Review of

DIMACS Special Year 1992-93
Combinatorial Optimization

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The six years that have passed since this special year gives enough time for us to provide a perspective on the successes (and small number of failures) of this Special Year. The organizing committee of the year was co-chaired by Laszlo Lovasz and Paul Seymour, with Vasek Chvatal, William Cook, Leslie Hall, Peter Hammer, David Johnson, William Pulleyblank and Lex Schrijver the other members of the organizing committee. We begin here with some general comments on the SY, and then provide more details about three main areas: workshops, visitors, and postdocs.

In retrospect, it is clear that the topic was extremely well-timed. Combinatorial optimization in the 1990s has changed grown from a mathematically interesting field with limited application to an area driven by application and computational power. The workshops held during the SY were the first sign of the enormous interest that would develop in computational combinatorial optimization. Furthermore, young researchers, many of whom have grown into influential researchers, began looking at these issues during the SY.

Another area of great interest with early roots in the SY is that of "approximation algorithms". Many important early results in this area were first presented during SY workshops. This area has since grown enormously in computer science and operations research.

In addition to the clear support of junior researchers, the SY was also clearly successful in its ability to attract senior researchers. It is this mix of senior and junior researchers that has led to much of the following success in the areas covered by the SY.

Overall, the SY was on a topic ready to greatly expand in importance. The SY brought together people who would become leaders in this area, and greatly aided the area at a time when it needed support.

Workshops

In this year, there were five major workshops and seven miniworkshops. The organizers of the year were prescient in a number of ways in their choice of workshop topics: we concentrate on two. The first is in their recognition of the importance of computational techniques in combinatorial optimization. They arranged for two workshops concentrating on this area. The first was on "Solving Hard Combinatorial Optimization Problems" organized by William Cook (then of Bellcore), Robert Bixby (Rice University), and David Johnson (of then Bell Labs). The conference report of the time discusses the organizers efforts to solve large traveling salesman instances and notes that the workshop increased interest in this work and that they increased their record to 4461 cities during the special year. Bixby and Cook (now joining Bixby at Rice), together with David Applegate (Rice) and Vasek Chvatal (Rutgers) have continued their work in this area solving increasingly larger problems including this year's solution of the optimal tour through the 13,509 US cities with population at least 500. Furthermore, the list of speakers at the workshop now reads like a "Who's Who" of computational combinatorial optimization, including Martin Savelsbergh (Georgia Tech), Sebastian Ceria (then a doctoral student at Carnegie Mellon, now at Columbia), Dan Bienstock (Columbia) and Andy Boyd (Texas A&M), to list only the junior people who were relatively new in the field at the time.

The second workshop on computational combinatorial optimization was the DIMACS Challenge Workshop on Cliques, Coloring, and Satisfiability, organized by Michael Trick (CMU) and David Johnson. This workshop resulted in a refereed volume published in the DIMACS Series published by the American Mathematical Society (DIMACS Series on Discrete Mathematics and Theoretical Computer Science, vol. 26, 1996). The instances generated during the Computational Challenge still form the basis for much computational work on these problems. Perhaps most interesting, the international flavor of this workshop provided the first glimpse to North American researchers of a European technique called "constraint programming", now a standard technique for addressing combinatorial optimization problems.

Since the DIMACS Special Year, the use of combinatorial optimization techniques has exploded, as seen clearest in the variety of commercial codes for solving hard integer programs: CPLEX, ILOG, XPRESS-MP, and many others now embed results that were first developed during the Special Year.

The second major topic for which interest has exploded since the special year is Approximation Algorithms. Philip Klein organized this conference. While billed as a "mini-workshop", the conference drew 60 researchers, as many as full workshops normally do. Perhaps the best picture of the effect of this conference was the variety of techniques for approximation (including linear programming, semi-definite relaxations, randomization, and so on) that were being explored. In the past six years, research on this topic has increased by orders of magnitude (as can be seen by looking at any recent STOC, FOCS, or IPCO conference proceedings). Young researchers of the time (like David Wiliamson (now IBM) and R. Ravi (now Carnegie Mellon)) had an opportunity to present their very important work. Since then, the amount of research done on this area would preclude any short conference covering the field, but at the time it was an important conference that covered the state of the art.

The other workshops (Disjoint Path Problems (Schrijver and Seymour), Probabilistic Algorithms for Combinatorial Optimization (Lovasz, Kannan, Saks, and Winkler) and Perfect Graphs (Chvatal, Lovasz, and Reed)) and miniworkshops also had a large effect on the participants, as can be seen when we discuss the visitors and postdocs.

Overall, the Special Year hit two "home runs" in working with computational combinatorial optimization and approximation algorithms before the large field realized the importance of these two areas.

Visitors

Like every DIMACS Special Year, there were a large number of visitors during the special year. The visitors ranged from well-known researchers in the field (Jan Karel Lenstra (CWI), Neil Robertson (Ohio State), Robin Thomas (Georgia Tech)) to new graduates (Mikkel Thorup (now with DIKU), Laura Sanchis (Colgate), David Fernandez-Baca (Iowa State)). Overall, there were about 24 people who spent at least one month at DIMACS. Giving the effect the year had on each of these people would grow this report beyond reasonable bounds, so we will limit ourselves to a sampling.

Robin Thomas (Georgia Tech) reports:

"I visited during the summer of 1993. During that time I worked with DIMACS member Paul Seymour and visitors Daniel P. Sanders and Neil Robertson. During the summer we started our project that eventually lead to a simpler proof of the Four-Color Theorem. The proof appeared in N. Robertson, D. P. Sanders, P. D. Seymour and R. Thomas, The four-colour theorem, J. Combin. Theory Ser. B 70 (1997), 2-44. There are also various surveys, including my recent article in the Notices. We built upon this work later. To give a recent example, my student Thomas Fowler will be defending his thesis on Thursday. In that thesis, he extends some of our ideas that we came up during the summer of 1993."

This work on the four-colour theorem is extremely important in that it greatly simplified the computer proof and decreased the computational requirements for verifying the proof. In doing so, this work has increased confidence in this fundamental result.

Henry Wolkowicz (University of Waterloo) spent most of the year at DIMACS. He reports:

> "My research since 92-93 has been mostly a result of my year at DIMACS (both at Rutgers and Princeton, since I had an office at both locations). For example, I am off to a conference on SDP in Berlin at Konrad-Zuse-Zentrum, organized by Christoph Helmberg (who was introduced to SDP due to this year.) I think that many other people started their research on SDP as a result of this year, e.g. Franz Rendl, Bob Vanderbei.

1. Research started there that continued past the year:
   My research since then has concentrated mainly on semidefinite programming, SDP. I started three main papers started there. These are often cited papers in the area of SDP. These papers concentrated on semidefinite relaxations for hard combinatorial problems; and the solutions of SDP using interior point methods.

2. Major results that occured during the year or as a consequence of the year:
   For me, the major result was the beginning of my research in the SDP area. This has become quite an active area over the last few years with many conferences held exclusively on SDP. Also, I organized a DIMACS workshop on the quadratic assignment problem, QAP, during the year (with Panos Pardalos) There was a follow-up workshop on SDP at the Fields Institute held several years later (also organized with Panos Pardalos).

3. Contacts made during the year:
   I first met both Bob Vanderbei and Svata Poljak during this year. They both became collaborators (as the above mentioned papers show). Svata unfortunately passed away; but, my contacts with Bob have continued. We also had many visitors come, e.g. Mike Overton (Courant Institute), Franz Rendl (Univ Graz), and so on."

Finally, Panos Pardalos spent much of the year at DIMACS and coorganized the workshop on Quadratic Assignment Problems. He states:

> "In 1993 I organized my first DIMACS Workshop: Quadratic Assignment and Related Problems (with Henry Wolkowicz) and the proceedings of this workshop published in DIMACS Series Vol. 16, American Mathematical Society (1994).
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> That book played a key role in research for QAP and Nonlinear Assignment Problems. Since then many people worked on these problems, The book is referenced a lot!
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> I met many people at DIMACS and started a lot of work. In particular I started my collaborations with people from AT&T (Murray Hill that time) Resende and Ramakrishnan.
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> Summer 1992 was my first year at DIMACS. Since then I organized several DIMACS workshops and visited DIMACS several times. It really influenced my research. I still work with people at AT&T and Princeton!"

Overall, it is clear that many visitors found the year a defining period in setting their research agendas.

Postdoctoral Students

There were four formal postdoctoral students during the year (people like Mikkel Thorup were also in their postdoctoral year, but were classified as visitors). Edith Cohen is now with AT&T Labs as a member of the technical staff; Shmuel Onn is a tenure stream faculty member of the Technion-Israel Institute of Technology; Ran Raz is on faculty of the Weizmann Institute of Science in Isreal; Gabor Simonyi is a Senior Research Fellow of the Hungarian Academy of Science.

Simonyi reports that his work on graph entropy received much forward impulse during the stay at DIMACS. During the year he met Michele Conforti (Padova) who subsequently invited him to give a minicourse at the University of Padova. A number of papers came out of the year. He also felt the opportunity to talk to people like Laszlo Lovasz to be invaluable and that interactions with other postdoctoral students to be important in his research.

Onn's research went in a number of directions due to the year at DIMACS. In particular his work on integer programming and Groebner basis theory then led to more recent work on colorful linear programming, an important generalization that has led to publications in some of the top journals in the field.

In summary, the postdoctoral students are all active researchers whose postdoctoral year gave them a running start on productive careers.

Summary

Correspondence with visitors and postdocs did reveal a few minor problems with the Special Year. In particular, the division of the year between Rutgers and Princeton led to some difficulty in communication, and there was some feeling there was too little interaction even among the visitors and permanent members at the Rutgers conference. These comments, though, were sporadic, so perhaps point more to individual difficulties rather than a systematic problem.

Overall, we believe that this year was very successful and occured at an ideal point of time. Issues of approximation and computation in combinatorial optimization were ready to explode, and the DIMACS SY provided the organization for that to happen. The workshops were important, the visitors felt their time there to be valuable, and the postdoctoral fellows were and continue to be successful in the field of combinatorial optimization.