MITACS LETTER OF INTENT

New Interior Point Methods and Software for
Convex Conic-Linear Optimization and
Their Application to Solve VLSI Circuit Layout Problems
Project Leader: Tamás Terlaky (NSERC Pin: 9319)

1 Description of project

RESEARCH TO BE ACCOMPLISHED:

Interior Point Methods (IPMs): IPMs [2] for Linear Optimization (LO) have gained extraordinary interest as an alternative to the, by now, classical simplex methods. This development opened the way to solve very large scale linear optimization problems in a size that was even not dreamed over fifteen years ago. By now, IPMs have a tremendous impact on many other areas and applications of optimization.

Recently a new framework of IPMs based on the novel concept of Self-Regular functions were introduced by J. Peng, C. Roos and T. Terlaky [1]. This framework not only presents a unified novel framework of IPMs for LO, but it allows to be generalized to more general Conic-Linear Optimization (CLO) problems such as linear semi-definite and second-order conic optimization.

Some of the appealing properties of the new approach:
1) unified analysis of small and large update IPMs;
2) improved complexity of large update large neighborhood IPMs;
3) narrowing the gap between the practice and theory of IPMs.

In this project we focus on:

- Extending the theory of Self-Regular functions to new areas, including various classes of conic-linear optimization problems;
- Exploring the possibility of using predictor-corrector methods in the frame of Self-Regular functions and implementing variants of the new IPMs for different classes of conic-LO problems;
- Banchmarking and exploring the power of the new IPMs when solving large scale LO problems.

Convex Optimization for VLSI Design: In the last six years, the investigators (along with their students and colleagues) have looked at three major overlapping research areas (see e.g. [3]:
(i) *Advanced Techniques in Graph Partitioning and Applications*,
(ii) *IPMs for Solving VLSI Circuit Layout Problems*
(iii) *Semidefinite optimization (SDO) relaxations.*

During this period, we have been able to formulate, develop and integrate the underlying mathematical models and optimization techniques that represent the design problems in several engineering research areas. A large part of the investigation into the *related areas* of VLSI circuit layout has allowed us to develop the underlying heuristics to solve the resulting NP-hard problems. Moreover, we can assess the quality of the solutions generated by these heuristic techniques; that is, *bounds* on the global optimal solutions have been developed.

We will review the research areas, modeling and solution techniques that have been developed to solve the outlined problems. We outline new directions that we plan to pursue in the next five years in the areas of convex optimization (including the new IPMs), research on SDO and applications, advanced search techniques and their *joint application* to VLSI circuit layout.

A major direction of our research over the next five years is aimed at the integration of IPMs that are used to find relative placements (possibly overlapping) and global routings with the advanced search techniques that are used to find non overlapping placements and final detailed routings. The last 10 years have seen tremendous improvement in need to solve larger combinatorial problems that are inherent in circuit/computer chip fabrication. This has coincided with a revolution in the theory behind optimization and in the ability to solve large scale optimization problems.

METHODOLOGY AND MATHEMATICAL TECHNIQUES INVOLVED:

In the past 15 years IPMs drive the research for more efficient algorithms to solve optimization problems. This research uses and contributes to duality theory, complexity theory, numerical linear algebra, asymptotic, local and global convergence analysis, numerical stability analysis, analysis of matrix functions. SDO and semidefinite relaxations of VLSI circuit layout problems, especially with quality warranty for the approximation results require various skills, among others deep understanding of matrix algebra, graph theory and combinatorial optimization,

RELEVANCE TO NONACADEMIC WORLD:

High performance algorithms and software to solve linear and conic-linear optimization problems have tremendous impact in today's competitive economy. Huge optimization problems arise in telecommunication and information technology, production planning, chip design etc. These application areas cry out for more powerful algorithms and efficient software.

The importance of the VLSI layout problems is evident for everyone. Moreover, contributions to the solutions of the related NP-hard problems contributes to the solution of other hard combinatorial problems, such as crew scheduling, frequency assignment in telecommunications etc.

References

[1] J. Peng, C. Roos, and T. Terlaky. Self-regular Proximities and New Search Directions for Linear and Semidefinite Optimization. (Submitted to *Mathematical Programming*), 2000.

[2] C. Roos, T. Terlaky, J.-Ph. Vial. *Theory and Algorithms for Linear Optimization – An Interior Point Approach*, John Wiley & Sons, London, England (1997).

[3] Zhao, Q., Semidefinite Programming and its Applications, PhD Thesis, Supervisors A. Vannelli and H. Wolkowicz, 1996.

2 Project Leader and Participants

For details on background and funding see the participants NSERC Form 100. The relevant form for the project leader is enclosed.

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Current funding: yearly $39,726.- NSERC Research grant.

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Current funding: yearly $24,00.- NSERC Research grant; $22,500.- Workshop funding in 2001.

Team Expertise The four applicants have long standing expertise in developing highly efficient optimization algorithms, developing and analyzing optimization models for various applications. The team has an ideal composition. Vannelli's expertise on VLSI design optimization combined with Wolkowicz's and Terlaky's and Peng's expertise in combinatorial and continuous optimization, IPMs and SDO ensures the successful completion of the project.

Detailed references can be found in Section A of the respective forms 100 and/or by using the URLS/web pages of the respective co-investigators.

3 Industrial Collaborations

IBM is the main industrial partner. IBM Canada, the Center of Advanced Studies (Robert F. Enenkel, Joe Wigglesworth) in cooperation with the OSL team László Ladányi, Katya Scheinberg) of IBM's Thomas Wattson Research Lab has already contributed by awarding a Faculty Partnership Award and a SUR grant (total value $107,000.-) to facilitate the algorithmic and implementation research on novel IPMs. . Moreover, Andrew R. Conn (IBM Wattson) has recently applied convex optimization for VLSI design and expressed his interest to collaborate in this project in conjunction with IBM Canada.

We are working actively to locate further industrial partners, specially in application areas. Recently, Material and Manufacturing Ontario offered to locate further industrial partners.

4 Potential Interactions with Current MITACS Projects

There is a potential for possible interaction with the following MITACS projects:
Complex Adaptive Networks for Computing and Communication (IT);
Column Generation Optimizer and Applications (Business);
Mathematical Modelling and Scientific Computation (Manufacturing).

In these projects large scale, frequently large scale combinatorial, optimization problems are examined. Those can be used to extend the test-bed of our novel IPMs; IPMs can be adapted to the special structure of those problem classes and specially the scientific computation project possibly can support our implementation activities. On the other hand, the modelling and algorithmic technologies to be developed in the project are potentially applicable in the above mentioned MITACS projects as well.

5 Budget

The yearly budget of the project is $205,000.-

- Support of eight graduate students yearly. Four with full support ($15000.- per year) and four with partial support ($10,000.- per year) from this budget: $80,000.- per year.
- Support of two post doctoral fellows at the rate of $36,000.- per year: $72,000.- per year.
- Technical assistance is needed to purchase on a regular base from McMaster's CIS to maintain the IBM-RS6000 workstation cluster, install new software and additional hardware: $5,000.- per year.
- Two high-end personal computer and accessories: $8,000.- per year.
- Purchase of software and supplies: $10,000.- per year.
- Conferences, travel: $10,000.- per year.

6 Referes

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