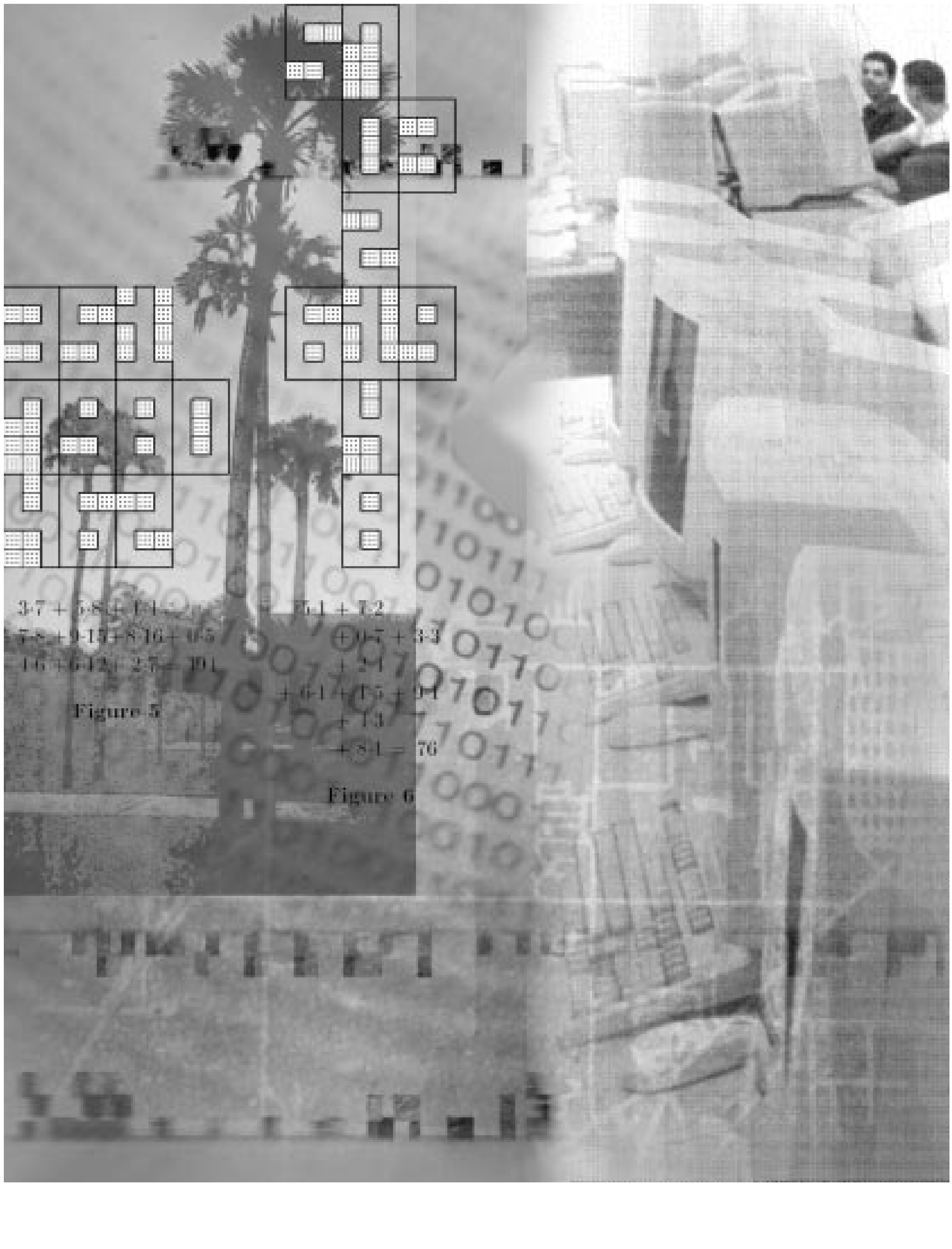
No 69

OPTIMA

Mathematical Programming Society Newsletter

JANUARY 2003



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Primal Integer Programming

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September 17, 2002

Primal integer programming is an area of discrete optimization that -- in a broad sense -- includes the theory and algorithms related to augmenting feasible integer solutions or verifying optimality of feasible integer points. This theory naturally provides an algorithmic scheme that one might regard as a generic form of a primal integer programming algorithm: First detect an integer point in a given domain of discrete points. Then verify whether this point is an optimal solution with respect to a specific objective function, and if not, find another feasible point in the domain that attains a better objective function value.

The field of primal integer programming has emerged in the 1960s beginning with the design of specific algorithms in combinatorial optimization and Gomory's all integer algorithms for the general integer programming case. While the field stayed active in theory over the past 40 years, the algorithmic focus has been nearly exclusively on combinatorial optimization problems. In fact, augmentation algorithms have been designed for and applied to a range of specific linear integer programming problems: augmenting path methods for solving maximum flow problems or algorithms for solving the min-cost flow problem via augmentation along negative cycles are of this type. Other examples include the greedy algorithm for solving the matroid optimization problem, alternating path algorithms for solving the weighted matching problem, or methods for optimizing over the intersection of two matroids. In fact, still many of the most recent combinatorial algorithms are of a primal nature; see for instance the combinatorial methods for minimizing a submodular function [12] [19] or the combinatorial algorithm for the independent path matching problem [20].

The attempt, however, to solve unstructured integer programs with a primal strategy had lost its popularity for at least two decades. Which developments did lead to this situation? What are the obstacles for a primal strategy in the general integer case? What is the state of the art? What are the next steps to be taken? These are some of the questions that I try to address in the following.

Let us begin by recalling that all the algorithmic schemes applied to integer programming problems without a-priori knowledge about the structure of the side constraints resort to the power of linear programming duality.

Dual type algorithms start solving a linear programming relaxation of the problem, typically with the dual simplex method. In the course of the algorithm one maintains as an invariant both primal and dual feasibility of the solution of the relaxation. While the optimal solution to the relaxation is not integral, one continues to add cutting planes to the problem formulation and reoptimizes. Within this framework, Gomory developed a method of systematically generating valid inequalities directly from a given simplex tableau; see [7, 8]. A disadvantage of a dual-type method is, however, that intermediate stopping does not automatically yield a primal feasible integral solution.

In contrast to dual methods, primal type algorithms always preserve integrality of the solution to the relaxation. They may be distinguished according to whether the algorithm preserves dual feasibility or primal feasibility or none of those. Note that it is impossible to preserve integrality and both dual and primal feasibility. The only representative of the first family of primal type methods is an "all integer algorithm" that appeared in [9]. We are not aware of interesting computational experiments with this method, however.

An alternative to design a primal type algorithm is to preserve integrality of the solution to the relaxation and simultaneously primal feasibility. In order to achieve this, one typically starts with a primal feasible simplex tableau. Iteratively, pivot steps are performed on entries equal to one, only. If such a pivot element cannot be detected by the standard dual simplex rule, a special cut row with this property is generated and then chosen for pivoting. When at any time the reduced cost coefficients of the tableau point into the "right direction", optimality is proved by the simplex criterion. The cuts one makes use of in this framework may be Gomory's rounding cuts as in [21], or problem specific cuts such as facet-defining cuts for the TSP in [18]. To the best of our knowledge, a method of this type for Integer Programming has first been suggested by Ben-Israel and Charnes [3]. They employed the fact that for any feasible solution of an integer program optimality can be proven by solving a subproblem arising from the non-basic columns of a primal feasible simplex tableau. Various specializations and variants of a primal cutting plane algorithm were later given by Young [21, 22] and Glover [6]. For an overview on this subject we refer to [11, 5]. Nemhauser and Wolsey [17] point out that because of poor computational experience, this line of research has been very inactive, an exception being the work of Padberg and Hong [18], where strong primal-type cutting planes are used with some success. According to [17] the reason for the poor computational performance of general primal cutting plane algorithms is that "it is necessary to produce valid inequalities that contain the one-dimensional faces (edges) on a path from the initial point to an optimal point", see also [13]. This is certainly one explanation why this line of research became inactive.

Recent theoretical advances regarding primal type algorithms and the theory of so-called test sets have also renewed the interest in primal cutting plane algorithms. Letchford and Lodi [15] propose a modern primal cutting plane algorithm for 0/1 programs. The main ingredient is the subproblem of "primal separation", see also [4, 16]. They give computational results on small randomly generated 0/1 multidimensional knapsack problems with up to twenty five variables. Their computational experiments reveal that the proposed algorithm is superior to the original algorithm of Young. However, the results do not provide evidence that primal cutting plane algorithms can become superior to dual cutting plane methods. Only future research and experiments can clarify this situation. I have doubts, however, that primal cutting plane algorithms will become an alternative to the "standard method" of today. One additional problem for primal cutting plane algorithms remains: To this day there is no primal cutting algorithm for mixed integer programs available, despite the fact that mixed integer programming models are the most important models of discrete optimization.

It is, however, important to remark that even if primal cutting plane algorithms will not work in practice, this will not imply that a primal augmentation approach will not work. An alternative to primal cutting plane algorithms is the Integral Basis Method [10]. It uses a completely different idea for solving the augmentation subproblem. After turning a feasible solution into a basic feasible solution of an appropriate simplex tableau, one manipulates the set of non-basic columns until either optimality of the given solution is proved or an "applicable" improving direction, i.e., an augmentation vector, is detected. In each manipulation step, one substitutes one column by new columns in a way that no feasible solutions are lost; this is known as a "proper reformulation" of a tableau according to [10]. The substitution is guided by the concept of irreducibility of lattice points. In contrast to generating a basis of a lattice one generates iteratively a minimal set of lattice points in the positive orthant that permits a representation of any feasible solution as a non-negative integer combination of the selected subset. This distinguishes the latter approach from the reformulation method of Aardal et al [1]. We refer to [10] for the theoretic foundations and computational results with the Integral Basis Method. We also remark that the method can be extended to mixed integer programming problems, see [14]. A predecessor of the Integral Basis Method for the special case of set partitioning problems was invented by Balas and Padberg about 25 years ago [2].

Computational results with the Integral Basis Method demonstrate that a couple of iterative substitutions of non-basic columns with a "bad" reduced cost coefficient yield a model in which the linear programming relaxation becomes significantly stronger than the original linear programming relaxation. Therefore, the effect of reformulating a tableau with the help of irreducible lattice points is not only interesting per se, but rather suggests a primal-dual approach for integer programming: perform Integral Basis Method steps in addition to cutting planes and branching. Each of the three operations, i.e., substitution of variables, cutting, and branching, has an impact on the model and on the other operations. This is -- in my opinion -- an area of research to advance our current ability to solve integer programming models. If we apply in addition to branching and cutting the operation of substituting variables, then we cannot lose performance, but gain a lot. This is where I see one future direction of research in integer programming algorithms.

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ISMP 2003

Copenhagen, Denmark

August 18 - 22, 2003

www.ismp2003.dk

The Mathematical Programming Society, the Technical University of Denmark, and the University of Copenhagen announce:

ISMP 2003 is approaching: The 18th International Symposium on Mathematical Programming takes place August 18-12, 2003 at the Technical University of Denmark, Copenhagen, in cooperation with the University of Copenhagen. It is the main scientific event of the Mathematical Programming Society held every 3 years on behalf of the Society. The Symposium attracts more than one thousand researchers from all areas of mathematical programming. At the symposium homepage www.ismp2003.dk you will find all information including the list of plenary and semiplenary speakers:

Susanne Albers,	University of Freiburg
Kurt Anstreicher,	University of Iowa
Sanjeev Arora,	Princeton University
Francis Clarke,	University of Lyon-1
William J. Cook,	Georgia Institute of Technology
Siemion Fajtlowicz,	University of Houston
Adrian Lewis,	Simon Fraser University
Tom Luo,	McMaster University
Renato Monteiro,	Georgia Institute of Technology
Stephen M. Robinson,	University of Wisconsin
Mikael Rönnqvist,	Linköping University
Rüdiger Schultz,	Gerhard-Mercator University Duisburg
Peter W. Shor,	AT&T Labs - Research
Miklós Simonovits,	Hungarian Academy of Sciences
Daniel A. Spielman,	MIT
Robin Thomas,	Georgia Institute of Technology
Laurence A. Wolsey,	Université Catholique de Louvain

A proceedings volume sponsored by Springer Verlag with a contribution from each speaker will be published as a special issue of Mathematical Programming and will be distributed to all participants at the symposium.

The scientific program will be complemented by an attractive social program: At ISMP 2003 you will have the opportunity to taste the traditional "City Hall" pancakes served at the City Hall and to participate in a cocktail party in the Celebration Hall at the University of Copenhagen. The conference dinner will take place at the famous Base Camp restaurant in the former naval area of the city, recently rebuilt into one of the main cultural centers of the city. Additional activities will be arranged in the scenic surroundings of the campus.

The homepage provides information about registration, travel, and accomodations, and offers possibilities for web-based abstract submission of contributed presentations as well as organized sessions.

The registration fees for ISMP2003 are:
MPS Member: 2100 DKK before/on April 30, 2003; 2700 DKK after April 30, 2003.
Non-MPS Member: 2600 DKK before/on April 30, 2003; 3100 DKK after April 30, 2003.
Student: 1100 DKK before/on April 30, 2003; 1600 DKK after April 30, 2003.

Special registration pricing including a one year membership to MPS is also available. See the homepage for details. In addition to the traditional congress material as booklet of abstracts and bag, registration includes the volume of invited lectures, admission to the opening reception, daily bag lunches, and transportation for the entire week.

We invite you to participate in the event and to submit an individual abstract or propose an organized session on some special topic of general interest. Each such session will consist of three talks. The submission procedure for both abstracts and sessions is described at the homepage: Just click on the "How to use this homepage" button.

Program committee:

Jørgen Tind (chair),	University of Copenhagen
Jens Clausen (cochair),	Technical University of Denmark
Rainer Burkard,	Technische Universität, Graz
Martin Grötschel,	ZIB, Berlin
Michael J. Todd,	Cornell University
Stephen J. Wright,	University of Wisconsin

Organizing committee:

Jens Clausen (chair),	Technical University of Denmark
Jørgen Tind (cochair),	University of Copenhagen
Hans Bruun Nielsen,	Technical University of Denmark
David Pisinger,	University of Copenhagen
Martin Zachariasen,	University of Copenhagen

Important dates:

April 30, 2003:	Deadline for early registration.
May 31, 2003:	Deadline for submission of abstracts.
August 18 - 22:	ISMP 2003

We look forward to welcoming you in Copenhagen.

Jørgen Tind and Jens Clausen

Call for Nominations

A. W. Tucker Prize

The next A.W. Tucker Prize will be awarded at the XVIII Mathematical Programming Symposium in Copenhagen, August 18-22, 2003 for an outstanding paper authored by a student. The paper can deal with any area of mathematical programming. All students, graduate or undergraduate, are eligible. Nominations of students who have not yet received the first university degree are especially welcome. The Awards Committee will screen the nominations and select at most three finalists. The finalists will be invited, but not required, to give oral presentations at a special session of the symposium. The Awards Committee will select the winner and present the award prior to the conclusion of the symposium.

The paper may concern any aspect of mathematical programming; it may be original research, an exposition or survey, a report on computer routines and computing experiments, or a presentation of a new and ingenious application. The paper must be solely authored and completed since 2000. The paper and the work on which it is based should have been undertaken and completed in conjunction with a degree program.

Nominations must be made in writing to the Chairman of the Awards Committee by a faculty member at the institution where the nominee was studying for a degree when the paper was completed. Moreover, nominators should send one copy each of: the student's paper; a separate summary of the paper's contributions, written by the nominee, and no more than two pages in length; and a brief biographical sketch of the nominee to each of the four members of the Tucker Prize Committee:

Prof. Rainer E. Burkard (Chair)
Institute of Mathematics B
Graz University of Technology
Steyrergasse 30
A-8010 Graz
Austria
burkard@tugraz.at

Prof. S. Thomas McCormick
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Prof. Leslie E. Trotter, Jr.
School of Operations Research and Industrial Engineering
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235 Rhodes Hall
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ltrotter@cs.cornell.edu

The Awards Committee may request additional information. The deadline for nominations is **February 1, 2003**.

Nominations and the accompanying documentation must be written in a language acceptable to the Awards Committee.

The winner will receive an award of $750 (U.S.) and a certificate. The other finalists will also receive certificates. The Society will also pay partial travel expenses for each finalist to attend the symposium. These reimbursements will be limited in accordance with the amount of endowment income available. A limit in the range from $500 to $750 (U.S.) is likely. The institutions from which the nominations originate will be encouraged to assist any nominee selected as a finalist with additional travel expense reimbursement.

Past Winners and Finalists:
1988: Andrew Goldberg
1991: Michel Goemans. Other finalists: Leslie Hall, Mark Hartmann
1994: David Williamson. Other finalists: Dick Den Hertog, Jiming Liu
1997: David Karger. Other finalists: Jim Geelen, Luis Nunes Vicente
2000: Bertrand Guenin. Other finalists: Kamal Jain, Fabian Chudak

The Lagrange Prize in Continuous Optimization

Nominations are invited for the newly established Lagrange Prize in Continuous Optimization, awarded jointly by the Mathematical Programming Society (MPS) and the Society for Industrial and Applied Mathematics (SIAM). The Prize will be presented for the first time at the XVIII International Symposium on Mathematical Programming in August 2003.

To be eligible, works should form the final publication of the main result(s) and should be published either (a) as an article in a recognized journal, or in a comparable, well-referenced volume intended to publish final publications only; or (b) as a monograph consisting chiefly of original results rather than previously published material. Extended abstracts and prepublications, and articles published in journals, journal sections or proceedings that are intended to publish non-final papers, are not eligible. The work must have been published during the six calendar years preceding the year of the award meeting.

Judging of works will be based primarily on their mathematical quality, significance, and originality. Clarity and excellence of the exposition and the value of the work in practical applications may be considered as secondary attributes.

Full details and prize rules are given at `http://www.mathprog.org/prz/lagrange.htm`

To nominate a publication for the prize, please send a copy of the paper and a letter of nomination by February 28, 2003 to the following address:

Stephen Wright
Computer Sciences Department
University of Wisconsin
1210 W. Dayton Street
Madison, WI 53706,
USA.
email: swright@cs.wisc.edu
Electronic submissions are preferred.

Call for Nominations

Beale-Orchard-Hays Prize

Nominations are being sought for the Mathematical Programming Society Beale-Orchard-Hays Prize for Excellence in Computational Mathematical Programming.

Eligibility

To be eligible a paper or a book must meet the following requirements:

1. It must be on computational mathematical programming. The topics to be considered include:
   (a) experimental evaluations of one or more mathematical programming algorithms,
   (b) the development of quality mathematical programming software (i.e., well-documented code capable of obtaining solutions to some important class of mathematical programming problems) coupled with documentation of the application of the software to this class of problems (note: the award would be presented for the paper that describes this work and not for the software itself),
   (c) the development of a new computational method that improves the state-of-the-art in computer implementations of mathematical programming algorithms coupled with documentation of the experiment that showed the improvement, or
   (d) the development of new methods for empirical testing of mathematical programming techniques (e.g., development of a new design for computational experiments, identification of new performance measures, methods for reducing the cost of empirical testing).
2. It must have appeared in the open literature.
3. Documentation must be written in a language acceptable to the Screening Committee.
4. It must have been published during the three calendar years preceding the year in which the prize is awarded.

These requirements are intended as guidelines to the Screening Committee but are not to be viewed as binding when work of exceptional merit comes close to satisfying them.

Frequency and amount of the award

The prize will be awarded every three years. The 2003 prize of $1,500 and a medal will be presented in August 2003, at the awards session of the 18th International Symposium on Mathematical Programming to be held in Copenhagen, Denmark.

Judgement criteria

Nominations will be judged on the following criteria:

1. Magnitude of the contribution to the advancement of computational and experimental mathematical programming.
2. Originality of ideas and methods.
3. Degree to which unification or simplification of existing methodologies is achieved.
4. Clarity and excellence of exposition.

Nominations

Nominations must be in writing and include the title(s) of the paper(s) or book, the author(s), the place and date of publication, and four copies of the material. Supporting justification and any supplementary materials are welcome but not mandatory. The Screening Committee reserves the right to request further supporting materials from the nominees. The deadline for nominations is March 15, 2003.

Nominations should be mailed to:

William Cook
Georgia Institute of Technology
School of Industrial and Systems Engineering
Atlanta, GA 30332-0205
USA
email: bico@isye.gatech.edu

The COIN-OR Open-Source Coding Contest: Win an IBM ThinkPad

At the 2000 International Symposium for Mathematical Programming (ISMP), COIN-OR (http://www.coin-or.org) was launched by IBM Research with the goal of promoting "open-source" software for operations-research professionals. Our lofty mission was to explore an alternative means for developing, managing, and distributing OR software so that OR professionals could benefit from peer-reviewed, archived, openly-disseminated software (much in the same way we already benefit from theory). In November 2002, a milestone toward the project's long-term objectives was reached when the INFORMS board unanimously accepted a proposal to become the new host of the COIN-OR initiative. To celebrate, we're throwing a contest!

Visit http://www.coin-or.org/contest.htm to find out how you can win an IBM ThinkPad. Prizes will be awarded August 2003 at the 2003 ISMP in Copenhagen, Denmark.

Robin Lougee-Heimer
IBM TJ Watson Research Center
ph: 914-945-3032 fax: 914-945-3434
robinlh@us.ibm.com
http://www.coin-or.org

Call for Papers

Mathematical Programming Series B
Special Issue on Large-Scale Nonlinear Programming

We invite research articles on algorithms for large-scale nonlinear programming for a forthcoming special issue of Mathematical Programming, Series B. The goal is to assess relative strengths and weaknesses of various computational approaches to solving large-scale nonlinear programming problems. Examples of such approaches are first-order vs. second-order methods, direct vs. indirect solution to linear equations, methods of estimating Lagrange multipliers, trust-region vs. step-length methods, and active-set vs. interior-point methods. All participants will be asked to provide performance profiles for their implementation on a common set of AMPL models, which can be downloaded from http://mathweb.mathsci.usna.edu/faculty/bensonhy/nonlinear.

Deadline for submission of full papers: July 31, 2003.

We aim at completing a first review of all papers by December 31, 2003.

Electronic submissions in the form of unencoded postscript files are encouraged. Instructions for authors submitting to Mathematical Programming can be found at http://link.springer.de/link/service/journals/10107/instr.htm. All submissions will be refereed according to the usual standards of Mathematical Programming.

Further information about this issue will appear at http://www.princeton.edu/~rvdb/MpbNlpIssue.html or can be obtained from the guest editors for this volume.

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3rd Annual McMaster Optimization Conference: Theory and Applications

(MOPTA 03)
July 30 - August 1, 2003,
McMaster University
Hamilton, Ontario, Canada
http://www.cas.mcmaster.ca/~mopta

The 3rd annual McMaster Optimization Conference (MOPTA 03) will be held at the campus of McMaster University. It will be hosted by the Advanced Optimization Lab at the Department of Computing and Software and it is co-sponsored by the Fields Institute and MITACS.

SCOPE

The conference aims to bring together a diverse group of people from both discrete and continuous optimization, working on both theoretical and applied aspects. We aim to bring together researchers from both the theoretical and applied communities who do not usually get the chance to interact in the framework of a medium-scale event.

Distinguished researchers will give one-hour long invited talks on topics of wide interest. Invited speakers include:

Laurent El Ghaoui,
University of California, Berkeley, CA
Lisa K. Fleischer,
Carnegie Mellon University, Pittsburg, PA
Minyue Fu,
University of Newcastle, NSW, Australia
Masakazu Kojima,
Tokyo Institute of Technology, Tokyo, Japan
George Nemhauser,
Georgia Institute of Technology, Atlanta, GA
Arkadi Nemrovski,
TECHNION, Haifa, Israel
Stratos Pistikopoulos,
Imperial College, London, UK
Margaret H. Wright,
Courant Institute, New York University, NY

CONTRIBUTED TALKS

Each accepted paper will be allotted a 25 minute talk. Authors wishing to speak should submit an abstract via the conference Web page in ASCII or LaTex source, to terlaky@mcmaster.ca by April 30, 2003. Please use "MOPTA 03" in the email subject line. Notification of acceptance / Program available: May 31, 2003. Deadline for early registration: June 30, 2003.

On behalf of the Organizing Committee
Tamás Terlaky, terlaky@mcmaster.ca (Chair, McMaster University)

Further information is available at
http://www.cas.mcmaster.ca/~mopta/

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mindsharpener

We invite OPTIMA readers to submit solutions to the problems to Robert Bosch (bobb@cs.oberlin.edu). The most attractive solutions will be presented in a forthcoming issue.

Slither Link

Robert A. Bosch
December 5, 2002

In a *slither link* puzzle, the goal is to find a cycle that consists of horizontal and vertical line segments and satisfies the adjacency conditions: for each square *s* and for every number *a*, if square *s* has the number *a* in it, then *s* must be adjacent to precisely *a* segments of the cycle. See Figure 1 for an example.

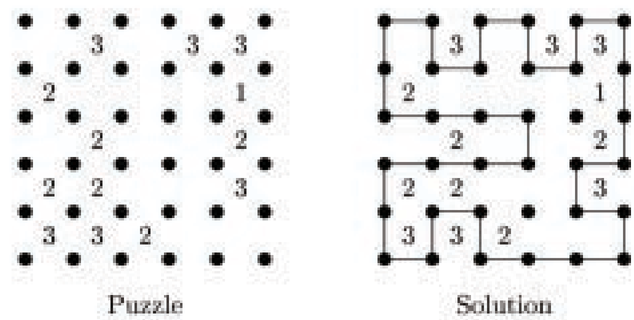


Figure 1

Slither link puzzles are available (as freeware and as shareware) for PDAs. Also, Hirofumi Fujiwara has a very nice slither link website:

http://www.pro.or.jp/~fuji/java/puzzle/numline/index-eng.html

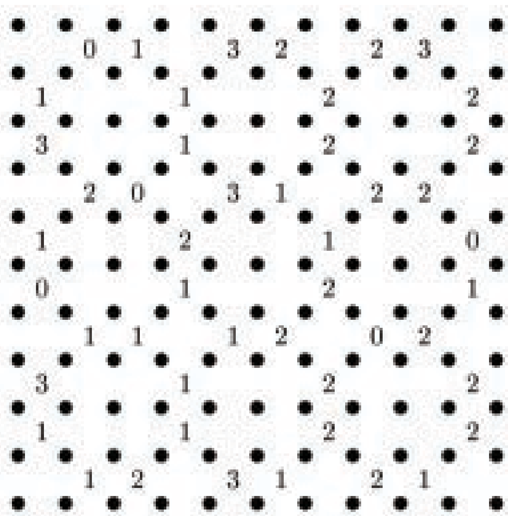


Figure 2

Problems

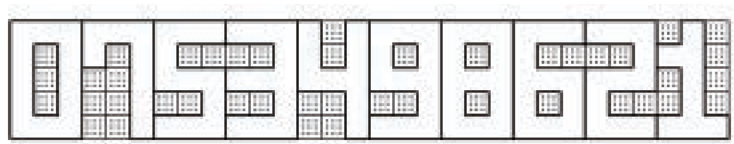
Interested readers may enjoy trying to solve the following problems:

1. Devise an integer programming formulation or a constraint programming formulation for solving slither link puzzles.

2. Solve the slither link puzzle displayed in Figure 2. This puzzle was devised by Hirofumi Fujiwara. It is the most difficult 10 x 10 puzzle at his site.

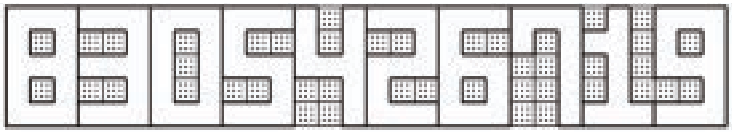
Digit Tiles Revisited

The previous installment of *Mindsharpener* concerned with arranging digit tiles. Figures 3 and 4 display the maximum value and minimum value arrangements of the tiles on a 5 x 30 board. (Recall that to compute the value of an arrangement, we add up, over all digits *d*, *d* times the number of white squares touched by the white squares of digit *d*.



$0{\cdot}2 + 7{\cdot}6 + 5{\cdot}7 + 3{\cdot}6 + 4{\cdot}7 + 9{\cdot}9 + 8{\cdot}10 + 6{\cdot}9 + 2{\cdot}6 + 1{\cdot}2 = 352$

Figure 3



$8{\cdot}3 + 3{\cdot}8 + 0{\cdot}9 + 5{\cdot}6 + 4{\cdot}6 + 2{\cdot}8 + 6{\cdot}5 + 7{\cdot}3 + 1{\cdot}3 + 9{\cdot}1 = 181$

Figure 4

One way to obtain these solutions is to model the problem as an asymmetric TSP. There are 11 cities. Cities 0 through 9 correspond to the ten digit tiles, and city 10 corresponds to a blank “dummy” tile. Let value [t1,t2] equal the contribution to total value that comes from placing digit tile t_1 just to the left of digit tile t_2. (For example, value[7,1] = (7+1)*2 = 16.) Let `x[t1,t2]` equal 1 if digit tile t_1 is placed just to the left of digit tile t_2, and 0 if not. Then, in OPL Studio, the model can be written as follows:

```
maximize sum(t1 in 0..10, t2 in 0..10) value[t1,t2]*x[t1,t2]
subject to {
  forall (t1 in 0..10) sum (t2 in 0..10) x[t1,t2] = 1;
  forall (t2 in 0..10) sum (t1 in 0..10) x[t1,t2] = 1;
  forall (t in 0..10) x[t,t] = 0;
  forall (t1, t2 in 0..10: t1<>t2) x[t1,t2] + x[t2,t1] <= 1;
};
```

For the maximization problem, no additional subtour elimination constraints were needed (in addition to the 2-city ones). For the minimization problem, only one additional subtour elimination constraint was needed.

Figures 5 and 6 display conjectured-to-be maximum value and conjectured-to-be minimum value arrangements on an unrestricted board. The Figure 5 arrangement was obtained by solving the following OPL Studio constraint programming formulation to optimality:

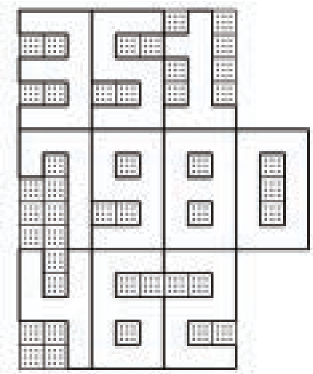
```
maximize sum(i in 1..3, j in 1..3) hvalue[x[i,j],x[i,j+1]]
      + sum(i in 1..2, j in 1..4) vvalue[x[i,j],x[i+1,j]]
subject to{
      forall(t in 0..9) sum(i in 1..3, j in 1..4) (x[i,j] = t) = 1;
};
```

The variable `x[i,j]` equals the number of the digit tile that is placed in the *i*th row and *j*th column of the board (which has three rows and four columns). Instead of `value[t1,t2]`, we have `hvalue[t1,t2]`, the contribution to total value that comes from placing digit tile t_1 just to the left of digit tile t_2, and `vvalue[t1,t2]`, the contribution to total value that comes from placing t_1 right above t_2. Note that the variables appear as subscripts in the objective function. At first glance, the constraints look wrong---each one contains two equals signs! But they make sure that each digit tile is placed exactly once. They do this by counting the total number of times that the `x[i,j]`'s equal t, and then asserting that the total must equal one.

The Figure 6 arrangement was obtained by solving a similar OPL Studio constraint programming formulation to optimality:

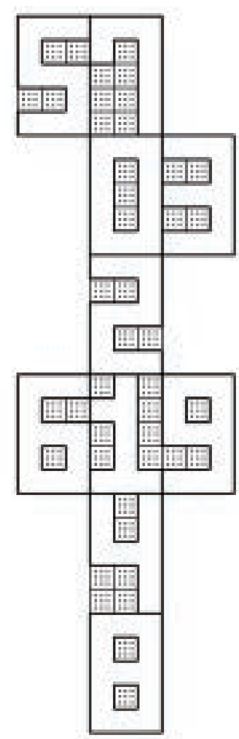
```
minimize sum(i in 1..6, j in 1..2) hvalue[x[i,j],x[i,j+1]]
      + sum(i in 1..5, j in 1..3) vvalue[x[i,j],x[i+1,j]]
subject to {
   forall(t in 0..9) sum(i in 1..6, j in 1..3) (x[i,j] = t) = 1;
   sum(i in 1..6) (x[i,2] = 10) = 0;
};
```

The last constraint ensures that the middle column of the arrangement---here, it was assumed that the board has six rows and three columns---does not contain any copies of tile 10 (the dummy tile).



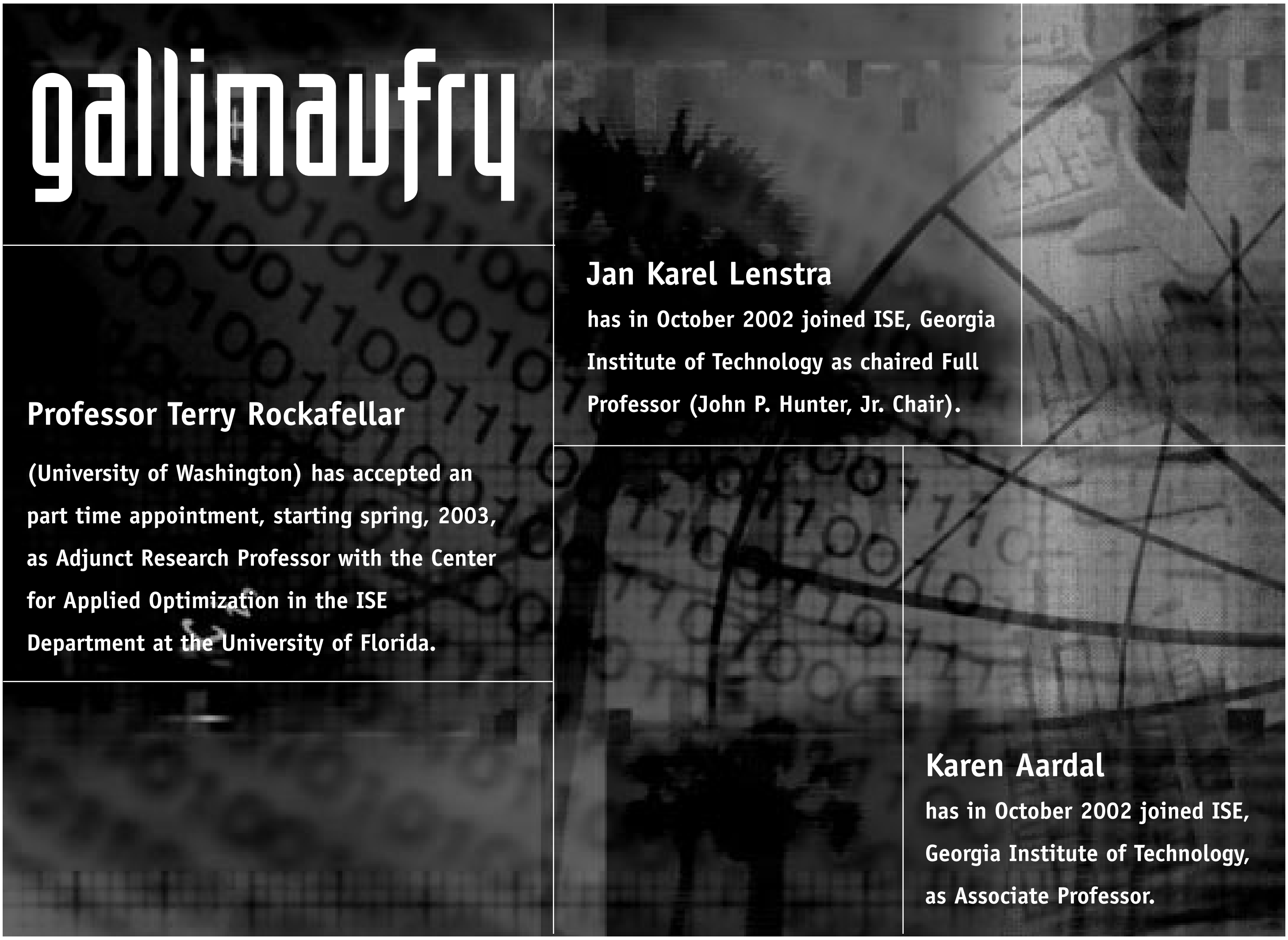
$3{\cdot}7 + 5{\cdot}8 + 1{\cdot}4$
$+ 7{\cdot}8 + 9{\cdot}15 + 8{\cdot}16 + 0{\cdot}5$
$+ 4{\cdot}6 + 6{\cdot}12 + 2{\cdot}7 = 494$

Figure 5



$5{\cdot}1 + 7{\cdot}2$
$+ 0{\cdot}7 + 3{\cdot}3$
$+ 2{\cdot}4$
$+ 6{\cdot}1 + 1{\cdot}5 + 9{\cdot}1$
$+ 4{\cdot}3$
$+ 8{\cdot}1 = 76$

Figure 6



gallimaufry

Professor Terry Rockafellar

(University of Washington) has accepted an part time appointment, starting spring, 2003, as Adjunct Research Professor with the Center for Applied Optimization in the ISE Department at the University of Florida.

Jan Karel Lenstra

has in October 2002 joined ISE, Georgia Institute of Technology as chaired Full Professor (John P. Hunter, Jr. Chair).

Karen Aardal

has in October 2002 joined ISE, Georgia Institute of Technology, as Associate Professor.

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