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Ioannis C. Demetriou
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Approximation and Optimization

Algorithms, Complexity and Applications

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Aims and Scope

Optimization has been expanding in all directions at an astonishing rate during the last few decades. New algorithmic and theoretical techniques have been developed, the diffusion into other disciplines has proceeded at a rapid pace, and our knowledge of all aspects of the field has grown even more profound. At the same time, one of the most striking trends in optimization is the constantly increasing emphasis on the interdisciplinary nature of the field. Optimization has been a basic tool in all areas of applied mathematics, engineering, medicine, economics and other sciences.

The series *Springer Optimization and Its Applications* publishes undergraduate and graduate textbooks, monographs and state-of-the-art expository works that focus on algorithms for solving optimization problems and also study applications involving such problems. Some of the topics covered include nonlinear optimization (convex and nonconvex), network flow problems, stochastic optimization, optimal control, discrete optimization, multi-objective programming, description of software packages, approximation techniques and heuristic approaches.

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Preface

This volume contains most of the invited papers that were presented at the Conference on Approximation and Optimization, held in Athens, Greece, on 29–30 June 2017.

The occasion being the 180 years celebration of the National and Kapodistrian University of Athens, the conference covered research issues in approximation and optimization by focusing on the development of algorithms, the study of their complexity, and relevant applications.

The individual papers have been written by leading experts and active researchers in their subjects. They are a mix of expository articles, surveys of new work, and applications. The topics have been drawn from approximation to discrete noisy data, data-dependent approximation, evolutionary optimization, machine learning, nonlinearly constrained optimization, optimal design of smart composites, optimization of multiband electric filters, portfolio selection, tax evasion as an optimal control problem, and the no-free-lunch theorem.

The book by content, expertise, and application areas will be useful to academics, researchers, industry experts, data science practitioners, business analysts, social sciences investigators, and graduate students.

Support for this conference came from the M.Sc. Program in Business Administration, Analytics, and Information Systems of the University of Athens and the Bank of Greece. We are grateful to our colleague Professor Yannis Stournaras, Governor of the Bank of Greece. Their support was crucial to the academic excellence of the program, to the participation from a wide range of countries, to the social activities, and to the publication of these proceedings. The conference received valuable assistance from the National and Kapodistrian University of Athens through Mrs. Katerina Skoura (Head of Administration) in the organization of the conference and staff in the Department of Economics. To all, we express our sincere thanks.

The authors of the papers deserve our editorial thanks for producing the papers so well and so promptly. Thanks are also due to the referees who were generous with their time and effort. And thanks also to Razia Amzad and the staff of Springer

for their help with publishing this book. It is a pleasure to acknowledge all of these contributions.

Athens, Greece — Ioannis C. Demetriou
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Introduction

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Abstract A brief survey is given to the papers of this volume that explore various aspects of approximation and optimization.

1 Survey

Approximation and optimization form important disciplines within mathematics that have a significant contribution to knowledge, applied knowledge, and computing. Many optimization problems occur naturally and many problems require approximation techniques to be solved. There is an explosion of methods and applications of these disciplines in recent times throughout science, engineering, technology, medicine, and social sciences.

The papers of this volume explore various aspects of approximation and optimization. Some present summaries of the state of the art in a particular subject and some others present new research results. A brief survey of the papers is given below.

Coralia Cartis, Nicholas Gould, and Philippe L. Toint in their paper *Evaluation Complexity Bounds for Smooth Constrained Nonlinear Optimization using Scaled KKT Conditions and High-order Models* consider evaluation complexity for solving convexly constrained optimization. They show that the complexity bound of $O(\epsilon^{-3/2})$ of their previous work for computing an ϵ-approximate first-order critical point can be obtained under significantly weaker assumptions. Further, they generalize this result to the case where high-order derivatives are available, the order being p say, resulting in a bound of $O(\epsilon^{-(p+1)/p})$ evaluations. Then, defining

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ϵ_P and ϵ_D to be the primal and dual accuracy thresholds, they also show that the bound of $O(\epsilon_P^{-1/2}\epsilon_D^{-3/2})$ evaluations for the general nonconvex case involving both equality and inequality constraints can be generalized to yield a bound of $O(\epsilon_P^{-1/p}\epsilon_D^{-(p+1)/p})$ evaluations under similarly weaker assumptions.

Data-dependent approximation is a new approach for the study of nonsubmodular optimization problems. It has attracted a lot of research especially in the area of social computing, where nonsubmodular combinatorial optimization problems have been recently formulated. Weili Wu, Yi Li, Panos Pardalos, and Ding-Zhu Du in their paper *Data-Dependent Approximation in Social Computing* present some theoretical results and discuss on related problems open to research.

Machine learning algorithms build efficient descriptive or predictive models to uncover relationships in the data. Multi-objective evolutionary optimization assists machine learning algorithms to optimize their hyperparameters, usually under conflicting performance objectives, and selects the best model for a prescribed task. Stamatios-Aggelos Alexandropoulos, Christos Aridas, Sotiris Kotsiantis, and Michael Vrahatis in their paper *Multi-Objective Evolutionary Optimization Algorithms for Machine Learning, a Recent Survey* consider relevant approaches for four major data mining and machine learning tasks, namely data preprocessing, classification, clustering, and association rules.

Optimization search and supervised learning are the areas that have benefited more from the concept of the no free lunch (NFL) theorem. In its rapid growth, NFL has provided new research results, which are also important in other scientific areas where the successful exploration of a search space is an essential task. Stavros Adam, Stamatios-Aggelos Alexandropoulos, Panos Pardalos, and Michael Vrahatis in their paper *No Free Lunch Theorem, a Review* survey research results in this field, reveal main issues, and expose particular points that are helpful in understanding the hypotheses, the restrictions, or even the inability of applying NFLs.

Revd. Michael Cullinan in his paper *Piecewise Convex-Concave Approximation in the Minimax Norm* presents an efficient algorithm for constructing an approximant to noisy data in order to obtain piecewise convexity/concavity with respect to the least uniform change to n data. Specifically, if q sign changes are allowed in the second order consecutive divided differences of the components of the approximant, then, own to the fact that the set of optimal vectors is connected, the least maximum change to the data is computed in only $O(qn \log n)$ operations, a remarkable result indeed. The author develops optimization techniques which obtain the solution by adjustments that depend on local information, so they avoid the disadvantage of the existence of purely local minima.

Ioannis Demetriou in his paper *A Decomposition Theorem for the Least Squares Piecewise Monotonic Data Approximation Problem* considers the least squares change to n univariate data subject to the condition that the first differences of the estimated values have at most q sign changes. The situation compared to the one in the previous paragraph where the objective function is the minimax norm is quite different, because in the least squares case the set of local minima is composed of discrete points. Hence any algorithm that uses local information will

stop at a local minimum. Here difficulties are caused by the enormous number of isolated local solutions of the optimization calculation that can occur in practice, namely $O(n^q)$. A theorem is stated that decomposes the problem into least squares monotonic approximation (case $q = 0$) problems to disjoint sets of adjacent data. The decomposition allows the development of a dynamic programming procedure that provides a highly efficient calculation of the solution in only $O(n^2 + qn \log n)$ operations. The solution to the problem is known by previous work of the author, but a proof is presented that provides necessary and sufficient conditions in a unified theorem.

The best uniform rational approximation of the sign function on two intervals was explicitly found by Zolotarëv in 1877, while half a century later this idea entered technology by Cauer's invention of low- and high-pass electrical filters. Andrei Bogatyrëv in his paper *Recent Progress in Optimization of Multiband Electrical Filters* discusses on a recently developed approach for the solution of the optimization problem that arises in the synthesis of multi-band, analogue, digital or microwave, electrical filters, based on techniques from algebraic geometry and generalizations of the Zolotarëv fraction.

Valery Kalyagin and Sergey Slashchinin in their paper *Impact of Error in Parameter Estimations on Large Scale Portfolio Optimization* examine how estimation error for means and covariance matrix of stock returns may affect the results of selected portfolios. They conducted different experiments using both real data from different stock markets and generated samples in order to compare the out-of-sample performance of the estimators and the influence of the estimation error on the portfolio selection. A new surprising phenomenon observed for large-scale portfolio optimization is that the efficiency of the obtained optimal portfolio is biased with respect to the true optimal portfolio.

The main concept of the paper *Optimal Design of Smart Composites* by Georgios Tairidis, Georgia Foutsitzi, and Georgios Stavroulakis stimulates research on the design, optimization, and control issues on smart structures. Optimal design problems related to smart composites are investigated. First, the mechanical properties of a smart composite can be tailored to meet required specifications. Beyond classical shape and layout optimization related to the layers of a composite, pointwise optimization leading to functionally graded composites or even topology optimization can be applied. Furthermore, some basic techniques regarding soft control based on fuzzy and neuro-fuzzy strategies are presented, along with optimization options and methods which can be used for the fine-tuning of the parameters of the system.

Motivated by the persistent phenomenon of tax evasion and the challenge of tax collection during economic crises, Paraskevi Papadopoulou and Dimitri Hristu-Varsakelis in their paper *Tax Evasion as an Optimal Solution to a Partially Observable Markov Decision Process* explore the behavior of a risk-neutral self-interested firm that may engage in tax evasion to maximize its profits. The firm evolves in a tax system which includes many of standard features such as audits, penalties, and occasional tax amnesties, and may be uncertain as to its tax status. They show that the dynamics of the firm can be expressed via a partially observable Markov decision process, use this model to compute the optimal behavior of the

firm, and investigate the effect of "leaks" or "pre-announcements" of any tax amnesties on tax revenues. They also compute the effect on firm behavior of any extensions of the statute of limitations within which the firm's tax filings can be audited, and show that such extensions can be a significant deterrent against tax evasion.