DIMACS Center
Rutgers University

DIMACS/LAMSADE PARTNERSHIP on Computer Science and Decision Theory: Applications of Notions of Consensus

Annual Report

October 2005

Ia. Participants in the program

Senior Leadership:

PI: Fred Roberts, DIMACS
Co-PI: Alexis Tsoukiàs, LAMSADE

Endre Boros, Rutgers University
Peter Fishburn, AT&T Labs – Research
Mel Janowitz, DIMACS
Brenda Latka, DIMACS
David Madigan, Rutgers University
S. Muthukrishnan, Rutgers University
Denis Bouyssou, LAMSADE
Vincent Mousseau, LAMSADE
Bernard Roy, LAMSADE
Daniel Vanderpooten, LAMSADE

Graduate Students:

Bruno Escoffier, LAMSADE
Meltem Öztürk, LAMSADE
Tiberius Bonates, Rutgers University
Marcin Kominski, Rutgers University
Milanic Martin, Rutgers University
Nilay Nogan, Rutgers University
Gabor Rudolf, Rutgers University

DIMACS/LAMSADE Workshop on Computer Science and Decision Theory

Organizers:
Mel Janowitz, DIMACS
Fred Roberts, DIMACS
Alexis Tsoukiàs, LAMSADE

Local Organizing Committee:
Denis Bouyssou, CNRS-Lamsade, Universite Paris Dauphine
Bruno Escoffier, CNRS-Lamsade, Universite Paris Dauphine
Meltem Öztürk, CNRS-Lamsade, Universite Paris Dauphine

Ib. Participating Organizations

Telcordia Technologies: Collaborative Research

Partner organization of DIMACS. Individuals from the organization participated in the program planning.

AT&T Labs - Research: Collaborative Research
Partner organization of DIMACS. Individuals from the organization participated in the program planning and research.

NEC Laboratories America: Collaborative Research
Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Lucent Technologies, Bell Labs: Collaborative Research
Partner organization of DIMACS. Individuals from the organization participated in the program planning and research.

Princeton University: Collaborative Research
Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Avaya Labs: Collaborative Research
Partner organization of DIMACS. Individuals from the organization participated in the program planning.

HP Labs: Collaborative Research
Partner organization of DIMACS. Individuals from the organization participated in the program planning.

IBM Research: Collaborative Research
Partner organization of DIMACS. Individuals from the organization participated in the program planning.

Microsoft Research: Collaborative Research
Partner organization of DIMACS. Individuals from the organization participated in the program planning and research.

LAMSADE (Laboratoire d'Analyse et Modélisation de Systèmes pour l'Aide à la Décision), Université Paris Dauphine
Partner organization of DIMACS. Individuals from the organization participated in the program planning and research.

The French National Center for Scientific Research (CNRS)
Funded the French site.

1c. Other Collaborators

The project involves scientists from numerous institutions in numerous countries. The resulting collaborations also involve individuals from many institutions in many countries.

II. Project Activities

Two leading research centers, DIMACS (the Center for Discrete Mathematics and Theoretical Computer Science, based at Rutgers University), and LAMSADE (the Laboratoire d'Analyse et Modélisation de Systèmes pour l'Aide à la Décision, based at Université Paris IX - Dauphine) have initiated an international collaboration organized around modern computer science applications of methods developed by decision theorists, in particular methods involving consensus and associated order relations. The project is exploring the connections between computer science and decision theory, developing new decision-theory-based methodologies relevant to the scope of modern CS problems, and investigating their applications to problems of computer science and also to problems of the social sciences that could benefit from new ideas and techniques. The project has featured exchange visits of graduate students and junior researchers and a workshop that introduced a broader community to the topics of the collaboration.

The project emphasizes computer science problems that arise in meta-search (combining the outputs of several search engines); collaborative filtering (using learning algorithms to make recommendations for books, movies, etc.); finding centrally located items in large databases, in particular biological ones and ones that arise in homeland security applications; combining ratings of software or hardware; in distributed computing when some processors fail and we seek to reach “agreement” among the remaining processors; finding efficient ways to compute consensus functions; and learning about individuals' preferences as they are revealed gradually in situations of economic cooperation and competition using the Internet.

The project is already having impact well beyond the small number of people participating in the exchange visits through a center-to-center exchange that involves a large number of scientists associated with the two centers in the related scientific discussions and interchanges. Moreover, the impact has been broadened through the workshop that introduced many of those both associated with and outside the two collaborating centers to this new field. The results should be broadly useful in emerging information technology applications, in areas of economics and political science where methods of decision theory have traditionally been applied, and in new areas of application of decision theory such as to problems of epidemiology and bio-terrorism.

There was an exchange of four graduate students during this year of the project. Bruno Escoffier and Meltem Öztürk visited DIMACS during the period November 2004 to January 2005. Tiberius Bonates and Marcin Kominski visited LAMSADE during the period May 2005 to June 2005. This has already resulted in the establishment of international Ph.D committees. Fred Roberts, PI, Rutgers, will server on Meltem Öztürk’s committee; Peter Hammer, Rutgers, will serve on Bruno Escoffier’s committee; Alexis Tsoukiàs, Co-PI, LAMSADE, will serve on Tiberius Bonates’ committee. Moreover, Escoffier has already prepared two joint papers, one with Hammer on polynomial approximation of the quadratic set covering problem and one with James Abello, DIMACS, on applying consistent sets to voting. Details of these exchanges are

given in the Project Training/Development section. Rutgers students, Milanic Martin, Nilay Nogan, and Gabor Rudolf are scheduled to visit LAMSADE in 2006.

Alexis Tsoukiàs visited DIMACS in October 2005 to begin the collaboration with the PhD students who will be visiting LAMSADE in 2006, coordinate with Fred Roberts on the future activities of the program, and work with Tibrius Bonates on his Ph.D thesis as well as their joint paper on "Logical Analysis of Data and Rough Sets Theory."

During the first year of the project the DIMACS - LAMSADE Workshop on Computer Science and Decision Theory was held October 27 – 29, 2004, at the Université Paris Dauphine. The workshop focused on modern computer science applications of methods developed by decision theorists, in particular methods involving consensus and associated order relations. The broad outlines concern connections between computer science and decision theory, development of new decision-theory based methodologies relevant to the scope of modern computer science problems, and investigation of their applications to problems of computer science and also to problems of the social sciences which could benefit from new ideas and techniques. The proceedings of the workshop were published as *Annales du LAMSADE No 3*, Universite Paris Dauphine, October, 2004, and was edited by the graduate students Meltem Öztürk and Bruno Escoffier. As a result of the workshop there will be a special issue of *Annals of Operations Research* on decision theory and computer science, edited by Fred Roberts (PI) and Alexis Tsoukiàs (Co-PI). This special issue is described in detail below.

III. Project Findings

Applying four valued logics to decision models

As a result of her DIMACS visit, jointly sponsored by DIMACS and its partner LAMSADE at the University of Paris IX, graduate student Meltem Öztürk completed work in modeling continuous positive and negative reasons in decision aiding. A language enabling one to explicitly take into account such reasons is Belnap's logic and the four valued logics derived from it. Öztürk explored the interpretation of a continuous extension of a four-valued logic as a necessity degree (in possibility theory). She found that "sub-normalized" necessity measures need to be considered in order to take full advantage of the four values. Four-valued logics are the natural logical frame for such an approach.

Modeling uncertainty in information

In decision analysis, models are constructed to represent the set of alternatives, the preferences of the decision maker, and the definition of rationality. Models need to account for imprecise and inconsistent information and decision makers who hesitate or are indifferent between preferences. Öztürk constructed models where the uncertainty of information is represented by intervals. In such models, some extended preference structures such as PQI interval orders are used to deal with the complex nature of decision maker preferences. Such orders introduce a third relation, weak preference, which models the decision maker's hesitation or indifference.

Polynomial approximation techniques for separating data into classes

Graduate student Bruno Escoffier was another visitor to DIMACS jointly sponsored by DIMACS and LAMSADE. Escoffier collaborated with Peter Hammer, RUTCOR, on approximating the Quadratic Set Covering Problem. Their main motivation came from Logical Analysis of Data, which is a methodology, based on a logical analysis, to detect structural information about datasets. A medical example is typical of the type of application of this research. You want to determine if an illness can be related to some other medical parameters of patients, such as finding a correlation between heart attack and cholesterol for instance. To analyze this, you collect data on these parameters for both ill and healthy people. More formally, each person gives data on several criteria (weight, cholesterol,...) and is represented as a point in p dimensional space. You have a set of positive points (ill people) and a set of negative points (healthy people). A first step in the analysis of this data produces a collection of positive and negative patterns. A positive (respectively, negative) pattern is a hypercube in p dimensional space that contains no negative points (respectively, no positive points). This collection is such that every point is covered. From a medical point of view, you would like to find a sub-collection of patterns such that: every point is covered and the volume of intersections between positive and negative patterns is as small as possible. This problem is NP-hard but several heuristic techniques have been used to solve it. Escoffier and Hammer showed that polynomial techniques can give good approximations in certain cases.

Applying consistent sets to voting

Escoffier also collaborated with James Abello, DIMACS, on a problem in social choice theory. Given a set of voters and a set of candidates in an election, voters' preferences can be represented as permutations. Of interest are consistent sets of permutations, that is, sets with no 3 x 3 embedded Latin Square. This ensures that the majority rule is transitive. Escoffier and Abello studied maximal consistent sets and the properties of such sets and related this to the complexity of some voting procedures that are in general NP hard, for example Caroll's voting system. Escoffier and Abello first met and began collaborating at the DIMACS/LAMSADE Workshop on Computer Science and Decision Theory, October 2004.

Online algorithms for covering problems

One of the projects of Tiberius Bonates, Rutgers graduate student, Pierre Tolla, LAMSADE, and Dominique Quadri, University of Paris graduate student, was to find online algorithms with non-trivial competitive ratios for the weighted versions of problems such as set covering and vertex covering and to obtain differential approximation results on the online versions of unweighted set covering and vertex covering problems, either under the existing online models or under new models. Bonates, Tolla, and Quadri found a way of adapting an existing algorithm to the solution of the weighted vertex and set covering problems under a slightly different online model than the one used for the unweighted case. The resulting algorithm is efficient both in terms of memory usage and number of operations and has a non-trivial competitive ratio, while the underlying online model is still realistic.

A Lagrangean relaxation algorithm for a quadratic knapsack problem

Bonates, Tolla, and Quadri investigated the application of Lagrangean relaxation to a quadratic separable integer problem with knapsack constraints. They applied a new Lagrangean decomposition approach to this problem. This idea is now being implemented and they expect to have the first numerical results soon. This work was started while Bonates visited LAMSADE and continued during a visit by Quadri to the United States in August 2005.

A new approach to the maximum cut problem

While Marcin Kaminski, Rutgers graduate student, was at LAMSADE he worked with Vangelis Paschos and Federico Della Croce, LAMSADE, on algorithmic aspects of the maximum cut problem. They studied exact algorithms for this problem and developed a new approach. A cut in an undirected simple graph is a partition of the vertex set into two disjoint subsets. Given a function that assigns weights to the edges of a graph, the weight of a cut is the sum of weights of the edges that have one endpoint in each subset of the cut. The maximum cut problem is to find a cut in the graph that has maximum weight. Known to be NP-hard for a long time, the problem received attention mainly in the context of approximation algorithms. Very little is known about classes of graphs where the problem can be solved in polynomial time, and not much research has been done on exact algorithms for maximum cut. Developing a new technique, Kaminski, Paschos, and Della Croce obtained an algorithmic scheme solving the maximum cut problem for graphs with bounded maximum degree Δ. The algorithm runs in time poly(n) * $O(2^{(1-2/\Delta)n})$ and uses polynomial space (where n is the number of vertices in the graph). This improves the previously known bounds for $\Delta \geq 8$. The same algorithmic technique applied to general graphs yields an algorithm running in time poly(n) * $O(2^{mn/(m+n)})$ and using polynomial space. This improves previously known bounds for $3 < m < 7n/5$ (where m is the number of edges in the graph).

IV. Project Training/Development

Bruno Escoffier and Meltem Öztürk visited DIMACS in November 2004, December 2004 and January 2005. Bruno Escoffier is a PhD student at Lamsade, Université Paris Dauphine. His research deals with complexity theory, combinatorial optimization and, more specifically, polynomial approximation of optimization problems. Meltem Öztürk is also a PhD student at Université Paris Dauphine. Her research is on the use of non-classical logics in preference modelling.

Rutgers graduate students Tiberius Bonates and Marcin Kaminski visited LAMSADE in May and June 2005. Marcin Kaminski's research interests are combinatorics, graph theory and their algorithmic applications. He has worked on exact graph coloring algorithms and related problems (maximal independent sets, maximal bipartite subgraphs). His other interests are in poset theory, probabilistic algorithms, and combinatorial optimization. Tiberius Bonates works on optimization and combinatorial methods applied to machine learning, mainly on boolean problems arising in the context of the classification method called Logical Analysis of Data. He

has developed algorithms to solve such problems using integer linear programming and heuristics.

Rutgers students, Milanic Martin, Nilay Nogan, and Gabor Rudolf are scheduled to visit LAMSADE in 2006.

The impact of the DIMACS visit on the graduate students from LAMSADE can best be expressed in their own words.

"During my stay at DIMACS, I met new people, had new contacts with different researchers in different fields (mathematicians from DIMACS, computer scientists from RUTCOR, industrial engineers from industrial department). These contacts were very interesting in the sense that I learned new things, dicovered new domains, had new ideas, etc. I met postdocs, graduate students, senior researchers. My contact with postdocs and graduate students helped me to better understand the university system of the United State, how the research is doing here etc. I had different contact with senior researchers. In Dimacs, I found different articles on my research domain (for example, I am working on non-classical logics, especially on four-valued logic and I found interesting works on this subject thanks to Ilya Muhnick) and heard about new ideas that are different from the ones used in Europe (for example, I discovered different use of lattices). Some talks with another visitor Vadim Mottl helped me to learn more about data mining. My meetings with Doctor Hammer were very fruitful for me also. His papers on country risk rating are really related to my domain and the subject is very interesting. I reserved a section on this subject on a paper that I am writing with my advisor for a special issue of International Journal of Intelligent Systems. I met also some researchers of industrial engineering department, especially Doctor Altiok since I am industrial engineer also. I hope that I can continue to have some contact with this department for future research.

The topic of my PhD thesis is on preference modelling where we use non-classical logics for our models. During my visit I learned some other approaches like the use of graphs etc., which I want to introduce in my models. I would like to continue to work on country risk rating with Doctor Hammer. As a result of our discussion, we realized that there are a variety of new things to do on the subject. I would be ready and glad to do some joint work with DIMACS and Rutcor as a visiting researcher or postdoc during a much longer time (6 months, one year). Thanks to my visit I discovered new approaches for preference modelling. My PhD topic is very theoretical and I had the opportunity to see some applications in classification problems of some models that are similar to mine. My discussions with researchers were much more related to my field of specialization. But I realized that some methods that we use for preference modelling could be also used in different fields, such as data mining."
Meltem Öztürk, LAMSADE

"My stay at DIMACS has been a great opportunity to meet people and to start collaborations with them. These collaborations will continue, they represent new directions in my work (see below). The research done here constitutes a great step in the progress of my PhD thesis. This stay was also very fruitful as it was my first stay in a foreign research lab. I could see how research is organized, how people work, what are the differences and similarities with the situation in France. I made some contacts with several people, mainly at DIMACS and at

RUTCOR. I especially met two PhD candidates, Tiberius Bonates and Marcin Kaminski, who will come to my laboratory in France in spring, as part of the same DIMACS/LAMSADE partnership. I also worked with senior researchers, James Abello from DIMACS and Peter Hammer from RUTCOR. In both cases, these works were productive, and are still on going, hence these collaborations should continue. As a matter of fact, another stay is about to be planned; I may come back to RUTGERS (for a week) in spring. I also hope to work with the two PhD. candidates who will visit my lab, since their research areas are strongly related to mine.

My visit was part of a partnership between LAMSADE (my lab in France), and DIMACS. This partnership is focused on connections between computer science and decision theory. The research area in my PhD concerns computer science, and thanks to this partnership (more especially my visit here, but also a workshop scheduled in Paris in October 2004) I learnt a lot about social choice and decision theory, and began to work on these topics. There are a lot of interesting connections, and this must constitute an interesting future direction in my work. Of course, the first step is to continue the collaborations started here during my stay.

My collaboration with James Abello is related to but is not directly in my research area. More precisely, this gave me the opportunity to work on social choice theory, and the relations between my area (complexity theory) and social theory must be a very fertile research direction. Moreover, the work with Peter Hammer was especially interesting to me as it is a direct application of my research field to a concrete problem (Logical Analysis of Data).

I also went to a lot of seminaries, on many different topics, mainly at DIMACS but also at Institute for Advanced Studies (Princeton), which is always a very rich and interesting experience."
Bruno Escoffier, LAMSADE

The LAMSADE visit had similar impact on the graduate students from Rutgers.

"The LAMSADE visit gave me the opportunity to establish contact with researchers working on topics closely related to my research interests at the time, e.g. combinatorial optimization, mathematical programming, and also with researchers that work in somewhat unrelated areas, such as approximation algorithms and online algorithms.

Alexis Tsoukiàs is professor at LAMSADE who works on applications of rough sets theory to machine learning, and demonstrated strong interest in combining the ideas of rough sets with those present in Logical Analysis of Data, which has been the main focus of my research for at least one year. We are discussing such an idea with Jose Figueira, an associate researcher at LAMSADE. Alexis' visit to DIMACS in October, 2005 will be very helpful for advancing in this direction.

Vangelis Paschos is another professor at LAMSADE, who introduced me to the topic of online algorithms for combinatorial optimization problems such as vertex covering and weighted set covering. We discussed some research directions that can lead to new algorithms and new online models for such problems.

I also worked with Dominique Quadri, who is currently a doctoral student at LAMSADE. She works under the supervision of Pierre Tolla and Eric Soutif and we started a study on the solution of a separable integer quadratic problem with knapsack constraints. Although this is a topic on which I had a previous interest, I had never actually worked on it and I am extremely interested about the possible outcome of this research.

The LAMSADE visit was remarkably beneficial to me, as it opened my view to different topics of study, broadening the horizons of my research, and as it introduced me to competent researchers with whom I plan to continue collaborating in the future."
Tiberius Bonates, RUTCOR

"I find my visit to LAMSADE very successful. Working with researchers at LAMSADE, I was introduced to algorithmic problems that I had not studied before and together we were able to design new, fast algorithms. There is a lot of room for improvement and I am planning to continue working with them in that field.

At LAMSADE I worked with Vangelis Paschos and Federico Della Croce on algorithmic aspects of the maximum cut problem. We studied exact algorithms for this problem and developed a technique that seems to be a new approach. Visiting LAMSADE was a great opportunity for me and I am sure I will also benefit from the visit in future. I am planning to continue the work with Prof. Paschos and Prof. Della Croce."
Marcin Kaminski, RUTCOR

V. Outreach Activities

Discussions between DIMACS and LAMSADE have led to the beginning of collaborations on the topic of IT support for government decision-making and public participation. Topics of interest include information sharing among government agencies, introducing automatic decision-making in government action, and intelligent information retrieval.

VI. Papers/Books/Internet

Books

B. Escoffier and M. Öztürk (eds.), *Annales du LAMSADE No 3*, Universite Paris Dauphine, October, 2004.

F. Roberts and A. Tsoukiàs (eds.), *Annals of Operations Research Special Issue on Decision Theory and Computer Science*, in preparation.

Many modern computer science problems involve issues that decision theorists have addressed for years, in particular issues involving preferences, consensus and associated order relations. Applications of methods of decision theory to problems of computer science place great strain on these methods due to the sheer size of the problems addressed, limitations on information possessed, and sequential nature of repeated applications. Hence, there is great need to develop a

new generation of methods to satisfy these requirements of CS applications. In turn, the new methods will provide powerful tools of use in problems of the social sciences (economics, political science, etc.) to which methods of decision theory have traditionally been applied as well as to newer areas of application of decision theory such as in policy-making concerning emerging diseases or bio-terrorism. The special issue aims to explore the connections between computer science and decision theory, present the state of the art in this fascinating and dynamic area and attract papers at the boundary between the two communities.

The interface between their disciplines is becoming increasingly relevant for both decision theorists and computer scientists. However, there is as yet in the literature no systematic presentation of these issues. We expect this special issue of the Annals of OR to become a reference publication for this increasingly important field.

We are collecting original contributions in areas such as:
- preference elicitation and learning of preferences;
- qualitative decision theory;
- logical representations of preferences;
- AI planning, action and causality;
- preference modeling and aggregation;
- data-base querying and repair;
- data mining and knowledge extraction;
- social choice theory;
- fusion of information;
- computational intractability of consensus functions;
- applications of decision theory in computer science;
- algorithmic decision theory;
- collaborative filtering;
- meta-search.

There have been 18 submissions and we expect to publish a volume of about 250 pages. We expect to be able to deliver the issue to the editor by June 2006.

Papers

T. Bonates and A. Tsoukiàs, “Logical Analysis of Data and rough sets theory,” in preparation.

F.D. Croce, M. Kaminski, and V. Paschos, “An exact algorithm for MAX-CUT in sparse graphs,” *Operations Research Letters*, submitted.

B. Escoffier and J. Abello, “Consistent sets of permutations and voting procedures,” in preparation.

B. Escoffier and P.L. Hammer, “Polynomial approximation of the quadratic set covering problem,” *Journal of Discrete Optimization*, submitted.

B. Escoffier and P.L. Hammer, "Approximation of the quadratic set covering problem," DIMACS Technical Report 2005-09, 2005.

M. Öztürk and A. Tsoukiàs, "Modelling continuous positive and negative reasons in decision aiding," special issue of *Decision Support System Journal*, submitted.

M. Öztürk and A. Tsoukiàs, "Bipolar preference modelling in decision: billatice approach," special issue of *International Journal of Intelligent Systems*, submitted.

M. Öztürk and A. Tsoukiàs, "Modelling continuous positive and negative reasons in decision aiding," DIMACS Technical Report 2005-03, 2005.

Talks

T. Bonates, "Optimization problems in the Logical Analysis of Data," LAMSADE, May 24, 2005.

B. Escoffier, "Polynomial approximation of NP-hard problems: the differential ratio," DIMACS Theoretical Computer Science seminar, December 13, 2004.

B. Escoffier and P.L. Hammer, "Polynomial approximation of the quadratic set covering problem," extended abstract submitted to LATIN 2006.

M. Kaminski, "3-colorability in the class of claw-free graphs," LAMSADE, May 24, 2005.

M. Öztürk, "Comparing intervals for decision aiding," DIMACS Computation and the Socio-Economic Sciences Special Seminar, November 29, 2004.

Web site

The main web site for the DIMACS/LAMSADE PARTNERSHIP on Computer Science and Decision Theory: Applications of Notions of Consensus

http://dimacs.rutgers.edu/Workshops/Lamsade/index.html

VII. Other Products

The main web sites for the workshop DIMACS/LAMSADE Workshop on Computer Science and Decision Theory

http://dimacs.rutgers.edu/Workshops/DecisionTheory/
http://l1.lamsade.dauphine.fr/dimacs/index.html

VIII. Contributions within Discipline

Probably the most important contribution of this project is the example it is setting for international collaborations among the senior and junior researchers of the United States and France in such an interdisciplinary area. The work of this project has led and will continue to lead to many of these collaborations.

IX. Contributions -- other Disciplines

This is an inherently interdisciplinary project. We expect that the connections between computer science, mathematics, statistics, decision theory, economics, psychology, etc. will continue to be brought to light during the course of this project.

X. Contributions -- Human Resource Development

This project provides support for an interchange of graduate students. This interchange is having a major impact on the research and careers of these students. The interactions that they have with other students in the institutions they visit impact the students of the hosting institution. This is documented in more detail in the section on Project Training/Development. Here are additional examples of the impact of the project. As a result of Meltem Öztürk's visit to DIMACS, Fred Roberts, PI, Rutgers, has agreed to be on her thesis committee. Öztürk will be defending her thesis in December 2005. Peter Hammer, Rutgers, will serve on Bruno Escoffier's committee. Escoffier will be defending in November 2005. Escoffier has been invited by Hammer for a return visit to Rutgers to continue their collaboration. Alexis Tsoukiàs, Co-PI, LAMSADE, will serve on Tiberius Bonates' committee.

XI. Contributions to Resources for Research and Education

XII. Contributions Beyond Science and Engineering