Newsjournal of the Society for Industrial and Applied Mathematics

siam news

Volume 35/ Number 4
May 2002

Applied Dynamical Systems: New SIAM Journal Posts First Papers

SIAM's only all-electronic journal became a reality last month with the posting of its first two papers:

"Hamiltonian Systems Near Relative Periodic Orbits," by Claudia Wulff and Mark Roberts (pages 1–43); and

"Stepwise Precession of the Resonant Swinging Spring," by Darryl D. Holm and Peter Lynch (pages 44–64).

"Everyone who has been associated with the development of *SIAM Journal on Applied Dynamical Systems* is excited that it is now online," says Martin Golubitsky, the journal's editor-in-chief. "The first two publications point to the intended scope of SIADS—from theory to application and soon to animation and experiment."

Editorial board member (and SIAM president-elect) James M. Hyman, now nearing the end of his term as SIAM vice president for publications, reports that he is "thrilled to see SIAM taking the lead in electronic publishing. SIADS provides the tools for authors to publish all aspects of their research in a format that can best convey the beauty, theoretical framework, and applications of dynamical systems."

Prospective authors can find details about the SIADS editorial policy, and about welcomed enhancements for their papers, including animated visualizations and internal linking, on the back page of Inside SIAM in this issue of *SIAM News*.

Interested readers can find the SIADS papers at:

http://epubs.siam.org/sam-bin/dbq/toclist/SIADS

Full text access to SIADS will be free for the remainder of 2002.

Imaging and Math Scientists See a Future of Continued Close Interaction

Tony Chan, dean of physical science in the College of Letters and Science at UCLA and a member of the organizing committee for the First SIAM Conference on Imaging Science, wrote the following personal perspective as an introduction to a series of "snapshots" from several of the conference speakers (see pages 4–8 in this issue of SIAM News*). David Wilson of the University of Florida, who chaired the organizing committee,* helped out with recollections of the early days of the SIAM Activity Group on Imaging Science.*

The first SIAM Conference on Imaging Science, held in Boston, March 4–6, came at a time of unusual prominence for imaging science. Object tracking in videos and facial recognition, long-standing problems for imaging scientists, had suddenly taken on new meaning and heightened urgency.

Long before 9/11, however, it was clear to many SIAM members that imaging science had matured and developed to a stage that there was sufficient interest to support an activity group and also to hold a national conference. Researchers were already talking about an activity group in imaging in the early 1990s. Things really got under way in March 1998, when then SIAM president Gilbert Strang, in an open forum at the SIAM–SEAS meeting in Knoxville, Tennessee, invited the audience to suggest new areas where SIAM should be putting its energy.

Gerhard Ritter immediately proposed that SIAM form an activity group in imaging science. Strang's response, also immediate, was positive. Not long afterward, with the bylaws of the recently created SIAM Activity Group on Life Sciences as a model, the SIAG on Imaging Science was created. The group's first officers were Gerhard Ritter, chair; Robert J. Plemmons, vice chair; Bernard Mair, secretary; and David Wilson, program director.

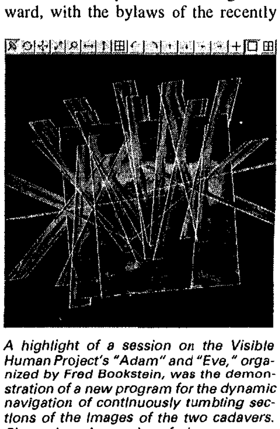
Of course, imaging science is a huge enterprise and has long been an established subject (in, for example, the medical, computer science, and electrical engineering communities). What got SIAM interested was the increasing realization that the kinds of mathematical and computational techniques being employed in imaging science have much in common with those used in other more traditional SIAM areas and that bringing imaging scientists together with computational and applied mathematicians would benefit both groups. Imaging science also has a wide variety of important applications that would be unwise for SIAM to overlook.

Judging from the Boston meeting, this thinking was valid. The meeting was extremely well attended (with 229 registered attendees) and offered a remarkable variety of mathematical topics and application areas. The meeting obviously benefited from the large number of academic and medical institutions in the Boston area, as participation of local attendees was significant. A particularly interesting and successful feature was that the last day of the three-day conference was held in conjunction with the first SIAM Conference on Life Sciences.

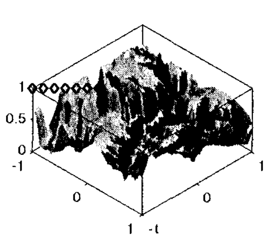
The meeting was organized around five plenary talks—Margaret Cheney, on synthetic aperture radar; Stan Osher, on PDEs and level sets; Stéphane Mallat, on geometric wavelets; Ed Dougherty, on morphology and genomics; and David Mumford, on stochastic image models—each associated with a number of related minisymposia. These topics represent some of the major recent mathematical developments in imaging science. With a total of 27 minisymposia, seven contributed sessions, and 14 poster presentations, the conference covered a broad spectrum of the main areas of imaging science, including compression, restoration, segmentation, tracking, recognition. . . . Also featured were a wide variety of applications, many in the medical and life sciences, others in com-

See **Imaging** on page 8

*The members of the organizing committee, in addition to Wilson and Chan, were Akram Aldroubi, Vanderbilt University; Fred Bookstein, University of Michigan; Longin Jan Latecki, University of Hamburg; Chris Johnson, University of Utah; Bernard Mair, University of Florida; Robert J. Plemmons, Wake Forest University; Gerhard Ritter, University of Florida; Guillermo Sapiro, University of Minnesota; and Michael Unser, Ecole Polytechnique Fédérale de Lausanne.



A highlight of a session on the Visible Human Project's "Adam" and "Eve," organized by Fred Bookstein, was the demonstration of a new program for the dynamic navigation of continuously tumbling sections of the images of the two cadavers. Shown here is a series of planes perpendicular to Eve's corpus callosum. Details on page 6.



Invited speaker Stanley Osher used a simulation of a Grand Canyon fly-through to illustrate dynamic visibility, one of several imaging applications of level set methods described in the talk. See page 5.

Making the Yellow Angels Fly: Online Dispatching Of Service Vehicles in Real Time

By Martin Grötschel, Sven O. Krumke, Jörg Rambau, and Luis M. Torres

Combinatorial online optimization is an area that has lots of applications and abundant potential for significant progress, both in theory and in practice. In this short note we sketch a typical large-scale online optimization problem: dispatching of service vehicles. We discuss some theoretical and practical issues that arise, and explain, very briefly, how we approach this problem mathematically. Online problems are a battlefield of heuristics, with many strong claims advanced about the quality of the solutions obtained. As shown below, careful modeling and the use of more mathematics can produce superior results.

[*On Wednesday, July 10, as one of five invited plenary speakers at the SIAM 50th Anniversary and 2002 Annual Meeting (Philadelphia, July 8–12), Martin Grötschel will discuss the "tremendous progress" of the last fifty years in the significantly overlapping fields of discrete mathematics and theoretical computer science, with a focus on large-scale real-world examples of the type presented here.—ed.*]

The Problem

The German automobile association ADAC (Allgemeiner Deutscher Automobil-Club), second in size only to the AAA, the largest such organization in the world, maintains a heterogeneous fleet of more than 1,600 service vehicles to help drivers whose cars break down on the road. All ADAC service vehicles have a distinctive yellow color, and the help provided by the experienced mechanics often appears to have been sent from heaven; for these reasons, the service vehicles are affectionally called "yellow angels." In this article we are a little more down-to-earth and just refer to them as "units."

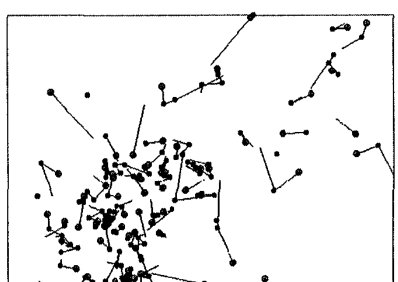


Figure 1. Partial snapshot of a real-world instance of the ADAC-problem (grey: units; black: events). Lines indicate currently planned tours.

ADAC runs five help centers (Pannenhilfezentralen), which are located throughout Germany and operate 24 hours a day, seven days a week. (Hu-

See **Yellow Angels** on page 10

siam®
SOCIETY for INDUSTRIAL and APPLIED MATHEMATICS
3600 University City Science Center
Philadelphia, PA 19104-2688

Nonprofit Org
U.S. Postage
PAID
Permit No 360
Bellmawr, NJ

Yellow Angels

continued from page 1

man) dispatchers have to reply to help requests ("events," for short) instantly. Their task is to assign a unit (equipped with GPS) to serve each customer and to predict the estimated time of arrival at the customer's location.

In addition to the ADAC fleet, about 5,000 units operated by service contractors can be employed to cover events that could not otherwise be served in time. In the continuously running planning process, a dispatcher can revoke a particular assignment to an ADAC unit, provided that the unit has not yet reached the customer.

There is no unique objective. The goals are high-quality service (e.g., short waiting times for the customers, preferably well below an hour but depending on the system load) and low operational costs (through measures like short total tour lengths and limited overtime expenditures). Figure 1 (page 1) shows a typical, obviously not uniform distribution of units (gray) and events (black) in a real-world instance of ADAC.

With increasing costs and request volume, ADAC's manual dispatching system has come under stress. The challenge is to design an automatic online dispatching system that will guarantee small waiting times for events and that will keep operational costs low. The modeling of such a task is not easy, as many technical and organizational side constraints—some hard, others soft—have to be considered, and it takes some time to figure out which constraints and objectives really count. We do not describe the complete model here but consider, as one example of a management decision, ADAC's imposition of a soft deadline on the service time of an event: The deadline can be missed at the cost of a linearly increasing lateness penalty (soft time windows).

In the remainder of this article we refer to the dispatching problem sketched above as the "ADAC-problem."

The Problem with the Problem

In fact, we face two problems. The first is the task of computing an optimal dispatch for a "snapshot" situation (that is, a dispatch that is optimal for a given set of events and contractors at some moment in time). Because it contains the classic vehicle-routing problem as a special case, this problem is NP-hard. The difficulty is that in the dynamic planning process, a dispatch now has to be returned in no more than 15 seconds (the "real-time problem").

A problem of this type can be described as a multidepot vehicle-routing problem with soft time windows. To date, most research in this area has considered hard time windows (see [1] and references therein for a survey of various problem types and exact algorithms; see [2] for a discussion of recent improvements in the efficiency of exact algorithms). For instant answers, the literature seems to suggest that use of metaheuristics is unavoidable ([4] describes a tabu search approach for problems with soft time windows; [3] presents an approach based on genetic algorithms). These metaheuristics, however, do not provide evaluations of their results, a significant drawback in our opinion.

Integer programming, the approach we prefer (maybe in conjunction with whatever heuristics turn out to be useful), often yields lower bounds on the costs that are unavoidable with any solution method. It was this lower-bound argument that convinced the ADAC not to simply pay one of the many commercial providers of metaheuristic software, but to let us look a little deeper into the problem.

The chellenge is to design en automatic online dispatching system that will guarantee small waiting times for events and that will keep operationel costs low.

The second problem we face is more subtle: We do not know where future events will pop up (the "online problem"). A decision that is "optimal" at some point in time can prove later to have been unwise. In particular, even if we were able to compute locally optimal dispatches for any snapshot situation, we would not necessarily obtain a dispatch that is (in hindsight) optimal for the whole planning period.

Toward a Solution

A closer inspection of the problem and typical instances leads us to expect that "snapshot optimization" does have potential. Time windows are helpful. Although they often seem to make routing problems harder, the contrary is true in our online situation. We compute optimal snapshot-dispatches whenever new events occur and use those results for subsequent routing decisions until the arrival of new events. In planning tours for the service units, we have each unit end its tour at its home base; in this way we avoid units' drifting far from home and requiring expensive return trips at the end of their shifts.

For the real-time problem, the ADAC-problem luckily turns out to have some structure that we can use to our advantage. Because it takes some time for a service unit to deal with an event and because the time windows for events are quite tight, tours in an optimal solution cannot be too long (at most four to five events per unit). So, again because of the time windows, chances are good that all relevant tours can be enumerated implicitly.

What comes to mind at this point is a well-known column-generation and set-partitioning approach: Generate all relevant tours and partition the set of events into a subset of tours, with some single events outsourced to the contractors. The fractional set-partitioning solution (LP relaxation) serves as a lower bound (unavoidable costs) for a snapshot-dispatch. This is basically what is done in most of the known exact algorithms for vehicle routing. Our task is to turn the known methods—which usually require substantial time for warmup or even preprocessing—into an algorithm that delivers provably good snapshot-dispatches within seconds.

We accomplish this with a dynamic pricing control in the column-generation procedure. Early in the optimization, we work on an extremely restricted search space for new tours, using a mix of heuristics to find new tours of restricted depth. The search space for new tours is extended as the estimates for the dual prices in the LP relaxation of the set-partitioning problem get closer to the truth.

Results

Our implementation of the column-generation method ZIBDIP (ZIB Dispatching via Integer Programming) was competing with an experimental metaheuristic prototype programmed for this particular purpose by ADAC's software

See **Yellow Angels** *on page 11*

Yellow Angels

continued from page 10

provider, Intergraph Public Safety (IPS). The evaluation was done on varying amounts of snapshot data. The results were conclusive: In this special application, the integer programming approach completely outperforms the meta-heuristic paradigm. ZIBDIP produced optimal (or optimal to within 1%) solutions for all real-world examples (up to 215 events for 98 units) within one to twenty seconds on a standard 800-MHz PC; the meta-heuristic, by contrast, was unable in several instances to get closer to optimality than 25%. In larger, artificially generated problems (up to 775 events for 215 units), this trend was vastly amplified.

The superb performance on real data convinced ADAC and IPS that our algorithm is the way to go for the snapshot-dispatches, and IPS agreed to implement the production software based on the ZIBDIP algorithm.

With the real-time issue solved to everyone's satisfaction, we turned our attention to the online issue. What quality would the repeated generation of optimal snapshot-dispatches deliver over time?

Although development of the final version of the online algorithm is still under way, we have run online tests comparing two strategies: planning snapshot-dispatches after each new job or at fixed frequencies (one to five minutes). The trend was slightly in favor of planning after each new job.

The results were promising: On average, the online costs were about 40% above the lower bound—not too bad, in our experience, for an online algorithm. We hope, however, to improve on these figures by utilizing estimates of future events in the snapshot-dispatches. This is work in progress and leads to most interesting questions as to how knowledge about the future can be exploited in combinatorial online optimization.

References

[1] J. Desrosiers, Y. Dumas, M.M. Solomon, and F. Soumis, *Time constraint routing and scheduling*, in *Network Routing, Handbooks in Operations Research and Management Science*, M. Ball, T. Magnanti, C. Monma, and G. Newhauser, eds., 8, Elsevier, Amsterdam, 1995, 35–140.

[2] J. Larsen, *Vehicle routing with time windows—finding optimal solutions efficiently*, DORSnyt (newsletter of the Danish OR society; in English), 116 (1999).

[3] S.J. Louis, X. Yin, and Z.Y. Yuan, *Multiple vehicle routing with time windows using genetic algorithms*, 1999 Congress on Evolutionary Computation, Piscataway, NJ, IEEE Service Center, 1999, 1804–1808.

[4] E. Taillard, P. Badeau, M. Gendreau, F. Guertin, and J.-Y. Potvin, *A tabu search heuristic for the vehicle routing problem with soft time windows*, Transportation Sci., 31 (1997), 170–186.

Martin Grötschel is a professor at TU Berlin and vice president of the Konrad-Zuse-Zentrum für Informationstechnik Berlin (ZIB); Sven O. Krumke and Jörg Rambau are researchers at ZIB, and Luis M. Torres is a PhD student.

Washington

continued from page 3

Health. CBCB is part of the National Institute for General Medical Sciences (NIGMS). Unlike, say, the Heart or Cancer Institute, NIGMS is interested in general medical issues like genomics and cellular biology. NIGMS and DMS have a joint program in mathematical biology. The NIH campus is in a beautiful wooded location, where buildings seem to be sprouting like mushrooms. To put things in perspective, the NIGMS budget for FY 2002 is $1.7 billion, as compared with $4.7 billion for all of NSF. The president's requested *increase* for NIH in FY 2003 is $3.7 billion—of the order of magnitude of the entire NSF budget.

Cassat was very receptive to the idea of cooperating with SIAM to bring computational scientists together with researchers associated with his institute. He also offered to be a point-of-contact for computational scientists interested in working with other NIH institutes. One valuable insight he provided is that breaking in to the NIH funding structure may require several attempts; SIAM members need to be persistent.

The final visit of this trip was to the Congressman from Boulder, Rep. Mark Udall (D-CO). Mark is a member of the House Science Committee and has been very helpful to SIAM on several occasions. Responding to advice from the staff of the Senate and House Appropriations Committees, we asked him to mention the importance of NSF in general, and of the investment in the mathematical sciences in particular, in his "member request" letter to the Appropriations Committee. Such letters have a major impact on committee deliberations, and we encourage readers in the U.S. to contact their own Representatives, urging them to include similar wording in their member request letters. For help in obtaining addresses, contact the SIAM office (jcrowley@siam.org).