporting, and enabling the involvement of its members and other researchers in this effort.

## 2.1 Overview of Research Activity

One of the principal foci of DIMACS' research is *special years*. Proposals for special year topics including suggested workshops, organizers and key participants are evaluated by a committee of permanent members; a selection is made about 2 years in advance to allow planning. The typical special year has about 6 workshops, postdoctoral trainees, and short and long term visitors (about 100 per year) selected for their interest in the SY topic; seminar and colloquium series are established. The workshops of a given year might attract 500 - 700 participants over the year; they attract scientists both nationally and internationally; they range from students to college faculty to established researchers and industry participants; they present papers, learn new research areas, and evaluate science for technology applications. While special years are especially visible, some workshops, visitors, etc are chosen independently of the topic.

*Implementation challenges* some of which are linked to special years focus on specific algorithm areas. Bibliographies, test data and data formats, and implementation proposals appear early in the year; at the end of the year an implementation workshop is held to share new results; these appear in refereed volumes. The implementations have provided deep insights into algorithms and empirical results have guided further theoretical investigations. These have been remarkably popular: the 1992-93 challenge drew 38 presentations of implementations on clique, coloring and satisfiability problems; the 1993-94 challenge on tree searching and algorithms for sparse and dynamic graphs already has 36 proposals.

Not all workshops, postdocs and visitors are within the special year topic. Some workshops are predecessors to potential special years intended to develop research activity, follow-ups to special years intended to harvest the scientific yield, or simply independent meetings that match the resources and goals of DIMACS. Similarly, some visitors and postdocs are chosen independently of special years.

Although the Rutgers site is the main physical location of DIMACS, offices and meeting locations are available at all four host sites; postdocs are at all locations with mentors (currently 5 at Rutgers, 2 at Princeton, 1 each at Bell Labs and BellCore, and 2 shared with Rutgers and the Institute for Advance Study.) All postdocs and visitors have a main office at one of the host sites and are accommodated at the others.

To further develop our knowledge transfer mission, DIMACS is proposing increments to our current activity: the molecular biology SY postdocs will be extended to two years to allow longer projects in suitable situations; we are developing research-industry joint postdocs (Curagen) to give experience with industry problems and experience, and we are proposing research working groups that can flexibly exploit opportunities to facilitate software development, workshop planning, and related activities.

## 2.2 Overview of Education and Knowledge Transfer

At the K-12 and College levels, DIMACS has programs that directly reach students in high-school and college, but is increasingly active in programs that train teachers (and teacher trainers), develop and adopt mathematics curricula, lead in mathematics reform, and undergraduate teachers. We sponsor a Young Scholars Program for high school students and REU programs. The Leadership Program is for lead mathematics teachers who are developing materials for discrete math teaching and training other teachers in the Mid-Atlantic region. Through alliances with the CMSCE and NJ SSI, we are working with state and national curriculum leaders so that materials developed and tested here will have a state and national impact on elementary and high school curricula.

Increased initiatives include supporting meetings of a national discrete math curriculum group and creating a DIMACS Education Coordinator position to assist with the increasing demands of existing programs. A pending RIMS proposal will have the education coordinator involving more of the permanent members in education. Our existing LP and YSP programs have stressed discrete math; developing this as the foundation of computing and increased use of computing including LINK and NETPAD are already underway.

# 3 Project Summary

A joint project of Rutgers University, Princeton University, AT&T Bell Laboratories, and Bellcore, the National Science and Technology Center for Discrete Mathematics and Theoretical Computer Science (DIMACS) aims to promote innovations in research and education in the interrelated fields of discrete mathematics and theoretical computer science. These are among the most rapidly growing fields of research in mathematics and computer science, and have wide applications to problems in fields such as telecommunications, networking, transportation, engineering, and cryptanalysis, as well as biology, chemistry, management, and decisionmaking. DIMACS is concerned with both the theoretical development of the fields represented and their practical applications. This proposal requests funds to support ongoing research and education activities, including Special Years focused on specific research topics, conferences and workshops in both research and education, long- and short-term visitor programs, postdoctoral fellowship programs, graduate research asssistantships, a variety of seminar series, activities for students and teachers at several levels, and publications.

# 4 Research

This section discusses accomplishments of the current funding period, proposed research and new thrusts. The accomplishments are organized by special years, other workshops, and other significant results. The following section discusses plans for future special years, workshops, and other initiatives. During the current grant, we have identified several opportunities to greatly increase the impact of our research program that we have been unable to fund. Plans include expanding the Special Year for Molecular Biology to 25 months; knowledge transfer of algorithms into technology demonstrations, and related items. The last section outlines capital equipment plans to support an increased visitor program, capabilities for on-line access to tech-reports, databases, and other information, and facilities for software demonstrations.

The introduction listed DIMACS' goals and several specific thrusts. Three words that might best capture what we seek to do in our core research area are: "creating intellectual infrastructure." Prior to DIMACS existence there were a few universities and industry labs of great excellence in discrete mathematics and theoretical computer science. While they served their researchers and students very well, they could not be national centers for the growing ranks at other institutions. DIMACS' vision for its own impact is far more than the sum of its pieces.

DIMACS seeks to be a *national resource* in discrete mathematics and theoretical computer science. Our workshops, special years, postdoc and visitor programs go far beyond ordinary conferences and sabbaticals. Special year tutorials reach a broad audience of college faculty, researchers, graduate students and postdocs all of whose research (and teaching) can gain. Timely research workshops give dozens to a hundred or more people an opportunity to join leading edge efforts on new problem areas such as molecular biology algorithms or new techniques such as probabilistic methods. The workshops provide a stimulating but informal atmosphere where ideas are shared and collaborations that extend far beyond the special years or our doors. The scientific expertise of our permanent members in NJ together with international experts enables DIMACS to organize state of the art meetings, to take timely risks on emerging topics that deserve attention, and to choose postdocs and other supported visitors that will electrify our activities. Our visitors from colleges and universities not only engage in research and they also take tutorials, research and plain old excitement home to invigorate education. Our nation-wide implementation challenges have opened doors for many to experiment with algorithms and implementations and creates important research opportunities. This is our vision of what we can do, and how broad and significant an impact it can have.

The following section reports on special years, workshops, etc. While we can document the level of participation at workshops, the technical reports of each year, and so on, we cannot document all the results of collaborations, individual research programs that are re-energized, or how much excellent science is done sooner rather than later. Some of the most exciting work does evolve over several years. The tremendous progress on Hadwiger's Conjecture (which explains the fundamental topological connection to coloring that underlies the four-

ABBREVIATIONS: Throughout this proposal, we use several abbreviations: PU (Princeton University), RU (Rutgers University), BL (AT&tT Bell Laboratories), BC (BellCore), PM (permanent member of DIMACS), V (short- or long-term visitor to DIMACS), PD (DIMACS postdoc), GS (DIMACS graduate student), DTR (DIMACS Technical Report).

color theorem) by Seymour (PM, BC), Robertson (V) and Thomas (V) developed over several years. Chvatal (PM,RU), et al's continuing progress in setting records for the Traveling Salesman Problem began in 1992 and continues. The breakthrough work on approximation of NP-complete problems relied on a result from DIMACS second special year in 1990-91 and the later work of DIMACS' visitors and permanent members. And the development of the field of on-line algorithms was shaped and stimulated by a DIMACS workshop in 199 attended by 22 students and 59 other researchers. It would be impossible to give a complete account of the large number of research results obtained at DIMACS or engendered by DIMACS programs since 1991.

## 4.1 Research Achievements

One of the most successful aspects of the structure of research activity at DIMACS, has been the Special Year program. A DIMACS Special Year acts as a focal point that encourages both formal and informal interactions between researchers studying different aspects of the same problem. Each Special Year has brought distinguished researchers, permanent DIMACS members, industry researchers, postdoctoral fellows, and graduate students from a different area of discrete mathematics and theoretical computer science together, for workshops, seminars, and implementation challenges. This section discusses, in turn, the special years, other workshops, implementation challenges, and addition results directly from the STC funding.

The success of a Special Year or even a single workshop cannot be measured immediately upon its conclusion, nor even a year or two later. A main feature of DIMACS workshops is to focus attention on open problems whose solutions will require new insight and will influence the field. Various teams of participants work on one problem or another during the course of the workshop and then continue to collaborate after its conclusion. Some problems are solved during a workshop, some soon after, some much later, and some remain open. In this section, we report on some of the continuing effects of special years and workshops offered in previous years and a selection of research results by our members and visitors and graduate students.

DIMACS special years consist of workshops, lecture and seminar series, selected visitors and postdocs all directed to a singly topic. We also have workshops that might be a prelude or followup to a special year or simply be independent of special year topics. This section discusses results of the three special years complete under this funding (the fourth topic, Mathematical Support for Molecular Biology is discussed in proposed research); other workshops and seminars; work by visitors and permanent members resulting from collaborations begun under prior funding, and other results of DIMACS support.

### 4.1.1 Special Year 1991-92: Graph Theory and Algorithms

The third DIMACS special year was chaired by Fan Chung (PM,BC) and Tom Trotter (PM,BC).[2] Special year activities centered on a series of four workshops:

- *Random Graphs and Randomized Algorithms*, September 16-19, 1991, Rutgers.
  *Chairs*: Milena Mihail (BC, PM), Joel Spencer (NYU)

[2] The organizing committee for the special year also included Ron Graham (PM,BL,RU), David Johnson (PM,BL), Richard Karp (Berkeley), Tom Leighton (MIT), Clyde Monma (PM,BC), Fred Roberts (PM,RU), Bob Tarjan (PM,PU), and Carsten Thomassen (Technical University of Denmark).

- *Planar Graphs*, November 18-21, 1991, Rutgers.
  *Chair*: Tom Trotter (PM, BC)

- *Graph Embeddings and Parallel Architecture*, January 13-15, 1992, Rutgers.
  *Chair*: Bruce Maggs (PM, NEC)

- *Expanding Graphs and Applications*, May 11-14, 1992.
  *Chairs*: Persi Diaconis (Harvard), Joel Friedman (PM,PU)

One of the most significant results from this Special Year grew directly out of a collaboration made possible by the visitor program. Paul Seymour (PM,BC) and DIMACS visitors Neil Robertson and Robin Thomas, made an impressive breakthrough on a generalization of the celebrated Four-Color Theorem, which says that any planar graph can be colored with only four colors in such a way that no two adjacent vertices have the same color. The generalization is a case of one of the most famous open problems in graph theory, called the Hadwiger conjecture, dating from 1943, which states that if a graph is not k-colorable, then it can be "contracted" to a complete subgraph with k+1 vertices. The Four Color Theorem is known to be equivalent to Hadwiger conjecture in the case $k = 4$. Seymour, Robinson, and Thomas proved Hadwiger's conjecture with k=5. One of the reasons for the interest in this conjecture is the desire for a satisfying proof of the Four Color Theorem; although a proof was given by Appel and Haken in 1976, their proof is not completely convincing to many, in part because it makes heavy use of a computer, but also because of problems with degeneracy. Continuing their collaboration which had begun in 1991-92, Seymour, Robinson, and Thomas worked with visitor Dan Sanders in 1993 to give a less complicated computer-aided proof; which both independently verifies the Four Color Theorem, and makes the general method more accessible to the mathematics community.

An interesting and surprising result coming out of the Special Year links pure combinatorics with applied problems: the DIMACS workshop on *Planar Graphs* played a key role in making it happen. Much of discrete mathematics and theoretical computer science is concerned with optimization problems. In practice, optimization algorithms must be modified dynamically on the basis of adversarial behavior (such as is a computer virus, a real-life opponent, or human error). An idealized version of such an adversarial situation can be modeled as 2-player graph coloring game. Tom Trotter (PM,BC) and Hal Kierstead (V) proved that 33 colors suffice to color a planar graph even when alternating turns with an adversary who is attempting to sabotage the effort. The most striking aspect of this result is that it seems difficult to prove that *any* finite number of colors is enough. The key idea behind the proof is the concept of admissibility, first employed by Guantao Chen and Richard Schelp in a Ramsey theoretic setting. Their result extends work done some 10 years ago by Chvátal, Rodl, Szemeredi and Trotter. Chen made a presentation on the Ramsey theoretic aspects of their work at the workshop; as a result, Kierstead and Trotter made the connection with graph coloring several weeks afterwards.

The special year workshop on *Graph Embeddings and Parallel Architecture*, held in January 1992, which was very well attended, bore fruit in the second half of the year. For example, in parallel computation it is important to design networks that are able to sustain a large number of worst-case faults with little degradation in performance. Most such networks have high vertex degree, and are hence often impracticable to build. Graduate student Ramesh

Sitaraman (PU) along with collaborators showed that in fact low-degree networks such as the butterfly and the mesh are indeed highly fault tolerant. This was an open problem presented at the workshop, after several speakers had discussed strategies for building fault-tolerance into interconnection networks. Moreover, the International Workshop on Interconnection Networks, held in July 1993 in Luminy (Marseilles) France, advertised itself as a "logical continuation" of this DIMACS workshop, evidence of much broader impact.

#### 4.1.2 Special Year 1992-93 - Combinatorial Optimization

This special year was chaired by László Lovász (PU and Budapest) and Paul Seymour (PM, BC).[3] The focal points for the year were four full-scale workshops:

- *Disjoint Path Problems*, November 16-20, 1992.
  *Chair*: Paul Seymour (PM, BC)
- *Probabilistic Algorithms for Combinatorial Optimization*, February 22-27, 1993. *Chairs*: Laszlo Lovász (PU and Budapest), Ravi Kannan (PM,BC), Michael Saks (PM,RU) and Peter Winkler (PM,BC)
- *Solving Hard Combinatorial Optimization Problems*, March 29-April 2, 1993.
  *Chairs*: Robert Bixby (Rice), William Cook (PM,BC), and David Johnson (PM,BL)
- *Perfect Graphs*, June 10-14, 1993.
  *Chairs*: Vašek Chvátal (PM,RU), Laszlo Lovász (PU and Budapest), and Bruce Reed (V)

Another successful component of the Special Year was a series of smaller workshops and mini-conferences on selected topics of current interest. Three were particularly noteworthy.

- *Approximation Algorithms*, March 24-26, 1993.
  *Chair*: Philip Klein (Brown)
- *The Quadratic Assignment Problem*, May 24-25, 1993.
  *Chairs*: Panos Pardalos (V) and Henry Wolkowitz (V)
- *Perfectly Orderable Graphs*, June 16-19, 1993. *Chair*: Vašek Chvátal (PM,RU)

The most dramatic outgrowth of the special year has been a series of demonstrations of the value of theory in improving the implementation of real programs. The work started before the special year had begun. For over a decade, computer codes for solving the notorious Traveling Salesman Problem have been tested on a standard set of problems or benchmarks, now available to the public under the name of TSPLIB. In the spring of 1992, a team consisting of David Applegate (PM,BL), Vašek Chvátal (PM,RU) William Cook (PM,BC), and Robert Bixby (Center for Research on Parallel Computation, Rice University) claimed a "gold medal" by solving fifteen previously unsolved problems from TSPLIB with sizes ranging from 417

[3]The organizing committee consisted of V. Chvátal (PM, RU), W. Cook (PM, BC), L. Hall (PU), P.L. Hammer (PM, RU), D.S. Johnson (PM, BL), W.R. Pulleyblank (IBM), and A. Schrijver (Amsterdam).

to 3038 cities (the largest previously solved TSPLIB problem had 2392 cities). Bixby and Cook (along with David Johnson) then organized the workshop *Solving Hard Combinatorial Optimization Problems*, in March of 1993, increasing the interest in this work and stimulating further development. In fact, by June 1993, the team broke its own record by solving a TSPLIB problem with 4461 cities, and have continued to make improvements. Another important role of DIMACS in this work was the openness of its computer system; for security reasons, Bell Labs and BellCore cannot offer remote logins to share data and code, however Bell Labs donated a disk to DIMACS to effect this collaboration.

The "mini-workshop" on *Approximation Algorithms*, which drew an audience comparable to the larger workshops, was devoted to exciting new developments in the field of approximation algorithms. These included new techniques for the design of heuristic or approximation algorithms, using linear programming, randomization, and other methods. Just as important were proofs establishing the impossibility of certain approximation tasks. This latter work used techniques based on the theory of interactive proofs, which resulted from the prior Special Year on Complexity Theory (1990-91).

The workshop on *Probabalistic Algorithms for Combinatorial Optimization* highlighted important new techniques for analyzing random walks (Markov chains). One important result using this technique grew out of a collaboration between DIMACS members and visitors. Ravi Kannan (PM,BC) and Laszlo Lovász (PU and Budapest) (workshop organizers) together with M. Simonovits (V), improved the running time of randomized volume, sampling, and integration algorithms. Due to these improvements, the original running time of $O(N^{27})$ (which was of theoretical interest though impractical) was reduced to $O(n^7)$ in 1992, and has since been reduced to $O(n^6)$, which is now near the range where practical implementations may be feasible.

Several important new results on approximate Max-flow Min-cut Theorems were obtained and presented by Satish Rao (PM, NEC) with Special Year visitors Eva Tardos, Vijay Vazirani, Serge Plotkin, and others, made possible by interactions fostered at DIMACS. This important and fast-developing area was featured in several seminar talks, workshop discussions, and informal research throughout the year. Strong connections with other themes of the Special Year, such as properties of the cut cone and mixing properties of Markov chains were discovered. The mixing rate of Markov chains was also the central theme of the second workshop, several seminar talks, and on-going research.

Both the workshops on *Perfect Graphs* and *Perfectly Orderable Graphs* led directly to settling many conjectures on the structure of perfect graphs. Many graphs which arise in scheduling, covering, and geometric problems turn out to be perfect; characterizing perfect graphs in terms of forbidden subgraphs has been a long outstanding problem in graph theory. Most significantly, Irena Rusu constructed an infinite family of perfect graphs simultaneously satisfying a list of key conditions. A DIMACS volume arising from the workshop, with the working title *Handbook of Perfect Graphs* is in preparation. One of the reasons for the success of the workshops was the use of an unorthodox format. In February, some 120 potential participants were presented with a list of open problems and a rudimentary bibliography on the subject; they were invited to add to both and to suggest other potential participants. In this way, around 150 people were eventually contacted; many of those who could not come to Princeton in June chose to remain on the mailing list and participated in the e-mail session that lasted over three months. The bibliography grew to more than 300 items by the end of

May.

### 4.1.3 Special Year 1993-94 - Massively Parallel Computing

Tom Leighton (MIT) and Bruce Maggs (CMU) co-chaired this Special Year, [4] which represented a significantly broader and multidisciplinary topic than those in previous years. The strategy of the special year has been to bring together experts in DIMACS areas with the engineers who build parallel supercomputers and the physical scientists designing solutions to what are known as "Grand Challenge" problems, such as earthquake prediction or the analysis of protein folding.

Although a Special Year at DIMACS generally lasts for 12 months, this special year had an early kick-off with two workshops in the spring of 1993.

- *Future Directions for Parallel Optimization*, April 30-May 1, 1993.
  *Chairs*: David Applegate (PM,BL), John Dennis (CRPC, Rice U.), and Irving Lustig (PU)

- Parallel Algorithms for Unstructured and Dynamic Problems, June 2-4, 1993.
  *Chairs*: Alberg G. Greenberg (PM,BL), and Andrew T. Ogielski (PM,BC)

The main portion of the Special Year began in September, as postdoctoral fellows and visitors began to arrive. The year featured six workshops, hosted at both Rutgers and Princeton.

- Models, Architectures, and Technologies for Parallel Computation Sept. 20 - 22, 1993.
  *Chairs*: Phillip Gibbons (BL), Richard Karp (UCB), Charles Leiserson (MIT), and Greg Papadopolous (MIT).

- *Parallel Algorithms: From Solving Combinatorial Problems to Solving Grand Challenge Problems*, November 17-19, 1993, Rutgers.
  *Chairs*: Jim Flanagan (CAIP, RU), Yossi Matias (PM, BL), and Vijaya Ramachandran (UT)

- *Organizing and Moving Data in Parallel Computers*, January 26-28, 1994, Princeton.
  *Chairs*: Christos Kaklamanis (PD, RU), Kai Li (PU), Greg Plaxton (UT), and Abhiram Ranade (UCB).

- *Interconnection Networks and Mapping and Scheduling Parallel Computations*, February 7-9, 1994, Rutgers.
  *Chairs*: Frank Hsu (Fordham), Arnold Rosenberg (UMass), and Dominique Sotteau (LRI, U. Paris-Sud).

- *Parallel Processing of Discrete Optimization Problems*, April 28-29, 1994, Rutgers.
  *Chairs*: P. M. Pardalos (U. Florida), M. G. C. Resende (PM, BL), and K. G. Ramakrishnan (BL).

[4]The organizing committee consisted of Alok Aggarwal (IBM), Sandeep Bhatt (PM, BC), Jim Flanagan (CAIP, RU), Albert Greenberg (BL), Dick Karp (UCB), Ken Kennedy (CRPC, Rice), Janos Komlos (PM, RU), Andrew Ogielski (PM, BC), Bob Sedgewick (PM, PU), and Chuck Seitz (Caltech).

- Specification of Parallel Algorithms, May 9-11, 1994, Princeton. [5]
  *Chairs*: Guy Blelloch (CMU), Mani Chandy (CRPC, Caltech), and Suresh Jagannathan (NEC).

The goal of this Special Year is to have a positive impact on the design of the next generation of parallel computers and parallel algorithms, and thus to enhance this country's position as the world leader in supercomputing. An ancillary goal of the special year is to develop New Jersey's leadership role in the field of high performance computing (HPC). One of the successes of the special year has been the ability of DIMACS to attract top researchers from other areas, including computer architects, application researchers, and commercial vendors.

Although it is too early to assess the impact of this Special Year, it is already possible to point out an important conceptual breakthrough that came in part from the DIMACS workshop *Models, Architectures, and Technologies for Parallel Computation*. This workshop attracted nearly 200 participants, including many students. Several participants remarked that this was the best workshop they had ever attended, noting the usefulness of extended communication and discussion specifically aimed at bridging the various areas represented. A consensus was established that parallel computer architecture is converging in the short term on machines based on commodity microprocessors, but that in the next five years we would begin to see hardware support for shared memory in these machines.[6] The consequences of convergence on a particular form of architecture are far reaching; it gives the architects a target to aim for, it gives the theoreticians a model in which to design algorithms, and it determines which Grand Challenge problems are likely to succumb to parallel computation in the near future.

At least two of the workshops will result in published, refereed DIMACS/AMS Volumes, including the workshop on *Interconnection Networks and Mapping and Scheduling Parallel Computations*, and *Parallel Processing of Discrete Optimization Problems*. One of the key successes of the latter workshop was initiating collaboration among the European participants and several researchers from the U.S. In addition, many participants stayed at DIMACS after the workshop working on joint projects.

The postdoc and visitor programs have already led to valuable new results. For example, Postdoc Edith Cohen (PD,PU) has developed new methods for reducing the numbers of processors and total work needed in parallel algorithms for basic problems such as network flow, matching, and shortest paths, by trading work for accuracy. Her results find solutions that are provably near-optimal. Postdoc Andrew Rau-Chaplin, has taken advantage of DIMACS resources to develop a monograph on parallel algorithms for distributed memory machines.[7] Teresa Przytycka's visit to DIMACS resulted in the invention of two parallel algorithms for solving problems on binary trees. The first grew from a collaboration with Martin Farach (PM, RU) and visitor Mikkel Thorup.

[5] A joint workshop with the Center for Research in Parallel Computation (CRPC) at Rice.

[6] This convergence was discussed in greater detail at a workshop on "Suggesting Computer Science Agenda(s) for High-Performance Computing", which was held in Arlington, Virginia, and was sponsored by the NSF, the the University of Maryland Institute for Advanced Computer Studies (UMIACS), and DIMACS.

[7] The coauthors are Quentin Stout (Michigan) and Russ Miller (Buffalo) to be published by MIT Press.

### 4.1.4 DIMACS Implementation Challenges

In recent years, there has been growing interest in the application of computational and statistical tools to problems in the analysis of algorithms. In many algorithmic domains worst-case bounds are too pessimistic and tractable probabilistic models too unrealistic to provide meaningful predictions of practical algorithmic performance; experimental approaches can provide useful knowledge where purely analytical approaches fail. Moreover, experiments can provide deeper insight into algorithmic mechanisms and therefore motivate and guide deeper analytical results. Furthermore, in recent years theoretical work on the design and analysis of algorithms has often become divorced from the original applications and implementation issues that motivated it. Experiments, with their requirements that algorithms actually be implemented in code and that meaningful test instances be found/created, bring application and implementation issues back to the fore. They also can greatly facilitate the technology transfer process, since they not only can help determine the best algorithms to use in various practical situations, but they also create the key artifact needed to put an algorithm into use: an implementation of it.

Despite the potential value of the experimental approach, however, there has not been a strong experimental tradition in the field of algorithm analysis. The *DIMACS Implementation Challenges* are a response to the perceived need for encouraging more work in this area. So far there have been three Challenges, a fourth one is being organized for the 1994-1995 Academic year, and we now expect these to be an annual event throughout the life of DIMACS, often (but not necessarily) tied to the subject of the current Special Year. In the following paragraphs we summarize the results of the first two Challenges, give a status report on the currently ongoing Challenge, and say a bit about the plans for future Challenges.

- 1st Challenge (90-91): Network Flows and Matching [8]

  This Challenge concentrated on problem areas of maximum flow, minimum cost flow, the assignment problem, and matching (both weighted and unweighted). The workshop proceedings are now available as Volume 12 of the DIMACS Series published by AMS, a 592-page volume containing 22 refereed papers. In addition more than 7 MB of standards, test instances and generators, algorithm codes, reference lists, etc.) are now available via FTP from the `\pub\netflow` directory at `dimacs.rutgers.edu`. These files, for the most part contributed by the participants, can be viewed as just as important a "product" of the Challenge as the Proceedings, and were used extensively by participants during the course of the Challenge (and afterwords).

  During the course of the year some 41 different groups submitted proposals and received feedback and suggestions from the Steering Committee. Almost all communication took place over the Internet. The majority of participants were from North America, but Europe, South America, and the Far East were also represented. Many projects involved students, but many also involved established researchers, both in industry and academia. (Companies with papers in the final proceedings include GTE, Lockheed, and IBM-Japan in addition to BellCore and AT&T Bell Laboratories).

[8] David S. Johnson (PM,BL) and Catherine C. McGeoch (V,Amherst College), Coordinators, with Mike Grigoriadis (PM,RU), Clyde Monma (PM,BC), and Bob Tarjan (PM,PU) on Steering Committee.

Approximatedly 60 people attended the three-day workshop, about 1/3 of whom had not personally taken part in the Challenge but were interested in the topic and/or experimental analysis. In addition to the 26 contributed papers, there were four tutorial sessions, three on the general problem domains and one on experimental methods. There were also three panel discussions. One evening session was devoted to informal, head-to-head competitions among participant's codes.

Among the conclusions of the Panel Discussions: The Goldberg-Tarjan push/relabel approach to network flow is now the method of choice for that problem. No such robust champion had yet emerged for min cost network flow, with most proposed techniques doing very well on some classes of instances and very poorly on others. (Subsequent work by Andrew Goldberg, inspired by this challenge, suggests that a well-tuned push/relabel approach may well be the winner here too, however.) For multi-commodity flow, approximation algorithms inspired by theoretical considerations turn out to beat traditional linear-programming based techniques when the number of commodities is high. For weighted matching problems where the weights correspond to distances in the plane, much larger instances can be solved than previously thought possible (e.g., instances with as many as 100,000 points to be matched). Finally, participants were unanimous in their desire for more Implementation Challenges (many suggesting that they had learned so much that they'd like to immediately have another Challenge on Network Flows and Matching!)

- 2nd Challenge (92-93): Clique, Coloring, and Satisfiability [9]

  The topics for this Challenge was chosen to fit in with the concurrent Special Year topic of Combinatorial Optimization. Both optimization and approximation algorithms were covered. Approximately 100 researchers attended the concluding workshop, which took place in October, 1993, and consisted of 38 presentations and poster sessions, two invited survey talks, and three panel discussions. (The poster sessions, originally viewed with some skepticism by those selected to present them, turned out to be a very effective format for a workshop of this type.) A refereed Proceedings is currently being prepared for inclusion in the AMS DIMACS Series, and the body of test instances, codes, etc. currently available from DIMACS via anonymous ftp continues to grow. The participants once again covered a broad spectrum, including a significantly increased participation from the Operations Research Community. Indeed, the ORSA-TIMS National Conference in April 1994 solicited the organization of a special Invited Session to communicate the results of the Challenge to that community.

  A sample of the conclusions: finding the maximum clique in graphs with approximately 400 nodes could be done routinely by a variety of techniques, but at present nothing seems to work consistently for dense 1000 node problems; general 100 node graph coloring problems seem very difficult to solve, while much larger problems generated from real-life register allocation problems are much easier; exact methods for satisfiability, based on improvements to the basic Davis-Putnam procedure, are able to solve prob-

[9] Michael Trick (V,GSIA-CMU, Coordinator, with Vašek Chvátal (PM,RU), Bill Cook (PM,BC), David Johnson (PM,BL), Catherine McGeoch (Amherst College), and Robert Tarjan (PM,PU) on Steering Committee.

lems (random instances in the so-called "critical region") up to 400 variables, but fail to terminate in a reasonable amount of time shortly thereafter; general heuristic approaches, such as tabu search and simulated annealing, seem to be robust, practical methods for approximately solving all of these problems.

- 3rd Challenge (93-94): Parallel Algorithms for Tree Searching and for Manipulating Sparse and Dynamic Graphs [10]

  As with the 2nd Challenge, this Challenge has a topic that fits with the ongoing Special Year theme, in this case Massively Parallel Computing. The use of massive parallelism in discrete combinatorial applications has received far less attention than in numerical applications. Despite the large body of theoretical work on parallel algorithms for combinatorial problems, it is unclear what kinds of parallel algorithms will be most effective in practice. The goal of this challenge is to provide a forum for a concerted effort to study effective algorithms for combinatorial problems, and to investigate the opportunities for massive speedups on parallel computers. The two specific topics chosen have so far drawn some 36 different proposals. Extended abstracts are due in August, and at the final special year workshop, the "DIMACS Parallel Implementation Challenge Workshop," which will be held in October 1994, with a Proceedings to be completed in 1995.

- 4th Challenge (94-95): DNA Sequence Determination [11]

  This Challenge, aligned with the upcoming Special Year on computational biology, is currently in the planning stages. One of the current proposed problems is to develop algorithmic methods for a series of benchmark problems dealing with DNA sequence determination from shotgun sequence data.

Future challenges are discussed in the proposed research section.

#### 4.1.5 Other Workshops and Seminars

While a special year is a major focus of activity, about half of the postdoc and visitor positions are filled without regard to the topic. Other workshops and seminars also take place. These workshop topics and committees meet the same criteria as others. Individual workshops can be a planning event for a later special year, or harvest yields of earlier years. Or just reflect an appropriate level of interest in an important research field.

- *Groups and Computation*, October 7-10, 1991. (42 participants; 13 students)

  A primary goal of this workshop, organized by Larry Finkelstein (Northwestern U.) and Bill Kantor (PM, RU & U. Oregon), was to foster a dialogue between researchers studying the complexity of permutation and matrix group computations and those engaged in

[10] Sandeep Bhatt (PM,BC), Coordinator, with David Culler (Berkeley), John Dennis (CRPC, Rice), David Johnson (PM,BL), Lennart Johnsson (Thinking Machines, Harvard), and Charles Leiserson (MIT) on the Steering Committee.

[11] Martin Vingron (GMD) and Ellson Chen (Applied Biosystems), Coordinators, with David Johnson (PM,BL), Joachim Messing (RU, Waksman Institute of Molecular Genetics), and Michael Waterman (USC) on the Steering Committee.

the development of practical computer algorithms. These two communities have collaborated to an unexpected extent, as they came to realize the commonality of their goals. They learned that a deeper understanding of the mathematical issues underlying group computations ultimately leads to faster algorithms; and that practical requirements can lead to new and faster theoretical algorithms.

The workshop resulted in significant improvements to Gap, the group theory system developed by Prof. J. Neubueser at RTWH Aachen, Germany. The improvements included corrected algorithms, faster algorithms based on theoretical improvements and ongoing work on a compiler. Several other collaborations were significantly strengthened as a direct result of the workshop. Kantor, Seress, and a student of Seress (P. Morje) are in the process of producing practical algorithms, for inclusion in Gap, for computing with Sylow subgroups of permutation groups.

D. Rockmore, G. Cooperman, L. Finkelstein and B. York began a seminar on the application of computational group theory, spectral analysis on finite groups and parallel algorithms for algebraic computations, to problems in the physical sciences. They have recently joined forces with several prominent crystallographers and mathematicians including scientists affiliated with Thinking Machines in Cambridge, focusing on applications to X-ray crystallography. Dan Rockmore has also collaborated with R. Beals and L. Babai on algorithms for matrix groups over number fields.

- *Computational Support for Discrete Mathematics.* March 12-14, 1992. (48;11)

  This workshop, organized by Nate Dean (PM,BC) and Gregory Shannon (Indiana), was intended to facilitate working relationships among a widespread group of researchers concerned with the development of general-purpose software and integrated software systems for various domains in "experimental" discrete mathematics, for the purpose of providing effective computational tools for research, applications prototyping, and teaching. The workshop has already played a major role in triggering LINK: a new DIMACS initiative in this area. LINK is an NSF funded project to build a comprehensive software system for combinatorial computing and experimental discrete mathematics that is efficient, portable, and extensible.

- *Constructive Models of Human Language*, March 20-22, 1992. (50;15)

  The goal of this workshop organized by Eric Ristad (PM,PU) and Stephen Levinson (AT&T) was to bring together theoretical computer scientists and theoretical linguists to develop the computational theory of human language. Participants included many of the world's most prominent generative linguists, cognitive psychologists, and learning theorists. The workshop has already had an impact on our understanding of how human languages are learned. In particular, we expect to see a new formal framework within which to study language learning, based on ideas presented at the workshop.

  Participants included many of the world's most prominent generative linguists, (including Stephen Anderson, Luigi Burzio, Osamu Fujimura, Moris Halle, Alec Marantz, J.R. Vergnaud, and Edwin Williams), cognitive psychologists (George Miller), and learning theorists (Eric Baum, Jorma Rissanen, Les Valiant, and Paul Vitanyi). Four graduate students gave presentations of dissertation work in various stages of completion. Two other graduate students received travel support in expectation of pursing related topics in their doctoral research.

- *Coding and Quantization*, October 19-21, 1992. (32;5)

  This workshop, jointly sponsored by the IEEE and organized by Robert Calderbank (PM,BL), G. David Forney (Motorola) and Nader Mayeri (RU), brought together researchers in two different communities, those who work in coding theory (and aim to increase the reliability of information transmission) and those who work in quantization (and aim to decrease distortion when an information source is compressed). The majority of attendees were engineers, with about 20% from local industry and government organizations. There was a good mixture of theoretical results and mathematical innovation that will be a part of future consumer electronics products such as 19.2 kb/s modems and subband coding schemes for video transmission.

  The workshop led to results reported in the October, 1993, issue of *Science* (a copy of which is included in the Appendix.) Most work on cyclic codes has emphasized "linear codes". consisting of all vectors $x$ over some finite field (commonly the integers mod 2, "binary codes") such that $Ax = 0$, for some matrix $A$. These codes have a clean structure that makes them simple to discover, to understand, and to encode and decode. Two codes which were assumed to be non-linear, the Kerdock and Preparata codes, have long been known to be "dual" to one another in a particular formal sense, even though mathematical *duality* is defined only for linear codes. For roughly 20 years this curious observation left coding theorists with the open question of whether these non-linear codes might not be duals in some stronger sense. Robert Calderbank (PM,BL), Hammons, Kumar, Neil Sloane (PM,BL) and Solé [DTR 93-50] recently resolved this question by showing that the Kerdock and Preparata codes are in fact linear, if one views them in the right way over the ring of integers mod 4 instead of mod 2, and that, over this larger alphabet, the two codes *are* mathematical duals. The mapping between the mod 2 and mod 4 versions of the codes is extremely simple.

- *Partitioning Data Sets: With Applications to Psychology, Vision and Target Tracking*, April 19-21, 1993. (40 participants)

  This workshop, organized by Ingemar Cox (PM,NEC) and Pierre Hansen (PM,RU) brought together about 40 participants from the Cluster Analysis, Target Tracking, Computer Vision and Psychology fields. Theoretical, tutorial presentations were interleaved with those focusing on recent research and applications. The workshop explored connections between graph clustering, partitioning and image processing techniques, and the use of methods from combinatorial optimization, such as quadratic and dynamic programming. In particular, the first, and very successful, application of unconstrained quadratic 0-1 optimization to image enhancing was discussed by Endre Boros (PM,RU).

- *Geometric Group Theory*, Jan 3-14, 1994 and March 17-20, 1994. (40;7)

  In recent years investigation of geometric and language-theoretic aspects of finitely presented groups has engendered a remarkable interplay between group theory, geometry, and the theory of automata and formal languages. Perhaps the best known result of this interplay has been the introduction of automatic groups, which include the hyperbolic groups of M. Gromov. Computational considerations, both practical and theoretical, have played an important role in these developments. There have been many conferences on geometric group theory, but none prior have focussed on the computational side of the subject. DIMACS and the Geometry Center at the University of Minnesota jointly sponsored two workshops on computational and combinatorial aspects of geometric group theory. A small workshop was held at the Geometry Center from January 3-14, 1994, to focus on programming and practical computation. The second DIMACS workshop, in addition to communicating the relevant results of the first workshop, covered a wider range of topics. The organizers for this pair of workshops are Gilbert Baumslag (CCNY), David Epstein (U. of Warwick), Robert Gilman (Stevens Institute of Technology), Hamish Short (CCNY), and Charles Sims (PM,RU).

- *Formal Power Series And Algebraic Combinatorics*, May 23-27, 1994. (150 Participants; 45 students)

  DIMACS hosted the 6th International Conference on Formal Power Series and Algebraic Combinatorics (FPSAC '94). This is the premier conference in the area of Algebraic and Enumerative Combinatorics. The conference focuses on algebraic combinatorics and its connections with enumeration, topology, geometry and theoretical computer science. The conference included invited survey lectures, contributed presentations, a problem session, and software demonstrations. Invited speakers include Anders Bjorner (Sweden), Ruth Charney (USA), Maylis Delest (France), Philip Hanlon (USA), David Jackson (Canada), Gil Kalai (Israel), Sergei Kerov (Russia), Christophe Reutenauer (Canada), Sheila Sundaram ( USA). The organizers of this conference are Louis Billera (Cornell University), Curtis Greene (Haverford College), Rodica Simion (The George Washington University, Chair), Richard Stanley (MIT).

- *Developing Computer Science Agenda(s) for High-Performance Computing*

  Working with Uzi Vishkin (Maryland) as organizer, DIMACS and UMIACS (University of Maryland Institute for Advanced Computer Studies cosponsored this workshop held in Arlington, VA. An edited volume of these papers is already at the ACM for publication. Thirty three representatives of the U.S. Computer Science and Engineering academia and industry responded to the following question: "Suppose that you are in charge of a budget of 5 billion dollars over the next ten years for advancing high-performance computing; what would be your technical agenda for making the greatest impact?" There was wide agreement that the programmability of parallel systems, their performance, and the portability of application software across a variety of parallel systems are some of the key issues facing the field. A strong case for continuation of exploratory research that will make general-purpose parallel computing ubiquitous was made in these papers. Issues such as how to make independent software vendors more active participants and harness more of the main stream computer system building industry into participation in this effort were also discussed.

In addition to workshops, there are a variety of seminar series, whose programs are included in the appendix.

- *Mixer Series.* In the fall of 1992, the Mixer Series replaced the DIMACS Forum; it was organized by Martin Farach (PD). 1993-94 saw the second iteration of this new tradition, organized by Christos Kaklamanis (PD). In the Mixer Series: there are four afternoon events within the first month or so of the academic year, one at each DIMACS site. Newcomers to DIMACS give talks at sites other than their own base site. In this way, the 120 permanent members can get a sampling of who is around for the year, and visitors and postdocs get to meet other members at all four institutions.

- *DIMACS Series.* The Theory of Computation Series and the Discrete Mathematics Series, both organized by Michael Saks (PM,RU) and originating in Fall, 1993, each convene weekly over lunch and provide an informal and high level research forum for DIMACS members, visitors, and graduate students. The DIMACS-RUTCOR industrial problem seminar organized by Michael Rothkopf (PM, RU) meets periodically in conjunction with his graduate course in case studies. A new bi-weekly series in Mathematics Education was also originated in Fall, 1993.

- *Biomathematics/Biocomputing Seminar Series.* (This series was initiated with DIMACS funds, but then was the subject of an supplementary grant proposal that has funded it since that time.) This series, now completing its second year, is part of DIMACS' expanding involvement in the biological sciences. This series of talks, which are held on an approximately monthly basis, exposes the DIMACS community to problems with biology, particularly within molecular biology. The talks are also advertised within the biology community and we often find that a significant fraction of the audience are working biologists. This series culminated this year in Phylogeny Day, May 26, 1994. The interest in this series is reflected in the major commitment to the Molecular Biology Special Year for 1994-95 with a series of 10 Distinguished Lecturer talks.

#### 4.1.6 Selected Other Results

The DIMACS visitors, postdocs, graduate students and permanent members are active in research that is not owed to workshops or is the continuing impact of workshops prior to this renewal. This section describes a few of the most exciting results. Appendix D, with publications, gives a complete picture of all research at DIMACS.

- Recently, Ikebe, Perles (V), Tamura and Tokunaga solved a problem on embedding rooted trees in the plane, posed by Micha Sharir (V) during a workshop in the 1989-90 DIMACS Special Year on Discrete and Computational Geometry. They proved that any rooted tree of $n$ vertices can be straight-line embedded into any set $S$ of $n$ points in the plane in general position so that the image of the root is arbitrarily specified.

- The work that began in that same Special Year at the workshop on Probabalistic Methods in Discrete & Computational Geometry led to a flurry of remarkable new results. R. Seidel (V) presented the "backwards analysis technique" which simplified the analysis of randomized geometric algorithms. He showed there how to use it in linear programming, and later, in several other contexts. Since then this idea, invented as a method of analyzing algorithms, has evolved into a tool for *devising* randomized algorithms.

The ground-breaking work of J. Matousek (V) on cuttings, epsilon approximations, and epsilon-nets although it is a breakthrough in the ar ea of *derandomization* of randomized algorithms, it is also of fundamental interest in combinatorics and combinatorial geometry, together with the seminal work of Kenneth Clarkson (PM,BL) and Peter Shor (PM,BL) on incremental randomized algorithms, the derandomization ideas provided some of the tools for new developments such as the recent discovery by Bernard Chazelle (PM,PU) of the first optimal (deterministic) algorithms for computing convex hulls and Voronoi diagrams in any fixed dimension: this successfully ended a 20-year old quest for an optimal solution to one of the most central but elusive problems in computational geometry. The same derandomization techniques play the major role in settling the complexity question for other problems, such as the diameter in dimension 3. Finally, the work of Chazelle, Matousek, and others reveals the fundamental relationship between epsilon nets and epsilon approximations and discrepancy theory. This major line of research owes its start, and much of its development, to the first DIMACS special year, and the collaborations that grew out of it.

- The problem of building evolutionary trees is a fundamental problem in computational biology. No efficient algorithm for building evolutionary trees was known, until DIMACS postdoc Martin Farach, former DIMACS postdoc Sampath Kannan and DIMACS visitor Tandy Warnow developed the algorithm presented in the paper "A Robust Model for Finding Optimal Evolutionary Trees" (DTR 93-22). This was one of two papers from ACM-STOC that was was selected as an Impact Paper at the CRA - Federated Computing Research Conference (1993) to be featured to the press. The techniques developed for this problem have important applications to problems beyond relationships among species. For example, the multiple alignment problem is central to the Human Genome Project, but no efficient algorithms are known to solve it. The clustering techniques developed for evolutionary tree constructions have proved to be useful heuristics in attacking this alignment problem.

- Anne Condon, Joan Feigenbaum (PM,BL), Carsten Lund (PM,BL), and Peter Shor (PM,BL) (DTR 93-10) gave a new characterization of $PSPACE$ that is used to show that certain $PSPACE$-hard functions are as hard to approximate as they are to compute exactly. They investigated properties of the "probabilistically checkable debate system" (PCDS), a natural generalization of the probabilistically checkable proof system studied recently by Babai et al., Feige et al., and Arora et al. A PCDS for a language $L$ consists of a probabilistic polynomial-time verifier $V$ and a debate between player 1, who claims that the input $x$ is in $L$, and player 0, who claims that the input $x$ is not in $L$. They show that there is a PCDS for $L$ in which $V$ flips $O(logn)$ random coins and reads $O(1)$ bits of the debate if and only if $L$ is in $PSPACE$. This paper is yet another result in the vein of startling approximation results whose origin was at DIMACS first special year in 1990-1991.

- Michael Saks (PM,RU) and F. Zaharoglou (GS,V) have studied consensus problems for distributed systems using topological methods. Much of the theory of distributed computing is concerned with problems of coordinating a set of processors. Various problems have been proposed to model simple coordination tasks. A famous result of Abu

Amara-Loui and Herlihy (based on a previous result of Fisher-Lynch-Patterson) says that, in the standard asynchronous shared-memory with atomic read/write, a very basic coordination task called "consensus" is impossible to do with absolute reliability. S. Chaudhuri conjectured that the same impossibility result extends to a weaker coordination task called "k-set consensus". Here this conjecture was proved by showing that the structure of the problem can be represented by topological space and the impossibility result follows from a fixed point theorem on that space.

- In an invited address at the bi-annual Workshop on Algorithms and Data Structures at Montreal in August 1993, Robert Tarjan (PM,PU) presented his dramatic new result with Philip Klein (V), a randomized linear-time algorithm for finding a minimum spanning tree in a connected graph with edge weights (DTR 93-71). The algorithm is a modification of one proposed by Karger and uses random sampling in combination with a recently discovered linear-time algorithm for verifying a minimum spanning tree.

- A computer is generally considered to be a universal computational device, in other words, it is able to simulate any physical computational device with a cost of at most a polynomial factor in the computation time. It is not clear that this is still true if quantum mechanics is taken into account. Several researchers have developed models for quantum mechanical computers and investigated their computational properties. Peter Shor (PM, BL) has shown that these computers can factor integers and find discrete logarithms in polynomial time. Polynomial time algorithms on ordinary computers for these problems are not known; this truly surprising result is expected to generate great activity to fully understand the power and feasibility of the quantum computing model.

- As one of ten papers presented by DIMACS authors or co-authors at 34th Annual IEEE Conference on Foundations of Computer Science (FOCS), November 3-5, 1993 in Palo Alto, California, H. Hampapuran (GS,RU) and Michael Fredman (PM,RU) presented their result on optimal bi-weighted binary trees and the complexity of maintaining partial sums. The *partial sum problem* concerns the design of a data structure for implementing the following operations on an array $A$. The operation $update(j,x)$ has the effect, $A[j] \leftarrow A[j] + x$, and the query operation $sum(j)$ returns the partial sum, $\sum_{i=1}^{j} A[i]$. Hampapuran and Fredman derive new upper and lower bounds for the optimal efficiency with which sequences of such operations can be performed in the semi-group model of computation. An important application of this problem arises in maintaining empirical cumulative distribution functions for statistical databases that are periodically updated. The new results concern the design of data structures that have optimal efficiency, taking into account the frequency with which the various update and query operations are performed.

- Another advance was made on understanding random matchings in graphs. With a simple graph $G$ associate the random variable $\xi(G)$, defined as the size of a matching chosen uniformly at random from the set of all matchings of $G$, and write $\mu(G)$ and $\sigma^2(G)$ for the mean and variance of $\xi(G)$. For a vertex $x$, write $p(\overline{x})$ for the probability that the random matching does not cover $x$. Jeff Kahn (PM,RU) and J.H. Kim (GS, RU) showed that for a regular $G$ the values $p(\overline{x})$, $\mu(G)$ and $\sigma^2(G)$ are remarkably well determined just by the degree and number of vertices. In particular, for any d-regular, n-vertex simple graph G, and $x \in V(G)$: (a) $p(\overline{x}) \sim d^{-1/2}$, and consequently $n - 2\mu(G) \sim nd^{-1/2}$, and (b) $\sigma^2(G) \sim n/(4\sqrt{d})$. The rates of convergence in these limiting statements depend only on $d$.

- In DTR 93-56, John Hershberger and Subhash Suri (PM,BC) propose a very simple ray shooting algorithm, whose only data structure is a triangulation. The query algorithm, after locating the triangle containing the origin of the ray, walks along the ray, advancing from one triangle to a neighboring one until the polygon boundary is reached. The key result of the paper is a Steiner triangulation of a simple polygon with the property that a ray can intersect at most $O(\log n)$ triangles before reaching the polygon boundary. The triangulation can be computed in linear sequential time, or in $O(\log n)$ parallel time using $O(n/\log n)$ processors. This gives a simple, yet optimal, ray shooting algorithm for a simple polygon. Using a well-known technique, the triangulation procedure can be extended to a multi-connected polygon with k components and n vertices, so that a ray intersects at most $O(\sqrt{k}\log n)$ triangles.

- Mikkel Thorup (V) reported a new approach to ambiguity of context-free grammars (DTR 93-61). This allows the LL and LR techniques to be generalized to solve the following problems for large classes of ambiguous grammars: construction of a parser that accepts all sentences generated by the grammar, and which always terminates in linear time; construction of a finite set of pairs of partial parse trees such that, if for each pair the two partial parse trees are semantically equivalent, the ambiguity of the grammar is semantically irrelevant.

#### 4.1.7 Notable work by Graduate and Undergraduate Students

DIMACS supports graduate students at Rutgers in computer science, mathematics and the RUTCOR (operations research) programs; and at Princeton in computer science. Many other students benefit from DIMACS programs and are advised by DIMACS permanent members. Appendix D includes a list of PhD theses supervised by DIMACS permanent members for the reporting period. A few notable results are discussed here.

Several DIMACS grad students earned Ph.D.s since the (91-92, 92-93, 93-94) the last renewal. Here we highlight notable results from three of the dissertations.

- Graduate student Iliana Bjorling-Sachs and advisor Diane Souvaine (PM,RU) solved a long-standing open problem by proving that every simple polygon with $n$ vertices and $h$ holes can be guarded using at most $\lfloor (n+h)/3 \rfloor$ guards. They also provided an $O(n^2)$ algorithm for placing the guards.

- Graduate student Jeong Kim (RU) has been studying the relationship of chromatic number and maximum degree for triangle-free graphs. Kim's results show a correct order of magnitude for both the chromatic (and list-chromatic) number of such graphs when the girth is at least 5. The previous best result was not even asymptotically sharp.

- Graduate student Adam Buchsbaum and advisor Robert Tarjan (PM,PU) introduced *data-structural bootstrapping*, a technique to design data structures recursively, and used it to design confluently persistent deques. This data structure requires $O(\log^* k)$ worst-case time and space per deletion, where $k$ is the total number of deque operations, and constant worst-case time and space for other operations.

- Graduate student Vivek Gore and advisor Eric Allender (PM,RU) proved an exponential lower bound on the size of constant-depth circuits of AND, OR, and MOD gates computing the permanent of a matrix. One striking thing about this result is that it holds only for circuits with an efficient rule telling how to construct the circuits (so-called "uniform" circuits). This is the first time that uniformity has been used to advantage in a circuit lower bound proof. Furthermore, Allender and Gore also show that the complexity class ACC is properly contained in the classes PP and $C_{=}P$.

- Rutgers undergraduate, Luz Pinzon and was an invited speaker at the AMS regional meeting in Washington, D.C. in April 1993 and also at the NJ MAA meeting in April 1993; at both meetings she talked about the research she did with Fred Roberts (PM, RU). She is now attending graduate school in operations research on a minority advancement fellowship.

## 4.2 Research Plans

As we have already explained in the Executive Summary DIMACS work is traditionally centered around Special Years. This was quite successful and though there are always suggestions for change (say 2 Special Half Years) we already have a firm commitment for the next two Special Years. Beyond those commitments, DIMACS will entertain proposals for Special Half-Years, Special Months, etc.

The selection of the topics of the special year is not an algorithmic problem. It requires scientific judgement based on the knowledge of all or most of the important developments in the area of discrete mathematics and computer science. A right decision is made possible by the critical scientific mass concentrated in the Center. We aim at selecting topics ripe for rapid development, having a high impact, and for which we have and can enlist from outside the critical level of know how.

In 4.2.1 we describe the 1994-1995 Special Year which will continue with some supplementary activities through 1995-1996. In 4.2.2 we give the plan of the 1995-1996 Special Year, in 4.2.3 we describe a detailed plan of a Combinatorial Number Theory Special Year which we did not accept yet, and some further ideas for possible special years. 4.2.4 contains ideas for new Implementation Challenges (see Part A of this chapter for the very successful earlier ones).

Finally 4.2.5 describes some new initiatives other than Special Years in DIMACS work.

### 4.2.1 Special Year 1994-95 - Mathematical Support For Molecular Biology

DIMACS is planning a 1994-95 "special year" on the topic Mathematical Support for Molecular Biology. The program will start in August 1994 and run through August 1995, with some supplementary activities scheduled for the 1995-96 year.

The fundamental premise of the special year is that some of the most central questions in molecular biology are essentially problems involving the combinatorial and algorithmic questions that DIMACS-type researchers are good at solving. The year is intended to expose a large portion of the community of discrete mathematicians and theoretical computer scientists to the problems of molecular biology that seem to be fundamentally problems of their field; to provide an opportunity for intensive collaboration to those discrete mathematicians and theoretical computer scientists who have already discovered these problems; to introduce some outstanding young people in the mathematical sciences community to the field of mathematical/computational biology in a very concentrated way; to forge lasting partnerships between mathematical scientists and biological scientists; to involve biologists in a primary role in defining the agenda of computational biology; to introduce molecular biologists to a community of mathematical scientists who are interested in helping them solve their problems; and to develop a long-term base and model for interdisciplinary research in this field.

The Special Year will be chaired by Joachim Messing and Fred Roberts of RU. It will be co-chaired by Lawrence Shepp of BL and Michael Waterman of U. of Southern California. The program will be supported by a distinguished steering committee, whose members in addition to the chairs and co-chairs are David Axelrod (RU), Michael Bulmer (RU), Charles Cantor (Boston U), Martin Farach (RU), Daniel Gusfield (UC Davis), Leroy Hood (U. of Washington), Richard Karp (UC Berkeley), Eric Lander (MIT), Eugene Lawler (UC Berkeley), Joshua Lederberg (Rockefeller), Joseph Naus (RU), Michiel Noordewier (RU), Wilma Olson (RU), David B. Searls (U. Penn), William Sofer (RU), Tandy Warnow (U. Penn), Peter Winkler (BC), and Andrew Yao (PU).

In many ways, this special year will be very different from our other special years. First of all, we expect the "year" to last 25 months, starting with a postdoctoral tutorial program in August 1994 and including a second year with a regular seminar series, the culmination of the algorithm implementation challenge, and a second year of postdoc training.

Second, this special year will be different in terms of size. We have asked NSF, NIH, DoE, and other agencies for significant additional funding to make this a larger year: To bring in visitors from the biological side and leaders in biocomputing; to involve a larger number of postdocs than usual; to keep the postdocs for a second year; and to put much more emphasis on postdoc training, including special tutorial programs and involvement of biological mentors.

Third, this special year will be different because it involves REAL and EXTENSIVE outreach to another community. The program will include extensive collaboration with biologists. The Waksman Institute for Molecular Genetics at Rutgers is a major partner in the special year. Its director, Joachim Messing, is co-chair of the year and many Waksman faculty will be involved in mentoring and tutoring our postdocs. There will be a partnership with our sister NSF S&T Center, the Center for Molecular Biotechnology at U. of Washington. Its director, Leroy Hood, will help kick off the year with a series of "distinguished lectures" in the Fall of 1994. There will be an exchange of visits with that Center. The Genome Center at U. of Pennsylvania is involved through the participation of two of its faculty members in our steering committee. One of the mini-workshops will be held there and some of the sessions of our seminar series will also be held at Penn. The Center for Theoretical and Applied Genetics at Rutgers will be involved through the participation of its director and associate director as mentors for the postdocs, and through the presence of its faculty on the steering committee and on workshop organizing committees. The Departments of Molecular Biology and of Ecology and Evolutionary Biology at Princeton will be involved as well. Scientists from those departments, as well as the other units already mentioned, have been busy preparing questions that they think mathematical scientists can help them with. A number of the leading senior figures in mathematical molecular biology from the biology side will be spending time visiting DIMACS during the special year. Prominent biologists will be and have been involved in the planning and organization of all major activities. Each workshop has both a mathematical organizer and a biological organizer, and the workshop organizing committees have a roughly equal number of mathematical and biological scientists.

Industrial participation in the special year is being encouraged and we have already obtained commitments to participate from a number of companies. The biotech company CuraGen has agreed to co-sponsor a special year postdoc. Seq Limited is working with us on organizing programs for biotechnology companies. The Vice President for Research at Roche Molecular Systems is co-organizer of our workshop on HIV Sequence Analysis. More and more companies are expressing an interest in being involved in the special year in various ways. We plan an industrial problems seminar and special industry-oriented sessions at the various workshops.

The Special Year program will be centered around a series of workshops, open to the entire community. The scheduled workshops are: Combinatorial Methods for Mapping and Sequencing DNA; Sequence Alignment; Phylogeny; and HIV Sequence Analysis. We will also be running the fourth "DIMACS Algorithm Implementation Challenge," to culminate in a workshop. Researchers will be challenged to develop algorithmic methods for DNA sequence determination from shotgun sequence data.

There will be a series of one day mini-workshops, organized around a topic of current interest, and frequently scheduled at the last minute. Among the topics already scheduled are Combinatorial Structures in Molecular Biology, DNA Topology and Regulation, Gross and Fine Structure of DNA, and Database Aspects of Biological Data. A series of four mini-workshops on protein structure will deal with Global Minimization of Nonconvex Energy Functions), Computational Geometry and Protein Structure, Sequence-Based Methods for Protein Folding, and Antibody Sequence and Structure.

We hope that, like past DIMACS special years, the year on Mathematical Support for Molecular Biology will influence the directions of the field for many years to come.

#### 4.2.2 Special Year 1995-96 - Logic and Algorithms

Bob Kurshan (PM, BL) and Moshe Vardi (Rice) are Co-Chairs of this special year. The basic goal is to bring together computer scientists who work in areas involving logic and combinatorics, with discrete mathematicians and theoretical computer scientists who would normally be attracted to DIMACS. Principal topics would include Computer-Aided Verification, Finite-Model Theory, and Proof Complexity and related workshops (still in planning stages) would examine and other interactions among logic, discrete mathematics and theoretical computer science. The main thrusts are:

- Computer-Aided Verification

  Computer-Aided Verification is the study of algorithms and structures applicable to verification of programs (with respect to a stated property). It draws upon ideas and results from graph theory, combinatorics, automata theory, complexity theory, Boolean functions and Boolean algebras, logic, Ramsey theory and linear programming. Since the DIMACS CAV workshop in 1990, the number of people working in computer-aided verification has dramatically expanded from about 15 to 100-200, including active research representations from the most serious centers of computer science research in North America, Europe, Asia and Australia. We credit this expansion in equal parts to the very successful workshop we held at DIMACS, and an idea whose time has come. Today, companies such as Intel, DEC, SUN and AT&T, which as recently as 1-2 years ago would have nothing to do with formal verification, now can't wait to get the most advanced tools available. As tool creation is driven directly from the theory, this creates an unusual opportunity to see theory put directly to practice, a stimulating and attractive reward.

Possible workshop topics include: reduction methodologies, timing verification/hybrid systems, theoretical issues of design methodologies, complexity issues in verification and experiences with existing tools.

- *Finite-Model Theory*

  Model theory is the study of mathematical structures which satisfy sets of axioms. Recently there has been much more focus on the FINITE models of a set of axioms, and some very lovely connections with theoretical computer science have resulted—including model-theoretic characterizations of complexity classes.

  Questions about embeddability of finite models in certain countable ones have led to a theory of homogeneous structures, of great interest to combinatorialists. Further, when a class of mathematical structures is equipped with probability measures (e.g. the case of random graphs), one is led to study the limiting probabilities of statements about the structures; the result is powerful meta-theorems called zero-one laws, which give conditions under which all limiting probabilities must be zero or one.

  Here are three suggestions for workshops which we might expect to see under the heading of finite-model theory: model theory and complexity classes, homogeneous structures, and zero-one laws.

- *Proof Complexity*

  The study of the computational complexity of proofs, including finding proofs, exhibiting proofs and verifying proofs, has been a fundamental area of both logic and computer science for many years. Recently there have been some spectacular results which, together with steady progress at the interface of logic and computer science, have helped to bring the two fields into closer touch. The question of the difficulty of FINDING proofs is of course central in logic; a theory is said to be DECIDABLE if there is an algorithm to do this. Now there is more focus on the question of whether there is an EFFICIENT algorithm to find proofs, but in the meantime, the classical question of whether the theory of the real numbers with arithmetic and exponentiation is decidable has been answered in the affirmative (modulo a number-theoretic conjecture). The LENGTHS of proofs have also fascinated researchers for years and form part of the basis of theoretical computer science, as well as proof theory. Related are questions of complexity of certain formal systems. Finally, the question of VERIFICATION of proofs, especially probabilistically, has had a huge boost from recent results which have application to the theory of the complexity of approximation problems. This work evolves from the area of interactive proofs and program-checking but also has links to coding theory and the algebra of polynomials. (Several permanent members of DIMACS are heavily involved.)

Some possible workshop topics: complexity of problems in logic, lengths of proofs, and proof-checking and approximability

- *Other Interactions*

  As usual, the purpose of this DIMACS Special Year topic is to be inclusive, rather than exclusive. There are certainly other areas, beyond the ken of the proposers, which will fit well with the theme we have in mind; this fourth "catch-all" subtopic is intended to encourage all scientists who might benefit from interaction with logicians, combinatorialists and computer scientists, and in particular with the topics we have listed.

The steering committee for the proposed year is well suited to these topics and many have research connections to more than one topic; the members are: Ed Clarke (CMU), Amir Pnueli, (Weizmann), Allen Emerson, (U. Texas), Joan Feigenbaum, (PM, BL) Eric Allender, (PM, RU), Gregory Cherlin, (PM, RU) Sam Buss, (UC San Diego), Laszlo Babai, (U. of Chicago), Richard Lipton, (PM PU) and Peter Winkler, (PM BC).

### 4.2.3 Proposed Future Special Years

A number of proposal area in preparation or under consideration for special years in the future. A few are mentioned here.

- *Applications of Combinatorial Number Theory*

  This is a young field originating from the works of Brun and Schnirelman early in this century. Later Paul Erdős played a dominant role in the advance of this field, and in the past 25 years the books of Halberstam and Roth, and Erdős and Graham indicated the birth of a new mathematical discipline. It addresses problems that often combine number theoretic an combinatorial elements - a type of problem that is occurring more frequently in applications. The area is now progressing rapidly as more problems are recognized, combinatorial methods are being developed and computers are enlisted in the solutions.

  The main objectives of this special year would be: to survey the recent advances in this field; to see what are the main lines and most important achievements in this field, and to make these achievements available for a wide mathematical community; to see where are the gaps to fill in; and to inspire further work in this field.

  The program of this special year would cover the following subjects: elementary-combinatorial methods of primality testing and factorization of integers; other combinatorial algorithmic number theory; multiplicative problems, divisors and applications; linear additive problems, integer programming; probabilistic methods, pseudorandom sequences of integers and pseudorandom binary sequences; and automata.

  The list is certainly not complete and, in particular, we expect and request further suggestions. We emphasize that in order to keep the size of the program within reasonable limits, we cannot cover all of computational number theory and some other related fields; we would like to concentrate on elementary-combinatorial aspects, and, depending on the financial support granted, hopefully to provide a limited look towards the fields dominated by algebraic, analytic, ergodic and other methods.

The proposed organizers are Ronald Graham (PM, BL) Jean-Louis Nicolas, Carl Pomerance, Andras Sárközy, and Endre Szemerédi (PM, RU).

Here are some other ideas that are being explored:

- *Random structures and Randomized Algorithms.*

  Randomization has been one of the most powerful methods touching almost every area of discrete mathematics and theoretical computer sciences. In particular, it overlaps with the research interests of almost every member of DIMACS. In addition, there have been a great deal of new developments in the application of randomization methods in various areas of random graphs, spectral graph theory, rapidly Markov chains, computational geometry, cryptography and complexity.

- *Computer-Aided Mathematics*

  Workshops on (1) Linear Programming as a proof method, (2) Efficient search for combinatorial objects (as in proof of 4-color theorem, Neil Sloane's work on constructing experimental designs, etc.), (3) Systems for support of discrete math and algorithm analysis (a follow-up to previous workshop on topic and this year's graph-drawing workshop).

- *Geometry and Graphics* Another special year concept in the "idea" stage is a geometry year linking three STCs: DIMACS, the Geometry Center, and the Graphics Center. The content linkage would be geometry and graphics. It would also return to DIMACS first special year on Discrete and Computational Geometry. David Dobkin (PM,PU) suggested the idea and Donald Greenberg (Graphics Center), Al Marden (former director, Geometry Center) and Richard McGehee (interim director) have expressed interest.

- *Discrete approaches to Game theory and Economics.*

- *Networks* This would address issues related to design of, flow and routing problems on, and computing with networks.

### 4.2.4 Other Workshops and Meetings

- *Learning Theory.* The Colt94 (Conference on Learning Theory) and ML94 (International Conference on Machine Learning) conferences are being held at Rutgers this year. DIMACS is sponsoring two small workshops in conjunction with these. A *Learning Tutorial Series* will be held immediately before the workshops on July 10, 1994. A DIMACS sponsored workshop organized by Pascal Koiran (RU,V) with 6 invited talks on Mathematical Theory of Neural Networks will also be held on July 8, 1994.

- *Discrete Tomography.* DIMACS and Bell Labs will sponsor a mini-workshop in September on Discrete Tomography. This will address the problem of reconstructing a point set in a discrete lattice from line sums in various directions in 2 or 3 dimensions. The problem arises from electron microscopy of crystals. Queustions addressed include how many directions must be measured; what are the limits on bounding box size to assure uniqueness of reconstructions; and conditions such as convexity for reconstruction. Larry Shepp (PM¡ BL) is the organizer.

- *Graph Drawing.* DIMACS is sponsoring a workshop on Graph Drawing in October 1994 that will address how abstract graphs and networks are represented geometrically. This problem has evolved considerably with progress in algorithms, computational geometry, topological graph theory and order theory. Applications include visual interfaces, database design and software engineering. Chairs are R. Tomassia (Brown) and I. Tollis (UT-Dallas).

- *Groups and Computation.* A followup to a previous workshop on Groups and Computation will be held in June 1995. Organizers are Larry Finkelstein (Northeastern), William Kantor (Oregon) and Charles Sims (PM, RU). This will continue the dialogue between theorists and practitioners begun at the 1991 DIMACS sponsored workshop reported on in the accomplishments.

- *MAA Meeting.* In Spring 1995, DIMACS is hosting a joint meeting of the NJ-MAA (New Jersey section of the Mathematical Association of America) and the Mathematics Association of Two Year College of New Jersey. This repeats a DIMACS hosted meeting in March 1992 that featured Ron Graham (PM, BL&RU) as a guest lecturer and Eric Jordan, a Princeton undergraduate who reported research on networks done with advisor Robert Tarjan (PM, PU).

- *LICS + CAV + CAM.* DIMACS has agreed to host 3 conferences with overlapping interests in conjunction with the special year on Logic and Algorithms: LICS (Logic in Computer Science), CAV (Computer Aided Verification), and CAD all in one week.

- *Other Proposals* Other workshops that have been proposed or are in pre-proposal stages include chordal graphs, combinatorial aspects of algebraic geometry, and

#### 4.2.5 The 5th, 6th, 7th, ... Implementation Challenges

It is expected that Implementation Challenges will now become an annual affair. Although topics (and organizers) have not yet been finalized for any Challenges beyond the fourth, here are some tempting possibilities. (Note that it is not intended that *all* challenge topics be aligned with the concurrent special year.) Some challenge topics under consideration are:

- *Fundamental data structures.* Much research has gone into shaving small factors off the running times of various data structure operations, such as those involving priority queues, dictionaries, union-find systems, etc. Are there situations where these can prove useful?

- *Linear programming.* This area is still a welter of conflicting claims, and new interior point methods seem to appear like clockwork. Perhaps it is time for a massive runoff on a wide variety of instance types?

- *Geometric Searching in High and Low Dimensions*
- *Pattern Matching*
- *Symbolic Algebra*
- *Network Design Problems*

#### 4.2.6 Other Thrusts

- *Simulations of Integrated Communications Systems*

  Albert Greenberg (PM, BL), Sandeep Bhatt (PM, BC), Richard Fujimoto (Georgia Tech), Andrew Ogielski ((PM, BC), David Nicol (William and Mary) and Diane Souvaine (PM, RU) have begun research on a modest level and submitted a concept paper to the NSF for this project. This work focuses on the development of mathematical models, high-performance simulation tools and libraries as well as realistic simulation scenarios for broadband networks and wireless communication services. Despite the recent publicity in the popular media, research in this area has not kept pace with industrial demands. The primary obstacle has been the size and immense complexity of large telecommunications systems.

  DIMACS will be a "neutral ground" for Bell Labs and BellCore, as well as involving graduate students, hosting workshops, and producing AMS-DIMACS volumes.

#### 4.2.7 New Thrusts and Initiatives

After 6 years, DIMACS has fully committed resources to existing programs. We also see some exciting opportunities that are not exploited due to lack of resources. In this section we discuss these incremental proposals; in the budget they are identified with an "R" for research increments.

**Working Groups.**

DIMACS frequently has project sized needs that are currently unmet. Some of these are related to publications and outreach, software, and start-up resources for core DIMACS activities. We have proposed a minimal increment to the budget for *working groups* that would fund these activities.

Currently most of our special years and some of the workshops produce refereed volumes for the AMS-DIMACS book series. It would be desirable to increase the number of workshops that produce volumes; also to have survey/tutorial volumes from special years and suitable workshops. Working group funds would be used to support short visits to DIMACS initiate such publications. DIMACS also seeks to increase the information resources available online. We are exploring a jointly funded postdoc with Princeton where Robert Sedgewick and Richard Lipton would supervise research in documents and DIMACS info-service would serve as a test-site.

Much of the fundamental research at DIMACS is ready for experimental implementations. These implementations can serve as engineering demonstrations and for comparing implementation methods. Doing these will not be technology transfer to the software developers or factory floors, but it will give testable software to the people who can evaluate it and turn it into technology. Our experiences in past years and expectations based on intense interest in the Molecular Biology SY and the verification component of the Logic and Algorithms SY indicate there are many opportunities for fundamental research done at DIMACS to be demonstrated.

For example, the LINK project arose out of the workshop on computational support for discrete mathematics. The four PI's began collaborating at that time, but there was a long lag time for them in writing the proposal, having it funded, and then gearing up. Another group trying to get a multi-institutional ongoing research project on simulations of intelligent network systems (they have just submitted a concept paper for the May 23, 1994 NSF deadline) has had many starts and stops.

Lastly, start-up activities are typically needed to assure the success of special years. By bringing in special year organizers for a week of planning, we would prevent stalls and get better plans.

There is firm commitment at DIMACS to using the base STC grant on timely initiatives rather than for ongoing projects. Nonethless, there is an intermediate position. An annual budget of $60,000 spendable dollars half for travel and half for subsistence, controlled by the DIMACS Executive Council, would be invaluable in launching various group projects spawned by DIMACS workshops or other activities. Groups could apply Funds might be used for gathering collaborators from different locations for an intense fortnight of research at DIMACS one each quarter, perhaps to work on a class of open problems posed at some DIMACS workshop.

In the case of LINK, there is a real need for a full-time C++ programmer for a year while additional funds are requested to maintain the master copy of LINK at DIMACS, merging in the submissions from all of the other sites and testing and debugging the master code. Perhaps in the Intelligent Network Systems case, funds might be requested for a graduate assistant to begin working on a project that would interrelate the work of two of the PIs at different sites and provide further documentation for the grant proposal in preparation.)

DIMACS has been developing two new types of postdoctoral fellows. In the hopes of increasing our ties with industry, DIMACS is exploring relationships with various companies, including CuraGen, Sarnoff, Merck, Hoechst Celanese, Siemens, and NEC, who might want to sponsor joint University-Industry Postdoctoral Fellows, recent Ph.D.s who will work 50% of the time in an industrial environment and 50% of the time in an academic setting. One such position is funded by Curagen in Connecticut and is currently seeking a suitable match (which may not materialize). DIMACS will continue to develop these positions; we hope that stable or early funding decisions will be the key to finding suitable candidates.

Similarly, two different programs for Research-Education Fellowships are being drafted. Both new Ph.D.s and more experienced faculty from other institutions would be welcomed to DIMACS to work 50% of the time on their own research and 50% of the time on projects within education. This concept is currently undergoing a successful dry run with a single fellow, Yanxi Liu, funded by an NSF Small Grant for Exploratory Research.

**Increased Outreach** We have already mentioned our goal that every special year and most workshops should produce refereed volumes for the AMS-DIMACS series. In addition we would will be seeking to produce survey volumes for some of these special years that give state of the art introductions to the research areas. The Molecular Biology year will begin with tutorials and we should encourage or fund, as necessary, publication of these materials.

**Second Years for Postdoctoral Fellows** A second need is to make some of our post-doctoral fellow positions last for two years. For the period of time at DIMACS to be most productive, the fellow cannot begin applying for jobs for the following year a mere two months after arrival. The budget shows 2 research postdocs at Princeton each year (one arriving and one in her second year) and 4 research postdocs at Rutgers each year (two arriving and two in her second year). There also needs to be 2 special year postdocs arriving each year, and 2 post-special year postdocs who are completing research projects begun the previous year. A separate proposal is seeking funding for this program.

## 4.3 Capital Equipment

**Central Compute Server** DIMACS has aging central computing facilities. We are moving towards a configuration which will meet the needs of our visitors and allows for a robust upgrade path. The proposed central computing facility is design with such an end in mind. In particular, we have a need for day-to-day general purpose computing. The SPARC station 1000 allows us to serve our constituents and more importantly gives us an incremental upgrade path from 2 to 4 processors.

While many of our users come here for a short time and may use DIMACS facilities only for routine computing, we have found an increased need to provide facilities for compute-intensive work. Notably the work of Vasek Chvátal relies on calculations that would be served by our proposed SPARC 10 with 512MB of RAM. More generally next year's special year in Mathematical Support of Molecular Biology promises to push DIMACS computing facilities to the limit. We expect our postdocs to be heavily involve in empirical work which requires significant computing facilities. In the long run, we foresee significant computing requirements from all our special years. The Implementation Challenge has become one of the most successful DIMACS tradition and our proposed facilities would facilitate their continued success.

Cost is budgeted to $67,385 with university discount prices. Details are in the budget section.

**Support Equipment** The support equipment has two functions: The X terminals are meant to provide access to the central computing facility, and the SPARC station 5's will be deployed to provide some computing facilities which do not require the extensive RAM available on the central server.

Cost is budgeted to $69,959 with university discount prices.

**Optical Jukebox** One of DIMACS main functions is community outreach. This purpose is in part fulfilled by the DIMACS Info server. Maintaining the DIMACS Info Service is very memory intensive, in particular, because we provide all DIMACS Technical Reports online in postscript form. The optical jukebox will allow DIMACS to continue serving this crucial role.

Cost is budgeted to $27,634 with university discount prices.

**Presentation Equipment** Increasingly we find that participants at workshops would like to be able to give software presentations. Our grant from the State of New Jersey will provide a workstation room with needed UNIX machines. We still have a need for portable architectures. We have found that we need IBM Compatible, Macintosh, and UNIX-based machines to allow us to both host industrial and academic researchers in a variety of areas–mathematics, computer science, biology, etc.–as well as to be able to give software demonstrations in many settings–small biotech companies, high schools, etc. In addition, the LCD panels allow software demonstrations during lectures. Finally, we frequently get requests for copies of speakers' slides from those who cannot attend. The scanner is meant to facilitate this process.

Cost is budgeted to $57,458 with university discount prices.

# 5 Education, Training, Knowledge Transfer, and Linkages to Other Sectors

During its first five years, DIMACS has developed a number of successful initiatives in education and knowledge transfer. These programs are described and their impact discussed in the section entitled "Progress". Based on this experience, DIMACS has developed a vision of its role in mathematics and computer science education that is considerably broader and more ambitious than the set of educational goals described in both the "Standards for Evaluation of Center"(May 1992) and the previous renewal proposal. This vision, and the new initiatives we have planned to work towards this vision, are described in the section entitled "Plans".

## 5.1 Progress

### 5.1.1 Programs for Teachers and Students

DIMACS' main success has been in creating excellent programs for both teachers and students, including the programs for graduate students and postdoctoral researchers discussed in the research section. These programs are described below; the numbers of teachers and students who participated during 1992-94 can be found in Table XX. Programs for undergraduates have been supported by the STC grant (or supplements); K-12 programs have been supported by separate NSF funding.

A major strength of the DIMACS education programs continues to be the partnership with the Rutgers Center for Mathematics, Science, and Computer Education (CMSCE). All our K-12 programs (see below) are informed by that collaboration.[12]

**Leadership Program in Discrete Mathematics.**[13] The purpose of this program is to develop a community of teachers who use discrete mathematics effectively and teach it to their colleagues. Each teacher attends five weeks of programs, spread over two summers, and four follow-up sessions during the intervening year. This program began in 1989, and has involved 330 teachers, with about 90% from the northeast. Originally a program for high school teachers, after the last renewal we successfully developed a parallel institute for middle school teachers. The current program, funded by NSF, has had an average of 40 new high school teachers and 40 new middle school teachers during each of the past three summers. DIMACS members participate as invited speakers and instructors in the program. Among the measures of success of the program are that participants continue to attend follow-up activities at their own expense, that over 70 participants stay connected through the *teachers@dimacs* email group, and that many participants are involved in the various outreach activities described in Section 5.1.2. According to evaluation materials collected,[14] the program is very successful at providing appropriate content, motivating teachers to try new teaching methods, and giving them the knowledge and confidence to train others.

[12] CMSCE Director Gerald A. Goldin is also Director of the New Jersey Statewide Systemic Initiative (NJ SSI) and serves on the DIMACS Executive Committee.

[13] Director Joseph G. Rosenstein (PM,RU) also serves as CMSCE Director of Secondary Mathematics Programs, and as DIMACS Associate Director of Education.

[14] Teacher Enhancement Proposal to NSF, April 1994

**Rutgers Young Scholars Program in Discrete Mathematics.**[15] Forty promising New Jersey high school students participate for four weeks during the summer and attend four follow-up sessions during the following school year. Rutgers undergraduates and graduate students serve as mentors. The program is especially effective in providing diverse role models, and reaching women (a 50-50 balance has been maintained among the participants and the instructors); it has also involved 18% black and hispanic students on average. Students and staff have been uniformly enthusiastic.[16] Starting this year, we are including "Problem Groups", in which 6-8 DIMACS members and visitors will lead small groups of students in research projects, which extend throughout the 4 weeks. This program is now in its fifth year and recently received NSF funding for its third two-year cycle.

**Research Experiences for Undergraduates (REU).**[17] Mathematically talented undergraduates are matched with DIMACS researchers to work for eight weeks during the summer, and to continue working throughout the academic year. The first year (1993) was limited to four Rutgers students. All four got significant results, and two have submitted them for publication. Participants were very enthusiastic; for example Joel Sokol wrote "I think it really gave me an idea of what it's like to be a researcher. ... In regular coursework, every problem I solve has already been solved by hundreds or thousands of students, but the work I did for the REU program was new. In all, I think it was a terrific experience, and one that I enjoyed immensely." In 1994, we recruited regionally, and selected 6 from over 30 applicants.

**AT&T Bell Labs/Bellcore Summer Training Program for Women and Minority Students.**[18] DIMACS has supported this program since 1990, providing computing courses, mentoring, and career counseling for xxx undergraduates each year. These courses give students a strong start for their summer projects, and help students learn to work with one another. (No STC funds are required for this project).

### 5.1.2 Serving as a Resource

Over the last few years DIMACS has become a resource for those involved in K-16 mathematics and computer science education. The teachers in the Leadership Program (LP) have served as knowledgeable partners in this endeavor in the following activities:

- Four issues of **In Discrete Mathematics**, [19] our newsletter for teachers, have been published; the mailing list has grown to include over 3000 educators nationwide. (The newsletter was proposed in the 1991 renewal.) Many of the articles are written by participants and faculty in the LP.

- Since 1992, 16 LP participants with special preparation have conducted 48 full-day **in-service workshops** in school districts, reaching a total of 1129 teachers, using a large collection of materials developed for this purpose. In addition, at least 79 participants of the 1989-1992 programs have given over 480 informal workshops, reaching over 10,000 teachers in over 25 states.

[15] Co-directors: Robert B. Davis (RU), M. O'Nan (PM,RU), and J. G. Rosenstein (PM,RU).

[16] Young Scholars Program Proposal to NSF, May 1993

[17] Director: W. Steiger (M,RU).

[18] Coordinated by N. Dean (PM, BC)

[19] The Newsletter was initially developed by J. G. Rosenstein, and is now edited by D. Franzblau.

- We are preparing a volume of over 30 successful classroom activities for teachers of grades 7-12, called **Greatest Hits in Discrete Mathematics**.[20] Each of the units is written and reviewed by LP alumni.

- We introduced a pilot project in which a team of teachers worked with and gave feedback to the developers of **LINK**, a DIMACS-sponsored NSF-funded software project for research and visualization in combinatorics and graph theory. (See Section 5.2.2 for details.)

- In 1993-94 a LP team tested 9th grade modules in their classrooms from the NSF-funded COMAP **ARISE project**, which is developing an innovative mathematics curriculum for grades 9-11.

We have been successful in other ways in making accessible to a national audience information on discrete mathematics and computer science in education, as well as on DIMACS in general.

The conference **Discrete Mathematics in the Schools: How Do We Make an Impact?** (proposed in the 1991 renewal) took place in October 1992.[21] There are two important outcomes of this conference – (a) the creation of a national group of leaders in discrete mathematics education, called the **Working Group in Discrete Mathematics**, to share information and support and to coordinate nationwide efforts to incorporate discrete mathematics in the K-12 curriculum; and (b) a **volume of articles based on the conference theme** is currently being prepared.

All DIMACS Technical Reports are now available online, and can be retreived by ftp. The Center installed its own **Gopher Server** which now utilizes **Mosaic** as a World Wide Web (WWW) Server. The Server provides information about current and upcoming visitors, a full calendar of events, and a complete listing of all technical reports with abstracts. It also provides access points to other servers on the Internet at sites such as NSF, the Society for Industrial and Applied Mathematics (SIAM), the Association for Computing Machinery, and the U.S Department of Education.

### 5.1.3 New Linkages

We have taken important initial steps in reaching out to new communities in industry (beyond telecommunications) and other sciences through our Special Years, Special-Year postdoctoral programs, and Research/Industry postdoctoral programs, described in the research section. We are working on developing more formal "knowledge transfer" activities, such as recent Industrial Problems Seminars, which were organized by Michael Rothkopf (PM, RU) and co-sponsored by DIMACS. We have introduced a pilot program of **Research and Education Fellowships** with one postdoc supported by a 1993-94 NSF SGER grant (described in Section 5.2.2).

[20] D. Franzblau is now managing editor of this volume.

[21] This theme will be revisited in a special session on education organized by J. G. Rosenstein at the SIAM Discrete Mathematics Conference in June 1994. It is also one of the topics now discussed in a new *Education Forum*, introduced and edited by D. Franzblau, in the *SIAM Discrete Math Activity Group Newsletter.*

DIMACS has played an active role in the incipient **New Jersey Statewide Systemic Initiative (NJ SSI)**[22], a major collaborative for improving mathematics, science, and technology education in the state. DIMACS is positioning itself as a statewide resource for curriculum development and teacher preparation in mathematics and computer science. DIMACS also provides internet access to SSI staff.

For example, as an outgrowth of the new **DIMACS Education Seminar**, a working group of faculty from mathematics, computer science, and education extensively reviewed and revised a "discrete mathematics" standard that will be included in the **New Jersey Mathematics Curriculum Framework**.

## 5.2 Plans

The programs described in the DIMACS 1991 renewal proposal and 1992 "Standards for Evaluation" have been put into place: we have expanded our postdoctoral programs; we have successfully extended our Leadership Program to middle-school teachers; we have established a REU program and maintained a Young Scholars Program. We have established the Working Group in Discrete Mathematics, have published a Newsletter and are preparing resource materials for teachers. More significantly, DIMACS is taking a longer range view of its educational mission. An Education Advisory Committee was formed to develop an education vision statement and discuss proposed activities; the results are described below.

### 5.2.1 Vision

DIMACS' primary mission is providing leadership in research in discrete mathematics and theoretical computer science. Part of this mission involves directly training and mentoring new researchers, as well as communicating research results to a range of audiences. This is reflected in the following two goals.

*1. DIMACS will, as an intrinsic component of its mission as a research center, provide leadership in educational programs for researchers, in areas related to DIMACS research strengths.*

*2. DIMACS will communicate research results, applications and their importance to appropriate communities within and beyond the mathematics and computer science research communities.*

More broadly, DIMACS is committed to contribute significantly to the current national effort in improving mathematics and science education, building on its links to the Rutgers Center for Mathematics, Science, and Computer Education (CMSCE), and the NJ Statewide Systemic Initiative (SSI). This is stated in the following goals.

*3. DIMACS will affirm the importance of improving mathematics education locally and nationally, and will work toward this goal in collaboration and partnership with the education community (teachers, schools of education, college and university faculty, and other organizations).*

*4. DIMACS will develop and sponsor innovative, model programs for teachers and students at all levels.*

[22] The NJ SSI, funded by NSF with matching funds from the NJ Departments of Education and Higher Education, is directed by G. A. Goldin and based at CMSCE.

*5. DIMACS will serve as a national resource and center for those developing policy, curriculum, software or other materials related to discrete mathematics in K-16 education.*

*6. DIMACS will encourage and support the involvement of its members and other mathematicians and computer scientists in mathematics and computer science education, and generate opportunities for them to do so.*

Finally, recognizing that high-level staff support, as well as support from the Director and Executive Committee is necessary to carry out any of these efforts, our final goal is as follows.

*7. DIMACS will provide administrative support and guidance for carrying out these goals.*

### 5.2.2 Implementing the Vision

How will DIMACS carry out the goals stated in this vision? In this section, we reiterate and expand on the goals of our vision statement, giving specific, high-priority initiatives that have been proposed or contemplated.

1. *DIMACS will continue to provide leadership in educational programs for researchers, as described in the progress report on research, by:*

   (a) sponsoring workshops to facilitate collaboration and exchange of knowledge among research mathematicians and computer scientists;

   (b) providing strong mentoring programs for graduate students and postdoctoral researchers;

   (c) publishing technical reports and proceedings, and making research results available electronically;

   (d) publishing survey articles and texts to introduce other researchers in mathematics and computer science to DIMACS areas.

2. *DIMACS will extend its efforts to communicate research results, applications and their importance to appropriate communities by:*

   (a) sponsoring a **Distinguished Lecture Series**, designed for college and high school teachers and students, as well as researchers in other areas;

   (b) sponsoring knowledge transfer programs, such as an expanded "Industrial Problems" seminar series, or workshops directed to specific industries, such as biotechnology or transportation;

   (c) providing **Special Year Tutorials** to enable the broader community to take advantage of the presence of researchers for the Special Year;

   (d) continuing to provide opportunities for postdoctoral training in interdisciplinary research, or involving university/industry collaboration.

3. *DIMACS will continue to work toward improving mathematics and computer science education generally by:*

(a) continuing its long-standing and productive partnership with the Rutgers Center for Mathematics, Science, and Computer Education, involving synergistic goals and collaborative activities (including LP, YSP, and the Gelfand Project);

(b) participating actively in the New Jersey Statewide Systemic Initiative (NJ SSI), and providing **inservice programs for SSI schools and districts**, conducted by teachers from the Leadership Program in Discrete Mathematics with active participation of DIMACS researchers;

(c) participating in the development of the emerging **New Jersey Mathematics Curriculum Framework**, informing the process with the perspectives of the research community;

(d) supporting a process of cultural change that opens doors to researchers in education and to educators in scientific research;

(e) creating and disseminating models for collaborations and partnerships between the research and education communities which can be replicated nationally;

(f) serving as a consultant on national policy issues involving discrete mathematics and computer science education;

(g) providing support to projects with significant educational components and exemplary programs in education.

4. *DIMACS will develop and sponsor innovative programs for teachers and students at all levels building on previous successes by:*

   (a) continuing to sponsor the **Leadership Program in Discrete Mathematics (LP)** (if a proposal submitted to NSF earlier this year is accepted), doubling its size, including a new institute for elementary school teachers (a number of whom have already participated in the middle school program and incorporated the program materials into their classrooms), and including programs for specific states and cities (e.g., Manhattan) which are adopting curricula in discrete mathematics;

   (b) sponsoring the **Regional Institute in the Mathematical Sciences** (if a proposal submitted to NSF earlier this year is accepted) to provide integrated summer and follow-up programs for teachers, researchers, and students, to introduce the concepts and techniques emerging from DIMACS research (e.g., Special Year topics) to a wider audience of both researchers and educators, and to stimulate new work on the open problems which have resulted; through cooperative activities, teachers will gain a better understanding of research and adapt their knowledge for subsequent use in the classroom, and researchers will gain a better understanding of education and become more involved in educational issues;

   (c) continuing sponsor the currently funded **Young Scholars Program** in Discrete Mathematics (YSP) for high school students, and developing and submitting proposals for subsequent funding;

   (d) continuing to sponsor the **Research Experience for Undergraduates Program (REU)**;[23]

[23]Funding for the REU program is requested as an education increment to the current STC grant.

(e) continuing to sponsor supporting activities for the Bell Labs/Bellcore programs for women and minority undergraduates;

(f) co-sponsoring the **Gelfand National Outreach Program**,[24] a program for students in grades 8-12, to encourage them to develop their mathematical ability by providing them challenging problems and informative responses. DIMACS researchers will serve as responders to participating students, and DIMACS will provide internet linkages for them.

(g) sponsoring research internships for high school teachers in conjunction with the New Jersey Business/Industry Education Collaborative (NJ BISEC).

5. *DIMACS will serve as a national resource and center for discrete mathematics in K-16 education by:*

   (a) continuing to publish the newsletter **In Discrete Mathematics: Discrete Mathematics in the Classroom**;[25]

   (b) continuing to provide **Workshops in Discrete Mathematics** in individual districts throughout the country, with trained workshop leaders provided through the Leadership Program in Discrete Mathematics;

   (c) convening annually the national **Working Group in Discrete Mathematics**, as well as other meetings and conferences for education leaders, to share information, coordinate efforts, and develop strategies for bringing discrete mathematics into classrooms and curricula;[26]

   (d) publishing **conference proceedings**, including the Proceedings of the 1992 Conference *Discrete Mathematics in the Schools: How Do We Make An Impact?*

   (e) publishing **curriculum materials for K-12 teachers** on discrete mathematics such as *Greatest Hits in Discrete Mathematics*, written by participants of the Leadership Program in Discrete Mathematics;

   (f) hosting and facilitating an **email network of K-12 teachers** who are using discrete mathematics in their classrooms;

   (g) developing and disseminating **curriculum materials for courses in college-level courses** in discrete mathematics and computer science (such as R. Sedgewick's introductory computer science course, or M. Saks' graph theory course);

   (h) facilitating and supporting the development and use of technology to enhance the learning of discrete mathematics, including LINK[27] and E-GEMS;[28] these activities

[24] DIMACS and CMSCE have co-sponsored a proposal to NSF to obtain support for this program; among the co-PIs (Member Israel Gelfand is the PI) are DIMACS Executive Committee members Ronald Graham and Gerald Goldin.

[25] Funding for the Newsletter is requested as an education increment to the current STC grant.

[26] Funding for these meetings is requested as an education increment to the current STC grant.

[27] LINK is an NSF-funded DIMACS-sponsored project, extending the software developed previously by the four co-PIs of the project. The project grew out of the DIMACS Workshop on Computational Support for Discrete Mathematics, March 1992. DIMACS has requested a supplement to the LINK grant to adapt LINK software for classroom use by teachers and students.

[28] E-GEMS is a proposal submitted to NSF under the leadership of Maria Klawe, a member of the DIMACS External Advisory Board, for creating mathematically-rich video games for middle school students which

will be informed by feedback from students in the YSP and teachers in the LP, and by scientific input from DIMACS members.

(i) developing and disseminating educational research projects that focus on the teaching and learning of discrete mathematics and computer science.

6. *DIMACS will encourage and support the involvement of its members and other researchers in mathematics and computer science education by:*

   (a) sponsoring a monthly **DIMACS Seminar on Education** which will inform mathematical scientists about national, state, and local developments in education and will enable them to explore possibilities for their own involvement in improving mathematics education;

   (b) **informing its members**, visitors, and other mathematical scientists about mathematics education activities and their significance by providing them with information about DIMACS education activities and by inviting them to participate in these activities;

   (c) **generating opportunities for and recruiting researchers to become involved in education**, as well as providing information and linkages with existing opportunities, including DIMACS-sponsored programs such as LP, YS, and REU;

   (d) highlighting DIMACS members' involvement in education, and activities of those who are successful in integrating commitments to both education and research in their professional lives;

   (e) establishing a full postdoctoral program of **Fellowships in Research and Education** at DIMACS. Building on a pilot program conducted this past year with NSF SGER funding, and continued this year with support of STC funds, DIMACS will develop and submit a proposal to expand this program which enables researchers to spend half their time on research and the other half learning about and participating in projects to improve mathematics education, positioning themselves to take on leadership roles in involving researchers in improving mathematics and computer science education. A proposal submitted earlier this year to NSF was not funded, but we are confident that a new proposal, addressing the concerns of the reviewers, will be successful. [29]

7. *DIMACS will provide administrative support and guidance to carry out these goals by:*

   (a) maintaining an active Education Advisory Committee (EAC) chaired by the Associate Director for Education who will also serve on the DIMACS Executive Committee;

incorporate the learning of mathematics and computer science.

[29] In testimony concerning FY 1995 appropriations to the Subcommittee on Independent Agencies of the House Appropriation Committee on May 5, 1994, four prominent mathematicians and mathematics educators urged a national postdoctoral program of precisely this type, arguing that this kind of program would be an effective way to "tap the resource" of "the American community of research mathematicians, acknowledged as the finest in the world" and enable us to "draw on their expertise throughout the educational process, as has been done in the former Soviet Union and Japan for decades." DIMACS is positioned to serve as a pilot program for such a national endeavor.

(b) appointing an Education Coordinator to provide programmatic and technical support to the EAC and serve as a liason for researchers and educators participating in DIMACS programs;[30]

(c) providing technical and administrative support to the DIMACS education and knowledge transfer programs.

Many of the proposed initiatives will require substantial amounts of time for activities which include making linkages, forging partnerships, organizing conferences, writing proposals, recruiting participation, and editing publications, the types of activities that are very labor-intensive, yet by themselves cannot be the basis for separate grant funding. In order for the proposed initiatives to take place, DIMACS needs an Education Coordinator for whom these are the primary responsibilities. During the past year, with one-year funding provided by the Rutgers University Provost, DIMACS hired Deborah Franzblau with half-time responsibilities for education; this has allowed us to undertake several new projects, including the research/education postdoc program, educational support for LINK, and the *Greatest Hits* volume.

Based on this experience, it is clear that the number and range of activities in this renewal proposal require at least one person at her level on a full-time basis. We are therefore requesting full-time funding for an Education Coordinator. NSF support for this position will enable DIMACS, over the period of the renewal grant, to work to implement its vision through each of the initiatives presented above.

[30] Funding for the position of Education Coordinator is requested as an education increment to the current STC grant.

# 6 Statement on Impact of Center Mode of Funding

The advent of the digital computer has uncovered a wide range of scientific problems dealing with the efficient processing and representation of information. The field of Computer Science was created in response to these problems, and its development over the last three decades has been paralleled by an enormous increase in research activity within the branch of mathematics known as Discrete Mathematics. This parallel development is based on a strong symbiotic relationship: on the one hand, Discrete Mathematics plays a central role as a tool for modeling and problem solving in Computer Science and on the other hand, Computer Science has had a major impact on the directions of research in Discrete Mathematics. In spite of this, direct cooperation between scientists of the two fields is not everywhere and always harmonic. It was the vision of the founders of the Center that it will provide a unique opportunity for this cooperation and indeed if fulfilled their expectations.

DIMACS' base is its permanent membership, consisting of over 120 scientists from Rutgers University, Princeton University, Bell Laboratories and Bell Communications Research. The research interests of its members cover a broad spectrum of ideas on the frontier of Discrete Mathematics and Computer Science theory. DIMACS serves as a major catalyst in these diverse areas. It creates an environment that stimulates information exchange and collaboration among the members of the four sponsoring institutions, visitors, postdoctoral fellows, and graduate students. This synergistic interaction is producing new results in discrete mathematics and theoretical computer science that ultimately find application in telecommunication, transportation, robotics, computer software design, manufacturing, and other fields. Examples of these applications can be found in the research section.

The combined strengths of the four participating institutions - coupled with the supporting role played by area universities, centers and industries - are unmatched anywhere in the world. DIMACS is universally recognized as THE world center for research in discrete mathematics and computer science. As shown by Appendix A, between 1991 and 1994 the Center had 139 visitors 96 of them from foreign countries. A glance at the list will show for the measure of international respect the Center enjoys from distinguished scientists. This in turn increases the interest of young researchers in the Center. This year the Postdoc Committee handled more than 200 applications. Appendix A includes DIMACS postdoctoral fellows, the institutions they came from, and where they have gone.

Furthermore, the supportive environment DIMACS provides for its four collaborating institutions encourages the voluntary participation of its permanent members in its activities. In many specialties this leads to a critical scientific mass that none of the institutions could achieve by itself. This in turn makes possible to select topics for special years and workshops that are ripe for rapid developments, are worth of increased attention and have a high impact. The workshops with attendance figures at the end of this section attest to the interest by participants from academia, industry laboratories, and graduate students.

There is growing recognition in the educational community that the disciplines represented by DIMACS can and should play a leading role in the efforts to reform mathematics curricula that have arisen in response to the new standards of the National Council of Teachers of Mathematics. In addition to the intrinsic importance of these disciplines, they are particularly well suited to building reasoning skills, conceptual understanding and enthusiasm for mathematics. DIMACS in partnership with the Rutgers Center for Mathematics and Science

Education, aims to play a leading role in these efforts and to provide a bridge between the discrete math research and education communities.

Again the Center Mode gives a unique opportunity to involve researchers in K-12 education and as discussed in Section V we are planning an extensive extension of our present programs.

Moreover, the office space and lecture rooms (at all four participating institutions) provide an excellent environment in which the various DIMACS programs and scientific interactions takes place. The small professional staff together with the always present volunteers makes it possible to organize workshops, and precollege educational programs relatively cheaply. See the attached lists. All of this indicates a fundamental difference between the Center mode of operation and individual investigator grants.

## DIMACS Sponsored Workshops

| Workshop | Dates | Total | Industry | Academic | Student |
|---|---|---|---|---|---|
| Neural Nets | 5/20-5/23/91 | 66 | 21 | 45 | |
| Random Graphs & Randomized Algorithms | 9/16-9/19/91 | 52 | 18 | 34 | 15 |
| Groups & Computation | 10/7-10/11/91 | 64 | 5 | 59 | 13 |
| 1st Challenge Experimental Analysis of Network Flows & Matching | 10/14-10/18/91 | 58 | 34 | 24 | 22 |
| Planar Graphs | 11/18-11/21/91 | 85 | 15 | 70 | 10 |
| Graph Embeddings & Parallel Architecture | 1/13-1/15/92 | 66 | 20 | 46 | 18 |
| Computational Support for Discrete Mathematics | 3/12-3/14/92 | 91 | 22 | 69 | 11 |
| Constructive Models of Human Language | 3/20-3/22/92 | 54 | 13 | 34 | 7 |
| Expanding Graphs and Applications | 5/11-5/14/92 | 74 | 16 | 58 | 8 |
| Coding & Quantization | 10/19-10/21/92 | 130 | 35 | 95 | |
| Probabalistic Algorithms for Combinatorial Optimization | 2/22-2/27/93 | 55 | | | 19 |
| Approximation Algorithms | 3/24/-3/26/93 | 60 | | | 13 |
| Solving Hard Combinatorial Optimization Problems | 3/29-4/2/93 | 85 | 15 | 70 | 40 |
| Partitioning Data Sets: | 4/19-4/21/93 | 25 | 4 | 21 | 2 |
| Future Directions for Parallel Optimization | 4/30-5/1/93 | 60 | | | 8 |
| Quadratic Assignment Problem | 5/24-5/25/93 | 40 | | | 10 |

**DIMACS Sponsored Workshops - Cont.**

| Workshop | Dates | Total | Industry | Academic | Student |
|---|---|---|---|---|---|
| Parallel Algorithms for Unstructured & Dynamic Problems | 6/2-6/4/93 | 107 | 23 | 84 | 22 |
| Perfect Graphs | 6/10-6/14/93 | 84 | 10 | 74 | |
| Perfectly Orderable Graphs | 6/16-6/19/93 | 20 | | | |
| Models, Architectures & Technologies for Parallel Computation | 9/20-/9/22/93 | 151 | 38 | 113 | 35 |
| 2nd Challenge: Clique, Coloring & Satisfiability | 10/11-10/13/93 | 100 | | | |
| Parallel Algorithms: From Solving Combinatorial Problems to Solving Grand Challenge Problems | 11/17-11/19/93 | 85 | 14 | 71 | 12 |
| Organizing & Moving Data in Parallel Computers | 1/26-1/28/94 | 113 | 19 | 92 | |
| Interconnection Networks & Mapping & Scheduling Parallel Computations | 2/7-2/9/94 | 50 | 17 | 33 | |
| Geometric Group Theory | 1/3-3/14/94<br>3/17-3/20/94 | 34 | 2 | 32 | 7 |
| Suggesting CS Agendas for HPCC | 3/14/94 | 95 | | | 2 |
| Parallel Processing of Discrete Optim. Problems | 4/28-4/29/94 | 41 | 10 | 31 | 15 |
| Specification of Parallel Algorithms | 5/9-5/11/94 | 32 | 8 | 24 | |
| FPSAC '94 | 5/23-5/27/94 | 152 | 19 | 133 | 45 |

# 7 Management Plan

Over the past year and a half a somewhat different and more regulated plan has evolved than that which was operational during the first three and a half years of the Center. These changes reflected the growth of the Center and the increasing diversity of the programs sponsored here. With personnel changes in all major positions effective from June 1, 1994 more reorganization become necessary, with the hope of maintaining the beneficiary effects of the regulations introduced by the former acting director.

a) Directors and Staff

The Center has a (new) Director (András Hajnal, Rutgers) and a (new) Co-director (Andy Yao, Princeton). The salaries for neither of these positions are paid by the DIMACS STC Grant. The Center now has a full time Associate Director for Research (Stephen Mahaney, Rutgers), who will have primary responsibility for the day-to-day operation of the Center. This is a new position, paid for by the grant, partially through the elimination of another staff position. (An increase in the annual budget is requested to accommodate this more senior position).

In addition, DIMACS has an Associate Director for Education (Joseph Rosenstein, (paid by) Rutgers) who is responsible for development and oversight of its educational programs. There is currently an Education Coordinator (Deborah Franzblau, Rutgers) temporarily funded by the Provost of Rutgers. Funds are requested to create a permanent position for her.

A few of our distinguished members bear the title of consulting director (Ronald Graham, Robert Tarjan, Tom Trotter) and are asked to do take part in the work of our main committees. The Center Administrator (Maryann Holtsclaw, Rutgers) oversees all financial aspects of DIMACS, and coordinates all activities of the 4 staff members for the Center. She also interacts with staff manager for precollege programs (Michelle Bartley-Taylor) and the Department Manager of the Princeton Computer Science department (Susanne Turk) as well as the DIMACS coordinator there (Sandy Barbu).

## 7.1 Executive Council and Executive Committee

Due to the increasing diversity of our programs and the need of wide ranging expertise the center must have quite a large principal committee, which will be called Executive Council and a smaller group, the Executive Committee. This smaller Executive Committee replaces the body of former consulting associate directors. The Executive Council will meet monthly, in between meetings the Executive Committee will be consulted.

The members of the Executive Committee appointed by the Director are:

A. Hajnal, (chair) Director
A. Yao, Co-director
S. Mahaney, Associate Director
J. Rosenstein, Associate Director for Education
F. Roberts, Special Year Organizer
E. Allender
D. Johnson
M. Saks

P. Winkler

The Executive Council has six more members delegated by the four participating institutions.

## 7.2 Standing Committees

In the last year DIMACS has renewed its standing committees to make recommendations on specific matters. These have worked very successfully and will be asked to continue to work with the same membership during this year. This is the list of the Standing Committees, and their chairman:

Equipment Committee - Martin Farach
Education Steering Committee - Michael Saks
Postdoc Committee - David Johnson
Project Review Committee - Joan Feigenbaum
Visitor Committee - Edward Coffman
Workshop Review Committee - Eric Allender
HPCC Committee - Stephen Mahaney

## 7.3 External Advisory Board

DIMACS has an External Advisory Board listed in Appendix F.

# A Senior Research Investigators

## A.1 Permanent Members of DIMACS

**Princeton Computer Science**

B. Chazelle
D. Dobkin
J. Friedman
A. LaPaugh
R. Lipton
E. Ristad
R. Sedgewick
K. Steiglitz
R. Tarjan
A. Yao

**Princeton Mathematics**

J. Conway
H. Kuhn
P. Sarnak

**Princeton Civil Eng.**

R. Vanderbei

**Rutgers Mathematics**

J. Beck
R. Bumby
G. Cherlin
I. Gelfand
S. Gindikin
G. Goldin
J. Kahn
J. Komlos
R. Lyons
M. O'Nan
F. Roberts
J. Rosenstein
M. Saks
S. Shelah
C. Sims
E. Sontag
S. Thomas
W. Vasconcelos

**Rutgers Computer Science**

E. Allender
V. Chvatal
M. Farach
M. Fredman
M. Grigoriadis
H. Hirsh
B. Kalantari
L. Khachiyan
M. Noordewier
D. Souvaine
W. Steiger
E. Szemeredi
A. Yasuhara

**Rutgers Statistics**

R. Gnanadesikan

**RUTCOR**

A. Ben-Israel
E. Boros
P. Hammer
P. Hansen
A. Hoffman
A. Kogan
A. Prekopa
M. Rothkopf
D. Shanno
A. Williams

**DIMACS**

V. DeBellis
D. Franzblau
A. Hajnal
S. Mahaney

**Bell Labs**
**Mathematics and Computer Science**

R. Alur
D. Applegate
B. Baker
J. Bentley
A. Buchsbaum
J. Bruno
R. Calderbank
K. Clarkson
E. Coffman
E. Cohen
J. Feigenbaum
P. Fishburn
S. Fortune
M. Garey
E. Gansner
R. Giancarlo
R. Graham
A. Greenberg
F. Hwang
G. Jacobson
D. Johnson
N. Karmarkar
M. Kearns
R. Kurshan
J. Lagarias
D. Lee
C. Lund
Y. Matias
M. Merritt
A. Netravali
A. Odlyzko
A. Orlitsky
A. Rajeev
N. Reingold
R. Schapire
R. Sethi
L. Shepp
P. Shor
N. Sloane
K-P. Vo
G. Wilfong
P. Wright
M. Yannakakis

**Bellcore**
**Mathematics & Computer Science**

A. Aho
B. Aiello
S. Bhatt
T. Carpenter
F. Chung
W. Cook
N. Dean
D. Durand
S. Haber
R. Jain
R. Kannan
A. Lenstra
J. McKenna
M. Mihail
C. Monma
A. Ogielski
J. Schotland
P. Seymour
S. Suri
T. Trotter
V. Venkatesan
V. Wei
P. Winkler

**Members at other institutions**

E. Baum
Bombieri
I. Cox
C. Giles
S. Jagannathan
J. Kilian
K. Lang
N. Littlestone
Y. Lyuu
J. Philbin
S. Rao
W. Smith

## A.2 Senior Research Visitors to DIMACS

**1990-91 Visitors**

Mariana Bolla
Graham Brightwell
Leonard Charlap
Hristo Djidjev
Ding-Zhu Du
Vladimir Gurvich
Refael Heiman
Marek Karpinski
Michal Karonski
Leonid Khachiyan
Hugo Krawczyk
Hanno Lefmann
Dmitrij Leshchiner
Jack Lutz
Ueli Maurer
Catherine McGeoch
Lyle McGeoch
Angus McIntyre
Noam Nisan
Jozsef Pelikan
Lorenzo Robbiano
Jeff Salowe
Edward Scheinerman
Steve Schibell
Gary Seitz
Alexander Sidorenko
Avi Wigderson

**1991-92 Visitors**

Mike Albertson
Jean-Claude Bermond
Andras Bezdek
Bella Bollobas
Graham Brightwell
Jim Burns
Richard Cole
Alain Darte
Aditi Dhagat
Paul Erdos
Hung-Lin Fu
Andrew Goldberg
Ervin Gyori
George Havas

Frank Hoffman
Glenn Hurlbert
Gil Kalai
Bill Kantor
Howard Karloff
Michal Karonski
Alexander Kelmans
Hal Kierstead
Zoli Kiraly
Ephraim Korach
Klaus Kriegel
Yaakov Kupitz
Joachim Lambeck
Hanno Lefmann
Nathan Linial
Hiroshi Maehara
Wolfgang Maass
Nikolai Mnev
Ian Munro
Seffi Naor
Han La Poutre
Yuval Rabani
Bruce Rothschild
Hans Schneider
Claus Schnorr
Miklos Simonovits
Nicolas Sourlas
Herbert Taylor
Prasad Tetali
Robin Thomas
Norihide Tokushige
William Trotter
Bern Ulrich
Anatoly Vershyk
Alison Wolff
Hu Xiaodong
Tudor Zamfirescu
Jenny Zito
Vladimir Zolotarev

**1992-93 Visitors**

Alexander Barvinok
Boris Cherkassky
Charles Colbourn
Michele Conforti
Gerard Cornuejols

Guoli Ding
Efim Dinitz
Peter Dolan
Peter L. Erdos
Stefan Felsner
Bruno Gaujal
Bert Gerards
Luis Goddyn
Michel Goemans
Nabil Kahale
Alexander Karzanov
Phil Klein
Jan-Karel Lenstra
Wolfgang Maass
Veni Madhavan
Edddy Mayoraz
Boris Mirkin
Roy Meshulam
Seffi Naor
Panos Pardalos
Teresa Przytycka
Serge Plotkin
Yuri Rabinovich
Andrew Rau-Chaplin
Bruce Reed
Franz Rendl
Szilard Revesz
Fred Rispoli
Neil Robertson
Joseph Romanovsky
Imre Ruzsa
Laura Sanchis
Daniel Sanders
Carla Savage
Bruce Sheperd
David Shmoys
M. Simonovits
Roman Smolensky
Sergey Tarasov
Eva Tardos

**1993-94 Visitors**

Leslie Ann Goldberg
Peter Hajnal
Peter Henderson
Sampath Kannan

Alexander Kelmans
Pascal Koiran
Peter Komjath
Danny Krizanc
Larry Lambe
Anna Lubiw
Jiri Matousek
Eddy Mayoraz
Angus McIntyre
Boris Mirkin
Lata Narayanan
Panos Pardalos
Toniann Pitassi
Pino Persiano
Vladimir Retakh
Fred Rispoli
Sunil Shende
Mikkel Thorup
Pilar de-la-Torre
Athanasios Tsantilas
Vijay Vazirani
Susanne Wetzel
Heather Woll

## A.3 DIMACS Post Doctoral Fellows

### 1991-1992

Uriel Feige
Affiliation: The Weizmann Institute
Destination: The Weizmann Institute
Field of Interest: Complexity of various interactive proof systems.

Raffaele Giancarlo
Affiliation: Columbia University
Destination: Bell Labs MTS

Sampath Kannan
Affiliation: University of Arizona
Destination: University of Arizona
Field of Interest: Program Checking, Group Theoretic Algorithms, Probablistic Algorithms, Learning Theory, Graph Theory and Combinatorics.

Carsten Lund
Affiliation: University of Chicago
Destination: Bell Labs MTS
Field of Interest: Computational Complexity Theory: Interactive Proof Systems, Circuit Complexity, Relationships among Complexity Classes, Probablistic Computation; Cryptography.

Ilan Newman
Affiliation: The Hebrew University of Jerusalem
Destination: University of Haifa
Field of Interest: Theoretical Computer Science and Combinatorics.

Mark Purtill
Affiliation: MIT
Destination: Institute Defense Analysis
Field of Interest: Matriod and Greediod Theory, Combinatorial Optimization and Theory of Computation.

Ronitt Rubinfeld
Affiliation: University of California/Berkeley
Destination: Cornell
Field of Interest: Program Result Checking, Randomness and Computation, On-Line Algorithms, Cryptography, Computational Complexity, Parallel Computation, Computational Geometry, Graph Theory, Combiantorics.

Feder Tomas
Affiliation: Stanford University
Destination: IBM Almaden
Field of Interest: Complexity Theory of Interactive Computing.

Mario Szegedy
Affiliation: University of Chicago
Destination: Bell Labs MTS
Field of Interest: Combinatorics; Graph Theory; Infinite Series, Combinatorial Geometry, Combinatorial Number Theory, Circuit Complexity, Algebraic Methods, Communication Complexity, Interactive Proof Systems, Combinatorial Algorithms.

Sandy Irani
Affiliation: University of California/Berkeley
Destination: Irvine
Field of Interest: On-Line Algorithms, Computational Complexity, Analysis of Algorithms, Randomized Algorithms, Graph Theory, and Combinatorics.

Alistair Sinclair
Affiliation: University of Edinburgh
Destination: University of California/Berkeley
Field of Interest: Design and Analysis of Algorithms, Computational Complexity, Randomized Computation, Approximation Algorithms for Combinatorial Problems, Combinatorial Optimization.

Laszlo Pyber
Affiliation: Mathematical Institute of the Hungarian Academy of Sciences
Destination: Mathematical Institute of the Hungarian Academy of Sciences
Field of Interest: Graph Theory, Asympototic Group Theory

Gabor Tardos
Affiliation: Eotvos University
Destination: MTA Matematikai Kutato
Field of Interest: Combinatorics, Theoretical Computer Science

Dirk Vertigan
Affiliation: Oxford University
Destination: University of Bonn
Field of Interest: Combinatorics, Discrete Mathematics, Matroid Theory, Graph Theory, Computational Complexity

Rajamani Sundar
Affiliation: Courant Institute
Destination: Courant Institute of Mathematical Sciences
Field of Interest: Theoretical Computer Science, Algorithms and Data Structures, Computational Complexity, Discrete Mathematics

Martin Farach
Affiliation: University of Maryland
Destination: DIMACS Center, Rutgers University
Field of Interest: Algorithmic Issues in Molecular Biology, Pattern Matching with Applications in Computer Vision, Design and Analysis of Sequential and Parallel Algorithms

**1992-1993**

Edith Cohen
Affiliation: Stanford University
Destination: Bell Labs MTS
Field of Interest: Combinatorial Optimization, Sequential and Parallel Algorithms, Lower Bounds

Christos Kaklamanis
Affiliation: Harvard University
Destination: DIMACS Center, Rutgers University
Field of Interest: Parallel Architectural Issues, Parallel Algorithms, On-Line Computation, Fault Tolerance, Randomized Algorithms

Shmuel Onn
Affiliation: Cornell University
Destination: Technion
Field of Interest: Computational and Combinatorial Geometry and Topology, Combinatorial Optimization

Gabor Simonyi
Affiliation: Mathematical Institute of the Hungarian Academy of Sciences
Destination: Hungarian Academy of Sciences
Field of Interest: Combinatorics and information theory; in particular: graph theory, extremal set theory and their interconnections with information theory.

Prasad Tetali
Affiliation: Courant Institute of Mathematical Sciences
Destination: AT&T Bell Laboratories
Field of Interest: Probablistic Methods, Randomized Algorithms, Derandomization, Distributed Computing, Communication Complexity, Circuit Complexity, and Probablistic Number Theory

Martin Farach
Affiliation: University of Maryland
Destination: DIMACS Center, Rutgers University
Field of Interest: Algorithmic Issues in Molecular Biology, Pattern Matching with Applications in Computer Vision, Design and Analysis of Sequential and Parallel Algorithms

**1993-1994**

Kequan Ding
Affiliation: University of Wisconsin
Destination: University of Illinois
Field of Interest: Combinatorics, Algorithms, Optimizations, Algebraic Geometry

Martin Farach
Affiliation: University of Maryland
Destination: Computer Science Department, Rutgers University
Field of Interest: Algorithmic Issues in Molecular Biology, Pattern Matching with Applications in Computer Vision, Design and Analysis of Sequential and Parallel Algorithms

Christos I. Kaklamanis

Affiliation: Harvard University

Destination: Currently Searching

Field of Interest: Parallel Architectural Issues, Parallel Algortihms, On-Line Computation, Fault Tolerance, Randomized Algorithms.

Pangfeng Liu

Affiliation: Yale University

Destination: Yale University

Field of Interest: Theory and Practice of High Performance Parallel Computing, Large Scale Astrophysical Simulations on Distributed-Memory Computers, Theoretical Frameworks which Analyze the Complexity of Message-Passing Programs.

Yanxi Liu

Affiliation: University of Massachusetts at Amherst

Destination: University of Massachusetts

Field of Interest: Geometric Reasoning, CAD & CAM, Applied Algebra, Computer Vision, Robotics, Constraint Satisfaction, Artificial Intelligence, Cybernetics.

Motakuri Ramana

Affiliiation: The Johns Hopkins University

Destination: Currently Searching

Field of Interest: Global Optimization with mphasis on Multi- Quadratic Programming, Combinatorial Optimization, Graph Theory, Numerical Analysis, and Complexity Issues in optimization.

Ran Raz

Affiliation: The Hebrew University of Jerusalem

Destination: Weizmann Institute

Field of Interest: Communication Complexity, Boolean Circuits, Computational Complexity Theory,

Aravind Srinivasan

Affiliation: Cornell University

Destination: Institute for Advanced Study

Field of Interest: Randomized Computation, Randomization; the probablistic method, randomized algorithms, Randomness; efficient computation, derandomization, probability ineqalities and random walks, Jobshop Scheduling and Sequential and distrinuted algorithms for graph problems, and the interaction of randomization with these problems.

Seth Jared Teller

Affiliation: The Hebrew University

Destination: The Hebrew University

Field of Interest: 3D Visibility Computations, Parallel Visibility Queries, Generalized Spatial Subdivisions. Finite element mesh generation, visibility and shadow computations, visualization of computational geometry algorithms, algorithm visualization, robust root finding, floating point bench marking and diagnostics, comparative cache architecture analysis, parametric surface modeling and rendering, 3D user design/evaluation, real-time texture specification.

# B Publications

## AMS-DIMACS Volumes

Fifteen hard bound volumes have been published in the DIMACS Series to date, the most recent (since the prior renewal) being:

- * *Discrete and Computational Geometry: Papers from the DIMACS Sepcial Year* (Vol. 6)
  Editors: Jacob E. Goodman, Richard Pollack and William Steiger
- * *On-Line Algorithms* (Vol. 7)
  Editors: Lyle A. McGeoch and Daniel D. Sleator
- * *Mathematical Methods of Analysis of Biopolymer Sequences* (Vol. 8)
  Editor: Simon Gindikin
- * *Planar Graphs*(Vol. 9)
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- * *Expanding Graphs* (Vol. 10)
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- * *Groups and Computation* (Vol. 11)
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  Editors: David S. Johnson and Catherine C. McGeoch
- * *Advances in Computational Complexity Theory* (Vol. 13)
  Editor: Jin-Yi Cai
- * *Coding and Quantization* (Vol. 14)
  Editors: Robert Calderbank, G. David Farney, Jr., and Nader Moayeri
- * *Computational Support for Discrete Mathematics* (Vol. 15)
  Editors: Nathaniel Dean and Gregory E. Shannon

### 1991 DIMACS Technical Reports

(91-1) *Connectivity of Consecutive-d Digraphs (II)*, D.Z. Du, D.F. Hsu, G.W. Peck

(91-2) *Rudimentary Reductions Revisited*, Allender, Gore

(91-3) *Counting Circular Arc Intersection*, Agarwal, Sharir

(91-4) *Niche Numbers*, Fishburn, Gehrlein

(91-5) *The Cell Structures of Certain Lattices*, Conway, Sloane

(91-6) *On the Success Probability of the Two Provers in One-Round Proof Systems*, Feige

(91-7) *Scaling Matrices to Prescribed Row and Column Maxima*, Rothblum, H. Schneider, M.H. Schneider

(91-8) *Stable Marriages: Substituting Linearity for Discreteness*, Roth, Rothblum, VandeVate

(91-9) *A Discounted-Cost Continuous-Time Flexible Manufacturing and Operator Scheduling Model Solved by Deconvexification Over Time*, Eaves, Rothblum

(91-10) *Optimality of Monotone Assemblies for Coherent Systems Composed of Series Modules*, Hwang, Rothblum

(91-11) *Approximation of the Spectral Radius, Corresponding Eigenvector and Second Largest Modulus of an Eigenvalue for Square Nonnegative Irreducible Matrices*, Gross, Rothblum

(91-12) *Taylor Expansions of Eigenvalue of Perturbed Matrices with Applications to Spectral RadII of Nonnegative Matrices*, Haviv, Ritov, Rothblum

(91-13) *Dynamic Recomputation Can't Extend the Optimality-Range of Priority Indices*, Rothblum, Rothkopf

(91-14) *Recent Results on Some no-so-Recent Hypergraph Matching and Covering Problems*, Kahn

(91-15) *On the Role of Discrete Bid Levels in Oral Auctions, Rothkopf*, Harstad

(91-16) *Applications of a New Space Partitioning Technique*, Agarwal, Sharir

(91-17) *The Modulus of Polynomials with Zeros on the Unit Circle - A Problem of Erdos*, Beck

(91-18) Workshop on Applications of Combinatorial Optimization in Science and Technology COST

(91-19) *Flat Polynomials on the Unit Circle-Note on a Problem of Littlewood*, Beck

(91-20) *Quasi-random 2 Coloring of Point Sets*, Beck

(91-21) *An Algorithmic Approach to the Lovasz Local Lemma. I.*, Beck

(91-22) *The Reversing Number of a Digraph*, Barthelemy, Hudry, Isaak, Roberts, Tesman

(91-23) *On Complexity of Subset Interconnection Designs*, Du

(91-24) *Fast Approximation Schemes for Convex Programs with Many Blocks and Coupling Constraints*, Grigoriadis, Khachiyan

(91-25) *Generalization of the Komogorov-Smirnov Goodness-of Fit Test, Using Group Invariance*, Feltz, Goldin

(91-26) *Transitions in Geometric Minimum Spanning Trees*, Monma, Suri

(91-27) *Relations Between Spectral and Classification Properties of Multigraphs*, Bolla

(91-28) *Scalings of Matrices Satisfying Line-Product Constraints and Generalizations*, Rothblum, and Zenios

(91-29) *On a Triangulation of the 3-ball and the Solid Torus*, Bohus, Jockusch, Lee, and Prabhu

(91-30) *A New All-Pairs Shortest-Path Algorithm*, Catherine C. McGeoch

(91-31) *Cycles of Length 0 Modulo 4 in Graphs*, Dean, Lesniak, Saito

(91-32) *Cycles Modulo 3*, Dean, Toft, Kaneko, Ota

(91-33) *Quo Vadis, Graph Theory?*, Roberts

(91-34) *On Heuristics for Steiner Minimum Trees*, Ding-Zhu Du

(91-35) *Improved Performance Guarantee of Randomized On-Line Graph Coloring*, Magnus M. Halldorsson

(91-36) *Workshop Summary: Structural Complexity and Cryptography*, Eric Allender, Jin-yi Cai, Joan Feigenbaum

(91-37) *Order Analogues and Betti Polynomials*, Lynne Butler

(91-38) *Note: On the Last New Vertex Visited by a Random Walk*, Lovasz, Winkler

(91-39) *A Digital Signature Scheme and a Public-Key Cryptosystems based on Elliptic Curves over* $Z_m$, Ueli M. Maurer

(91-40) *Rounds in Communication Complexity Revisited*, Noam Nisan, Avi Widgerson

(91-41) *How to Compute the Volume*, Laszlo Lovasz

(91-42) *PSPACE is Provable by Two Provers in One Round*, Jin-Yi Cai, Anne Condon, Richard J. Lipton

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(91-47) *Generalization of an Engineering Principle*, F.K. Hwang, U.G. Rothblum

(91-48) Renewal Proposal to National Scientific Foundation Science and Technology Centers

(91-49) *Search Problems in the Decision Tree Model*, Laszlo Lovasz, Moni Naor, Ilan Newman, Avi Wigderson

(91-50) *Program Checkers for Probability Generation*, Sampath Kannan, Andrew Yao

(91-51) *Combinatorial Geometry*, Janos Pach, Pankaj K. Agarwal

(91-52) *Interactive Proofs with Space Bounded Provers*, Ronitt Rubinfeld

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(91-59) *Limitations on Conclusions Using Scales of Measurement*, Fred S. Roberts

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(91-69) *Monotone Optimal Multi-Partitions Using Schur Convexity with Respect to Partial Orders*, Frank K. Hwang, Uriel G. Rothblum, RUTCOR, Larry Shepp

(91-70) *Majorization and Schur Convexity with Respect to Partial Orders*, Frank K. Hwang, Uriel Rothblum, RUTCOR

(91-71) *Covering With Latin Transversals*, Noga Alon, Joel Spencer, Prasad Tetali

(91-72) *Three Thresholds for a Liar*, Joel Spencer, Peter Winkler

(91-73) *Approximate Solution of Matrix Games in Parallel*, M.D. Grigoriadis, L.G. Khachiyan

(91-74) *Proper and Unit Tolerance Graphs*, K.P. Bogart, G. Isaak, L. Langley, P.C. Fishburn

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(92-3) *An Implementation of the Generalized Basis Reduction Algorithm for Integer Programming*, William Cook, Thomas Rutherford, Herbert E. Scarf and David Shallcross

(92-4) *DIMACS Implementation Challenge Workshop Algorithms for Network Flows and Matching*, David S. Johnson and Catherine C. McGeoch

(92-5) *Stable Matchings and Linear Inequalities*, Hernan G. Abeledo, Uriel G. Rothblum

(92-6) *Linear Decision Trees: Volume Estimates and Topological Bounds*, Anders Bjorner, Laszlo Lovasz and Andrew C.C. Yao

(92-7) *Diagonal Matrix Scaling is NP-Hard*, Leonid Khachiyan

(92-8) *On the Rate of Convergence of the Ras Method*, Bahman Kalantari and Leonid Khachiyan

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(92-11) *A Complexity Index for Satisfiability Problems*, E. Boros, Y. Crama, P.L. Hammer and M. Saks

(92-12) *On the Distribution of Multiplicative Translates of Sets of Residues* (mod$p$), J. Hastad, J.C. Lagarias and A.M. Odlyzko

(92-13) *Keller's Cube-Tiling Conjecture is False in High Dimensions*, Jeffrey C. Lagarias and Peter W. Shor

(92-14) *On A Problem of Erdos and Lovasz II:* $n(r) = O(r)$, Jeff Kahn

(92-15) *The Complexity of Computing Maximal Word Functions*, Eric Allender, Danilo Bruschi and Giovanni Pighizzini

(92-16) *A Family of Generators of Minimal Perfect Hash Functions*, Bohdan S. Majewski, Nicholas C. Wormald, Zbigniew J. Czech and George Havas

(92-17) *Convex Polygons with Few Vertices*, Peter C. Fishburn

(92-18) *Convex Polygons with Few Intervertex Distances*, Peter C. Fishburn

(92-19) *A Generalization of the Pure Literal Rule for Satisfiability Problems*, E. Boros and P.L. Hammer

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(92-21) *Horn Function Minimization and Knowledge Compression in Production Rule Basis (Extended Abstract)*, Peter L. Hammer and Alexander Kogan

(92-22) *Horn Functions and Their DNFs*, Peter L. Hammer and Alexander Kogan

(92-23) *Balancing Problems in Acyclic Networks*, Endre Boros, Peter L. Hammer, Mark E. Hartmann and Ron Shamir

(92-24) *An Optimal Algorithm for Generating Minimal Perfect Hash Functions*, Zbigniew J. Czech, George Havas and Bohdan S. Majewski

(92-25) *On Aschbacher's Local C(G;T)Theorem*, Daniel Gorenstein and Richard Lyons

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(92-29) *Lecture Notes on the New AKS Sorting Network*, V. Chvatal

(92-30) *A Uniform Circuit Lower Bound for the Permanent*, Eric Allender and Vivek Gore

(92-31) *Boolean-Combinatorial Bounding of Maximum 2-Satisfiability*, Jean-Marie Bourjolly, Peter L. Hammer, William R. Pulleyblank and Bruno Simeone

(92-32) *A General Class of Heuristics for Minimum Weight Perfect Matching and a* $\log\log n$*-Error Special Case in* $O(n \log\log n)$*-Time*, Celina Imielinska and Bahman Kalantari

(92-33) *Improved Dynamic Dictionary Matching*, Amihood Amir, Martin Farach, Ramana M. Idury, Johannes A. La Poutre and Alejandro A. Schaffer

(92-34) *The Meaningfulness of Ordinal Comparisons for General Order Relational Systems*, Fred S. Roberts and Zangwill Samuel Rosenbaum

(92-35) *Data Structural Bootstrapping, Linear Path compression, and Catenable Heap Ordered Double Ended Queues*, Adam L. Buchsbaum, Rajamani Sundar, Robert E. Tarjan

(92-36) *Hamilton Cycles and Games on Graphs*, Xiaoyun Lu

(92-37) *Consensus Functions and Patterns in Molecular Sequences*, Boris Mirkin and Fred S. Roberts

(92-38) *On the Satisfiability Problem for the Ground Case of First Order Theories*, Alberto Policriti and Prasad Tetali

(92-39) *Graph Planarity and Related Topics*, A.K. Kelmans

(92-40) *On Universal Threshold Graphs*, P.L. Hammer and A.K. Kelmans

(92-41) *Approximations to Solutions to Systems of Linear Inequalities*, Osman Guler, Alan J. Hoffman, and Uriel G. Rothblum

(92-42) *Formulation of Linear Problems and Solutions by a Universal Machine*, B. Curtis Eaves and Uriel G. Rothblum

(92-43) *Locally Random REductions in Interactive Complexity Theory*, Joan Feigenbaum

(92-44) *Two-Thirds is Sharp for Affine Scaling*, Leslie A. Hall and Robert Vanderbei

(92-45) *Determining Single Connectivity in Directed Graphs*, Adam L. Buchsbaum and Martin Carlisle

(92-46) *Monte Carlo and Markov Chain Techniques for Network Reliability Sampling*, Adam L. Buchsbaum and Milena Mihail

(92-47) *The Cocycle Lattice of Binary Matroids*, Laszlo Lovasz

(92-48) *Cube Tiling of $R^n$ and Nonlinear Codes*, Jeffrey C. Lagarias and Peter W. Sher

(92-49) *Laplacian Spectra and Spanning Trees of Threshold Graphs*, P.L. Hammer and A.K. Kelmans

(92-50) DIMACS Scientific Achievements: Highlights of the First Four Years

(92-51) *Weighted Multidimensional Search and its Application to Convex Optimization*, David Fernandez-Baca

(92-52) *A Tight Bound for Edge Guards in Monotone Polygons*, Iliana Bjorling-Sachs and Diane L. Souvaine

(92-53) *Combinatorial Optimization: some Problems and Trends*, Laszlo Lovasz

(92-54) *Combinatorial Complexity of Signed Discs*, Diane L. Souvaine and Chee-Keng Yap

(92-55) *Nonpolyhedral Relaxations of Graph-Bisection Problems*, Svatopluk Poljak and and Franz Rendl

(92-56) DIMACS Annual Report - December 1992

(92-57) *Cycles in Bipartite Graphs and an Application in Number Theory*, Gabor N. Sarkozy

(92-58) *A Counterexample to Borsuk's Conjecture*, Jeff Kahn and Gil Kalai

(92-59) *A Problem of Furedi and Seymour on Covering Intersecting Families by Pairs*, Jeff Kahn and Gil Kalai

(92-60) *The Power of Adaptiveness and Additional Queries in Random-Self-Reductions*, Joan Feigenbaum

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(93-01) *A Randomized Algorithm for Finding Maximum with $O((logn)^2)$ Polynomial Tests*, Hing F. Ting and Andrew C. Yao

(93-02) *Projective Orientations of Matroids*, I. M. Gelfand, G. Rybnikov and D. Stone

(93-03) *k-Neighborhood Covering and Independence Problems*, Shiow-Fen Hwang and Gerard J. Chang

(93-04) *A Polynomial-time Algorithm for the Phylogeny Problem When the Number of Character States is Fixed*, R. Agarwala and D. Fernandez-Baca

(93-05) *Monotone Gray Codes and the Middle Levels Problem*, Carla D. Savage and Peter Winkler

(93-06) *Optimal Compression of Propositional Horn Knowledge Bases: Complexity and Approximation*, Peter L. Hammes and Alexander Kogan

(93-07) *On Computing Algebraic Functions Using Logarithms and Exponentials*, Dima Grigoriev, Michael Singer, and Andrew Yao

(93-08) *Hilbert Series of Group Representations and Grobner Bases for Generic Modules*, Shmuel Onn

(93-09) *Asymptotic Results for Permutation Groups*, Laszlo Pyber

(93-10) *Probabilistically Checkable Debate Systems and Approximation Algorithms for PSPACE-Hard Functions*, Anne Condon, Joan Feigenbaum, Carsten Lund, Peter Shor

(93-11) *The $L(2,1)$-Labeling Problem on Graphs*, Gerard J. Chang and David Kuo

(93-12) *A Tight Bound for Edge Guards in Rectilinear Monotone Polygons*, Iliana Bjorling-Sachs

(93-13) *Combinatorial Optimization and Computations in the Ring of Polynomials*, Alexander I. Barvinok

(93-14) *Testing Simple Polygons*, Esther M. Arkin, Patrice Belleville, Joseph S.B. Mitchell, David Mount, Kathleen Romanik, Steven Salzberg, Diane L. Souvaine

(93-15) *Enumerating Consecutive and Nested Partitions for Graphs*, G. J. Chang and F. K. Hwang

(93-16) *Confluently Persistent Deques via Data-Structural Bootstrapping*, A. L. Buchsbaum and R. E. Tarjan

(93-17) *On the Structure of Co-Critical Graphs*, Anna Galluccio, Miklos Simonovits, Gabor Simonyi

(93-18) *Convex Relaxations of 0-1 Quadratic Programming*, Svatopluk Poljak and Henry Wolkowicz

(93-19) *Indefinite Trust Region Subproblems and Nonsymmetric Eigenvalue Perturbations*, Ronald J. Stern and Henry Wolkowicz

(93-20) *A First-Order Isomorphism Theorem*, Eric Allender, Jose Balcazar, and Neil Immerman

(93-21) *Dept Reduction for Noncommutative Arithmetic Circuits*, Eric Allender and Jia Jiao

(93-22) *A Robust Model for Finding Optimal Evolutionary Trees*, Martin Farach, Sampath Kannan, and Tandy Warnow

(93-23) *Consecutive Cuts and Paths, and Bounds on $k$-Terminal Reliability*, Heidi J. Strayer and Charles J. Colbourn

(93-24) *Weighted Independent Perfect Domination on Cocomparability Graphs*, Gerard J. Chang, C. Pandu Rangan and Satyan R. Coorg

(93-25) *The Russian Option: Reduced Regret*, Larry Shepp and A. N. Shiryaev

(93-26) *A Dual Russian Option for Selling Short*, Larry Shepp and A. N. Shiryaev

(93-27) *Non-Stanley Bounds for Network Reliability*, Jason I. Brown and Charles J. Colbourn

(93-28) *Some Open Problems on Reliability Polynomials*, Charles J. Colbourn

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(93-31) *Constructing Language Instances Based on Partial Information*, Laura A. Sanchis

(93-32) *Research Problems in Discrete Geometry: Packing and Covering*, William Moser and Janos Pach

(93-33) *Inverse Theorems in Additive Number Theory*, Melvyn B. Nathanson

(93-34) *Trust Regions and the Quadratic Assignment Problem*, Stefan E. Karisch, Franz Rendl, and Henry Wolkowicz

(93-35) *Entropy Splitting Hypergraphs*, Gabor Simonyi

(93-36) *Workshop on Parallel Algorithms for Unstructured & Dynamic Problems*, Bill Aiello, Albert G. Greenberg, Andrew Ogielski

(93-37) *Quasi-Acyclic Propositional Horn Knowledge Bases: Optimal Compression*, Peter L. Hammer and Alexander Kogan

(93-38) *Parallel Processing of Discrete Optimization Problems*, Grama Y. Ananth, Vipin Kumar, and Panos M. Pardalos

(93-39) *The Simplex Algorithm with a New Primal and Dual Pivot Rule*, Hsin-Der Chen, Panos M. Pardalos, and Michael A. Saunders

(93-40) *On Lattice-Free Polytopes*, Michel Deza and Shmuel Onn

(93-41) *On Edge Bijections of Graphs*, A. K. Kelmans

(93-42) *On a Covering Property of Maximal Sperner Families*, Peter L. Erdos and Niall Graham

(93-43) *Relationships Among PL, # L, and the Determinant*, Eric Allender and Mitsunori Ogiwara

(93-44) *Half-integral Flows in a Planar Graph With Four Holes*, Alexander V. Karzanov

(93-45) *An Efficient Algorithm for Dynamic Text Indexing*, Ming Gu, Martin Farach and Richard Beigel

(93-46) *Fast Comparison of Evolutionary Trees*, Martin Farach and Mikkel Thorup

(93-47) *A New Approach to the Construction of Optimal Designs*, R.H. Hardin and N.J.A. Sloane

(93-48) *Covering Arrays and Intersecting Codes*, N.J.A. Sloane

(93-49) *The Nordstrom-Robinson Code is the Binary Image of the Octacode*, G. David Forney,Jr., N.J.A. Sloane and Mitchell D. Trott

(93-50) *A Linear Construction for Certain Kerdock and Preparata Codes*, A. R.Calderbank, A. R.Hammons, Jr., and P. Vijay Kumar

(93-51) Operating Manual for Gosset: *A General-Purpose Program for Constructing Experimental Design (Second Edition)*, R.H.Hardin and N.J.A. Sloane

(93-52) *The Zsub4-Linearity of Kerdock, Preparata, Goethals and Related Codes*, A.R.Hammons,Jr., P.Vijay Kumar, A.R.Calderbank, N.J.A. Sloane, and Patrick Sole

(93-53) *Quaternary Constructions for the Binary Single-Error-Correcting Codes of Julin, Best and Others*, J.H. Conway and N.J.A. Sloane

(93-54) *Expressing (a sup2 + bsup2 + csup2 + dsup2)sup3 as a Sum of 23 Sixth Powers*, R.H. Hardin and N.J.A. Sloane

(93-55) *Dsub4, Esub8, Leech and Certain Other Lattices are Symplectic*, J.H. Conway and N.J.A. Sloane

(93-56) *A Pedestrian Approach to Ray Shooting: Shoot a Ray, Take a Walk*, John Hershberger and Subhash Suri

(93-57) *Finding a Shortest Diagonal of a Simple Polygon in Linear Time*, John Hershberger and Subhash Suri

(93-58) *Matrix Searching with the Shortest Path Metric*, John Hershberger and Subhash Suri

(93-59) *Can Visibility Graphs Be Represented Compactly?*, Pankaj K. Agarwal, Noga Alon, Boris Aronov, Subhash Suri

(93-60) *Shortcutting Planar Digraphs*, Mikkel Thorup

(93-61) *Controlled Grammatic Ambiguity*, Mikkel Thorup

(93-62) *Minors and the Chromatic Index of r-graphs*, K. Kilakos and B. Shepherd

(93-63) *A Note on a Conjecture of Toft*, T. R. Jensen and F. B. Shepherd

(93-64) *On Enumeration of Near to Best Solutions in Discrete and Dynamic Programming*, Joseph V. Romanovsky

(93-65) *Instance-Hiding Proof Systems*, D. Beave, J. Feigenbaum, R. Ostrovsky, and V. Shoup

(93-66) *The Least Possible Value at Zero of Some Nonnegative Cosine Polynomials*, Szilard Gy. Revesz

(93-67) *Approximation Clustering for Homogeneous Data Tables*, Boris Mirkin

(93-68) *Generalization of the Tetrad Representation Theorem*, Glenn Shafer, Alexander Kogan and Peter Spirtes

(93-69) *Some Experimental and Theoretical Results on Test Case Generators for the Maximum Clique Problem*, Laura A. Sanchis and Arun Jagota

(93-70) *Eigenvalues and Expansion of Regular Graphs*, Nabil Kahale

(93-71) *A Randomized Linear-Time Algorithm for Finding Minimum Spanning*, Philip N. Klein and Robert E. Tarjan

(93-72) *Symmetric Quasi-Definite Matrices*, Robert J. Vanderbei

(93-73) *Affine-Scaling Trajectories Associated with a Semi-Infinite Linear Program*, Robert J. Vanderbei

(93-74) *Brownian Bandits*, Avi Mandelbaum and Robert J. Vanderbei

(93-75) *Interior-Point Methods for Max-Min Eigenvalue Problems*, Franz Rendl, Robert J. Vanderbei, and Henry Wolkowicz

(93-76) *Bipartite Dimensions and Bipartite Degrees of Graphs*, Peter C. Fishburn and Peter L. Hammer

(93-77) *An Analog of Freiman's Theorem in Groups*, Imre Z. Ruzsa

(93-78) *On Reducing the Cut Ratio to the Multicut Problem*, Nabil Kahale

(93-79) *Random Debaters and the Hardness of Approximating Stochastic Functions*, Anne Condon, Joan Feigenbaum, Carsten Lund and Peter Shor

(93-80) *On Sums With Small Prime Factors*, Gabor Sarkozy

(93-81) *Fast Parallel Algorithms for Finding Hamiltonian Cycles and Trees in Graphs*, Gabor Sarkozy

(93-82) *A Geometric Approach for Denoting and Intersecting TR Subgroups of the Euclidean Group*, Yanxi Liu

(93-83) *Isoperimetric Inequalities and Eigenvalues*, Nabil Kahale

(93-84) *Notes on the Kolakoski Sequence*, Vasek Chvatal

(93-85) *On the Diameter of the Symmetric Traveling Salesman Polytope*, Fred J. Rispoli

(93-86)

(93-87) *Wkshop on Models, Architectures & Technologies for Parallel Computation*, P.B.Gibbons, R.M.Karp, C.E.Leiserson, G.M.Papadopoulos

(93-88) *On Lattices Equivalent to Their Duals*, J. H. Conway and N.J.A. Sloane

(93-89) *Optimization Methods for Computing Global Minima of Nonconvex Potential Energy Functions*, Panos M.Pardalos, David Shalloway, and Guoliang Xue

(93-90) *Wkshop on Parallel Algorithms: From Solving Combinatorial Problems to Solving Grand Challenge Problems*, James Flalnagan, Yossi Matias, and Vijaya Ramachandran

(93-91) *Balancing Updates vs Queries for the Partial Sum Problem*, Haripriyan Hampapuram and Michael L. Fredman

(93-92) DIMACS Annual Report

(93-93) *On the Very Weak 0-1 Law for Random Graphs With Orders*, Saharon Shelah

## 1994 DIMACS Technical Reports

(94-01) *Inverse Theorems for Subset Sums*, Melvyn B. Nathanson

(94-02) *Ballot Numbers, Alternating Products and the Erdos-Heilbronn Conjecture*, Melvyn B. Nathanson

(94-03) *Independence of Solution Sets and Minimal Asymptotic Bases*, Paul Erdos, Melvyn B. Nathanson and Prasad Tetali

(94-04) *A Local Rule Based Theory of Virus Shell Assembly*, Bonnie Berger, Peter Shor

(94-05) *Self-Affine Tiles in R*, Jeffrey Lagarias, Yang Wang

(94-06) *Tournament Certificates*, Peter Fishburn, Jeong Han Kim, Prasad Tetali

(94-07) *On the Complexity of Horn Minimization*, Endre Boros, Ondrej Cepek

(94-08) *Computing over the Reals with Addition and Order: Higher Complexity Classes*, Felipe Cucker, Pascal Koiran

(94-09) *Decomposition of Partially Defined Boolean Functions*, Endre Boros, Vladimir Gurvich, Peter Hammer, Toshihide Ibaraki Alexander Kogan

(94-10) *A Weak Version of the Blum, Shub & Small Model*, Pascal Koiran

(94-11) *A Pseudo-algorithmic separation of lines*, William Steiger, Ileana Streinu

(94-12) *A Bound of 4 for the Diameter of the Symmetric Traveling Salesman Polytope*, Fred Rispoli, Steven Cosares

(94-13) *Combinatorial Bases in systems of Simplices & Chambers*, Tatiana V. Alekseyevskaya *Complement of a Complex Hyperplane Arrangement*, Grigori Rybnikov

(94-14) *Toward a Measure for P*, Eric Allender, Martin Strauss

(94-15) *A Note on Set Mappings with Meager Images*, Peter Komjath

(94-16) *A Sublinear-time Randomized Approximation Algorithm for Matrix Games*, Michael Grigoriadis, Leonid Khachiyan

(94-17) *Normal Numbers and Sources for BPP*, Martin Strauss

(94-18) *Measure on Small Complexity Classes, with Applications for BPP* Eric Allender, Martin Strauss

(94-19) *Coordination Complexity of Parallel Price-Directive Decomposition*, Michael Grigoriadis, Leonid Khachiyan

(94-20) *DIMACS Workshop on Parallel Processing of Discrete, Optimization Problems April 28-29, 1994*, P. Pardalos, M.G.C. Resende, K.G. Ramakrishnan

(94-21) *An Interior Point Method for Bordered Block Diagonal, Linear Programs*, Michael Grigoriadis, Leonid Khachiyan

(94-22) *Randomizing Optimal Geometric Algorithms (Extended Abstract)*, Larry Shafer, William Steiger

(94-23) *Rook Placements and Cellular Decomposition of Partition Varieties*, Kequan Ding

(94-24) *Rook Placements and Partition Varieties $P\backslash M$*, Kequan Ding

(94-25) *On Garsia-Remmel Problem of Rook Equivalence*, Kequan Ding, Paul Terwilliger

(94-26) *Classification of Partition Varieties*, Kequan Ding

(94-27) *The Parallel Implementation of N-body Algorithms*, Pangfeng Liu

(94-28) *Noncommutative Symmetric Functions*, Israel Gelfand, Daniel Krob, Alain Lascoux, Bernard Leclerc, Vladimir Retakh, Jean-Yves Thibon

(94-29) *An NC Algorithm for Depth-First Search of Graphs of Bounded Genus*, Justin R. Smith and Olga Rayskina

(94-30) *Score Certificates for Tournaments*, Jeong Han Kim, Prasad Tetali, Peter Fishburn

(94-31) *On the Complexity of Some Basic Problems in Computational Convexity: II. Volume and mixed volumes*, Peter Gritzmann and Victor Klee

(94-32) *Perfect Graphs are Kernel Solvable*, Endre Boros and Vladimir Gurvich

(94-33) *Optimal Space Distributed Order-Preserving Lists*, Michael Saks and Fotis Zaharoglou

(94-34) *Upper and Lower Bounds for Selection on the Mesh*, Anne Condon and Lata Narayanan

(94-35) *A spectral technique for coloring random* 3*-colorable graphs*, Noga Alon and Nabil Kahale

(94-36) *A Comprehensive Manual for NETPAD Users with Exercises on Discrete Mathematics*, Yanxi Liu

(94-37) *Algorithms for Quantum Computation: Discrete Log and Factoring*, Peter W. Shor

## 1991 Theses Supervised by DIMACS Members

*Optimality Conditions and Algorithms for Homogeneous and Quadratic Minimization over Spheres and their Applications in Local Optimization* Ansu Bagchi - Advisor: Bahman Kalantari (Rutgers U./CS Dept.)

*An Euclidean Metric for Genetic Sequence Comparison*, K. Balasubramanian - Advisor: Richard J. Lipton (Princeton U./CS Dept.)

*On Some Combinatorial Problems in Discrepancy and Geometry*, Geza Bohus - Advisor: Jeffrey Kahn (Rutgers U./Math Dept.)

*Lower Bounds in Parallel Computation*, Shiva Chaudhuri - Advisor: Ravi Boppana

*The Immersion Relation on Webs*, Guoli Ding - Advisor: P.D. Seymour (Bellcore)

*Frugal Methods for the Independent Set and Graph Coloring Problems*, Magnus Halldorsson - Advisor: Ravi Boppana

*Finitely Constrained Classes of Homogeneous Directed Graphs and Well Quasi-ordered Families of Tournaments*, Brenda Latka - Advisor: Gregory Cherlin (Rutgers U./Math Dept.)

*Decomposition Problems in Computational Geometry*, Leonidas Palios - Advisor: Bernard Chazelle (Princeton U./CS Dept.)

*Graph Entropy and Formula Complexity*, Jaikumar Radhakrishnan - Advisor: Endre Szemeredi (Rutgers/CS Dept.)

*Lower Bounds in Geometric Searching*, Burton Rosenberg - Advisor: Bernard Chazelle (Princeton U./CS Dept.)

*Aleph-Zero Stable Lie Algebras*, Richard Rosengarten - Advisor: Gregory Cherlin (Rutgers U./Math Dept.)

*Analysis of Heapsort*, Russel Schaffer - Advisor: Robert Sedgewick (Princeton U./CS Dept.)

*Competition Graphs, Threshold Graphs, and Threshold Boolean Functions*, Chi Wang - Advisor: Fred Roberts (Rutgers U./Math Dept.)

*Competitive Paging and Dual-Guided On-Line Weighted Caching and Matching Algorithms*, Neal Young - Advisor: Robert E. Tarjan (Princeton U./CS Dept.)

## 1992 Theses Supervised by DIMACS Members

*Computational Geometry With Imprecise Data and Arithmetic*, C. Bradford Barber - Advisor: David P. Dobkin (Princeton U./CS Dept.)

*Data-Structural Bootstrapping and Catenable Deques*, Adam L. Buchsbaum - Advisor: Robert E. Tarjan (Princeton U./CS Dept.)

*Vertex Enumeration Methods and Continuous Location Theory*, Pey-Chun Chen - Advisor: Pierre Hansen (Rutgers U./RUTCOR)

*Lyapunov Function Techniques for Stabilization*, Yuandan Lin - Advisor: Edwardo Sontag (Rutgers U./Math Dept.)

*Ham-Sandwich Cuts and Related Problems*, Chi-yuan Lo - Advisor: William Steiger (Rutgers U./CS Dept.)

Xiaoyun Lu - Advisor: Jeffrey Kahn (Rutgers U./Math Dept.)

*Some Stochastic Problems in Fiber Production*, Michael Murr - Advisor: Andras Prekopa (Rutgers U./RUTCOR)

*Fully Dynamic Graph Algorithms and Their Data Structures*, Monika H. Rauch - Advisor: Robert E. Tarjan (Princeton U./CS Dept.)

*Generalized Graph Colorings and Unit Interval Graphs*, Denise Sakai - Advisor: Fred Roberts (Rutgers U./Math Dept.)

*The Max Cut Problem*, Caterina De Simone - Advisor: Pierre Hansen (Rutgers U./RUTCOR)

*Communication and Fault Tolerance in Parallel Computers*, Ramesh Sitaraman - Advisor: Robert E. Tarjan (Princeton U./CS Dept.)

*Topics in Optimization and Combinatorics*, Xueqing Tang - Advisor: Adi Ben-Israel (Rutgers U./RUTCOR)

*Computational Complexity for Selection Problems with Parity-Like Tests*, Hing Fung Ting - Advisor: Andrew C. Yao (Princeton U./CS Dept.)

*Perfect Matchings in Benzenoid Systems*, Maolin Zheng - Advisor: Pierre Hansen (Rutgers U./RUTCOR)

## 1993 Theses Supervised by DIMACS Members

*The Stable Matching Problem*, Heran Abeledo - Advisor: Uriel G. Rothblum (Rutgers U./RUTCOR)

*Controllability of Discrete-Time Nonlinear Systems and Some Related Topics*, Francesa Albertini - Advisor: Eduardo Sontag (Rutgers U./Math Dept.)

*Trustworthy Computations*, Sigal H. Ar - Advisor: Jin-Yi Cai (Princeton U./CS Dept.)

*Disjoint Maximal Independent Sets*, David Arasmith - Advisor: Peter Winkler (Bellcore)

*Computational Geometry with Imprecise Data and Arithmetic*, Brad Barber - Advisor: D.P. Dobkin (Princeton U./CS Dept.)

*Variations of the Art Gallery Theorem*, Iliana Bjorling-Sachs - Advisor: Diane Souvaine (Rutgers U./CS Dept.)

*Data-Structural Bootstrapping and Catenable Deques*, A.L. Buchsbaum - Advisor: R.E. Tarjan (Princeton U./CS Dept.)

*Scheduling and Behavioral Transformations for Parallel Systems*, Liang-Fang Chao - Advisor: Andrea S. LaPaugh (Princeton U./CS Dept.)

*Minimum Spanning Tree Verifications, Fast Priority Queues, and Massively Parallel Factoring*, Brandon Dixon - Advisor: Robert E. Tarjan (Princeton U./CS Dept.)

*Lower Bounds for Uniform Constant Depth Circuits*, Vivek Gore - Advisor: Eric Allender (Rutgers U./CS Dept.)

*A General Class of Heuristics for Constrained Forest and Cycle Problems*, Celina Imielinska - Advisor: Bahman Kalantari (Rutgers U./CS Dept.)

*On Ramsey Theory*, Xin Ke - Advisor: Jozsef Beck (Rutgers U./Math Dept.)

*Non-Combinatorial Approaches to Two Combinatorial Problems*, Jeong Han Kim - Advisor: Jeffrey Kahn (Rutgers U./Math Dept.)

*Applications of Zero-One Linear Programming with Multiple-Choice Constraints*, Keh-Wei Lih - Advisor: Pierre Hansen (Rutgers U./RUTCOR)

*Lyapunov Function Techniques for Stabilization*, Y. Lin - Advisor: Eduardo Sontag (Rutgers U./Math Dept.)

*Multigrid Algorithms on Massively Parallel Computers*, Lesley R. Matheson - Advisor: Robert E. Tarjan (Princeton U./Cs Dept.)

*Some Stochastic Problems in Fiber Production*, Michael Murr - Advisor: Andras Prekopa (Rutgers U./RUTCOR)

*Transferring Previously Learned Back-Propagation Neural Networks to New Learning Tasks*, Lorien Y. Pratt - Advisor: Haym Hirsh (Rutgers U./CS Dept.)

*Fully Dynamic Graph Algorithms and Their Data Structure*, M.H. Rauch - Advisor: R.E. Tarjan (Princeton U./CS Dept.)

*Generalized Graph Colorings and Unit Interval Graphs*, Denise Sakai - Advisor: Fred Roberts (Rutgers U./Math Dept.)

*Foundations of Recurrent Neural Networks*, Hava Siegelmann - Advisor: Eduardo Sontag (Rutgers U./Math Dept.)

*Communication and Fault Tolerance in Parallel Computers*, R.K. Sitaraman - Advisor: R.E. Tarjan (Princeton U./CS Dept.)

*Combinatorial Algorithms for Boolean and Pseudo-Boolean Functions*, Xiaorong Sun - Advisor: Peter L. Hammer (Rutgers U./RUTCOR)

*Computational Complexity for Selection Problems with Parity-Like Tests*, Hing Fung Ting - Advisor: Andrew Yao (Princeton U./CS Dept.)

*The Remainder Form and Cord-Slope Form in Global Optimization with Interval Methods*, Junjie Xiong - Advisor: Pierre Hansen (Rutgers U./RUTCOR)

*Distributed Data Structures and Wait-Free Computation*, Fotis Zaharoglou - Advisor: Michael Saks (Rutgers U./Math Dept.)

*Perfect Matchings in Benzenoid Systems*, Maolin Zheng - Advisor: Pierre Hansen (Rutgers U./RUTCOR)

## 1994 Theses Supervised by DIMACS Members

*Groups of Finite Morley Rank with Strongly Embedded Subgroups*, Tuna Altinel - Advisor: Gregory Cherlin (Rutgers U./Math Dept.)

*Random Algorithms, Derandomization and Independent Sets*, Andras Fundia - Advisor: Michael Saks (Rutgers U./Math Dept.)

*The Partial Sum Problem: Tight Upper and Lower Bounds*, Haaripriyan Hampapuram - Advisor: Michael Fredman (Rutgers U./CS Dept.)

*Discrepancy and Bandwidth*, Robert Hochberg - Advisor: Jozsef Beck (Rutgers U./Math Dept.)

*Positional Games on the Infinite Chessboard*, Andras Pluhar - Advisor: Jozsef Beck (Rutgers U./Math Dept.)

*Finding Trees and Cycles in Graphs; Existence Theorems and Fast Parallel Algorithms*, Gabor N. Sarkozy - Advisor: Endre Szemeredi (Rutgers U./CS Dept.)

*The Structure of the Subgroup Lattice*, James Sharp - Advisor: Simon Thomas (Rutgers U./Math Dept.)

## Selected Publications in Education

DeBellis, V.A. and Goldin, G.A., "Interactions between cognition and affect in eight high school students' individual problem solving." In Proc. of the Thirteenth Annual Meeting of PME-NA, (1991), edited by R.G. Underhill, pp. 29-35.

DIMACS, Rosenstein, J., Ed. "In Discrete Mathematics: Using Discrete Mathematics in the Classroom," Newsletter including contributions from teachers. Four issues, (1991, 1992, 1993 and 1994),

Franzblau, D., "New Models for Courses in Discrete Mathematics," Newsletter of the SIAM Activity Group on Discrete Mathematics, vol 4, 2, (1993-94).

Roberts, F., Rosenstein, J., and Franzblau, D., *Discrete Mathematics in the Schools: How do we make an impact,* proceedings of a conference, in preparation.

# C Disclosure of Inventions, Patent Applications, and Patents New Software, New Tools

Not applicable.

# D External Advisory Committee

**1995**

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**1996**

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**1997**

Dr. Lászlo Lovász
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Notes: Richard Shaker and Maria Klawe have agreed to stay on to fill unexpired terms.

The executive committee will be restructured on July 1, 1994 and the old committee felt that the replacement selections should be deferred to the new members.

# E Standards for Documenting Effectiveness

DIMACS

(Center for Discrete Mathematics & Theoretical Computer Science)

Rutgers University

Standards for Evaluation of Center

May 1, 1992

The standards for evaluation of the activities of the Center for Discrete Mathematics and Theoretical Computer Science should be based on the following three general perspectives:

1. The intrinsic merit of the research and educational activities of the Center;

2. Relation of the research conducted to the goals of the Center; and

3. Utility and relevance of the Center's activities to the broader community.

Judgment of the extent to which the Center has satisfactorily met these standards should be made by a team of experts, capable of making such an assessment.

A. Research Activity

Documentation of the research of the Center will consist of the following data:

1. Technical reports.

2. Published conference proceedings and related monographs.

3. Abstracts of lectures held under the Center's auspices.

4. Published journal articles by Center members:

(a) Permanent members

(b) Visitors, postdoctoral fellows, and graduate students supported by the Center.

5. Organizational plan of "special years." In particular, the significance of the topics selected.

6. A report by the director describing (a) the major achievements of the Center, (b) the impact of the Center's research on directions the field is taking, (c) impact of the Center on the professional careers of the participants, and (d) the kinds of collaborations achieved and/or stimulated by the Center.

Assessment of this research activity should be based on its quality as measured by its significance and impact on the field. Especially important for this judgment will be an evaluation of the choice of topics for the special year research thrusts and for individual research workshops run by the Center.

B. Educational Activity

The educational activities of the Center will include the following items:

1. Training of graduate students at Rutgers and Princeton Universities.

2. Instructional component of the existing Bell Labs/Bellcore summer training program for selected undergraduates.

3. High school and middle school mathematics teachers program on topics of discrete mathematics and theoretical computer science.

4. Summer training program for selected high school students on topics of discrete mathematics and theoretical computer science.

Assessment of these educational programs should be based on their impact: For graduate students, as measured (a) by the numbers trained and receiving advanced degrees; (b) the special quality of their education as a result of their involvement in Center activities; (c) special forms of teaching experience within the Center's pre-college and undergraduate programs. For the various undergraduate and high school student programs, as measured by the number of students influenced to go into mathematics or science. For the high school mathematics teacher training program, as measured by the impact of the program on mathematics and science curriculum in high schools and on the number of high school teachers reached by the program (either directly or indirectly by their interaction with teachers enrolled in the program).

Data will be provided including the list of all individuals involved in the educational programs, both as recipients or instructors. Furthermore, the high school teacher and student programs will have their own annual separate peer reviewed assessments to judge their effectiveness.

C. Knowledge Transfer

The following items relate to the Center's knowledge transfer activities:

1. The number of long-term and short-term visitors to the Center, both senior and junior faculty, scientists from industry and government, and postdoctoral fellows.

2. Dissemination of the research accomplishments of the Center members through publication of technical reports, conference proceedings, monographs, and journal articles.

3. Participation by non-permanent members in the Center's research workshops and rotating seminar series.

4. Dissemination of instructional materials developed as part of the Center's educational programs.

Assessment of these knowledge transfer activities should be based on the quality of the published materials, the level of participation by non-permanent members, and based on the scope of the visitor program, the quality and extent of dissemination of all published research and educational materials, and the level of participation of non-permanent members in the Center's workshops and seminars. Careful records will be kept related to each of these activities.

D. Management Organizational Structure

The organizational structure of the Center consists of the following components:

1. An external Scientific Advisory Board to advise and evaluate the Center annually on all facets of its program.

2. An Executive Committee, consisting of members from the four participating institutions - Rutgers and Princeton Universities, AT\&T Bell Laboratories, and Bell Communications Research - with responsibility for determining the over-all policy and activities of the Center, meeting regularly on a monthly basis. In particular, the Executive Committee has the responsibility for approving topics for the "special year" and individual research workshops.

3. A Director (from Rutgers), a Co-Director (from Princeton), and an Associate Director (from Rutgers), are responsible for the day-to-day operation of the Center, including budgetary and staff management. The Center will also have an Associate Director for Education.

4. A "Special Year" Organizational Committee with a representative from each of the four participating institutions, and augmented by senior external experts in the given topic (varying from year-to-year) with responsibility for organizing the full panoply of activities of the special year.

5. A Personnel Committee, with representatives from each of the four participating institutions, as well as the Director, Co-Director, and Associate Director, with responsibility to select all long-term and short-term visitors to the Center (other than those directly connected with the "special year") and also to select all post-doctoral fellows to be supported by the Center.

6. A Rotating Seminar Committee, with representatives from each of the four participating institutions, with responsibility for organizing the bimonthly "DIMACS" day, a day-long series of lectures and informal discussions on a focused research topic, usually with industrial applications, rotating among the four institutions.

7. Individual organizing committees for each of the research workshops, as submitted by the proposers and approved by the Executive Committee.

Assessment of this management organizational structure will be measured in terms of its effectiveness in carrying out the stated mission and goals of the Center.

E. Impact on Science Infrastructure

The following factors relate to the Center's impact on science infrastructure in the United States.

1. Possible long-range impact on computational processes and techniques as a result of the Center's research and knowledge transfer.

2. Impact on the size of the pool of experts in discrete mathematics and theoretical computer science through the Center's training of graduate students.

3. Impact on the general level of mathematics training at the precollege and college level through the Center's various educational programs.

4. Significance of the Center's somewhat unique multiinstitutional organizational structure as a model for university-industrial collaboration.

Assessment of items 2 and 3 will be made as part of the general evaluation of the Center's educational programs. Item 1 can be gauged only after a several year period. Item 4 should be related to the degree of success of the Center, which should determine the extent to which other multiinstitutional collaborative research efforts will wish to model themselves along the Center's lines.

F. Affirmative Action

The Center should also be judged on its success in having women and minorities participate in the research and educational activities of the Center: postdoctoral fellows, visitors, seminar lecturers, graduate students, and undergraduate and pre-college programs. The same applies to the appointment of staff personnel.

Assessment will be based on demonstrated effort by the Center management to attract and retain members of underrepresented groups in its various activities and in its operation.

G. Need for a Center

Documentation concerning the extent of interaction among the participating institutions of the Center, including evidence of the effectiveness of the Center mode of operation to achieve the stated scientific and educational objectives.

Assessment should be based on a determination of how effectively the Center is able to function as a single organization and how well it manages to integrate the participating institutions in its various activities.