Book of Abstracts

PGMO Days 2019

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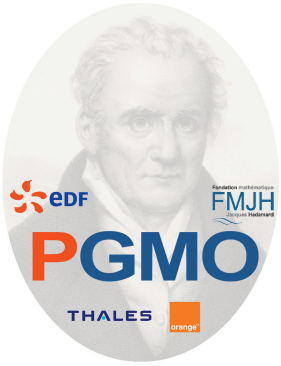

Preface

This volume contains the extended abstracts of the talks presented at PGMODAYS 2019 held on December 3–4, 2019 at EDF Labs Paris-Saclay.

We especially acknowledge the support of EDF, Orange, Thales, FMJH, Labex LMH and ICODE institute. We thank GDR Jeux, GDR MASCOT-NUM, GDR MOA, GDR RO, ROADEF, SFdS, SMAI, SMF, CNRS, Ecole polytechnique, ENSTA and Inria. We are also grateful to the organizers of invited sessions.

November 20, 2019
Palaiseau – Orsay

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Organizers of Invited Sessions

Algebraic and geometric tools for optimisation and statistics	Elias Tsigaridas
Recent advances in optimization for machine learning	Émilie Chouzenoux and Jean-Christophe Pesquet
Bilevel programming and applications (in general, and in the energy field)	Luce Brotcorne and Miguel Anjos
Polynomial optimization and applications	Simone Naldi, Mohab Safey El Din and Victor Magron
Recent advances in solving large-scale optimal power flow problems	Julie Sliwak and Miguel Anjos
Shape optimization and applications	Alex Ferrer
The advent of prosumers: challenges and opportunities	Miguel Anjos

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Teaching Self-Driving Cars to Be Responsible: A Mathematical Formalism of the Duty of Care

Shai Shalev-Shwartz[1,2]

[1]Mobileye, an Intel company
[2]The Hebrew University of Jerusalem

An important element in making self-driving cars a real product, rather than a science project, is to provide clear safety guarantees. We argue that statistical guarantees give a very weak safety and propose instead a white-box, interpretable, mathematical model for safety assurance, which we call Responsibility-Sensitive Safety (RSS).

Distributional reinforcement learning

Rémi Munos[1]

[1]DeepMind, Paris

I'll talk about recent work related to the distributional reinforcement learning approach where the full return distribution is learnt instead of its expectation only. We generalize Bellman equations to this setting and describe a deep-learning approach for approximating those distributions. I will report experiments on Atari games.

Contributions to the mean field games theory

Charles Bertucci[1]

[1]Université Paris Dauphine

The PGMO Prize 2019 is awarded to Charles Bertucci for his PhD thesis entitled "Contributions à la théorie des jeux à champ moyen". His PhD, completed at the Université Paris Dauphine under the supervision of Pierre-Louis Lions, is concerned with the study of several problems of significant interest arising in the theory of mean field games. His work has been recognized as an extremely important contribution to the theory with the introduction of deep and original techniques.

Integer optimization and machine learning, some recent developments

Karen Aardal[1]

[1]Delft Institute of Applied Mathematics, Delft University of Technology

In recent years the interface between machine learning and integer optimization has quickly been developing. We will give some examples of recent developments in the use of machine learning for learning how to branch and cut, and the use of integer optimization in adversarial machine learning.

Dynamic Programming for IP

Friedrich Eisenbrand[1]

[1]Swiss Federal Institute of Technology, Lausanne

In this talk, I will survey some recent results on the complexity of integer programming in the setting that lends itself to dynamic programming approaches. These include the general integer programming problem in standard form with small coefficients and integer programming problems with block structure. The field of parameterised complexity has developed tools to provide lower bounds on the complexity of IP in these cases. The goal of this talk is to give an overview on recent progress and open problems.

Combinatorial Aspects of the Unit Commitment Problem

Cécile Rottner[1]

[1]Sorbonne Université

The PGMO Prize 2019 is awarded to Cécile Rottner for her PhD thesis entitled "Aspects combinatoires du Unit Commitment Problem". Cécile Rottner obtained her PhD from Sorbonne Université under the supervision of Pascale Bendotti of EDF R&D and Pierre Fouihoux of the computer science lab LIP6. In her thesis, she investigates the Unit Commitment Problem from the point of view of combinatorial and discrete optimization. She is awarded the PGMO Prize 2019 in recognition of her impressive treatment of the Unit Commitment Problem which contains a broad spectrum of novel and relevant insights and approaches.

SOLVING SPARSE POLYNOMIAL SYSTEMS USING GRÖBNER BASES

Elias Tsigaridas[1]

[1]Inria Paris, France, elias.tsigaridas@inria.fr

Keywords: sparse polynomial system, Gröbner basis, Newton polytope, mixed volume, eigenvalues

Gröbner bases are one the most powerful tools in algorithmic non-linear algebra. Their computation is an intrinsically hard problem with complexity at least single exponential in the number of variables. However, in most of the cases, the polynomial systems coming from applications have some kind of structure. For example, several problems in statistics and optimization involve sparse systems where the input polynomials have a few non-zero terms.

We present an algorithm to compute Gröbner basis that exploits the sparsity of the input polynomials by exploiting their Newton polytopes. We do not assume that all the polynomials have the same sparsity structure, that is the same Newton polytope. This is the first algorithm with these properties. Under regularity assumptions, it performs no redundant computations and allows us to solve sparse polynomials systems over the torus.

The complexity of the algorithm depends on the Newton polytopes and it is similar to the complexity of the algorithms based on sparse resultants. Hence, we close a 25-years (complexity) gap between solving strategies based on resultants and Gröbner bases. Additionally, for particular families of sparse systems, we use the multigraded Castelnuovo-Mumford regularity to further improve the complexity bounds.

Joint work with Matias Bender and Jean-Charles Faugère.

Solving linear Diophantine systems through Polyhedral Omega and applications in optimization

Zafeirakis Zafeirakopoulos[1]

[1]Institute of Information Technologies, Gebze Technical University, zafeirakopoulos@gtu.edu.tr

Keywords: Linear Diophantine systems, Polyhedral Geometry, Optimization, Generating Functions

Polyhedral Omega (PO) is an algorithm for solving linear Diophantine systems, i.e., for computing a multivariate rational function representation of the set of all non-negative integer solutions to a system of linear equations and inequalities. PO combines methods from partition analysis with methods from polyhedral geometry. In particular, we combine MacMahon's iterative approach based on the Omega operator and explicit formulas for its evaluation with geometric tools such as Brion's decompositions and Barvinok's short rational function representations. This synthesis of ideas makes Polyhedral Omega the simplest algorithm for solving linear Diophantine systems available to date. Given a rational generating function representation of a feasible region defined by linear equations and inequalities, there are different ways of obtaining the optimum with respect to some linear functional. One advantage of PO is that it can obtain a decomposition of the feasible region to simplicial cones (called symbolic cones), without resorting to rational function representations. After presenting Polyhedral Omega, we will discuss possible applications in optimization.

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Combinatorial Matrix Theory in Multivariate Statistics: the Case of Structural Equation Models

Bibhas Adhikari[1] Elizabeth Gross[2] Marc Harkonen[3] Elias Tsigaridas[4] Dane Wilburne[5]

[1]Indian Institute of Technology Kharagpur, India, bibhas@maths.iitkgp.ac.in
[2]University of Hawai'i at Mānoa, USA, egross @math.hawaii.edu
[3]Georgia Institute of Technology, USA, marc.harkonen@gmail.com
[4]INRIA Paris, France, elias.tsigaridas@inria.fr
[5]York University, Canada, drw@yorku.ca

Keywords: Graphical models, combinatorics, multivariate statistics

Many operations on matrices can be viewed from a combinatorial point of view by considering graphs associated to the matrix. For example, the determinant and inverse of a matrix can be computed from the linear subgraphs and 1-connections of the Coates digraph associated to the matrix. This combinatorial approach also naturally takes advantage of the sparsity structure of the matrix, which makes it ideal for applications in linear structural equation models. Another advantage of these combinatorial methods is the fact that they are often agnostic on whether the mixed graph contains cycles. As an example, we obtain a symbolic representation of the entries of the covariance matrix as a finite sum. In general, this sum will become similar to the well known trek rule, but where each half of the trek is a 1-connection instead of a path. This method of computing the covariance matrix can be easily implemented in computer algebra systems, and scales extremely well when the mixed graph has few cycles.

Model Consistency for Learning with Low-complexity Priors

Jalal FADILI[1] Guillaume GARRIGOS[2] Jérôme MALICK[3]
Gabriel PEYRÉ[4] Lorenzo ROSASCO[5] Silvia VILLA[5]

[1]ENSICAEN, CNRS, France [2]Université de Paris, France [3]CNRS, LJK, France
[4]École Normale Supérieure, CNRS, France [5]Università degli Studi di Genova, France

Keywords: Supervised learning, Stochastic optimization, Structured sparsity, Low-rank, Support recovery

We consider supervised learning problems where the prior on the underlying distribution is an assumption of low complexity (such as low rank or structured sparsity). An important question in that setting is the one of model consistency, which asks whether or not an estimator shares the *same low complexity*.

It is known in Inverse Problems that model consistency holds under appropriate non-degeneracy conditions. However such conditions typically fail for highly correlated designs (typical in learning) and it is observed that estimators obtained by regularization methods, eventually approximated with stochastic optimization methods, tend to select models having a *larger complexity*.

In this talk, we provide the theoretical underpinning of this behavior for a large class of low-complexity models, and we show that estimators obey a *sandwich* principle. More precisely, their complexity is always found in between the complexity of the expected distribution, and the complexity of a certain dual certificate. We will also investigate the role of stochastic algorithms in this setting, and underline the need for using *variance-reduced* methods for this result to hold.

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Matrix Completion on Graphs: Modeling Interactions

Angshul Majumdar

Indraprastha Institute of Information Technology, Delhi, India, angshul@iiitd.ac.in

Keywords: Matrix Completion, Matrix Factorization, Graph Signal Processing, Deep Learning

Various biological and human-sensing problems can be recast as link prediction between two graphs. For example consider the problem of drug-target repositioning [1, 2]. Some of the drugs are known to interact with certain target proteins, the goal is to see if the same drugs will interact with other targets as well. Without any knowledge about drugs and targets, the best approach is to frame it as matrix completion [3]. In practice, meta-information about both drugs and targets are known, from which fully connected graphs can be constructed among them. In such a case, the problem needs to reformulated as predicting links between the drug and target graphs [4]. In this talk, we will touch upon various problems arising in social networks [5] and bioinformatics [6, 7], that can be modeled thus. We will talk about various signal processing and machine learning models, including deep learning, that are being currently developed to tackle the problem.

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Improving the convergence of Stochastically perturbed Nesterov's accelerated Forward-Backward

Gersende Fort[1]

[1]Institut de Mathématiques de Toulouse & CNRS, France
gersende.fort@math.univ-toulouse.fr

Keywords: Stochastic Optimization, Monte Carlo methods, Perturbed MM algorithms, Accelerated Forward-Backward methods, Averaging, over-relaxations

Motivated by problems arising in Statistical Learning, we consider the convergence of perturbed Nesterov's accelerated forward-backward algorithm when applied to compute the minimum of a convex composite function. We address the case when the perturbation only deals with the gradient step, with a special emphasis on situations when the gradient is an expectation : different Monte Carlo strategies will be discussed - including biased Monte Carlo -, possibly combined with averaging techniques and over-relaxations. We will first show the need to improve on previous results in the literature in the case of (biased) stochastic approximations; then, we will discuss the impact of these algorithmic strategies on the rate of convergence, both theoretically in terms of long-time behavior of the functional, and numerically.

This talk is based on joint works with J.F. Aujol (IMB), P. Gach (IMT) and E. Moulines (Ecole Polytechnique).

Routing and Slot Allocation in 5G Hard Slicing

Nicolas Huin[1] Jérémie Leguay[1] Sébastien Martin[1] Paolo Medagliani[1]

[1]Huawei Technologies, France, firstname.name@huawei.com

Keywords: 5G, Hard slicing, Flex Ethernet, Column and row generation

5G promises to improve the scalability, end-to-end latency, and capacity of networks. It also aims to ease the management of networks by allowing network operators to slice their network, subdividing the resource between tenants, which may have different Quality of Service constraints. While current solutions (soft slicing [1]) provide logical isolation, tenants can still impact each other when overloading their slices.

Flex Ethernet [2] (FlexE) is a standard technology that provides strict isolation between slices (hard slicing) by using time multiplexing and a schedule with fixed-size slots. Each slice is assigned to a given number of slots and cannot overflow to others slices slots. But the smallest granularity possible is 1 Gb: using FlexE can lead to wasted allocated bandwidth.

For a given slice, i.e., a set of un-splittable requests with QoS constraints, finding the routing of each request and the slot allocation of each link defines the Routing and Slot Allocation problem. We propose a matheuristic approach based on Column Generation to solve it. It provides solution, on an IP-RAN scenarios, with an optimality gap smaller than 7%, while reducing the reservation cost by 4% compared to a greedy algorithm. We further improve our lower bounds by proposing new valid inequalities.

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Routing in deterministic networks

Jonatan Krolikowski[1] Jérémie Leguay[1] Sébastien Martin[1] Paolo Medagliani[1]

[1]Paris Research Center, Huawei Technologies Co. Ltd. firstname.lastname@huawei.com

Keywords: network telecommunication, optimization, deterministic latency, bounded jitter

Historically, vertically integrated industrial applications are migrating to versatile IP infrastructures. In order to support tight latency and reliability requirements, Internet standards are evolving to ensure (i) deterministic latency and bounded jitter, and (ii) zero packet losses in the network. In the context of deterministic networks, we present two centralized algorithms: one that maximizes traffic acceptance during the planning phase and one that achieves online admission of flows. With the enhancement of the model, we improve the upper bound and the quality of column-based solutions for the planning problem. We show in realistic cases that we reach an optimality gap of a few percent in a few seconds. Finally, we propose an ultra-fast and adaptive greedy algorithm that solves the online admission problem.

Extended formulations for the Virtual Network Functions Placement and Routing Problem

Ahlam MOUACI[1] Éric GOURDIN [1] Ivana LJUBIĆ[2] Nancy PERROT[1]

[1]Orange Labs, France, {ahlam.mouaci, eric.gourdin, nancy.perrot}@orange.com
[2]ESSEC Business School, France, ivana.ljubic@essec.edu

Keywords: Combinatorial optimization, Branch-and-Price, Extended formulation, Software Defined Networking, Network Function Virtualization, Service Function Chaining.

In this talk we present a problem faced by network service providers in which a set of Virtual Network Functions (VNFs) has to be installed in a telecommunication network at minimum cost. For each given origin-destination pair of nodes (commodities), a latency-constrained routing path has to be found that visits the required VNFs in a pre-defined order. We have proven that the problem is NP-hard in a strong sense, even for a single commodity and without latency and precedence constraints. In this presentation we provide two extended formulations to model it, along with two families of valid inequalities. To tackle the problem from a computational perspective, we provide theoretical results that allow us to relax one family of variables to do our Branch-and-Price algorithm. We also propose an alternative path-based MILP formulation which is used to provide heuristic solutions. All these ingredients are combined in a Branch-and-Price framework and computationally tested on a wide range of realistic instances. Our results are also compared with Integer Linear compact formulation. Computational results indicate that our both extended formulations are more efficient compared to the compact formulation in term of bounds. The results also indicate that our MILP-heuristic provides high-quality solutions.

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Improving MCTS approaches for Vehicle Routing Problems

Hyoseok KIM[1], Jean-Yves Lucas[2], Thomas Triboulet[3], Tristan Cazenave[4]
[1]EDF R&D, France, hyoseok.kim@ensiie.fr,
[2]EDF R&D, France, jean-yves.lucas@edf.fr,
[3]EDF R&D, France, thomas.triboulet@edf.fr,
[4]LAMSADE Université Paris-Dauphine PSL , France, tristan.cazenave@lamsade.dauphine.fr,

Key words: Vehicle Routing problem, NRPA, MCTS, heuristics, transport.

Introduction : Utility companies manage large quantities of technical interventions. Itineraries that minimize cost and duration must be constructed. Real problems are too big to be tackled with mathematical programming approaches [1]. Progress in Tree Search techniques enable to test these methods on Vehicle Routing Problems. Nested Rollout Policy Adaptation is a recent refinement of MCTS and was tested on TSP [2] and VRP [3] problems. The objective of this work was to improve NRPA algorithm and adapt it to actual business problems.

Improving NRPA : NRPA uses probabilities of elementary actions to simulate solutions of the problem. Probabilities are refreshed depending on results of simulations. Several techniques were used to improve the algorithm by refining the criteria of probability refreshing.

Improving the model : The algorithm was first tested on literature data sets : Solomon VRPTW instances. The algorithm was then improved to take into account specificities of the business problems. It assigns appointments depending on technician skills and deals with limited numbers of technicians and priority between appointments.

Numerical Results : EDF current tool is based on greedy algorithm and local search approach. First results obtained with the implemented version of NRPA shows significant improvements compared to those produced by the current EDF tool both on academic and industrial data sets

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A DSS based on hybrid metaheuristic for waste collection routing problem with time windows

Islem Kaabachi[1,2] Saoussen Krichen[2]

[1]Université Paris Est, CERMICS, 77455 Marne-la-Vallée, France
islamkaa@hotmail.com
[2]Université de Tunis, Institut Supérieur de Gestion, LARODEC, Tunisia
saoussen.krichen@gmail.com

Keywords: Metaheuristics, Vehicle routing problem, Genetic algorithm, Case study, DSS

In this paper, a specific problem in the context of solid waste collection namely municipal solid waste collection problem is discussed. In the literature, the waste collection problem is mostly modeled as a Vehicle Routing Problem with Time Windows (VRPTW) ([1], [2], [3]), but to model the issue in the real world, the collection is mainly performed using trucks with different capacities, which yields to the context of using heterogeneous fleet of trucks to perform waste collection. The main objective of this problem is to minimize the total traveled distance while using a minimum number of trucks in order to decrease the transportation cost.

For this problem, a mathematical model is proposed in which the total collected waste for each collection area do not exceed the truck capacity and the truck must return to the depot after loading waste in the landfill. Moreover, the waste collection must be within the service time window. The proposed modeling is tested with CPLEX using real data. Considering the NP-hardness of this problem, a hybrid genetic algorithm is proposed to solve the large scale instances. The performance of the proposed algorithm is highlighted through the implementation of a Decision Support System (DSS).

The computational results show that the proposed algorithm reached optimal solutions. The results are also compared to existing approaches for evaluating the performance of the proposed algorithm. Moreover, it is tested using a real case study of the solid waste collection process applied by a Tunisian municipality.

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Delay propagation on a suburban railway network

Guillaume Dalle[1] Yohann De Castro[2] Axel Parmentier[1]

[1]CERMICS, École des Ponts ParisTech, France, guillaume.dalle@enpc.fr
[2]ICJ, École Centrale de Lyon, France

Keywords: train delay, Dynamic Bayesian Network, probabilistic programming, variational inference, Pyro

Understanding and predicting train delays is fundamental to passenger information, traffic regulation and robust scheduling. A major challenge for delay prediction is the amount of interactions between trains: since they must share the same resources, one train's delay can affect many others by blocking the track or monopolizing a driver.

Working on a dataset of recorded event times from the Paris suburban railway system (RER), we construct a delay propagation model that exploits the limited information available. To compensate for our ignorance of precedence relations between events (on which standard methods rely, see [1]), we identify infrastructure constraints as the main interaction vector.

This leads to the definition of a hidden "network delay" expressing the amount of congestion on the network's edges. Its probabilistic evolution is structured as a heterogeneous Dynamic Bayesian Network, which enables propagation. The event times for each train follow a random walk influenced by the network delay.

We first perform a statistical analysis on a simplified version of our model: a Vector AutoRegressive process of order 1 with partial and noisy observations, whose weights matrix we seek to estimate. In this setting, we exploit Fano's method and obtain a lower bound on the minimax estimation risk, i.e. the worst-case error of the best possible algorithm.

We then propose a generic implementation that separates the expression of the model from the learning and prediction process. This is achieved by encoding the model as a probabilistic program, to which we apply Stochastic Variational Inference using the Python library Pyro [2].

We finally present numerical tests, both on a simulated dataset and on the actual event logs. While these tests underline the computational limitations of our approach, they also demonstrate its feasibility and predictive potential, mostly when it comes to severe traffic disruptions.

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Linear–Quadratic optimal control for a class of stochastic Volterra equations: solvability and approximation

Eduardo Abi Jaber [1] Enzo Miller[2] Huyen Pham[3]

[1]University of Paris 1 Pantheon-Sorbonne., France, eduardo.abi.jaber@gmail.com
[2]University Paris-Diderot, France, enzo.miller@polytechnique.org
[3]University Paris-Diderot, France, pham@math.univ-paris-diderot.fr

Keywords: Stochastic control, non Markovian, fractionnal noise, delays

We provide an exhaustive treatment of Linear–Quadratic optimal control problems for a class of stochastic Volterra equations of convolution type, whose kernels are Laplace transforms of certain signed matrix measures which are not necessarily finite. These equations are in general neither Markovian nor semimartingales, and include equations with delays or the fractional Brownian motion with Hurst index smaller than 1/2 as a special case. We establish the correspondence of the initial problem with a possibly infinite dimensional Markovian one in a Banach space, which allows us to identify the Markovian state variables. Using a refined martingality verification argument combined with a completion of squares technique, we prove that the value function is of linear quadratic form in these state variables with a linear optimal feedback control, depending on Banach space valued Riccati equations, for which we provide generic existence and uniqueness results. Furthermore, we show that the value function of the stochastic Volterra optimization problem can be approximated by that of conventional finite dimensional Markovian Linear–Quadratic problems, which is of crucial importance for numerical implementation.

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Optimal Probabilistic Control of the Vibrating String under Random Initial Conditions

René Henrion[1]

[1]Weierstrass Institute Berlin, Germany, henrion@wias-berlin.de

Keywords: probabilistic constraints, optimal control

Probabilistic constraints have recently attracted growing interest in PDE constrained optimization with uncertain parameters. For instance, in gas transport one may be interested to drive some current initial state of the system to stationarity within a given period of time. Most typically, the initial state is not precisely known but may be estimated by means of measurements. This uncertainty leads, given any control, to an uncertain terminal state of the system too. Hence, one can only hope for some 'epsilon-stationary' terminal state achieved with a given minimum probability. Under certain simplifying assumptions the gas dynamics can be reduced to a couple of one-dimensional wave equations. As a preparatory step to solve the original problem, we therefore consider the optimal probabilistic Neumann boundary control of a vibrating string under uncertain initial conditions. We present the model, its structural properties and its algorithmic solution along with numerical results.

Representation formulas for limit values of long run stochastic optimal controls

Rainer Buckdahn[1] Juan Li[2] Marc Quincampoix[1] Jérôme Renault[3]

[1]Univ Brest, UMR CNRS 6205, LMBA France marc.quincampoix@univ-brest.fr
[2] School of Mathematics, Shandong University, P. R. China. juanli@sdu.edu.cn,
[3] TSE (Université Toulouse 1 Capitole), France.jerome.renault@tse-fr.eu

Keywords: Optimal control, Stochastic Control, Ergodic Control

A classical problem in stochastic ergodic control consists of studying the limit behavior of the optimal value of a discounted integral in infinite horizon (the so called Abel mean of an integral cost) as the discount factor λ tends to zero or the value defined with a Cesàro mean of an integral cost when the horizon T tends to $+\infty$. We investigate the possible limits in the norm of uniform convergence topology of values defined through Abel mean or Ceàro means when $\lambda \to 0^+$ and $T \to +\infty$, respectively. Here we give two types of new representation formulas for the accumulation points of the values when the averaging parameter converges. We show that there is only one possible accumulation point which is the same for Abel means or Cesàro means. The first type of representation formula is based on probability measures on the product of the state space and the control state space, which are limits of occupational measures. The second type of representation formulas is based on measures which are the projection of invariant measure on the space of relaxed controls. We also give a result comparing the both sets of measures involved in the both classes of representation formulas. An important consequence of the representation formulas is the existence of the limit value when one has the equicontinuity property of Abel or Cesàro mean values. This is the case, for example, for nonexpansive stochastic control systems.

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Multiple Decision-Makers in a Collective Self-Consumption Context: Bilevel Optimization

Saad BALBIYAD[1] Rebecca JEFFERS[2]

[1]EDF Lab Paris-Saclay, France, saad.balbiyad@edf.fr
[2]EDF Lab Paris-Saclay, France, rebecca.jeffers@edf.fr

Keywords: Collective Self-consumption, Bilevel optimization, MCCP, QCP

In the context of the fight against climate change and the need to reduce our dependence on traditional fuel sources, the French government aims to put in place legislation to promote the adoption of distributed renewable energy. One example of such legislation is that on collective self-consumption enacted the 26 July 2016 [1], defining the process of collective self-consumption as the fact of self-consuming with multiple producers. We focus on a special case of collective self-consumption agreement where multiple Decision-Makers with conflicting objectives are allowed: an aggregator that decides how the produced energy is distributed among agreement's members, and consumers that minimize their energy bills in response to the energy distribution set by the aggregator.

This generates a hierarchical decision problem which is modeled as a bilevel optimization problem. The aggregator is the leader and agreement's members are followers.

The obtained bilevel problem is solved by using a single-level reduction by expressing the lower level's optimality with KKT conditions [2]. We explore two kinds of formulations. The first one gives a Mathematical Program with Complementarity Constraints (MPCC), and the second one gives a Non Convex Quadratically Constrained Program (QCP). Solving linear approximations for the obtained problems, we get an UB and a LB for the original bilevel program.

Results provide a practical tool to visualize clients possible behavior in a collective self-consumption agreement.

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Minimizing Energy and Link capacity Utilization in ISP Backbone Networks: Bi-level approach

Ikram Bouras[2], Rosa Figueiredo[1], Michael Poss[2], Fen Zhou[1]

[1] University of Avignon, LIA, 84911 Avignon, France {firstname.lastname}@univ-avignon.fr
[2] University of Montpellier, LIRMM UMR CNRS 5506, 34090 Montpellier, France
{firstname.lastname}@lirmm.fr

Keywords: *Energy-aware engineering, Bi-level programming, Cutting plane, Branch-and-Cut.*

With the tremendous growth of Internet traffic, the network energy consumption is inherently growing fast with a rate of 10% per year, which exceeded 350 TWh and represented 1.8% of the worldwide electricity consumption in 2012. It is even reported that communication networks will consume as much as 51% of the global electricity in the worst case by 2030 if its energy efficiency is not improved enough. Thus, the problem of energy efficiency is becoming critical for nowadays communication networks. To reduce energy consumption, green networking has attracted a lot of attention from device manufacturers and Internet Service Providers (ISP). In the literature, energy-aware traffic engineering problem is proposed to minimize the total energy consumption by switching off unused network devices (routers and links) while guaranteeing full network connectivity [1].

In this work, we are interested in the problem of energy-aware Traffic Engineering (TE) while using multi-path routing to minimize link capacity utilization in ISP backbone networks. We consider the ISP backbone network modeled by the bi-directed graph $G(V, A)$, where V is the set of routers and A represents the set of communication links.

The studied optimization problem selects a set of routers (nodes) and links (arcs) to be activated with minimum energy consumption. In addition, each traffic demand has to use a multi-path flow minimizing the total link capacity utilization. This problem is a generalization of the fixed charge network design problem with shortest path constraints studied in [2].

To formulate the problem, we propose a new bi-level integer linear programming model where the objective of the upper level problem is to activate network devices minimizing the energy consumption and the lower level represents a multi-path routing protocol.

We solve the above model exactly by reformulating it as a MILP replacing the second level problem (Minimum cost flow problem) by three different types of optimality conditions: KKT, residual network optimality conditions, and inequalities eliminating sub-optimal flows.

We compare the three formulations numerically on different network topologies: Polska, Geant and Abilene networks. The two first types of constraints are used to construct compact formulations that are fed into MILP solvers and solved with default configuration. In addition, an iterative cutting plane and branch-and-cut algorithms are implemented using the inequalities that eliminate unfeasible flows. For all these instances, we found that the iterative cutting plane and branch-and-cut algorithms outperform the compact formulations that use KKT or residual network optimality conditions.

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Random Allocations, Fairness and Implementability in Stackelberg Security Games

Victor Bucarey[1,2] Martine Labbé[1,2]

[1]Département d'Informatique, Université Libre de Bruxelles, Brussels, Belgium.
[2] INOCS, Inria Lille-Nord Europe, France. {vbucarey, mlabbe}@ulb.ac.be

Keywords: Fairness, Implementability, Stackelberg Security Games

In this talk we discuss the impact of fairness constraints in Stackelberg Security Games. Fairness constraints can be used to avoid discrimination at the moment of implementing police patrolling. We present two ways of modelling fairness constraints, one with a detailed description of the population and the other with labels. We discuss the implementability of these constraints. In the case that the constraints are not implementable we present models to retrieve pure strategies in a way that they are the closest in average to the set of fairness constraints. This last problem has a nice interpretation as a Combinatorial Optimization Problem.

This work is an extension of the previous work presented in [1].

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McKean Stochastic Optimal Control of an Energy Storage System to reduce demand variability

Maxime Grangereau[1] Emmanuel Gobet[2]

[1]EDF R&D - Ecole polytechnique (CMAP), France, maxime.grangereau@edf.fr
[2]Ecole polytechnique (CMAP), emmanuel.gobet@polytechnique.edu

Keywords: Energy Management, Stochastic Optimal Control, McKean interaction

We consider a system, e.g., a smart-grid, characterized by its own exogenous production and consumption, connected to the network and to a controllable energy storage system, like a battery for instance. We control this energy storage system and aim at limiting simultaneously the power demand peaks on the network, the storage system aging and the fluctuations of the power supplied by the network. While the first two components of the cost are related to the trajectory of the system, and therefore to the standard stochastic optimal control paradigm, the last one is more related to the probability distribution of the system, and therefore to the McKean stochastic optimal control paradigm.

We propose here to model the problem of energy storage control as a McKean stochastic optimal control problem with scalar interactions. For this class of problems, we derive necessary and sufficient optimality conditions, using the stochastic Pontryagyn principle. This gives rise to a particular McKean-Forward Backward Stochastic Differential Equation. Some existence results for a solution to this class of problems are obtained in the general case. In the Linear-Quadratic case, some explicit closed-loop feedback formulas for the optimal control are available. In the non-quadratic case, a first order expansion of the optimal control with respect to the non-quadratic terms can be efficiently computed. The performance of our approach is demonstrated through numerical examples in both the linear-quadratic and quasi linear-quadratic cases.

Arbitrage with Power Factor Correction using Energy Storage

Md Umar Hashmi[1] Deepjyoti Deka[2] Ana Bušić[1] Lucas Pereirać[3] Scott Backhaus[2]

[1]INRIA, DI ENS, Ecole Normale Supérieure, CNRS, PSL Research University, Paris, France
[2]CNLS, Los Alamos National Laboratory, USA
[2]Madeira-ITI/ LARSyS and prsma.com, Funchal, Portugal

Keywords: energy storage, battery, arbitrage, power factor correction, convex optimization

The importance of reactive power compensation for power factor (PF) correction will significantly increase with the large-scale integration of distributed generation interfaced via inverters producing only active power. In this work, we focus on *co-optimizing* energy storage for performing energy arbitrage as well as local power factor corrections. The joint optimization problem is non-convex, but can be solved efficiently using a McCormick relaxation along with penalty-based schemes.

The co-optimization formulation is used to operate inverter connected storage devices in distribution grids for co-optimizing arbitrage and power factor correction (PFC), both with or without perfect information. Using numerical simulations on real data and realistic storage profiles, we show that energy storage can correct PF locally without reducing arbitrage profit. It is observed that active and reactive power control is largely decoupled in nature for performing arbitrage and PFC. The primary reason for PFC being *decoupled* from arbitrage profit is because, in most instances, PF can be corrected by adjusting reactive power output. The reactive power is primarily governed by converter size and active power, and unlike storage active power output, which is constrained by capacity and ramp constraint. It is also noteworthy that increasing the converter size would improve the mean PF without any significant change in arbitrage profit for the same ramping battery. In the current work, we consider a stringent case of maintaining PF for every operational point, though the methodology can be extended to the case with penalties on average PF.

Furthermore, we consider a stochastic *online* formulation of the problem with uncertain load, renewable and pricing profiles. We develop a model predictive control based storage control policy using auto-regressive forecast for the uncertainty. Using numerical simulations we observe that PFC is primarily governed by the size of the converter and therefore, look-ahead in time in the online setting does not affect PFC noticeably. However, arbitrage profit is more sensitive to uncertainty for batteries with faster ramp rates compared to slow ramping batteries.

Full paper can be found on ArXiv [1].

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Chance Constrained AC Optimal Power Flow with Sparse Polynomial Chaos Expansion

David Métivier[1] Marc Vuffray[1] Sidhant Misra [1]

[1]Center for Nonlinear Studies and Theoretical Division,
Los Alamos National Laboratory, USA
metivier@lanl.gov

Keywords: AC Optimal Power Flow, Chance Constrain, Sparsity, Polynomial Chaos Expansion, Uncertainty Quantification

This work inscribes itself in a long line of research aiming at incorporating uncertainty into the Optimal Power Flow (OPF). Two types of approximations are usually deployed when solving the stochastic OPF problem: either linearizing the physics equations (i.e. turning AC to DC), or linearize the effect of uncertainty by considering it's small. Our work [1] accounts for the full non-linearity of the AC power flow physics when quantifying the effect of uncertainty.

Our method builds on the work by [2] which proposed the use of Polynomial Chaos Expansion (PCE) for modeling the effect of uncertainty. PCE was shown to be a promising and accurate method for solving stochastic AC-OPF; however it suffers from a critical lack of scalability that precludes its use for large test cases. In this work, we show that by exploiting the sparsity contained in the network structure and leveraging properties of the power flow physics we are able to construct a scalable PCE, coined sparse-PCE, that can be employed to solve stochastic AC-OPF on large test cases within acceptable computational time.

Method In the PCE approach, all uncertain variables are expanded with respect to an orthogonal basis. Specifying the uncertainty then reduces to determining the coefficients with respect to this basis. We develop ways to improve the scalability of the PCE based uncertainty quantification by exploiting: (i) Sparsity: Typical power grid structures result in weak dependencies between variables separated by long network distance. Promoting sparse PCE coefficients reduces the number of variables. (ii) Properties of the power flow physics: Terms of order three or more in the PCE-PF equations can be neglected while preserving the impact of uncertainty on the nonlinear PF. We show that the resulting sparse-PCE algorithm is able to solve stochastic AC-OPF problems on more than systems with more than thousand buses within minutes.

Application We apply our proposed uncertainty quantification method for solving stochastic AC-OPF with chance-constraints.

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Design of a charging infrastructure for electric vehicles under a stochastic driving range

Mouna Kchaou-Boujelben[1] Céline Gicquel[2]

[1]United Arab Emirates University, Al Ain, United Arab Emirates
[2]Université Paris Saclay, LRI, Université Paris Sud, Orsay, F-91405, France, celine.gicquel@lri.fr

Keywords: Electric vehicle, charging stations, stochastic facility location, chance-constrained programming

Electric vehicles (EVs) are one of the promising solutions to face environmental and energy concerns. One of the major barriers towards the large scale adoption of EVs is the lack of charging stations to recharge vehicles during long-distance trips, i.e. during trips whose length exceeds the vehicle range. We consider the problem of optimizing the deployment of an infrastructure based on fast charging stations in order to enable EV drivers to carry out long-distance trips. This leads to the formulation of a facility location problem in which the demand to be served is not located at nodes of the underlying network but rather is represented by a set of trips to be refueled. This combinatorial optimization problem is known as the flow refueling location problem (FRLP). In the FRLP, a trip is said to be 'covered' or 'refueled' if the charging stations located on the corresponding path allow an EV driver to travel from his point of departure to his destination and back without running out of fuel. The objective is to select the best locations for EV charging stations so a to maximize the number of drivers which will be able to carry out their trip while complying with the available limited investment budget.

The coverage of a trip depends mainly on two parameters: the battery energy status when the EV leaves a charging station and its power consumption. A trip will be covered if, for each pair of consecutive stations visited when traveling along the corresponding path, the energy available in the battery when leaving the first station is high enough to provide the power needed by the vehicle to reach the second station. Most previously published papers assume that these two parameters are deterministically known. However, in practice, they are subject to many uncertainties due e.g. to the age of the battery, the weather and the traffic conditions. We thus propose an extension of the FRLP in which the uncertainties related to the energy available in the battery after recharging at a station as well as the power consumption on each portion of the road network are explicitly taken into account.

This leads to the formulation of a chance-constraint program in which we seek to maximize the number of drivers for which the probability of running out of fuel when carrying out their trip is below a certain threshold. We propose to use a solution approach based on a partial sample approximation of the stochastic parameters and compare its performance with the one of a previously published approach based on Bonferroni's inequality. We carry out numerical experiments on a set of medium-size randomly generated and real life instances. Our results show that the proposed partial sample approximation approach outperforms the Bonferroni approach in terms of solution quality and gives station locations which provide a significantly improved demand coverage in practice.

Stochastic Model for the Uncertainties in the Long-Term Prediction of Run-of-River Hydropower Generation

M. Thuilliez[1] V. Sessa[1] M. Bossy[2] E. Assoumou[1] S. Simões[3]

[1]MINES ParisTech, PSL - Research University, CMA - Centre de Mathématiques Appliquées, France
margot.thuilliez@gmail.com, {valentina.sessa, edi.assoumou} @mines-paristech.fr
[2] Université Côte d'Azur, Inria, France
mireille.bossy@inria.fr
[3] CENSE - Centre for Environmental and Sustainability Research Energy and Climate DCEA-FCT/Universidade NOVA, Portugal
sgcs@fct.unl.pt

Keywords: energy modeling, machine learning, uncertainties analysis

One of the big challenges taken in the European project Clim2Power is the integration of climate variability into the short- and long-term planning processes of sustainable energy systems. By combining high resolution weather forecasts and enhanced energy system model, Clim2Power provides an improved guidance to power systems' stakeholders.

One part of this project deals with the daily prediction of the national run-of-river hydropower generation based on the precipitations and the air temperature of some European climate regions. Translating time series of meteorological forecast into time series of run-of-river hydropower generation is not an easy task as it is necessary to capture the complex relationship between the availability of water and the generation of electricity. Indeed, this kind of hydropower generation is limited by the flow of the river in which the power plants are located. Moreover, the water flow is a nonlinear function of the weather variables and the physical characteristics of the river basins. Finally, the impact of the weather variables on the river flow may occur with a certain delay, whose determination depends on physically based phenomena (e.g., melting snow-local temperature).

In this work, the prediction of the hydropower capacity factor is obtained by using machine learning (ML) techniques. We compare the performance of several well-established regression algorithms in terms of correlation coefficient, adjusted coefficient of determination, mean absolute and mean square percentage errors. The models with the highest accuracy is then chosen for the modeling and prediction of the hydropower production. Our preliminary experiments showed that the algorithms based on ensemble of trees and the artificial neural networks perform quite well in most of the evaluative criteria.

An additional output provided by the ML algorithms is the corresponding modeling error. We propose to build a stochastic model for this uncertainty whose dynamics aims to reproduce the statistical characteristics of the prediction deviation with respect to its long-term mean, and so be able to enrich the ML prediction with probabilistic anomalies indicators aggregated at the scale of countries.

Strategic behaviour of risk-averse agents under stochastic market clearing

Vincent Leclère[1] Andy Philpott[2]

[1]École des Ponts ParisTech, France, vincent.leclere@enpc.fr
[2]University of Auckland, New Zealand, a.philpott@auckland.ac.nz

Keywords: Stochastic Programming, Stochastic Equilibrium, Strategic Game

The last decade has seen a dramatic growth in renewable electricity generation from wind and solar energy. These generation sources have close to zero short-run marginal cost (SRMC) and so increases in their capacity have a depressing effect on prices in wholesale electricity markets. Wind and sunshine are also intermittent, and so backup thermal generation is often required to cover periods when wind and sunshine are not available. If backup plant is not flexible, then the most efficient dispatch on average will come from the solution to a stochastic programming problem that maximizes the expected welfare from a dispatch with respect to a given probability distribution (that is common to all agents). Stochastic dispatch and pricing mechanisms of this form have been studied for over ten years (see [1]), and their properties are becoming well understood. As shown by [4], it is not possible to have a dispatch solution that maximizes expected welfare and matching prices that provide revenue adequacy and short-run cost recovery in every random outcome.

In this paper we explore stochastic dispatch and pricing mechanisms that account for the risk aversion of agents. Further we consider a strategic game, where each agent might misrepresent its risk aversion. We show the effect of such market power. The approach draws heavily on the theory of coherent risk measures and risked competitive equilibrium studied in the papers ([2],[3],[5]).

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Generating Specialized Biased Experts for Electricity and Pollution Forecasting using Online Mixture

Mathias Bourel[1] Jairo Cugliari[2] Yannig Goude[3] Jean-Michel Poggi4

[1]Universidad de la República, Uruguay, mbourel@fing.edu.uy
[2]Université Lumière Lyon 2, France, jairo.cugliari@univ-lyon2.fr
[3]EDF R&D, Université Paris Sud, France, yannig.goude@edf.fr
[4]Université Paris Descartes, Université Paris Sud, France, jean-michel.poggi@math.u-psud.fr

Keywords: Sequential Aggregation, Ensemble Methods, Electricity Load Forecasting, Air Pollution

The practical interest of using ensemble methods has been highlighted in several works. Sequential prediction provides a natural framework for adapting ensemble methods to time series data. In the context of sequential prediction, experts make predictions at each time instant, and the forecaster must determine step by step, the future values of an observed time series. To build the prediction, the idea is to combine before each instant the forecasts of a finite set of experts producing a mixture. To do so, a deterministic and robust view of the prediction of individual sequences is proposed in the literature [2]. Empirical studies were conducted on different areas [4] like air quality, prediction of daily workload in a call centre, and finally for the prediction of electricity consumption. These studies focus on the rules of aggregation of a set of experts and examine how to weight and combine the experts.

The aim of this project is to add insight on how these online mixture methods succeed to enhance the prediction performance over individual experts. For this, we mainly adopt an applied point of view, making extensive use of numerical experiments. First, after a study of the prediction mean square error we propose a set of graphical and analytical tools able to track down the contribution of the individual experts in the mixture. This is illustrated using heterogeneous experts for pollution forecasting. Then, we use the concept of diversity [1, 3] to propose new algorithms to enrich the set of original individual predictors. We show by means of numerical experiments the appropriateness of our procedure using simuated data and electricity demand datasets.

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Privacy Preserving Synthetic Smart-Meters Data

Ganesh Del Grosso[1] Georg Pichler[1] Pablo Piantanida[1,2]

[1]L2S, CentraleSupélec-CNRS-Université Paris Sud, 3 rue Joliot-Curie, Gif-sur-Yvette, France,
[2] Montreal Institute for Learning Algorithms (Mila), Université de Montréal, QC, Canada,
piantani@mila.quebec

Keywords: Privacy, Power Grids, Generative Models, Deep Learning.

Power consumption readings taken from the users of an electricity company are very useful data that can have a considerably impact in optimizing the performance of Power Grids. In addition, live power consumption readings can help to detect anomalies and prevent faults in power grids. However, this data contains sensitive information about households from which readings were taken. The goal of our work is to generate artificial power consumption curves that are faithful to natural ones while ensuring privacy for all households used for training the corresponding generative models. We introduce a novel network architecture based on convolutional neural networks [1]. To assess the quality of the produced curves, we make use of different indicators (e.g., mean, maximum-mean ratio, skewness). The performances are investigated on real-data from energy consumption households.

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Co-Clustering for multivariate functional data for the Analysis of Electric Power Consumption

C. Bouveyron[1] L. Bozzi[2] J. Jacques[3] A. Schmutz[4]
[1]Université Côte d'Azur, Lab. Dieudonné, France, charles.bouveyron@math.cnrs.fr
[2]EDF R&D, France, laurent.bozzi@edf.fr
[3]Université de Lyon, Lyon 2 & ERIC EA3083, France, julien.jacques@univ-lyon2.fr
[4]Lim France & ERIC EA3083, France, aschmutz@lim-group.com

Key words: Co-clustering, multivariate functional data, electric power consumption.

After the installation of 300.000 smart meters "Linky" between 2009 and 2011 in the area of Lyon and Tours, the authorities have decided to generalize these meters throughout the territory. By 2021, 35 million meters should be replaced in French households by Linky meters, allowing electricity operators to record electricity consumption. For an operator like EDF with 27 millions of residential dwellings, these new smart meters represent a great opportunity to gather customer consumption data and therefore to improve client knowledge. Indeed, so far, customer data were recorded only every six months, while with the smart meter, the data can be taken up to every second. In practice, EDF plans to access the data every half hour, which means 17472 measures per year for each of the 27 million clients. Nevertheless, this data flood may also be a drawback since they represent a mass of data to store and manage. To this end, it will be necessary to build « summaries » of these data, and one of the way to achieve that is to cluster the data. However, because of the nature of the data, which are time series for each customer, the interest in the simultaneous clustering of customers and time increases considerably.

In [1], the funLBM co-clustering model has been proposed, which allows to build "summaries" of these large consumption data through co-clustering. An R package called funLBM corresponding to this model ois available on CRAN.

The Linky meters do not only measures electric power consumption but also other parameter as indoor and outdoor temperatures of households. Consequently, we don't have anymore one times series by customer but several ones. In the present work, an extension of the funLBM co-clustering model to the case of multivariate curves is proposed.

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Signature-Based Disaggregation of Electricity Demand

Xueqi Dai[1] Themis Palpanas[1]

[1]University of Paris, France, daixueqi@hust.edu.cn
[2]University of Paris, France, themis@mi.parisdescartes.fr

Keywords: electricity demand, disaggregation, time series, motif discovery, similarity search

Several applications need access to detailed knowledge of the electricity consumption patterns of individual consumers. Therefore, there is an increasingly pressing need for analyzing detailed smart meter data, which collect sequences (or time series) of electricity consumption data, aggregated at the level of households. In our work, we describe scalable and robust techniques for disaggregating the smart meter data, in order to identify the signatures, namely, the characteristic usage patterns, of different appliances. Existing techniques are focused on the definition of these signatures. In contrast, we focus on the detection of known signatures in large historical and fast live data, as well as in the extraction of previously unknown, candidate signatures.

Scalable detection of known signatures of variable length: We use our state of the art time series management solutions in order to enable fast similarity search in very large time series collections. Our techniques can answer similarity queries (i.e., detect signatures) of different lengths [1], since electrical equipment signatures can have slight variations in their duration (e.g., the time duration of a washing machine cycle).

Fast extraction of previously unknown candidate signatures of variable length: We automatically search for repeating characteristic patterns, i.e., patterns in the smart meter consumption data that repeat approximately the same unusually often. This method allows us to extract previously unknown signatures, which we can then study in more detail in order to classify them. Once again (and contrary to the current state of the art), we describe techniques that can efficiently operate on patterns of different lengths [2].

The experimental results show that we can successfully identify unknown, or previously unseen signatures. This translates to a significant benefit for the analysts, since it saves them a considerable amount of time and effort, when compared to their current analysis pipelines.

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Partial Recovery in the Graph Alignment Problem

Georgina Hall[1] Laurent Massoulié[2]

[1]Decision Sciences, INSEAD, Fontainebleau, France georgina.hall@insead.edu
[2]Dyogene, INRIA, Paris, France laurent.massoulie@inria.fr

Keywords: Graph Alignment Problem, Partial Recovery, Erdos-Renyi correlated matrices

We consider two adjacency matrices A and B, obtained by generating two correlated (n, q, s) Erdös-Renyi graphs with adjacency matrices A_1 and A_2, and taking $A = A_1$ and $B = \Pi^{*T} A_2 \Pi^*$, where Π^* is a permutation matrix. We present conditions on n, q, and s under which one can recover, both theoretically and computationally, a permutation matrix whose overlap with Π^* is larger than a fixed fraction of the nodes. We also present conditions on n, q and s under which recovery is impossible.

A moment approach for entropy solutions to scalar conservation laws

Swann Marx[1] Tillmann Weisser[2] Didier Henrion[3] Jean Bernard Lasserre[3]

[1]LS2N, École Centrale de Nantes & CNRS UMR 6004, F-44000 Nantes, France marx.swann@gmail.com
[2] Theoretical Division and Center for Nonlinear Studies, Los Alamos, USA tweisser@lanl.gov
[3] LAAS-CNRS, 7 avenue du Colonel Roche, Toulouse, France henrion@laas.fr, lasserre@laas.fr

Keywords: polynomial optimization, nonlinear PDEs, numerical simulation

In this talk, we will propose a new numerical scheme, based on the so called Lasserre hierarchy, which solves scalar conservation laws. Our approach is based on a very weak notion of solution introduced in [1], which is called *entropy measure-valued solution*. Among other nice properties, this formulation is linear in a Borel measure, which is the unknown of the equation, and moreover it is equivalent to the well-known entropy solution formulation. Our aim is to explain that the Lasserre hierarchy allows to solve such a linear equation without relying on a mesh, but rather by truncating the *moments* of the measure under consideration up to a certain degree. This talk is based on some recent results, provided in [2].

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Globally Optimal Solution to Inverse Kinematics of 7DOF Serial Manipulator

Pavel Trutman[1] Mohab Safey El Din[2] Didier Henrion[3] Tomas Pajdla[1]

[1]CIIRC CTU in Prague, pavel.trutman@cvut.cz, pajdla@cvut.cz
[2]Sorbonne Université, Inria, LIP6 CNRS, mohab.safey@lip6.fr
[3]LAAS-CNRS, FEE CTU in Prague, henrion@laas.fr

Keywords: Kinematics, Redundant Robots, Optimization and Optimal Control

The Inverse Kinematics (IK) problem is to find robot control parameters to bring it into the desired position under the kinematics and collision constraints. We present a global solution to the optimal IK problem for a general serial 7DOF manipulator with revolute joints and a quadratic polynomial objective function. We show that the kinematic constraints due to rotations can all be generated by second degree polynomials. This is important since it significantly simplifies further step where we find the optimal solution by Lasserre relaxations of a non-convex polynomial systems. We demonstrate that the second relaxation is sufficient to solve 7DOF IK problem. Our approach is certifiably globally optimal. We demonstrate the method on 7DOF KUKA LBR IIWA manipulator and show that we are able to compute the optimal IK or certify in-feasibility in 99.9% tested poses.

The Impact of Quadratization in Convexification-Based Resolution of Polynomial Binary Optimization

Sourour Elloumi[1,2] Amélie Lambert[2] Arnaud Lazare[1,2] Elisabeth Rodríguez-Heck[3]

[1]UMA Ensta Paris-Tech, France, sourour.elloumi@ensta-paris.fr, arnaud.lazare@hotmail.fr
[2]Cedric-CNAM, France, amelie.lambert@cnam.fr
[3]RWTH Aachen University, Germany, rodriguez-heck@or.rwth-aachen.de

Keywords: Nonlinear programming, Binary programming, Convexification, Quadratization

Polynomial Binary Optimization (PBO) without additional constraints is an NP-hard problem finding applications in areas such as operations research and discrete mathematics but also in more distant fields like computer vision or physics. Recently, the case of optimizing functions of degree at least three has attracted much interest and there have been significant methodological advances in solving higher-degree (PBO) problems.

Several resolution approaches of (PBO) work in two phases: first, an equivalent linear or quadratic problem is defined by introducing auxiliary variables and in the second phase the (lower degree) reformulated problem is solved. This class of approaches aims at drawing benefit from the literature, algorithms and software available for the linear and the quadratic case.

In our work, we focus on approaches that use quadratic reformulations (quadratizations) in the first phase and then solve the quadratization using a convex reformulation in the second phase. Given a quadratization (QP) of (PBO), a new method called `Polynomial Quadratic Convex Reformulation (PQCR)` has been introduced in [3]. (PQCR) is based on the idea of building a family of parameterized equivalent convex formulations of the quadratization (QP). The strongest formulation within this family is the one which provides the tightest continuous relaxation bound, and is obtained from the dual solution of a semidefinite programming relaxation of (QP). The strongest formulation is then selected and solved via a branch-and-bound algorithm, the performance of which potentially benefits from the sharp bound of the formulation. In (PQCR), a simple algorithm is used for the quadratization of (PBO). Our objective is to improve the results presented in [3] by using alternative quadratization procedures such as those introduced in [1, 2]. We present the result of some preliminary experiments evaluating the impact of different quadratizations on the resolution performance of (PQCR).

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An Inertial Newton Algorithm for Deep Learning with Convergence Guarantees

Camille Castera[1,*] Jérôme Bolte[2] Cédric Févotte[1] Edouard Pauwels[1,3]

[1]IRIT, Université de Toulouse, CNRS, France, *corresponding author: camille.castera@irit.fr
[2]Toulouse School of Economics, Université Toulouse 1 Capitole, France
[3]DEEL, IRT Saint Exupery, Toulouse, France

Keywords: Nonsmooth Nonconvex Stochastic Optimization, Deep Learning, Dynamical Systems

We introduce a new second-order inertial method for machine learning called INDIAN [1], exploiting the geometry of the loss function while requiring only stochastic approximations function values and generalized gradients. This makes the method fully implementable and adapted to large scale optimization problems such as the training of a deep neural network.

The algorithm combines both gradient-descent and Newton features as well as inertia. It is a discretized and split version of a dynamical system introduced in [2]. We provide a strong meaning to each hyperparameter of the model by making a connection to Newton's second law.

We prove the convergence of INDIAN to critical points for almost any *classical* deep learning problems. To do so, we provide a well suited framework to analyze deep learning losses, involving tame optimization and Clarke subdifferential [3, 4]. In this framework we provide a step by step proof recipe combining continuous dynamical system analysis together with discrete stochastic approximations in the lines of [5].

From an empirical point of view the algorithm shows promising results on popular benchmark problems, as well as some appealing generalization properties.

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Learning step sizes for unfolded sparse coding

Pierre Ablin Thomas Moreau Mathurin Massias Alexandre Gramfort

Université Paris-Saclay, Inria, CEA, Palaiseau, 91120, France

Keywords: Sparse coding, neural networks, unsupervised learning

The sparse linear regression problem – also called Lasso – has found numerous applications in the past years. Consider a dictionary $D \in \mathbb{R}^{n\times m}$ and a regularization parameter $\lambda \in \ ]0, 1[$. For an input $x \in \mathbb{R}^n$, the Lasso problem writes:

$$z^*(x) \in \arg\min_{z\in\mathbb{R}^m} F_x(z) \quad \text{with} \quad F_x(z) \triangleq \frac{1}{2}\|x - Dz\|^2 + \lambda\|z\|_1 \ .$$

The resolution of this convex problem yields sparse codes $z^*(x)$ with few non-zero coefficients. In this work, we are interested in the fast minimization of F_x, in the context of computing the solution $z^*(\cdot)$ for many inputs $\{x_1, \cdots, x_N\}$, with fixed values for D and λ. The Iterative Shrinkage-Thresholding Algorithm (ISTA) is a simple and popular iterative algorithm to solve the Lasso. It starts from $z^{(0)}(x) = 0$ and iterates:

$$z^{(t+1)}(x) = \mathrm{st}\left(z^{(t)}(x) - \alpha D^\top(Dz^{(t)}(x) - x), \alpha\lambda\right) \ ,$$

where st is the soft-thresholding operator $\mathrm{st}(x, u) = \mathrm{sign}(x)\max(|x| - u, 0)$, and $\alpha > 0$ is the step size. One iteration of ISTA can be rewritten as $z^{(t+1)}(x) = \mathrm{st}\left(W_1 z^{(t)}(x) + W_2 x, \alpha\lambda\right) = \phi(z^{(t)}(x), x, W_1, W_2, \alpha)$, where $W_1 = I_m - \alpha D^\top D$ and $W_2 = \alpha D^\top$. This equation defined a recurrent neural network (RNN), where st plays the role of the non-linearity.

The authors in [1] proposed to unroll this RNN and to learn betters weights W_1, W_2 through backpropagation, defining a new procedure called Learned ISTA (LISTA). This unrolled network Φ_Ω with T layers of parameters $\Omega = (W_1^t, W_2^t, \alpha^t)_{t=1}^T$ is a mapping $\mathbb{R}^n \to \mathbb{R}^m$ defined by recursion: $z^{(t+1)}(x) = \phi(z^{(t)}(x), x, W_1^t, W_2^t, \alpha^t)$, and $\Phi_\Omega(x) = z^{(T)}(x)$. The weights Ω of the network are trained to solve the Lasso *i.e.*

$$\Omega^* \in \operatorname*{argmin}_\Omega \mathbb{E}_x[F_x(\Phi_\Omega(x))] \ ,$$

where the expectation is taken with respect to some input distribution of x denoted $p(x)$. In our work, we assume that $p(x) > 0$ whenever $\|D^\top x\|_\infty = 1$. Consider a deep network Φ (with T large) trained by minimizing this expected risk, and assume that W_1^t, W_2^t, α^t converge towards W_1^*, W_2^*, α^*. Our main result shows that $W_1^* = I_m - \alpha^* D^\top D$ and $W_2^* = \alpha^* D^\top$. This is to say that asymptotically, the network only learns a step size α^*. This justifies the use of networks where only a step size is learned, with the much simpler architecture $\Omega = (\alpha^t)_{t=1}^T$. We show and explain why these networks perform well in a very sparse setting. Thanks to the much reduced complexity, they need fewer samples to be trained.

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General Risk Measures for Robust Machine Learning

Émilie Chouzenoux[1] Henri Gérard[2] Jean-Christophe Pesquet[1]

[1]CentraleSupélec, Inria Saclay, Université Paris-Saclay, France
emilie.chouzenoux@centralesupelec.fr, jean-christophe@pesquet.eu
[2]Université Paris-Est, CERMICS (ENPC), Labex Bézout, France,
hgerard.pro@gmail.com

Keywords: Risk measures, robust statistics, machine learning, convex optimization, divergences, Wasserstein distance)

A wide array of machine learning problems are formulated as the minimization of the expectation of a convex loss function on some parameter space. Since the probability distribution of the data of interest is usually unknown, it is often estimated from training sets, which may lead to poor out-of-sample performance. In this work, we bring new insights in this problem by using the framework which has been developed in quantitative finance for risk measures [1]. We show that the original min-max problem can be recast as a convex minimization problem under suitable assumptions. We discuss several important examples of robust formulations, in particular by defining ambiguity sets based on φ-divergences and the Wasserstein metric. We also propose an efficient algorithm for solving the corresponding convex optimization problems involving complex convex constraints [2]. Through simulation examples, we demonstrate that this algorithm scales well on real data sets.

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Modeling transmission link's degradation caused by weather phenomena - the special case of FSO networks

Marinela Shehaj[1] Dritan Nace[1] Michał Pióro[2] Ilya Kalesnikau[2]

[1]Sorbonne Universités, Université de Technologie de Compiègne, CNRS, Heudiasyc UMR 7253, France,
marinela.shehaj@hds.utc.fr, dritan.nace@hds.utc.fr
[2]Institute of Telecommunications, Warsaw University of Technology, Poland,
m.pioro@tele.pw.edu.pl, i.kalesnikau@tele.pw.edu.pl

Keywords: FSO, robust optimization, multi-commodity flows, resilient and survivable networks, linear and mixed integer programming.

In this work we consider communication networks sensitive to weather conditions such as Free Space Optics (FSO). The network optimization problem we study is how to dimension the network links at the lowest cost, and at the same time assure the traffic demand satisfaction at an acceptable level for all weather conditions. This work is in continuation of the work presented in [1]. To deal with this problem we have proposed in the above cited work a mathematical formulation together with an optimization approach. We have considered the network design problem corresponding to FSO networks resilient with respect to multiple partial link failures and solved it through a cut-generation algorithm. The failures we are dealing with are due to adverse weather conditions and we need to ensure robustness, which makes the problem more difficult. To construct this approach we start with building a reference failure set which uses weather data records. Still, this set does not necessarily covers all future failure states but gives a good idea of what the network should be protected. Hence, we have proposed to approximate the reference failure set with a special kind of virtual failure set called K-set, parameterized by an integer value K, where K is less than or equal to the number of all links in the network. For a given K, the K-set contains all states corresponding to all combinations of K, or less, simultaneously affected links. We have extended this work by considering simultaneous degradations of K nodes (meaning degradation of all adjacent links). Finally, inspired by the hitting set problem a new idea was to find a large number of subsets of two or three affected links and to use all possible combinations (composed of 2 or at most 3 of this subsets) to build a new virtual failure set that covers as much as possible the reference failure set that we got from the study of real weather data records. Next, this new failure set will serve as input for our cut-generation algorithm so that we can dimension the network at a minimum cost and for a satisfactory demand realization. This investigation is the subject of our current research, which will be part of the presentation to PGMODays 2019. Numerical results will illustrate the effectiveness of our findings.

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Optimizing Battery Usage for a Telecommunications Company Participating in a Curtailing Market

Isaias F. Silva[1,2] C. Bentz[2] M. Bouhtou[1] M. Chardy[1] S. Kedad-Sidhoum[2]

[1]Orange Labs, France, isaias.faria;mustapha.bouhtou;matthieu.chardy@orange.com
[2]Cedric-Cnam, France, cedric.bentz;safia.kedad_sidhoum@cnam.fr

Keywords: Energy Storage Optimization, Curtailing Market, Telecommunications

Using batteries as backup in case of power outages is common in telecommunications companies since they provide critical services and need to keep their services always online [3]. Such batteries are used in conjunction with other devices. In order to guarantee that they are always available in case of a power outage, strict usage rules must be considered. In addition, the company may use those batteries to participate in the energy market. Indeed, since the energy prices vary over time, batteries can be used to cover the energy demands when these prices are high. The batteries will then be preferably recharged when these energy prices are low [2]. Another energy market for which the use of batteries can be profitable for the company is the Curtailing Market [4]. In this context, the company can be incited to cut down its consumption by receiving a reward in exchange (i.e. performing a curtailing) when the total demand is larger than the production [1]. Usually such a reward depends on the amount of energy not bought during a curtailing.

Managing batteries while respecting the safety usage rules (e.g. immediate recharge at a constant rate) and the rules imposed by the energy markets (e.g. minimum and maximum curtailing duration) is a key aspect of the problem. Such a management is fundamental to keep the network safe in case of power outages and to improve the revenue for the company. Our focus is to optimize the total energy cost of the company in the single battery case.

We propose a solving approach based on the enumeration of a small subset of curtailings that can be performed over the planning horizon, and that allows to formulate the problem as a longest path problem in a directed acyclic graph. We then provide several natural assumptions that ensure that this graph has a polynomial number of vertices, and thus that the problem can be solved in polynomial time.

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Sequential Learning in Resource Allocation Games as Path Planning Problems with Side-Observations

Dong Quan Vu[1] Patrick Loiseau[2] Alonso Silva[3] Long-Thanh Tran[4]

[1]Nokia Bell Labs France, AAAID Team. [2]Univ. Grenoble Alpes & Inria, CNRS Grenoble INP LIG & MPI-SWS.
[3]Safran Tech, Signal and Information Technologies. [4]Univ. of Southampton, Electronic & Computer Science Department

Keywords: Resource Allocation Game, Online Combinatorial Optimization, Regret-Minimization.

Resource allocation games are used to model a vast range of practical problems. Particularly, two of the most renowned are the Colonel Blotto game (CB game) and the Hide-and-Seek game (HS game). Due to the space limit, henceforth we focus on the CB games and omit the details about the HS games. In CB games, two players, each with a fixed amount of budget, simultaneously allocate their (indivisible) resources on n battlefields, each player's payoff is the aggregate of the values of battlefields where she has a higher allocation. These games have been profoundly studied but mostly limited to the one-shot and full-information version. In most of the applications, a repeated game with incomplete information proves to be a more natural model; however, it is not trivial how one can efficiently learn in this online version of the games due to their extremely large search-space. Our contributions are twofold: (i) we show that the CB games and HS games can be cast as path planning problems with side-observations (SOPPP), an instance of the combinatorial bandits with side-observations framework proposed by [1]; (ii) we propose a novel algorithm for SOPPPs that obtains important improvements comparing to the state-of-the-art.

In SOPPP, at each stage t, the learner chooses a path, say $\tilde{\boldsymbol{p}}_t$, on a directed acyclic graph G. Each edge e on G is adversarially embedded with a loss $\boldsymbol{\ell}_t(e)$. The learner's incurred loss is the sum of losses corresponding to the edges belonging to $\tilde{\boldsymbol{p}}_t$. At the end of stage t, the learner observes the losses on the edges belonging to $\tilde{\boldsymbol{p}}_t$ plus several other edges' losses, called the side-observations. This partial observability is between the semi-bandit and full-information settings. The learner's objective is to minimize the expected regret. The question of designing an efficient algorithm with good regret-guarantees for SOPPP has not been completely solved. The best benchmark in the literature is the FPL-IX algorithm, proposed by [1], having a running time in $\mathcal{O}(T^{3/2})$ guaranteed only with high probability and under the condition that there exists an efficient oracle solving the involved optimization problem at each stage. We propose *a novel algorithm*, called Exp3-OE, that belongs to the class of Exp3 algorithms. It always runs efficiently in $\mathcal{O}(E^3T)$ time (E is the number of edges of G) without any auxiliary oracles or procedures. Two major novel elements of Exp3-OE are: (i) we use the *implicit exploration* technique controlled by a fixed parameter to improve the regret guarantee; (ii) we introduce a completely novel application of the classical *weight-pushing* technique, i.e., to efficiently compute our loss estimator. We prove that Exp3-OE yields an expected regret bound matching the order with the one provided by FPL-IX. Moreover, under a special assumption (satisfied in many situations, e.g., CB games), Exp3-OE improves the regret bound by a factor of $\sqrt{n}$ (here, n is the length of the longest path in G). Finally, we return to the problem where a learner repeatedly plays a CB game (with a budget of k units of resource) against an adversary; her feedback at the end of each stage is her gains from the battlefields but not the adversary's allocations. We first introduce a graphical representation of the learner's action set where each edge represents a certain allocation to a certain battlefield and each path corresponds a (pure) strategy. We then notice that in this setting, the learner can actually deduce, without extra cost, several side-information from the above-mentioned feedback, i.e., we have cast the CB game into the SOPPP framework. Therefore, by applying Exp3-OE, we obtain a regret at most $\mathcal{O}(n^{3/2}\sqrt{Tk})$ and Exp3-OE is guaranteed to run polynomially in terms of k and n. Note finally that the SOPPP model goes beyond the considered games and it can be applied for learning in other network-based environments.

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Optimizing Network Investments and Designing of Offers for an Operator

Adrien CAMBIER[1,2] Matthieu CHARDY[1] Rosa FIGUEIREDO [2]
Adam OUOROU[1] Michael POSS[3]

[1]Orange Labs, Châtillon, France, adrien.cambier@orange.com
[2]LIA, Université d'Avignon, Avignon, France
[3]LIRMM, Université de Montpellier, CNRS, Montpellier, France

Keywords: MILP, OR for telecommunications, Investments optimization, Capacity expansion

An increase in the number of users as well as in users demands leads to exponential traffic growth. This traffic growth pushes telecommunication companies to expand their network through important investments (several billion to improve the mobile network in the last six years). They want indeed to satisfy the request of their subscribers in speed and volume to remain competitive. However, excessive or useless investments over the time horizon should be avoided. As a service provider, operators can use subsidies to avoid unnecessary investments. This has led to the design of mobile master plans, whose modeling under a Mixed Integer Linear formulation has been studied in [3]. This modeling integrate both subscriber and network investments. They consider two types of network investments: densification (new pieces of equipment on an existing site) and coverage extension by installing the new technology. These three types of investments are jointly optimized at each period of the time-horizon while satisfying capacity and strategical guidelines constraints (see [2]). The model from [3] tackles the case of a new generation to be installed on existing sites, which is the current case for the French affiliate. However, new sites are installed in other contexts. In particular, 5G arrival comes with a change of paradigm and the migration from a macro-cell network to a multi-scaled cell network, with new microcell networks sites being cheaper but far more numerous in order to cover the whole territory. Another limitation of [3] is that each telecommunication site is associated with its own pool of subscribers, which assumes that there is no overlapping between sites coverage. This assumption leads to overdimensioning since sites coverage overlapping exists in real networks and hence a technology installed on a neighbor site could have been sufficient to serve the subscribers. Allowing the possibility of installing new sites and assessing the earnings due to sites coverage overlapping in dimensionning, are hence important stakes for an operator.

Our modeling contribution over our previous work [3] is two-fold. We model the sites coverage overlapping and the possibility of installing new sites (equipped only with the newest technology) on the areas not yet equipped. We provide a mixed integer formulation that tackles the two cases, and linearize it in a classical way. We reinforce the model with several valid inequalities and adapt the heuristics from our previous works. We prove the NP-hardness of our formulation, even in the case of a single generation, single module and mono period framework, by a reduction to the set covering problem.

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Expressiveness, Robustness and Stability of Landscape Features

Quentin Renau[1] Johann Dreo[2]
Carola Doerr [3] Benjamin Doerr [4]

[1]Thales Research & Technology, France, quentin.renau@thalesgroup.com
[2]Thales Research & Technology, France,
[3]Sorbonne Université, CNRS, LIP6, France
[4]École Polytechnique, Institut Polytechnique de Paris, CNRS, LIX, France

Keywords: Exploratory Landscape Analysis, Black-Box Optimization, Automated Algorithm Configuration

Exploratory Landscape Analysis (ELA) [3] aims at measuring the characteristics of an optimization problem through a set of numerical values called *features*, with the hope to use these indicators for an automated selection and/or configuration of a suitable solver. ELA has been used successfully applied to a broad range of classical optimization problems, and forms state of the art in a rapidly growing number of disciplines. However, there are various elementary aspects on ELA that are far from being well understood.

Our worked addresses four basic properties:

- **expressiveness:** How well does a feature discriminate between different optimization problems?
- **stability:** How robust is the feature value against the sampling strategy?
- **influence of sample size:** Does the number of sample points influence the feature value?

We analyze these questions on 7 out of the 17 features sets covered by the flacco package [2]. Our test bed are the 24 noiseless BBOB functions [1]. To answer the second we compare three different sampling methods: uniform iid sampling, Latin Hypercube Sampling and Sobol' sequences, and take into account the randomness of these generators. We show that the impact of the sample generator is much more important than anticipated.

This presentation is based upon [4] and is supported by the PGMO/LabeX LMH project "Self-adjusting parameters choices in heuristic optimization".

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ℓ_0-Regularized Huber Loss Function

Deniz Akkaya[1] Mustafa Ç. Pınar[2]

[1]Bilkent University, Turkey, deniz.akkaya@bilkent.edu.tr
[2]Bilkent University, Turkey mustafap@bilkent.edu.tr

Keywords: Huber loss function, sparsity, local minima, global minima

We investigate the solution of the non-convex optimization problem defined using a positive scalar β:

$$\min_{x\in\mathbb{R}^n} F(x) \equiv \Phi(x) + \beta\|x\|_0,$$

where the term $\|x\|_0$ counts the non-zero elements of the vector x, and $\Phi(x) = \sum_{i=1}^{M} \phi_\gamma(r_i(x))$ with $r_i(x) = a_i^T x - d_i$, $i = 1, \ldots, m$. Furthermore, the function $\phi_\gamma(t) : \mathbb{R} \to \mathbb{R}$, known as the Huber loss function [1], is defined using a positive scalar γ as

$$\phi_\gamma(t) = \begin{cases} \frac{t^2}{2\gamma} & \text{if } |t| \le \gamma \\ |t| - \frac{\gamma}{2} & \text{if } |t| > \gamma. \end{cases}$$

The Huber loss function is one of the central tools of the field of robust statistics (and regression) where an estimator is sought under deviations from the Gaussian nature of the errors in the observations. It is also quite useful in engineering applications as demonstrated in [2]. There are literally hundreds of papers focusing on the sparsity-regularized least squares problem:

$$\min_{x\in\mathbb{R}^n} \|Ax - d\|_2^2 + \beta\|x\|_0 \tag{1}$$

where $A \in \mathbb{R}^{M\times N}$ and $d \in \mathbb{R}^M$, see e.g., [3, 4] where optimality conditions and algorithms are presented for problem (1). To the best of the authors' knowledge, no similar study concerning F is available. We prove that by solving an auxiliary convex optimization problem using the Huber loss function one can find a local minimizer of F. We then give necessary and sufficient conditions under which a local minimizer is strict. We also prove that the set of global minimizers is non-empty. We investigate bounds on the parameter β for which global minimizers are sparse.

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Unconstrained nonlinear relaxations in global optimization

Simon Boulmier[1]

[1]LocalSolver/ Université Grenoble Alpes, France,
sboulmier@localsolver.com

Keywords: global optimization, nonlinear programming, augmented lagrangian algorithm, Wolfe duality, unconstrained optimization.

The global optimization of mixed-integer nonlinear programs is a very ambitious goal, with many practical applications. Here, we consider the broadest class of such problems, where no convexity or regularity assumptions are made. We only require that an expression graph representing the objective and constraints be given.

The most common approach to solve these generic problems is the *reformulation convexification* technique. It uses a symbolic reformulation to express the problem in a standard form, such as the one introduced in [1], that facilitates the implementation of various tools like convex relaxations and bound tightening techniques. Some of the most successful global solvers [2, 3] follow this approach and make use of decades of engineering in mixed-integer linear programming for robustness and efficiency.

Since the work of [4], we know that the hybridation with nonlinear programming can lead to substantial improvements. However, linear relaxations still rule in most global optimization solvers and remain the default setting. This presentation summarizes a three years long work at LocalSolver, where we implemented a global optimization solver that can use both linear and nonlinear relaxations. Instead of a dynamic approach like in [4], we show that nonlinear relaxations can be competitive by themselves (even if, of course, a hybrid approach will always be better). For that purpose, we implemented a nonlinear optimization algorithm specifically designed to solve our nonlinear relaxations. Its success is based on a duality result and on augmented lagrangian relaxations, both leading to unconstrained relaxations of the problem.

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HYBRIDIZING SIMULATED ANNEALING WITH RADIAL BASIS FUNCTION NETWORKS MODEL FOR GLOBAL OPTIMIZATION PROBLEMS

Hemmak Allaoua[1]

[1]Mohamed Boudiaf University of Msila, Algeria, allaoua.hemmakr@univ-msila.dz

Keywords: Global Optimization, Radius Basis Function Network, Simulated Annealing, Hybridizing Metaheuristics

In most cases, many problems in several fields involve the determination of global optimum of multidimensional function with a great number of local optima. Despite their contribution in terms of efficiency, the existing methods still reveal a major handicap to escape the trap of the local optimum.This paper presents a new scenario of hybridizing the global and stochastic metaheuristics, Simulated Annealing (SA), with a Radial Basis Function Networks Model (RBFNM) to deal such problems. The proposed approach, called Enhanced Simulated Annealing (ESA), aims to take advantage of the power of neuron networks in terms of optimization. Supervised learning is applied to build a network model that can simulate the objective function. Our goal is to provide a new tool to both improve the solution quality and avoid premature convergence of SA. It is a low-level relay hybridization since the RBNFM is incorporated in the SA algorithm instead of the neighborhood process. A comparison between SA and BNFNM is performed to show the efficiency of the new approach applied on some standard test optimization functions known as multi-dimensional and with several local optima. Despite the cost in terms of computing time, the results are encouraging and promising in terms of convergence..

Optimization of the power mix and the remuneration of the electric vehicles with VGI facilites

Pierre NICOLAS[1] Frederic LANTZ[2] Maria Juliana SUAREZ FORERO[12]

[1]Renault, France, pierre.nicolas@renault.com

[2]IFP School, France, frederic.lantz@ifpen.fr, maria-juliana.suarez-forero@renault.com

Keywords: Energy mix, Storage, Electric vehicles

In the context of the *Fossil Free Island* project, responding to the challenge of energy transition and looking for energy independence, Porto Santo, a Portuguese island in Madeira region develops a strategy on electric vehicles with intelligent and reversible recharge. Recharge system forecasts would take into account the island driving conditions and drivers behaviour as well as meteorologic characteristics, since a storage system supporting the power grid service will allow to expand intermittent renewable energies sources. Nowadays, power supply is provided mainly by thermal power plants with 85% of the annual production and about 15% by photovoltaic and wind power units. Nevertheless, without specific seasonality of airstreams and without extreme variations of solar irradiation all along the year in the region, both resources, solar and wind power, may be exploited for immediate consumption when meteorologic conditions correspond to customers demand and for storage and delayed restitution when production exceeds demand.

A priori, an energetic analysis takes us to see the influence of the mix distribution between photovoltaic and wind power on the needed storage capacity. For having a considerable high renewable energies percentage on the total production, a system with a dominant photovoltaic installed power needs much more storage capacity -till it is necessary to provide electricity during the hours without sun irradiation- but with a smaller installed capacity needed -till during the daily hours the irradiation presence is rather constant-. Whereas, with a dominant percentage of wind power it is harder to predict the moments of the day with airstreams. It would be necessary to have a higher installed capacity with a smaller storage capacity.

We build an optimization model for the power system considering different remuneration modes for car owners. The integer programming model is solved for a typical period with an hourly time step and different intermittent REn production levels. In the objective function we introduce the cost of the power units and the household electricity demand is given. The car batteries can be plugged on the grid to charge or discharge according the level of local demand curve or according to a tariff signal.

Data from the local transmission system operator EEM are used for this model (year 2017). The optimal distribution of these resources involving economic, behavioral and stochastic parameters are analysed considering the level of car batteries remuneration.

Quantifying the value of flexibility: demand response versus storage

Ana Paula Chorobura[1] Wim van Ackooij[2] Claudia Sagastizábal[3] Hasnaa Zidani[1]

[1]ENSTA Paris, France, ana-paula.chorobura@ensta-paris.fr, hasnaa.zidani@ensta-paris.fr
[2]Électricité de France (EDF), France, wim.van-ackooij@edf.fr
[2]State University of Campinas (UNICAMP), Brazil, sagastiz@unicamp.br

Keywords: Multi-objective programming, Energy management tools, Sensitivity analysis

Intermittent sources of energy represent a challenge for electrical networks, particularly regarding demand satisfaction at peak times. Energy management tools such as load shaving or storage systems can be used to mitigate abrupt variations in the network. The value of different mechanisms to move energy through time is determined by a multi-objective programming approach, that aims at minimizing operating costs as well as carbon emissions. We consider a model similar to [2]; see also [1] with the important difference that we extend the approach to the multi-objective case. Namely, in addition to the usual cost-minimization we incorporate an environmental concern, referred to minimizing fuel emissions. For solving the multi-objective optimal control problem we used the algorithm presented in [3]. By combining the output with sensitivity theory, the new technique builds a three-dimensional Pareto front, in which the usual information on indifference costs is accompanied by a third dimension that provides the decision maker with a quantitative measure to evaluate the relative impact of the two conflicting objectives. The interest of the methodology is assessed on three instances representing typical configurations in Brazil, Germany and France, respectively corresponding to a system that is hydro-dominated, thermo-dominated, and with a balanced mix of hydro and thermal power.

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Economical assessment of different usage of microgrid battery storage in the UK market context

M. Kadkhodaei[1] A. Vignon[2]

[1]Ecole Polytechnique, France, maryam.kadkhodaei@polytechnique.edu
[2]Schneider Electric, France, antoine.vignon@se.com

Keywords: Electricity Consumption Optimization, Ancillary services, Aggregator, FFR, STOR)

Due to carbon reduction policies share of renewable energies has increased. One of the emerging solutions for handling the intermittency of these resources is development of the Microgrids with battery storages. The battery storage could be used to reduce the electricity bill or to gain revenue from ancillary services. The objective of this project is to conduct an economical study on commercial microgrid with onsite PV production and battery storage located in the UK, to find the most beneficial usage of the battery. Three use cases are defined :

1. Optimization of electricity consumption
2. Optimization of revenue of ancillary services
3. Optimization of electricity consumption and ancillary service revenue at the same time

The ancillary services considered in this project are Firm Frequency Response (FFR) and Short-term Operating Reserve (STOR), operated through an aggregator of flexibilities. The saving of each case is analyzed based on one year data and the potential interaction between the microgrid and the aggregator is discussed. The result of this study shows that the most beneficial use-case is using the battery for optimizing electricity consumption and providing FFR service at the same time while using the battery only for ancillary services is not profitable.

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Optimal Design of a District Cooling System Design by Mixed Integer Linear Programming

Bingqian Liu[1,2,3] Côme Bissuel[1] François Courtot[2] Céline Gicquel[3] Dominique Quadri[3]

[1]EDF R&D, France, come.bissuel@edf.fr, bingqian.liu@edf.fr
[2]EDF R&D China, China, francois.courtot@edf.fr
[3]LRI, Université Paris-Sud, France, celine.gicquel@lri.fr,dominique.quadri@lri.fr

Keywords: Local Cooling System, Optimal design, Branch & Bound

In a district cooling system, chillers convert electricity to cooling power which is distributed through an underground pipe network to the buildings in the district. Designing such a system involves choosing the type and number of chillers to be installed as well as the ice storage capacity. These decisions should take into account not only the construction costs, but also the operation costs of the system during its whole lifetime. In order to accurately compute these operation costs, a detailed schedule describing, on a hourly basis, the on/off status and the load allocation of each chiller should be built for an horizon spanning a whole year. Furthermore, the deployment of a district cooling system is usually not a one-shot decision but rather a process in which investment decisions are made step by step, following the development of the district over the years. This implies that a multi-year strategic deployment plan should be built.

This optimization problem can be formulated as a mixed-integer linear program (MILP). However, its huge size makes it intractable for current MILP solvers. In order to reduce it, we consider a deployment plan involving a limited number of years and we use the clustering approach described in [1] to select a small set of typical and extreme days to represent as best as possible the various conditions under which the system will be operated. The resulting MILP is then solved by a customized Branch & Cut algorithm exploiting the hierarchical relationship between the construction and operation variables: see [2]. We provide preliminary computational results based on a real-life case study in China. These results show that the customized algorithm significantly outperforms the generic Branch & Cut algorithm embedded in CPLEX solver in terms of computation time.

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SMS++: a Structured Modelling System for Optimization

Antonio Frangioni[1] Rafael Durbano Lobato[1]

[1]Dipartimento di Informatica, Università di Pisa, Italy, [frangio/rafael.lobato]@di.unipi.it

Key words: Modelling Systems, Energy Optimization, Decomposition, Stochastic Optimization

Large-scale infrastructures like energy systems have to be constructed and upgraded, over the span of multiple decades, to satisfy current needs while adapting to technological, societal, and political changes that are hard to foretell far in advance, all at the least cost (not only economical, but also societal and environmental). In an effort to provide decision-makers with much-needed tools to manage these complex systems, highly intricate mathematical models have to be constructed and solved. These have to represent the system under analysis with an appropriate degree of accuracy, capturing phenomena at time resolutions spanning from decades to minutes, and accounting for different forms of uncertainty description. A hierarchical combination of heterogeneous decomposition methods, together with specialized solution methods for specific sub-structures of the model, is crucial to make these huge-scale optimization problems tractable. Efficiently implementing such algorithms is a daunting task, especially if modelling flexibility is required and distributed computation is used to exploit HPC systems, which is necessary to tackle real-world instances.

In order to facilitate the implementation and maintenance of complex models having several nested layers of structure, and general and flexible algorithms for solving them, the innovative, open-source *Structured Modeling System++* (SMS++) is being developed, supported by the H2020 project "plan4res" and by the PGMO project "Multilevel Heterogeneous Distributed Decomposition for Energy Planning with SMS++". In the Case Studies of plan4res, devoted to the strategic assessment of the whole European energy system for the next decades, the Unit Commitment problem emerges at the lowest layer. It is a hard (especially when uncertainty is considered [1]) Mixed-Integer Nonlinear optimization problem regarding the short-term (say, daily) scheduling of generation units. Higher layers concern the mid-term (say, yearly) management of energy reservoirs (water, gas, ...) in the face of several uncertainties (climate, demand, ...), and finally the long-term evolution of the energy system (construction/decommissioning of generators and energy lines, investments in different generation technologies, ...). The currently available modelling and solving tools do not offer adequate support for fully exploiting this kind of structure, making dealing with these models an herculean task in terms of programming; this is the issue that the SMS++ system primarily seeks to address. We will present its current state of development, focussing in particular on recent improvements concerning the representation of uncertainty, which are meant to facilitate the transformation of complex deterministic models into stochastic ones. Specific SMS++ facilities for "general-purpose decomposition techniques" will then allow to efficiently produce multi-level decomposition approaches to these problems.

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Stochastic lot-sizing problem with remanufacturing: a dual dynamic decomposition approach

Franco Quezada[1] Céline Gicquel[2] Safia Kedad-Sidhoum[3]

[1]Sorbonne Université, France, franco.quezada@lip6.fr
[2]Université Paris-Saclay, France, celine.gicquel@lri.fr,
[3]Conservatoire national des arts et métiers, France, safia.kedad_sidhoum@cnam.fr

Keywords: Lot-sizing, remanufacturing, multi-stage stochastic process, dynamic programming decomposition, SDDiP

We consider an uncapacitated multi-item multi-echelon lot-sizing problem within a remanufacturing system involving three production echelons: disassembly of used products brought back by customers, refurbishing of the recovered parts and reassembly into like-new finished products. We aim at optimizing the production planning for the corresponding three-echelon system over a multi-period horizon. Production planning involves making decisions about the production level (i.e. which products and how much of them should be made), the timing (i.e. when the products should be made) and the resources to be used. Within a remanufacturing context, production planning includes making decisions on the used products returned by customers, such as how much and when used products should be disassembled, refurbished or reassembled in order to build new or like-new products. The main objective is to meet customers' demand for the remanufactured products in the most cost-effective way.

We consider a stochastic environment, in which the input data of the optimization problem are subject to uncertainty. We propose a multi-stage stochastic integer programming approach relying on scenario trees to represent the uncertain information structure and develop a stochastic dual dynamic integer programming algorithm to solve the problem on large-size scenario trees. More specifically, we investigate a stochastic dynamic programming formulation of the problem based on continuous state variables, which allows us to decompose the problem into a series of single-node subproblems. We then reformulate the obtained sub-problems by using a binary approximation of the continuous state variables, allowing us to use the SDDiP algorithm proposed in [2] to solve the problem. We also study an approximate version of the SDDiP algorithm in which a cutting-plane generation phase based on continuous state variables is carried out to build an approximation of the expected cost-to-go functions. The proposed stochastic dynamic programming formulation provides a starting point for the application of such decomposition methods to production planning problems. Additionally, our numerical results show that the proposed method is capable to obtain near-optimal solutions in practicable computation times for large-size instances, showing its applicability to real-world optimization problems. For further details, we refer the reader to [1].

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Scenario and Stage Decompositions for Planning Energy Investment under Uncertainty

Felipe Atenas[1] Claudia Sagastizábal[2] Wim van Ackooij[3] Welington de Oliveira[4]

[1]University of Chile, felipe.e.atenas@gmail.com
[2]Unicamp, sagastiz@unicamp.br
[3]EDF R&D OSIRIS, wim.van-ackooij@edf.fr
[4]CMA, Mines ParisTech, welington.oliveira@mines-paristech.fr

Keywords: Energy Management, Stochastic Programming, Progressive Hedging

We consider multistage risk-averse stochastic programming models for the generation expansion planning problem for energy systems with here-and-now investment decisions. The resulting problem is coupled both along scenarios and stages. An important algorithm for dealing with this kind of problems is the Progressive Hedging Algorithm (PHA), which decomposes the problem by scenarios. For every iteration and scenario, the PHA requires solving a quadratic problem (QP) that, depending on the number of stages, can be itself a large scale optimization problem. To overcome this difficulty, we equip the PHA with a stage decomposition yielding relatively more, but significantly smaller QPs.

A Decomposition Method by Component for the Optimization of Maintenance Scheduling

T. Bittar[1,2] P. Carpentier[3] J-Ph. Chancelier[1] J. Lonchampt[2]

[1]CERMICS, École des Ponts ParisTech jean-philippe.chancelier@enpc.fr
[2]EDF R&D, PRISME Department thomas.bittar@edf.fr, jerome.lonchampt@edf.fr
[3]ENSTA Paris, pierre.carpentier@ensta-paris.fr

Keywords: Maintenance scheduling, decomposition-coordination, stochastic optimization

In order to improve the reliability and performance of its hydroelectric fleet, EDF (Électricité De France) seeks to optimize the maintenance scheduling of the components of hydroelectric power plants. In this work, we address an idealized maintenance scheduling optimization problem. We study a system which consists of several physical components (turbines, alternators, generators) that share a common stock of spare parts. Over time components experience random failures that occur according to known failure distributions. Thus the dynamics of the system is stochastic. The goal is to find a deterministic preventive maintenance strategy that minimizes the expected cost depending on maintenances and on the occurrences of forced outages of the system. The numerical experiments should involve systems constituted of up to 80 components thus leading to high-dimensional optimization problems. To overcome the curse of dimensionality, we use the interaction prediction principle [1] to decompose the original optimization problem into a sequence of independent subproblems of smaller dimension. Each subproblem consists in optimizing the maintenance on a single component. The resulting algorithm iteratively solves the subproblems with the blackbox algorithm MADS [3] and coordinates the components. The maintenance optimization problem is a mixed-integer problem. However decomposition methods are based on variational techniques so they are not suited for these kind of problems. It is therefore needed to relax the dynamics of the system as well as the cost functions in the formulation of the maintenance optimization problem. The relaxation parameters have an important influence on the output of the optimization by decomposition and must be appropriately chosen. We apply the decomposition method on relaxed systems with up to 80 components. The more demanding case takes around 20 hours of computation time. We show that in high dimension it outperforms the blackbox algorithm applied directly on the original problem.

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Anchor-Robust Solutions for the Resource-Constrained Project Scheduling Problem

Pascale Bendotti[1,2] Luca Brunod-Indrigo[1,2] Philippe Chrétienne[2]
Pierre Fouilhoux[2] Adèle Pass-Lanneau[1,2]

[1]EDF R&D, EDF Lab Paris-Saclay, 91120 Palaiseau
{pascale.bendotti, luca.brunod-indrigo, adele.pass-lanneau}@edf.fr
[2]LIP6, CNRS, Sorbonne Université, 75005 Paris {philippe.chretienne, pierre.fouilhoux}@lip6.fr

Keywords: project scheduling, resource constraints, robust optimization, solution stability.

In the classical Resource-Constrained Project Scheduling Problem (RCPSP), a set of jobs must be scheduled under precedence constraints and with limited renewable resources so that the makespan of the schedule is minimized. In practice processing times can be uncertain parameters, which motivates robust approaches. An application arising at EDF is to schedule maintenance operations to be performed during a nuclear power plant outage.

We consider the RCPSP when processing times can take any value in an uncertainty set containing their nominal values. The aim is to take uncertainty into account when choosing a *baseline schedule*, i.e., a solution of the RCPSP instance for the nominal values of processing times. A robust-static baseline schedule (i.e., a solution feasible for any uncertainty realization) would have a very large makespan. In order to find a solution meeting a predetermined makespan M, we extend the concept of *anchored jobs* formerly introduced in [1]. Any baseline schedule can be associated with a resource flow [2] encoding the feasibility of the schedule for the resource constraints. A subset of jobs is said to be *anchored* w.r.t. a baseline schedule and a resource flow if for any uncertainty realization in the uncertainty set, the baseline schedule can be repaired into a feasible schedule associated with the same resource flow, without changing the starting times of anchored jobs. The Anchor-Robust RCPSP is then to find a baseline schedule with makespan at most M, an associated resource flow and a max size subset of anchored jobs.

The Anchor-Robust RCPSP is considered for a budgeted uncertainty set, in which a fixed number of processing times may deviate from their nominal value. We show that for budgeted uncertainty the Anchor-Robust RCPSP can be formulated with mixed-integer programming, using graph models from [1]. We also present heuristic approaches that have been successful on benchmark instances from the PSPLib, and report how solutions of the Anchor-Robust RCPSP have been integrated into a decision-aiding tool.

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Constrained Multi-Objective Optimization under Uncertainty with Multi-fidelity Approximations

Mickaël Rivier[1,2] Pietro M Congedo[1]

[1]DeFI Team, CMAP - Ecole Polytechnique, Inria Saclay - Ile de France, France,
mickael.rivier@inria.fr, pietro.congedo@inria.fr
[2]ArianeGroup, Le Haillan, mickael.rivier@ariane.group

Keywords: Multi-objective optimization, optimization under uncertainty, multi-fidelity

We present here a novel method to tackle multi-objective optimization under uncertainty problems. In particular, the aim is to handle both robust and reliability-based optimization problems, where robustness and reliability measures can be estimated with tunable fidelity. Some previous works [1, 2, 3] rely on the concept of Bounding-Box. In these contributions, robustness and reliability measures are approximated by a Bounding-Box (or conservative box), which is roughly a uniform-density representation of the unknown objectives and constraints. It is supplemented with a surrogate-assisting strategy in [2, 3], which is very effective to reduce the overall computational cost, notably during the last optimization iterations.

We propose in this work an extension of the previous method, allowing for objects other than Bounding-Boxes. Such non-uniform approximations have been proposed in previous works like [4] and [5]. Among others, sampling and Gaussian measure approximations are presented and quantitatively compared. We give extensive insights on joint samplings construction and propose suitable Pareto dominance rules and POP (Pareto Optimal Probability) computations for these new measure approximations. The method is assessed on several algebraic test-cases in terms of convergence rate and robustness. Finally, it is applied to the shape optimization of an Organic Rankine Cycle (ORC) turbine.

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Online Computation with Untrusted Advice

Spyros Angelopoulos[1] Christoph Dürr[1] Shendan Jin[1]
Shahin Kamali[2] Marc P. Renault[3]

[1] CNRS and Sorbonne University, France, spyros.angelopoulos, christoph.durr, shendan.jin@lip6.fr
[2] University of Manitoba, Canada, shahin.kamali@umanitoba.ca
[3] University of Wisconsin mrenault@cs.wisc.edu

Keywords: Online computation, competitive analysis, advice complexity, robust algorithms, untrusted advice.

The advice model of online computation captures the setting in which the online algorithm is given some partial information concerning the request sequence. This paradigm allows to establish tradeoffs between the amount of this additional information and the performance of the online algorithm. However, unlike real life in which advice is a recommendation that we can chose to follow or to ignore based on trustworthiness, in the current advice model, the online algorithm treats it as infallible. This means that if the advice is corrupt or, worse, if it comes from a malicious source, the algorithm may perform poorly. In this work, we study online computation in a setting in which the advice is provided by an untrusted source. Our objective is to quantify the impact of untrusted advice so as to design and analyze online algorithms that are robust and perform well even when the advice is generated in a malicious, adversarial manner. To this end, we focus on well- studied online problems such as ski rental, online bidding, bin packing, and list update. For ski-rental and online bidding, we show how to obtain algorithms that are Pareto-optimal with respect to the competitive ratios achieved; this improves upon the framework of Purohit *et al.* [1] in which Pareto-optimality is not necessarily guaranteed. For bin packing and list update, we give online algorithms with worst-case tradeoffs in their competitiveness, depending on whether the advice is trusted or not; this is motivated by work of Lykouris and Vassilvitskii [2] on the paging problem, but in which the competitiveness depends on the reliability of the advice. Furthermore, we demonstrate how to prove lower bounds, within this model, on the tradeoff between the number of advice bits and the competitiveness of any online algorithm. Last, we study the effect of randomization: here we show that for ski-rental there is a randomized algorithm that Pareto-dominates any deterministic algorithm with advice of any size. We also show that a single random bit is not always inferior to a single advice bit, as it happens in the standard model.

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Bayesian Optimization Under Uncertainty for Chance Constrained Problems

Mohamed Reda El Amri[1] Christophette Blanchet-Scalliet[1] Céline Helbert[1] Rodolphe Le Riche[2]

[1]Université de Lyon, Ecole Centrale de Lyon, Institut Camille Jordan,
mohamed-reda.el-amri@ec-lyon.fr,
christophette.blanchet@ec-lyon.fr,
celine.helbert@ec-lyon.fr
[2]CNRS LIMOS, Mines Saint-Etienne, leriche@emse.fr

Keywords: Gaussian Processes, Chance constrained optimization, Adaptive design of experiments

Chance constraint is an important tool for modeling the reliability on decision making in the presence of uncertainties. Indeed, the chance constraint enforces that the constraint is satisfied with probability $1 - \alpha$ $(0 < \alpha < 1)$ at least. In addition, we consider that the objective function is affected by uncertainties. This problem is challenging since modeling a complex system under uncertainty can be expensive and for most real-world stochastic optimization will not be computationally viable.

In this talk, we propose a Bayesian methodology to efficiently solve such class of problems. The central idea is to use Gaussian Process (GP) models [1] together with appropriate acquisition functions to guide the search for an optimal solution. We first show that by specifying a GP prior to the objective function, the loss function becomes tractable [2]. Similarly, using GP models for the constraints, the probability satisfaction can be efficiently approximated. Subsequently, we introduce new acquisition functions to iteratively select the points to query the expensive objective and constraint functions. Finally, we present numerical examples to validate our approach compared to benchmark results.

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A Tight-and-Cheap Relaxation for the ACOPF Problem

Christian Bingane[1] Miguel F. Anjos[2] Sébastien Le Digabel[1]

[1]Polytechnique Montreal, Canada, christian.bingane@polymtl.ca, sebastien.le-digabel@polymtl.ca
[2]University of Edinburgh, UK, anjos@stanfordalumni.org

Keywords: Global optimization, optimal power flow, power systems, convex relaxation

Computational speed and global optimality are a key need for pratical algorithms of the optimal power flow (OPF) problem. Recently, we proposed a tight-and-cheap conic relaxation [1] for the ACOPF problem that offers a favourable trade-off between the second-order cone [2] and the semidefinite [3] relaxations for large-scale meshed networks in terms of optimality gap and computation time. In a recent paper [4], we show theoretically and numerically that this relaxation can be exact and can provide a global optimal solution for the ACOPF problem. Also, numerical results on PGLib-OPF test cases with up to 588 buses show that the tight-and-cheap relaxation on average dominates the quadratic convex relaxation [5].

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Improving Clique Decompositions of Semidefinite Relaxations for Optimal Power Flow Problems

Julie Sliwak[1,2,3] Miguel F. Anjos[3,4] Lucas Létocart[2] Jean Maeght[1] Emiliano Traversi[2]

[1]RTE, France, firstname.lastname@rte-france.com

[2]University Paris 13, France, letocart@lipn.univ-paris13.fr, traversi@lipn.univ-paris13.fr

[3]Polytechnique Montréal, Canada

[4]University of Edinburgh, United Kingdom, Miguel.F.Anjos@ed.ac.uk

Keywords: Clique Decomposition, Optimal Power Flow, Semidefinite Programming

The Alternating Current Optimal Power Flow (ACOPF) is a challenging problem due to its significant nonconvexity, which means that only local optimality can be reached by first-order KKT conditions. Semidefinite relaxations are a powerful tool to prove global optimality: they provide tight lower bounds useful for global optimization approaches [1]. Small-to-medium-sized Semidefinite Programming (SDP) problems are efficiently solved by interior point state-of-the-art solvers. Clique decomposition techniques enable the resolution of some larger sparse problems [2, 3, 4]. However, there are many different ways to compute clique decompositions. In this presentation, we show that different clique decompositions are not equivalent in terms of resolution time by comparing different chordal extension algorithms on RTE and other MATPOWER public datasets. Moreover, we show theoretically that applying clique decomposition techniques to SDP relaxations of ACOPF formulated in complex variables is not equivalent to applying such techniques to the same problems formulated in real variables. We also compare the computational performance of reformulations coming from the complex SDP and from the real SDP problem. Finally, we propose a new clique combination algorithm that improves the computational performance of a given decomposition by adding more edges to the chordal extension.

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Solving Alternative Current Optimal Power Flow to Global Optimality with Quadratic Reformulation Using Semi-Definite Programming and Branch-and-Bound

Hadrien Godard[1,2,4] Sourour Elloumi[1,2] Amélie Lambert[2,3] Jean Maeght[4] Manuel Ruiz[4]

[1]UMA ENSTA Paris, France
[2]CEDRIC, Paris, France
[3]CNAM, Paris, France
[4]RTE Réseau de Transport d'Electricité, France

Keywords: Optimal Power Flow, Semi-Definite Programming, Branch-and-Bound, Quadratic Reformulation, Global Optimization

Alternative Current Optimal Power Flow (ACOPF) is naturally formulated as a non-convex problem. In that context, solving (ACOPF) to global optimality remains a challenge when classic convex relaxations are not exact. We use semidefinite programming to build a quadratic convex relaxation of (ACOPF). We show that this quadratic convex relaxation has the same optimal value as the classical semidefinite relaxation of (ACOPF) which is known to be tight. In that context, we build a spatial branch-and-bound algorithm to solve (ACOPF) to global optimality that is based on a quadratic convex programming bound. An advantage of our approach is that we capture the strength of semidefinite programming bounds into a quadratic convex program that is known to be faster to solve.

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A Difference-of-Convex Approach for Optimal Power Flow Problems with Probability Constraints

Wim Van Ackooij[1] Sophie Demassey[2] Paul Javal[1,2] Hugo Morais[1]
Welington de Oliveira[2] Bhargav Swaminathan[1]

[1] Edf R&D, EDF Lab, Palaiseau France
[2] CMA Mines Paristech, Sophia Antipolis, France

Keywords: Optimal Power Flow, Difference of Convex, Chance Constraints

Handling uncertainties in power system operation leads to challenging Optimal Power Flow (OPF) problems combining nonconvexities and stochasticities [1]. In this work, we consider an OPF problem in which the uncertainties are modeled using a probability constraint. This constraint includes the inherent uncertainties of production and load-levels forecasts. It is a natural and generix way to model a constraint guaranteeing feasibility "as much as possible" [2]. For numerical tractability, we approximate the nonconvex and hard-to-evaluate probability function by a Difference-of-Convex function that is easily assessed via Monte-Carlo simulation. The resulting Difference-of-Convex model for the chance-constrained OPF is handled by a specialized proximal bundle method. Studies of convergence of the algorithm shows convergence to a *critical* point of the resulting problem, under mild assumptions. Convergence to a *B-stationary* point of the original chance-constrained OPF problem can be proved using added assumptions.

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Improvement of condition-based maintenance for a guaranteed level of service on a fleet of equipment

Yves Langeron[1] Antoine Grall[2] Christophe Bérenguer[2]

[1]ICD, Université de Technologie de Troyes, France, yves.langeron@utt.fr, antoine.grall@utt.fr
[2]GIPSA-Lab, Grenoble INP, France, christophe.berenguer@grenoble-inp.fr

Keywords: Stochastic process, availability, condition-based maintenance

Condition-based maintenance aims at considering the current condition of systems or devices in maintenance decision-making. Considering condition-based maintenance policies rather than systematic periodic ones allows to optimize maintenance resources by performing maintenance work only when needed [1]. In the case of multi-component systems or fleets, specific planning and grouping strategies are considered [3, 2]. This work deals with a fleet of equipments which are deteriorating with usage. The equipments have to fulfill several types of missions with different priorities and requirements. Resources dedicated to maintenance are limited and the main aim is to improve the maintenance strategy to ensure a minimal global availability of the whole fleet at any time. Each device is modeled by its lifetime which is described as the sum of two Weibull distributed random variables. The first one represents the time the system is in the nominal working state. The second one corresponds to the deteriorated working state. The sole knowledge on the device state is related to an alarm indicating the change from nominal to degraded state. Dynamic maintenance approaches including device conditions are considered with successive maintenance planning on finite time horizon related to missions durations. Parametric decision rules based on each component remaining useful lifetime are considered. They are compared numerically using Monte Carlo simulation.

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Design of optimal maintenance strategies using piecewise deterministic Markov processes

Benoîte de Saporta[1] François Dufour[2] Huilong Zhang[3]
[1]Montpellier University, France, benoite.de-saporta@umontpellier.fr
[2]Bordeaux INP, France, francois.dufour@math.u-bordeaux.fr
[3]Bordeaux University, France, Huilong.Zhang@math.u-bordeaux.fr

Key words: Impulse control, numerical approximation, stochastic process, availability.

This aim of this project is to propose a maintenance policy which performance is close to the optimal maintenance cost for a multi-component equipment subject to random degradation and failures. We first propose a generic model for the dynamics of such equipments based on piecewise deterministic Markov processes (PDMPs). PDMPs are a generic class of non-diffusive random hybrid processes introduced by Davis in the 80's [1]. Basically, the process follows deterministic trajectories punctuated by random jumps.

The maintenance optimisation problem consists in selecting the maintenance dates and operations (do nothing, change or repair for each component) in order to minimize some cost while keeping a high level of availability. This translates into an impulse control problem for PDMPs. The optimal performance is called the value function of the problem [2]. It can be obtained by iterating some dynamic programming operator.

We implemented the approximation procedure described in [3] on a four-component model. Then we proposed to design a feasible maintenance policy that generates a cost close to the optimal one based on the family of strategies defined in [4]. In this talk, we will present and discuss the numerical results we obtained for the four-component model.

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Principal Component Analysis for a Bundle of Functional Time Series and its Application in Prediction

Qin Fang[1]

[1]Department of Statistics, London School of Economics and Political Science, U.K.

Keywords: Functional time series; Autocovariance; principal component analysis; eigenanalysis; multivariate time series

Modelling and forecasting a bundle of functional time series arise in a broad spectral of real applications. It is a challenging task even when the number of time series is moderately large. In this paper, we explore the principal component analysis for a bundle of functional time series (ts-PCA) in the sense that we transform original series into new low-dimensional subseries. Those subseries are uncorrelated both contemporaneously and serially, and hence can be analyzed separately. Technically it involves an eigenanalysis for a positive definite matrix. Simulation study shows that this proposed method is effective in revealing the true underlying low-dimensional structure. Application to daily electric load datasets is also reported.

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Prediction of building epoch from unconstrained images using deep learning : an expert level ?

José Menoci Neto[1] Céline Hudelot[1] Thierry Duforestel[2]

[1]CentraleSupélec, MICS Laboratory, Paris Saclay University, France, j.menoci@student-cs.fr , celine.hudelot@centralesupelec.fr

[2]EDF, France, thierry.duforestel@edf.fr

Keywords: image classification,building analysis, building age estimation, deep learning, expert level reasoning

In this paper, we present first results on a study that aims at evaluating the benefits of deep-learning based image interpretation approaches for smart building renovation decision-aided systems. Indeed, street-view building pictures are a rich source of information that seems to be of high interest in the evaluation of the interest of building renovation actions. In this context, we focus, here, on a first task that consists into the automatic epoch estimation of individual houses from unconstrained pictures of their external views.

Like the interpretation of medical images, building epoch estimation, if performed by humans, requires great expertise and many expert rules to tackle subtle cases in which class (here epoch) and image relevance are in opposition. For instance, external views of old houses whose facades have been renovated present a lot of visual clues that suggest a more recent epoch than the real one and require complex reasoning on these clues. Automatic epoch estimation of individual houses using only data-driven approaches is thus a very challenging task [1] and we propose to bring human expertise into the learning process.

In this first work, we propose a transfer-learning scheme to learn a prediction model of house epoch from a few coarsely annotated images. We also compare our approach with a recent patch-based approach [3].We then study, using recent visual explanations approaches [2] the relevance and the level of the expertise of the model prediction. We present and discuss our first experimental results in this paper.

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Towards closing the gap between the theory and practice of SVRG

Othmane Sebbouh[1] Nidham Gazagnadou[1] Sami Jelassi[2]
Francis Bach[3] Robert M. Gower[1]

[1]Télécom Paris, Institut Polytechnique de Paris, othmane.sebbouh@gmail.com,
nidham.gazagnadou@telecom-paris.fr, robert.gower@telecom-paris.fr
[2]ORFE Department, Princeton University, sjelassi@princeton.edu
[3]INRIA - Ecole Normale Supérieure, PSL Research University, Paris, francis.bach@inria.fr

Keywords: Stochastic variance-reduced methods, SVRG, optimal mini-batch

SVRG [1] is one the first stochastic variance-reduced methods for solving the empirical risk minimization. Is is based on an inner-outer loop structure: a reference full gradient is evaluated in the outer loop, after which $m \in \mathbb{N}$ steps of an inner loop are executed where the reference gradient is used to build a variance-reduced estimate of the current gradient. Yet there is a significant gap between the parameter settings that the analysis suggests and what is known to work well in practice.

In particular, the current analysis shows that m should be of the order of the condition number. However, setting m to the number of data points works well in practice. Furthermore, the inner iterates of the current analysis must be reset using averaging after every outer loop. Yet in practice SVRG works best when they are updated continuously and not reset. We provide an analysis of these practical settings achieving the same complexity.

We also provide a more general analysis by using arbitrary sampling, allowing all forms of mini-batching. Thus, we can set the parameters such as the mini-batch and step sizes in such a way that produces a more efficient algorithm in practice, as we show in numerical experiments.

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A consistent relaxation of optimal design problems for coupling shape and topological derivatives

Samuel Amstutz[1], Charles Dapogny[2], Alex Ferrer[3]

[1]Ecole Polytechnique, France, samuel.amstutz@polytechnique.edu
[2]CNRS - Université Grenoble Alpes, charles.dapogny@univ-grenoble-alpes.fr
[3]Ecole Polytechnique, France, alex.ferrer@polytechnique.edu

Keywords: shape optimization, topology optimization, shape derivative, topological derivative

I will present a general procedure for approximating a 'black and white' shape and topology optimization problem in linear elasticity with a density optimization problem, allowing for the presence of 'grayscale' regions. The construction relies on a regularizing operator for smearing the characteristic functions involved in the exact optimization problem, and on an interpolation profile, which endows the intermediate density regions with fictitious material properties. In particular, this framework includes the classical SIMP model.

Under mild hypotheses on the smoothing operator and on the interpolation profile, we prove that the features of the approximate density optimization problem (material properties, objective function, etc.) converge to their exact counterparts as the smoothing parameter vanishes. Notably, the Fréchet derivative of the approximate objective functional with respect to the density function converges to either the shape or the topological derivative of the exact objective, depending on whether it is evaluated at the boundary of the domain or in its interior. These results shed new light on the connections between these two different notions of sensitivities for functions of the domain and on the construction of consistent interpolation schemes. This latter also applies to the bi-material case.

Related algorithms, including level-set formulations and the incorporation of perimeter penalization, will be discussed and illustrated by numerical examples.

TOPOLOGY OPTIMIZATION IN BRITTLE FRACTURE MECHANICS USING LEVEL-SETS

J. Desai[1 3] G.Allaire[2] F. Jouve[1]

[1] Laboratoire J.L. Lions (UMR CNRS 7598), Université Paris Diderot, Paris, France, jouve@ljll.univ-paris-diderot.fr

[2] CMAP, École Polytechnique, CNRS, Université Paris-Saclay, 91128 Palaiseau, France, gregoire.allaire@polytechnique.fr,

[3] Institut de Recherche Technologique SystemX, 91120 Palaiseau, France, jeet.desai@irt-systemx.fr

Keywords: Level-sets, Topology optimization, Fracture mechanics, Damage model

The laws governing brittle fracture, proposed by A.A. Griffith have been reformulated as minimization of a mechanical energy [4]. The reformulation renders the fracture problem in a variational form. A damage gradient model governs the progressive degradation in solids. Such a model can be effectively used to approximate the mechanical energy and thus the variational form [5]. The variational form is however an inequation.

Shape or topology optimization of structures using level-sets is a well-known technique where a scalar function describing a shape implicitly is advected along a shape derivative [2]. The shape derivative can be easily computed using the Cea's technique [3]. However this approach demands a variational equation.

In order to apply Cea's technique to the fracture model, we propose a penalization model approximating the variational inequation as a variational equation. The computation of the shape derivative paves the way for an iterative algorithm devoted to minimize the fracture or the elastic energy. In our numerical implementation, the shape evolution is driven by a body-fitted discretization strategy [1]. Numerical examples in $2D$ and $3D$ will be proposed to show the efficiency of the method.

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Topology optimization of support structures for thermo-mechanical constraints in powder bed additive manufacturing

Martin Bihr[1] Grégoire Allaire[2] Beniamin Bogosel[2]

[1]Safran Tech, France, martin.bihr@safrangroup.com

[2]Ecole Polytechnique, France, gregoire.allaire@polytechnique.fr, beniamin.bogosel@polytechnique.edu

Keywords: Topology Optimization, Additive Manufacturing, Thermo-mechanic

In metal additive manufacturing, especially with the SLM (*Selective Laser Melting*) technology, support structures are often needed to ensure the manufacturability of the part. Being extra-material, thoses structures need to be removed and do not participate to the final use of the part. We propose, as in [1], a mathematical model and optimization constraints to obtain optimal support design with a levelset topology optimization process. Following [2], a new optimization criteria has been studied allowing the supports to prevent thermal deformations induced by the laser beam, as explained in [3]. They may also be used to evacuate the heat accumulated in the part during the manufacturability, and reduce the amount of residual stresses.

Moreover, the constructibility is ensure by a constraint developped in [4] that takes into account the layer by layer assembly.

These aggregate optimization constraints allow the design of optimal supports and the manufacturability of the part, that has been experimentaly verified.

The optimization algorithm used relies on the level set method and on the computation of shape derivatives by the Hadamard method. In this approach, only the shape and topology of the supports are optimized for a given structure,

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Online Restart Strategies for SGD

Scott Pesme[1] Aymeric Dieuleveut[2]

[1]EPFL, Switzerland, scott.pesme@epfl.ch

[2] École polytechnique, France, aymeric.dieuleveut@polytechnique.edu

Keywords: SGD, piecewise constant step sizes, convergence diagnostics

Stochastic gradient descent (SGD) is a central key of many algorithms in machine learning. However, practical implementations, especially in deep learning, do not reflect what theory suggests. Though Polyak-Ruppert averaging with polynomially decaying step sizes achieve the minimax optimal statistical rates, most practitioners use piecewise constant learning rates without iterate averaging. We focus on proposing and analysing an online statistic which indicates a good time to restart the SGD algorithm with a reduced step size.

Under appropriate conditions, iterates of a constant step size SGD recursion constitute a Markov chain which converges exponentially fast to a unique stationary distribution. The initial conditions are forgotten quickly, however the iterates do not converge but oscillate around the global optimum θ^* in a region of size $\gamma^{1/2}$, where γ is the step size. Detecting the saturation of the iterates and then reducing the step size by restarting the SGD recursion can lead to fast algorithms and reflects what is used in practical settings.

Several online statistics with cheap computational cost have been proposed in order to detect the iterates' saturation. One of them was proposed by Pflug in 1983 and is based on the running average of successive gradient inner products $\langle f'_n,\ f'_{n+1}\rangle$. The SGD recursion is restarted with a reduced step size when the inner product $\langle f'_n,\ f'_{n+1}\rangle$ is detected as negative. This algorithm, while it was proposed a long time ago, is still at the center of recent discussions. With a detailed analysis of Pflug's statistic in the least squares setting, we show that this procedure cannot lead to an adequate convergence diagnostic. Indeed the statistic has a signal-to-noise ratio which is too low and therefore leads to abusive restarts that are uncorrelated with the saturation of the iterates.

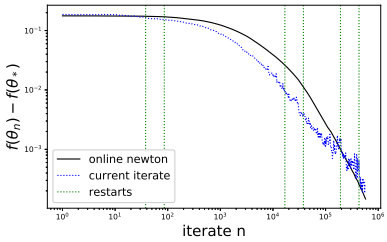

Figure 1: SGD using our novel statistic to detect restarts.

We propose a novel algorithm based on the evolution of $\|\theta_n - \theta_{restart}\|^2$, where $\theta_{restart}$ is the iterate from which we have last restarted our SGD recursion. This quantity has the benefit of being computationally cheap to calculate and is directly linked to the evolution of $\|\theta_n - \theta^*\|^2$. We provide experimental results showing satisfactory convergence rates on synthetic and real datasets. For example, in Figure 1 we see the performance of our algorithm when performing a logistic regression on the covertype dataset. At each restart detected by our statistic (vertical dotted lines), the step size is halved. We achieve similar convergence rates as the online newton algorithm, which is experimentally state of the art for logistic regression.

Bregman Proximal Method Revisited for Solving Variational Inequalities with Singularities

Kimon Antonakopoulos[1] E.Veronica Belmega[2] Panayotis Mertikopoulos[1]

[1]Univ. Grenoble Alpes, Inria, CNRS, Grenoble INP, LIG, 38000 Grenoble, France, kimon.antonakopoulos@inria.fr

[2]ETIS / ENSEA - Univ. de Cergy-Pontoise - CNRS belmega@ensea.fr, panayotis.mertikopoulos@imag.fr

Keywords: variational inequalities, monotone operators, convex optimization,stochastic optimization

Tracing their origins to the seminal work of Stampacchia, variational inequalities provide a general and useful unifying framework which captures a wide range of convex-structured problems, such as convex minimization, saddle points, Nash equilibria etc. Being more precise, given a convex subset $\mathcal{X} \subset \mathbb{R}^d$, a monotone operator $A : \mathcal{X} \to \mathbb{R}^d$ and a prox-friendly function f, our main subject of interest would be to solve the *Stampacchia variational inequality*:

$$\text{Find } x^* \in \mathcal{X} \text{ such that } \langle A(x^*), x - x^* \rangle + f(x) - f(x^*) \geq 0 \text{ for all } x \in \mathcal{X} \qquad \text{(SVI)}$$

Throughout the existing extensive literature related to the above problem, one can distinguish two main regularity condition assumed for obtaining several convergence rate guaranteess (for example [3], [2]):

- *Boundedness:* $\sup_{x \in \mathcal{X}} \|A(x)\|_* < +\infty$
- *Lipschitz continuity:* $\|A(x) - A(x')\|_* \leq \beta \|x - x'\|$ for some $\beta > 0$

Despite the fact that the above conditions do not appear particularly restrictive, they may fail to hold in a wide array of practical applications- ranging from Poisson inverse problems and generative adversarial networks to resource sharing and energy efficiency maximization in wireless communications, and many others. Inspired by the work of Bauschke, Bolte, Teboulle in [1] and Teboule in [4], our contribution is to recover the success of two popular algorithms, that of Mirror-Descent and Mirror-Prox for this more general landscape which operators which possible singularities. In particular, we introduce two new regularity conditions which generalize the traditional ones and we show that under these optimal convergence rate guarantees can be shown.

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An Adaptive Stochastic Optimization Algorithm for Resource Allocation

Xavier Fontaine[1] Shie Mannor[2] Vianney Perchet[1,3]

[1]ENS Paris-Saclay, France, fontaine@cmla.ens-cachan.fr, perchet@cmla.ens-cachan.fr
[2]Technion, Israel, shie@ee.technion.ac.il
[3]Criteo Research, France

Keywords: Stochastic optimization, online learning, adaptive algorithms, resource allocation

We consider the problem of resource allocation where a decision maker repeatedly divides a budget between several resources, each with diminishing returns. More specifically this decision maker has access to $K \in \mathbb{N}$ resources and at each time step $t \in \mathbb{N}$, he has to split a total budget of weight 1 and to allocate $x_k^{(t)}$ to each resource $k \in [K]$, which generates the reward $f_k(x_k(t))$. Overall his reward is then

$$F(x^{(t)}) = \sum_{k\in[K]} f_k(x_k^{(t)}) \quad \text{with} \quad x^{(t)} = (x_1^{(t)}, \dots, x_K^{(t)}) \in \Delta^K,$$

where the simplex $\Delta^K = \left\{(p_1, \dots, p_K) \in \mathbb{R}_+^K;\ \sum_k p_k = 1\right\}$ is the set of possible convex weights. We assume that the reward functions f_k are concave, zero at zero and non-decreasing. The objective of the decision maker is to maximize the cumulated reward, or equivalently to minimize the regret $R(T)$, defined as the difference between the optimal reward $F(x^\star)$ and the average reward over $T \in \mathbb{N}^*$ stages. At each time step $t \in \mathbb{N}^*$ the decision maker observes a noisy version of $\nabla F(x^{(t)}$ as in stochastic optimization. Our problem can actually be seen as a convex optimization problem for separable functions.

We construct an algorithm that is adaptive to the complexity of the problem, expressed in term of the regularity of the reward functions, measured by the exponent β in the Łojasiewicz inequality. Our parameter-independent algorithm recovers the optimal rates for strongly-concave functions and the classical fast rates of multi-armed bandit. Moreover, it improves existing results on stochastic optimization for intermediate cases.

The overall idea of our algorithm is to imbricate binary searches. In the case of $K = 2$ resources it queries a point repeatedly until it learns the sign of the gradient of the reward function, or at least with arbitrarily high probability. Then it proceeds to the next step of a standard binary search. In the case of $K \geq 3$, we define a binary tree with the K resources and we handle the computations of the gradients using the case $K = 2$ as a black box and using successive and imbricated binary searches. We prove the following bound on the regret, in the case where $\beta \leq 2$:

$$\mathbb{E}[R(T)] \leq \kappa \cdot cK \left(\log(T)^{\log_2(K)+1}\right)^{\beta/2} T^{-\beta/2}.$$

Artificial Intelligence and optimal policies for prosumer integration

Elizaveta Kuznetsova[1] Miguel F. Anjos[1,2]

[1]Polytechnique Montreal, Canada, elizaveta.kuznetsova@polymtl.ca
[2]University of Edinburgh, United Kingdom, anjos@stanfordalumni.org

Keywords: Small-scale prosumer, energy policy, artificial intelligence

The emergence of small-scale electricity prosumers may lead to various scenarios: prosumers may increase the variability of total net load and eventually disconnect from the grid. Alternatively, they may remain connected and provide flexibility for the overall system. Current policy may promote disconnection. Indeed, the commodity cost in the typical electricity bill is modest, other costs compensates grid services and pays for environmental initiatives [1]. The integration of high numbers of small-scale prosumers is an important challenge. Its success relies on the energy policy, and policy suitability can be tested prior to its real-life implementation. We propose a computational agent-based framework to represent an electricity system composed of heterogeneous smart stakeholders (prosumers, distribution companies, grid operator). The decision-making model is a key for the agents' intelligence. While the decision-making behaviour of some agents can be formulated as a single-objective optimization model (minimizing the cost of energy procurement), the behaviour of other agents appears to be more complex. The grid operator actions will depend on the decisions of prosumers who have negligible individual effect but collectively may have greater impact. Deep Learning may be used to capture these undesirable load fluctuations and propose corrective policies to mitigate their effect.

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Pleiad: A Python Framework to Optimize Residential Power Consumption

Hugues Souchard de Lavoreille[1] Juan A. Gomez-Herrera[2] Miguel F. Anjos[3]

[1]MINES ParisTech, Université PSL, France, hugues.souchard_de_lavoreille@mines-paristech.fr
[2]GERAD and Polytechnique Montreal, Canada, juan.gomez@polymtl.ca
[3]University of Edinburgh, United Kingdom, anjos@stanfordalumni.org

Keywords: Python, demand response, energy systems, scheduling, mixed-integer linear programming

Demand response is a strong lever one can play with in order to achieve more flexibility in energy systems. In the last years, the development of research about Home Energy Management Systems paved the way for optimization-based approaches for scheduling energy consumption. In our work, we generalized the MILP model developed in [1] to a general class of energy systems in which an arbitrarily large network binds several objects (appliances, batteries, PV modules, ...) together and enables them to exchange power. Dwellings, aggregators, but also buildings and groups of dwellings fall within this scope.

We developed a Python framework called Pleiad, enabling to schedule the energy consumption of such a network by optimizing a custom cost function and with a customizable MILP model. The framework provides support tools for network instantiation, for designing the rules governing the creation of the MILP model but also for the visualization of results. We also implemented a library of appliances written in the formalism of Pleiad, whose technical specifications derive from industrial products or from the scientific literature. The library contains existing grid tariffs and tools to simulate the output of PV production as well.

A small case study was performed, in which we studied the flexibility potential of a dwelling equipped with a battery, PV modules and with the appliances of the library.

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Peer-to-peer Electricity Market Analysis: from Variational to Generalized Nash Equilibrium

Hélène Le Cadre* Paulin Jacquot† Cheng Wan‡ Clémence Alasseur§

Keywords: Peer-to-Peer Energy Trading, Preferences, Prosumers, Variational Equilibrium, Generalized Nash Equilibrium.

We consider a network of prosumers involved in peer-to-peer energy exchanges [3], with differentiation price preferences on the trades with their neighbors, and we analyze two market designs: **(i)** a centralized market, used as a benchmark, where a global market operator optimizes the flows (trades) between the nodes, local demand and flexibility activation to maximize the system overall social welfare; **(ii)** a distributed peer-to-peer market design where prosumers in local energy communities optimize selfishly their trades, demand, and flexibility activation. We first characterize the solution of the peer-to-peer market as a Variational Equilibrium [1] and prove that the set of Variational Equilibria coincides with the set of social welfare optimal solutions of market design **(i)**. We give several results that help understanding the structure of the trades at an equilibrium or at the optimum. We characterize the impact of preferences on the network line congestion and renewable energy surplus under both designs. We provide a reduced example for which we give the set of all possible generalized equilibria, which enables to give an approximation of the price of anarchy. We provide a more realistic example which relies on the IEEE 14-bus network, for which we can simulate the trades under different preference prices. Our analysis shows in particular that the preferences have a large impact on the structure of the trades, but that one equilibrium (variational) is optimal. Finally, the learning mechanism needed to reach an equilibrium state in the peer-to-peer market design is discussed together with privacy issues. This talk is based on our recent paper [2].

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*VITO/EnergyVille research center, Thor scientific park, Genk, Belgium, helene.lecadre@energyville.be
†EDF R&D, OSIRIS, Inria, CMAP Ecole polytechnique, CNRS, France, paulin.jacquot@polytechnique.edu
‡EDF R&D, OSIRIS, France, cheng.wan.05@polytechnique.org
§EDF R&D and FIME, Energy Markets research center, France, clemence.alasseur@edf.fr, the author's research is part of the ANR project PACMAN (ANR-16-CE05-0027)

Spectral Bounds For Graph Partitioning Problems

Miguel F. Anjos[1,2] José Neto[3]

[1]School of Mathematics, University of Edinburgh, James Clerk Maxwell Building, Peter Guthrie Tait Road, Edinburgh EH9 3FD, United Kingdom
[2]GERAD & Polytechnique Montréal, QC, Canada H3C 3A7
[3]Samovar, CNRS, Télécom SudParis, Institut Polytechnique de Paris, 9 rue Charles Fourier, 91011 Evry, France
anjos@stanfordalumni.org, Jose.Neto@telecom-sudparis.eu

Keywords: Graph partitioning, max k-cut, adjacency matrix eigenvalues, adjacency matrix eigenvectors

Given an undirected edge-weighted graph and a positive integer k, the maximum k-cut problem consists in finding a partition of the node set of the graph into k subsets so as to minimize the sum of the weights of the edges having their endpoints in different subsets of the partition. A new class of bounds for this problem is introduced, extending previous results on the maximum (2-)cut problem, and we show that they can strictly improve over other eigenvalue bounds from the literature. The variant of the problem when the subsets of the partition have prescribed sizes is also considered, and we present a new class of similar bounds for the latter.

For both problems, the expressions of the new bounds involve the eigenvalues of the weighted adjacency matrix as well as its eigenvectors through given geometric parameters that are related to the maximum (2-)cut problem.

Computational results illustrating the potential impact of the new bounds are reported.

On the minimum $s-t$ cut problem with budget constraints

Hassene Aissi A. Ridha Mahjoub

University of Paris Dauphine, France, aissi,ridha.mahjoub@lamsade.dauphine.fr

Keywords: multiobjective optimization, $s-t$ cut, linear programming, approximation algorithm

We consider in this presentation the budgeted version of the minimum $s-t$ cut problem. Let $G=(V,A)$ be a directed graph with two distinguished nodes s and t, and consider k non-negative cost functions $c^1,\ldots,c^k : A \leftarrow \mathbb{Z}_+$, and $k-1$ budget bounds $b_1,\ldots,b_{k-1}$ where k is a constant. The goal is to find a $s-t$ cut C satisfying budget constraints $c^h(C) \leqslant b_h$, for $h=1,\ldots,k-1$, and whose cost $c^k(C)$ is minimum. We study the linear relaxation of the problem and give necessary and sufficient conditions for which it has an integral optimal basic solution. We also give a strongly polynomial time combinatorial algorithm for solving it. As a corollary, we obtain a $(1,k)$-pseudo-approximation algorithm for the problem.

New Results for the Flow Shop problem with Conflict Graph

Nour ElHouda TELLACHE[1] Mourad BOUDHAR[2] Farouk YALAOUI[3]

[1]CERMICS Laboratory, ENPC, 6-8 avenue Blaise Pascal, 77455 Marne-la-Vallée Cedex 2, France,
nourelhouda.tellache@enpc.fr

[2]RECITS Laboratory, USTHB university, BP 32 El-Alia,Bab-Ezzouar, Algiers, Algeria,
mboudhar@yahoo.fr

[3]LOSI Laboratory, UTT university, 12 rue Marie Curie BP 2060, 10010, Troyes Cedex, France,
farouk.yalaoui@utt.fr

Keywords: Flow Shop, Conflict Graph, MILP, MIQCP, Matheuristics, Makespan.

The flow shop problem can be described as follows: a finite set $\{J_j, j = 1, \ldots, n\}$ of n jobs that have to be processed on a given set $\{M_i, i = 1, \ldots, m\}$ of m machines. Each job J_j consists of m operations $\{J_{ij}, i = 1, \ldots, m\}$, where J_{ij} has to be processed on machine M_i for p_{ij} time units. Furthermore, all the jobs have the same processing order through the machines. The objective is to find a schedule that minimizes the maximum completion time (makespan). In some practical applications, we may have additional constraints where some jobs conflict with each other, in which case we cannot process them at the same time on different machines. We study the problem when these constraints are given by a simple and undirected graph $G = (V, E)$, called the conflict graph (the problem is denoted FSC).

The two-machine FSC problem is known to be NP-hard even when restricted to split graphs and complements of complete bipartite graphs [2]. For the case of unit-time operations, the two-machine FSC problem remains NP-hard for arbitrary conflict graphs. However, this latter problem is solvable in polynomial time when restricted to special graph classes [1, 2].

For the basic flow shop problem with $m \leq 3$, the search for an optimal schedule can be restricted to permutation schedules. When the conflict constraints are taken into account, we have found an example in which this result is no longer valid even for $m = 2$. However, when all the operations have the same processing time, we prove that any optimal schedule can be transformed into a no-wait permutation schedule.

On the other hand, we discuss four Mixed-Integer Linear Programming (MILP) models for different versions of the problem, a Mixed Integer Quadratically Constrained Program (MIQCP) and a set of matheuristics. The experimental study shows that, for the case of arbitrary processing times, the corresponding MILP model can solve instances of size up to 12 job-2 machine, 8 job-3 machine and 5 job-5 machine. However, the best matheuristic solves instances of size up to 400 job-2 machine, 30 job-3 machine and 6 job-5 machine. Regarding the case of unit-time operations, one of the proposed MILP models outperforms the other models and generates efficiently an optimal solution for instances of size up to 450 jobs. The efficiency of the latter model rely heavily on the fact that there exists an optimal no-wait permutation schedule.

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Tensor Decomposition for High-dimensional Hamilton-Jacobi-Bellman Equations

Sergey Dolgov[1] Dante Kalise[2] Karl Kunisch[2]

[1]University of Bath, United Kingdom, s.dolgov@bath.ac.uk
[2]University of Nottingham, United Kingdom, dante.kalise@nottingham.ac.uk,
[2]University of Graz, Austria, karl.kunisch@uni-graz.at,

Keywords: Dynamic Programming, Optimal Feedback Control, Hamilton-Jacobi-Bellman Equations, Tensor Calculus, High-dimensional Approximation

This talk showcases ongoing research within the PGMO project TIDAL: Taming the Curse of Dimensionality in Dynamic Programming. A tensor decomposition approach for the solution of high-dimensional, fully nonlinear Hamilton-Jacobi-Bellman equations arising in optimal feedback control and estimation of nonlinear dynamics is presented. The proposed method combines a tensor train approximation for the value function together with a Newton-like iterative method for the solution of the resulting nonlinear system. The effectiveness of tensor approximations circumvents the curse of dimensionality, solving Hamilton-Jacobi equations with more than 100 dimensions at modest cost. The linear scaling of the computational complexity with respect to the dimension allows to solve optimal feedback control problems over high-dimensional state spaces. The synthesis method is effectively applied to the optimal feedback stabilization of nonlinear parabolic PDEs.

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Exact Verification of Piecewise Affine Dynamical Systems

Assalé Adjé[1]

[1]Lamps, Université de Perpignan Via Domitia, France assale.adje@univ-perp.fr

Keywords: Discrete-time Piecewise Affine Systems, Piecewise Quadratic Lyapunov Functions, Optimization in Dynamical Systems, Semi-Definite Programming, Verification

The proposed work addresses the verification problem for a class of discrete-time piecewise affine dynamical systems. A verification problem consists in checking whether a given set is a (time)-invariant for the system i.e. the state-variable belongs to the given set whatever the time. In this work, we are interested in sublevel sets of convex quadratic forms i.e. possibily degenerated ellipsoids. The verification problem is reduced to check whether all the reachable values are contained in the ellipsoid. If this is not the case, we have to exhibit a reachable value outside the ellipsoid. Usually classical techniques in computer science such as abstract interpretation [2], to prove that a property does not hold is very difficult. However, in our case, since we consider sublevel sets of functions, the verification problem can be reduced to an optimization one. Hence, if we solve exactly the optimization problem, we can completely decide whether the property holds or not.

The optimization problem that we obtain consists in maximizing a convex quadratic function over the reachable values set of a discrete-time piecewise affine system. The difficulty here is to handle the infinite sequences. Hence, we propose to use piecewise quadratic Lyapunov functions [1] to construct an operator norm. This operator norm is then relaxed using semi-definite programming. The particular conditions on our piecewise quadratic Lyapunov functions allow to replace the infinite sequences of the reachable values set by finite interesting sequences. Finally, the exact resolution of the optimization problem is reduced to the evaluation of a finite number of elements.

Note that this work extend the affine case proposed in [3].

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The Logic of Containing Tumors

Yannick Viossat[1] Robert J. Noble[2]

[1]Université Paris-Dauphine, France, viossat@ceremade.dauphine.fr
[2]ETH Zurich, Switzerland, robert.noble@bsse.ethz.ch

Keywords: Mathematical oncology, optimal control, pharmacoresistance, adaptive therapy

Many cancer treatments are administered at the maximal tolerated dose, and eventually fail as the tumor becomes resistant. When a cure is highly unlikely, an alternative is to use the minimal effective dose, that is, the minimal dose that allows to contain the tumor while ensuring a sufficient quality of life to the patient. The hope is to diminish both treatment toxicity and selection for resistance to treatment, allowing us to control the tumor for a longer time. Experimental results are promising.

We study how to maximize the time at which tumor size becomes higher than a given threshold. For simple models with two type of cells, sensitive and fully resistant to treatment, we find that under very general conditions, containment strategies are optimal, or almost optimal. This unifies a number of previous approaches. The clinical gains with respect to more aggressive treatments crucially depends on the tumor growth model. In particular, our results are much more robust to modifications of the basic model for Gompertzian growth than for logistic growth. Finally, if resistant cells retain some sensitivity to treatment, the optimal strategy is typically to first contain the tumor with a low-dose treatment but eventually switch to maximal tolerated dose. This is the opposite of what other authors have found, and we will explain why.

This is part of the PGMO project "Optimization of a new type of cancer therapy".

A Multi-Leader-Follower Game for Demand-Side Management

Didier Aussel[1] Sébastien Lepaul[2] Léonard von Niederhäusern[3]

[1]PROMES-CNRS and University of Perpignan, France, aussel@univ-perp.fr
[2]OSIRIS, EDF R&D, France sebastien.lepaul@edf.fr
[3]CMM and University of O'Higgins, Chile leonard.vonniederhausern@uoh.cl

Keywords: Bilevel optimization, Demand-side management, Equilibrium theory, Smart grid

Among other concerns, the constantly increasing consumption of energy, the breakthrough of renewable energies in the production mix, and the need to be economically viable constitute tremendous challenges for energy companies nowadays. At the center of the preoccupations, the supply-demand balance in the grid has to be ensured at all times. Whereas the old paradigm consisted in adapting the production to the demand, the converse method has been on the rise for the past thirty years: adapting the demand to the production is known as *demand-side management* (DSM). Several techniques exist to implement DSM: we present here a model for *load shifting*, in which energy suppliers offer prices to a set of clients who shift their consumption in order to minimize their bill and the inconvenience due to the shifts.

Mathematically, this takes the form of a *multi-leader-follower game* (MLFG). Whereas bilevel optimization problems usually model the interaction between one leader and one follower, MLFGs not only consider the hierarchical interaction between followers and leaders, but also the interactions among followers and among leaders. This leads to many difficulties in the handling of such problems. In this talk, we present a way to obtain feasible solutions with the help of various assumptions on the leaders' and on the followers' variables, explain why these assumptions are necessary, and thus provide intuition concerning the complexity of MLFGs. Finally, we provide some numerical results.

Strategic bidding in Price Coupled Regions

Luce Brotcorne[1] Jérôme De Boeck[2,1] Bernard Fortz[2,1]

[1]INOCS, INRIA Lille Nord-Europe, France, {luce.brotcorne,bernard.fortz}@inria.fr
[3]UniversitÃ© libre de Bruxelles, Belgium, {jboeck,bernard.fortz}@ulb.ac.be

Keywords: Unit commitment, market equilibrium, day-ahead market, bilevel optimization.

The classical Unit Commitment problem (UC) can be essentially described as the problem of establishing the energy output of a set of generation units over a time horizon, in order to satisfy a demand for energy, while minimizing the cost of generation and respecting technological restrictions of the units (e.g., minimum on/off times, ramp up/down constraints). The UC is typically modelled as a (large scale) mixed integer program and its deterministic version, namely the version not considering the presence of uncertain data, has been object of wide theoretical and applied studies over the years.

Traditional (deterministic) models for the UC assume that the net demand for each period is perfectly known in advance. However, in practice, the demand is dictated by the amounts that can be sold by the producer at given prices on the day-ahead market, leading to strategic bidding problems. One difficulty therefore arises if the optimal production dictated by the optimal solution to the UC problem cannot be sold at the producer's desired price on the market, leading to a possible loss. Another strategy could be to bid for additional quantities at a higher price to increase profit, but that could lead to infeasibilities in the production plan. Furthermore, the mechanism of the bidding market considered has a considerable impact on the spot prices and the quantities bought to retailers and producers, complexifying the structure of the problem. We consider Price Coupling of Regions (PCR) as bidding market, a coupling that links national day-ahead markets in order to increase the global welfare.

Our aim is to model and solve the UC problem with a second level of decisions ensuring that the produced quantities are cleared at market equilibrium in a coupled day-ahead market. In their simplest form, market equilibrium constraints are equivalent to the first-order optimality conditions of a linear program. The UC in contrast is usually a mixed-integer nonlinear program (MINLP), that is linearized and solved with traditional Mixed Integer (linear) Programming (MIP) solvers. Taking a similar approach, we are faced to a bilevel optimization problem where the first level is a MIP and the second level linear.

In this talk, we assume that demand curves and offers of competitors in the market are known. The market considered is a PCR of the EU that considers several day-ahead markets coupled through a transmission network. Following the classical approach for these models, we present the transformation of the problem into a single-level program by rewriting and linearizing the first-order optimality conditions of the second level. A discretization of the possible optimal spot prices is made and valid inequalities are proposes to obtain a tight MILP formulation. Some aggregation and disaggregation techniques taking advantage of the properties of PCR improves considerably the computation times. A heuristic applicable to special ordered sets is also presented to reduce the number of binary variables when discretizing a continuous variable.

Bilevel optimization applied to strategic pricing in electricity markets and extension to markets with massive entry of renewable energies and distributed generation

A. Jofré[1] D. Pereda[1] L. Brotcorne[2]

[1]University of Chile, Chile, ajofre@dim.uchile.cl,dpereda@dim.uchile.cl
[2]Inria Lille - Nord Europe, France, luce.brotcorne@inria.fr

Keywords: Bilevel optimization, Energy markets, Nash equilibrium, Mathematical program with equilibrium constraints.

In this work, we present a bilevel programming formulation associated with a generator strategically choosing a bid to maximize profit given the choices of the other generators. More precisely, given a specific generator, we define a set of scenarios for the remaining agents and maximize the expected profit of the chosen company over all scenarios, this approach was presented by Baíllo et al. [1] and studied in the linear case by Fampa et al. [3]. Here is assumed that, after the clearing of each market mechanism, information about the submitted aggregate offer and demand curves is made publicly available and agents can then build scenarios for its rivals bids. The capability of the agent represented by the leader to affect the market price is considered by the model. The follower of the problem is the electric system operator, which runs a minimum cost program that respects physical network constraints. In this work, no transmission constraints and convex piecewise linear functions as cost and bids were considered. A penalty algorithm is formulated together with an efficient algorithm for solving the follower problem, and convergence to a local maximum is proven.

This formulation is also compared with the Nash equilibrium formulation, where the competition process is simulated until a set of price equilibrium bids is obtained. It was proven in Jofré et al. [2] that the mixed Nash strategies equilibrium exists in even a more general network, considering transmission constraints. In this work, it is shown that if the probabilities associated with the scenarios approach are close to those of the mixed strategies equilibrium, then the expected payoffs under both formulations are close and that under small resistance values and Schweppe et al [4] approximation for the losses due to thermal considerations, the payoffs on the simplified model are close to the ones from the more general network.

These ideas are extended and applied to the case where we have massive entry of renewable energies and distributed generation.

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On facing demand forecast uncertainties by means of Robust Optimization

Jean-Christophe Alais

Air Liquide R&D, France, jean-christophe.alais@airliquide.com

Keywords: Air Separation Unit, Demand forecast, Robust Optimization

Air Separation Units (ASUs) extract oxygen, nitrogen and argon from the air. The first challenge of an ASU operator is to satisfy the demand while this demand can vary a lot in the presence of uncertainties. Hence, it is of paramount importance for them to cope efficiently with the unshrinkable forecast errors on the clients consumptions. Indeed, while forecast can be improved in a certain extent, the range of the uncertainty can be captured for preventing unexpected behaviours with a proper level of risk mitigation measure. To this end, the so-called *Robust Optimization* approach (see [1]) is applied to the ASUs production planning, with regards to their clients consumptions.

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Constraint Generation for Risk Averse Two-Stage Stochastic Programs

R. Mínguez[1] W. van Ackooij[2] R. García-Bertrand[3]

[1]ESCISSION Company, Spain, roberto.minguez@escission.com
[2]EDF-Electricité de France-R&D, France wim.van-ackooij@edf.fr
[3]Dep. of Electrical Engineering, University of Castilla-La Mancha, Spain raquel.garcia@uclm.es

Keywords: Stochastic programming, decision analysis under uncertainty, CVaR, Risk aversion

A significant share of stochastic optimization problems in practice can be cast as two-stage stochastic programs. If uncertainty is available through a finite set of scenarios, which frequently occurs, and we are interested in accounting for risk aversion, the expectation in the recourse cost can be replaced with a worst-case function (i.e., robust optimization) or another risk-functional, such as conditional value-at-risk [1]. In this paper we are interested in the latter situation especially when the number of scenarios is large. For computational efficiency, we suggest an algorithm which will rather build on a (clustering and) constraint generation methodology. This strategy was efficiently made to work in [2] in the case wherein the risk-functional is a worst-case operation, but under special structure. The algorithm proposed in [2] adds a single set of constraints at each iteration while gradually moving towards a fully extended formulation. In the two algorithms presented in this paper, typical iterations will increasingly add sets of constraints until the required accuracy is achieved. Both algorithms rely on a dynamic scenario aggregation technique. We are concerned with both general and fixed recourse situations, the latter implying that the duals of all second-stage linear problems share the same feasible set. We establish convergence of these two algorithms and demonstrate their effectiveness through various numerical experiments.

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Optimal reserve sizing for frequency regulation

Adrien Le Franc[1,2], Pierre Carpentier[3],
Jean-Philippe Chancelier[1], Michel De Lara[1]
[1]Cermics ENPC, [2]Efficacity, [3]ENSTA, France

Keywords: Stochastic optimization, robust optimization, microgrid, frequency reserve

Reserve mechanisms are activated when a frequency deviation reports power disequilibrium on the electric grid. Delivering reserve power is attractive for energy storage owners, especially when combining other domestic usages such as energy arbitrage or peak shaving. We present a model for optimally sizing power reserves for a microgrid equipped with a battery and managing local electricity consumption and production.

We focus on a daily problem where we want to compute both optimal hourly reserves and a minute-scale power management policy. In the first place, reserves are bidded day-ahead, which introduces an open-loop decision variable. Second, power is managed during the day to minimize the operation cost of the microgrid which includes penalties if reserves are not delivered when significant frequency deviations are observed. This results in a second stage problem formulated as a multistage stochastic problem.

Our main concerns relate to the time decomposition of the problem which involves several time scales and information structures, and to the nature of the stochastic process for modeling frequency deviations for which we propose a robust approach. Our work is inspired by real world industrial challenges and data reported by Schneider Electric.

Self-Adjusting Mutation Rates with Provably Optimal Success Rules

Benjamin Doerr[1] Carola Doerr[2] Johannes Lengler[3]

[1]École Polytechnique, CNRS, LIX, Palaiseau, France
[2]Sorbonne Université, CNRS, LIP6, Paris, France
[3]ETH Zürich, Department of Computer Science, Zürich, Switzerland

Keywords: Optimization, Parameter Selection, Dynamic Algorithm Configuration

The one-fifth success rule is one of the best-known and most widely accepted techniques to control the parameters of evolutionary algorithms. While it is often applied in the literal sense, a common interpretation sees the one-fifth success rule as a family of success-based updated rules that are determined by an update strength F and a success rate s. We analyze in this work how the performance of the (1+1) Evolutionary Algorithm (EA) on LeadingOnes depends on these two hyper-parameters. Our main result shows that the best performance is obtained for small update strengths $F = 1 + o(1)$ and success rate $1/e$. We also prove that the running time obtained by this parameter setting is asymptotically optimal among all dynamic choices of the mutation rate for the (1+1) EA, up to lower order error terms. We show similar results for the resampling variant of the (1+1) EA, which enforces to flip at least one bit per iteration.

Reference: The presentation is based on results communicated at GECCO 2019 [1].

Acknowledgments: Our work is supported by LMH (Labex Mathématiques Hadamard)/PGMO project 'Analysis of Evolutionary Algorithms: Beyond Expected Optimization Times'. It is also supported by the Paris Ile-de-France region.

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Towards Dynamic Algorithm Selection

Anja Janković[1] Carola Doerr[1]

[1]Sorbonne Université, CNRS, LIP6, Paris, France

Keywords: continuous black-box optimization, randomized search heuristics, exploratory landscape analysis, online algorithm selection and configuration

Black-box optimization of a previously unknown problem can often prove to be a demanding task. In order for the optimization process to be as efficient as possible, one must recognize the nature of the problem at hand and choose the algorithm (the *algorithm selection* problem, AS) and/or the parameter configuration (i.e., the *algorithm configuration* problem, AC) exhibiting the best performance for that type of problem. The problem characterization is done via underlying fitness landscape features [1], which allow to identify similarities and differences between various problems. Our ambition is to extend classical AS/AC techniques, mostly covered in literature from an *offline*, i.e., static perspective, to the *online* setting, in which it will be possible to switch between different algorithms and/or configurations depending on the part of the optimization process.

Here we present first steps towards an adaptive landscape analysis. This talk is based on the paper presented at the Student Workshop of this year's GECCO conference [2]. Our approach is aimed at taking a closer look into how landscape features evolve during the optimization process and whether this information can be used to discriminate between different problems. The motivation of our work is to understand if and how one could exploit the information provided by the features to improve on dynamic algorithm selection and configuration. Put differently, our goal is to leverage landscape analysis to adjust the choice of the algorithm on the fly, i.e., during the optimization process itself. Our next step towards an online algorithm selection will be coupling feature information to performance of continuous black-box optimizers by building a *performance regression model*, inspired by Per Instance Algorithm Configuration approach [3]. This presentation is based upon work supported by the PGMO/LabeX LMH project "Self-adjusting parameters choices in heuristic optimization".

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An Improved Generic Bet-and-Run Strategy for Speeding Up Stochastic Local Search

Thomas Weise[1] Zijun Wu[1] Markus Wagner[2]

[1]Institute of Applied Optimization, Faculty of Computer Science and Technology, Hefei University, Hefei, China
[2]Optimisation and Logistics Group, University of Adelaide, Adelaide, Australia

Keywords: Optimization, Restarts, Black-Box Optimization

A commonly used strategy for improving optimization algorithms is to restart the algorithm when it is believed to be trapped in an inferior part of the search space. Building on the recent success of BET-AND-RUN approaches for restarted local search solvers, we introduce a more generic version that makes use of performance prediction. It is our goal to obtain the best possible results within a given time budget t using a given black-box optimization algorithm. If no prior knowledge about problem features and algorithm behavior is available, the question about how to use the time budget most efficiently arises. We first start $k \geq 1$ independent runs of the algorithm during an initialization budget $t_1 < t$, pause these runs, then apply a decision maker D to choose $1 \leq m < k$ runs from them (consuming $t_2 \geq 0$ time units in doing so), and then continue these runs for the remaining $t_3 = t - t_1 - t_2$ time units. In previous BET-AND-RUN strategies, the decision maker $D = \mathsf{currentBest}$ would simply select the run with the best-so-far results at negligible time. We propose using more advanced methods to discriminate between "good" and "bad" sample runs with the goal of increasing the correlation of the chosen run with the a-posteriori best one. In over 157 million experiments, we test different approaches to predict which run may yield the best results if granted the remaining budget. We show (1) that the currentBest method is indeed a very reliable and robust baseline approach, and (2) that our approach can yield better results than the previous methods.

Reference: The presentation is based on results communicated at AAAI 2019 [1]. This work builds upon [2].

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Algorithmic configuration by learning and optimization

Claudia D'Ambrosio [1] Antonio Frangioni[2] Gabriele Iommazzo[1,2] Leo Liberti[1]

[1]CNRS LIX, École Polytechnique, Palaiseau, France,
{dambrosio, giommazz, liberti}@lix.polytechnique.fr
[2]Dip. di Informatica, Università di Pisa, Pisa, Italy,
frangio@di.unipi.it

Keywords: algorithmic configuration, mathematical programming, machine learning, optimization solver

1 Introduction

We propose a methodology, based on machine learning and optimization, for selecting a solver configuration for a given instance. General-purpose Mathematical Programming (MP) solvers have long lists of user-configurable parameters; tweaking them influences how the available algorithmic components work and interact, therefore it can have a significant impact on the quality of the obtained solution and/or on the efficiency of the solution process. Good solvers have effective default parameter configurations, carefully selected to provide "good" performances in most cases. Furthermore, solvers may embed heuristics that try to automatically adapt the parameter configuration to the characteristics of the instance at hand. However, default/automatic parameter configurations may still be highly suboptimal with specific instances, which require a manual search for the best parameter values. The motivation for this work lies in the fact that, due to the large amount of available parameters, manual tuning is highly nontrivial and time-consuming. This setting is an instance of the Algorithm Configuration Problem (ACP)[1].

Our approach for addressing the ACP on MP solvers is based on a two-fold process:

(i) in the *Performance Map Learning Phase* (PMLP), we employ supervised Machine Learning (ML) techniques [2] in order to learn a performance function of the solver, which maps some features of the instance being solved, together with a given parameter configuration, into some measure of solver efficiency and effectiveness;

(ii) the formal properties defining the ML methodology underlying the PMLP are translated into MP terms; the resulting formulation, together with constraints encoding the compatibility of the configuration parameter values, is called the *Configuration Space Search Problem* (CSSP), a Mixed-Integer Nonlinear Program (MINLP) which, for a given instance, finds the configuration providing optimal performance w.r.t. the performance function.

The main novelty of our approach lies in the fact that we explicitly model and optimize the CSSP using the mathematical description of the ML technique used to learn the performance function. This is in contrast to most of the existing algorithmic configuration approaches, which instead employ heuristics such as experimental design methods [3], local searches [4], genetic algorithms [5], evolutionary strategies [6] and other methods [7, 8].

Deep Learning Numerical Methods for Hamilton Jacobi Equations

Nidhal GAMMOUDI

UMA, ENSTA Paristech, France, nidhal.gammoudi@ensta-paristech.fr

Keywords: Deep neural networks, Hamilton Jacobi equations, optimal control, state constraints.

In this work we use deep neural networks to approximate solutions of some first order Hamilton Jacobi equations derived from non linear deterministic optimal control problems.

Following recent approaches (for example [1], [2], [3] and [4]), our algorithm removes the direct dependency between the state space dimension and the resolution complexity.

We will illustrate our method on some optimal control problems with state constraints.

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Learning to Price: Structured Learning to scale up Column Generation

Axel Parmentier

Ecole des Ponts Paristech, France, axel.parmentier@enpc.fr

Keywords: Structured Learning, Column Generation, Path problem, Matheuristic, Stochastic Vehicle Scheduling Problem, Chance Constrained Capacitated Vehicle Scheduling Problem

In this work, we suppose that we want to solve large instances of a difficult path problem on an acyclic digraph, and that we have at our disposal a black-box solver that can only handle instances of moderate size. The difficult path problem may be non-linear, stochastic, chance-constrained, etc, and it may be itself the problem of interest, or the pricing subproblem of a column generation. We introduce a methodology that leverages the black-box solver to build a heuristic that can handle large instances of the difficult path problem. We start by building with our black-box solver a database that contains instances of moderate size of our difficult path problem and their optimal solutions. Then, we train on our database a structured learning approach that approximates our difficult path problem by a (much easier to solve) usual shortest path problem. The result is a mapping that transforms any instance of the difficult path problem into an instance of the usual shortest path problem that approximates well the initial instance. If the problem of interest is the difficult path problem, our heuristic to solve large instances is simply to solve their approximations by a usual shortest path problem. For problems that are solved by column generation, we introduce matheuristics that solve the approximation of the pricing subproblem instead of solving the true pricing subproblem. Since the usual shortest path problem does not belong to the prediction problems traditionally used in structured learning, we also introduce a maximum likelihood technique to train a structured prediction function which uses a shortest path problem as prediction problem. Numerical experiments show the efficiency of our approach on a stochastic vehicle scheduling problem and on a chance constrained capacitated vehicle scheduling problem.

Null Space Gradient Flows for Constrained Optimization with Applications to Shape Optimization

F. Feppon[12] G. Allaire[1] C. Dapogny[3]

[1]Centre de Mathématiques Appliquées, École polytechnique, Palaiseau, France
[2]Safran Tech, Magny-les-Hameaux, France, florian.feppon@polytechnique.edu
[3]Laboratoire Jean Kuntzmann, Université Joseph Fourier, Grenoble, France

Keywords : nonlinear constrained optimization, first order methods, gradient flows, topology optimization)

A gradient flow algorithm is proposed for solving generic equality or inequality constrained optimization problems set on Hilbert spaces. Our ultimate goal is non parametric shape optimization, for which more classical optimization methods are often difficult to use because of the infinite dimensionality or the need for tuning algorithm parameters. We rely on a variant of classical gradient flows for equality constrained problems : the search direction is a combination of a null space step and a range space step, which are aimed to reduce the value of the minimized objective function and the violation of the constraints, respectively. Inequality constraints are specifically addressed by solving a dual quadratic programming subproblem of size the number of active or violated constraints, which allows to detect the subset of these to which the optimization trajectory needs to remain tangent. We then extend the method to quite general optimization sets equipped with a suitable manifold structure, and notably to sets of shapes as it occurs in shape optimization with the framework of Hadamard's boundary variation method. The cornerstone of this latter setting is the classical operation of extension and regularization of shape derivatives. Some numerical comparisons on simple academic examples are performed to illustrate the behavior of our algorithm. Its numerical efficiency and ease of implementation are finally demonstrated on more realistic shape optimization problems.

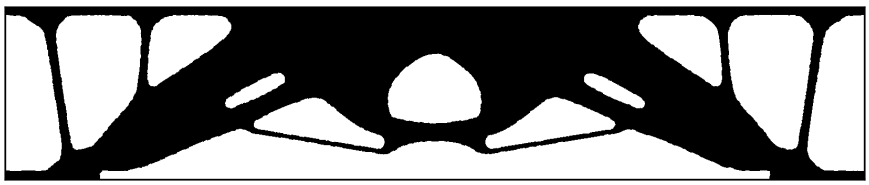

FIGURE 1 – An optimized shape for a 2-d bridge featuring 10 load constraints (from [1]).

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Coupled optimization of both structure and mechanical connections (location and number)

L. Rakotondrainibe[1,2] G. Allaire[2] P. Orval[1]

[1]Technocentre RENAULT, 1 Avenue du Golf, 78 084 Guyancourt cedex, France,
lalaina.rakotondrainibe@renault.com, patrick.orval@renault.com
[2] Centre de Mathématiques Appliquées, Ecole Polytechnique, Route de Saclay, 91128 Palaiseau, France,
gregoire.allaire@polytechnique.fr

Keywords: Topology optimization, Level-set method, Topological derivative, Mechanical connections

One of the issues for the automotive industry is weight reduction. For this purpose, topology optimization is used for mechanical parts and usually involves a single part. Its connections to other parts are assumed to be fixed. We propose here a coupled topology optimization of both the structure of a part and its connections (location and number) to other parts. Connection models (e.g. rigid support and long standard bolt with pre-stressed state) are idealized to be enough representative and cost-effective whereas the structure, represented by a level-set function, is more realistic. A coupled optimization of the structure and the location of rigid supports is performed to minimize the volume of an engine accessories bracket under a compliance constraint. The structure is optimized with Hadamard's boundary variation method [1]. The positions of the rigid supports are optimized with a parametric gradient-based algorithm. Thereafter, the concept of topological derivative [2, 3] is adapted to create an idealized bolt at the best location. This method is based on an asymptotic expansion that expresses the sensitivity of an objective function with respect to the creation of a small idealized bolt. This approach is implemented with a 3d academic test case for a problem of compliance minimization. This coupled topology optimization (shape and connections) provides more satisfactory performance of a part than the one given by classical shape optimization alone. The approach presented in this work is therefore one step closer to the optimization of assembled mechanical systems.

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Robust topology optimization of nanophotonic devices

Nicolas Lebbe[1,2,*] Charles Dapogny[2] Edouard Oudet[2] Karim Hassan[1] Alain Glière[1]

[1]Université Grenoble Alpes, CEA, LETI, MINATEC Campus, F-38054 Grenoble, France
[2]Université Grenoble Alpes, CNRS, Inria, Grenoble INP, LJK, F-38041 Grenoble, France
* lebbe.nicolas@gmail.com

Keywords: topology optimization, level-set method, nanophotonics, robustness

We are interested in the shape and topology optimization of nanophotonic devices [3, 4] using the Hadamard shape derivative and level-set methodologies [1]. Our studies have led us to take into account physical uncertainties in the models in order to obtain robust devices according to environmental parameters such as the incident wavelength of the laser, the ambient temperature or uncertainties concerning the geometry manufactured by the lithography-etching process. Mathematically we are interested in the following worst-case optimization problem

$$\max_{\Omega} \min_{|\delta| \leq C} \mathcal{J}(\mathbf{E}_\Omega, \delta) \tag{1}$$

where $\Omega \subset \mathbb{R}^3$ is the optimized shape, $\mathbf{E}_\Omega$ the electric field solution of the time-harmonic vector wave equation [2] using Ω, δ an uncertain parameter with maximal amplitude C and $\mathcal{J}$ the objective functional which is typically the output power. The results obtained by applying a multi-objectives optimization method to the resolution of problem (1) will be presented.

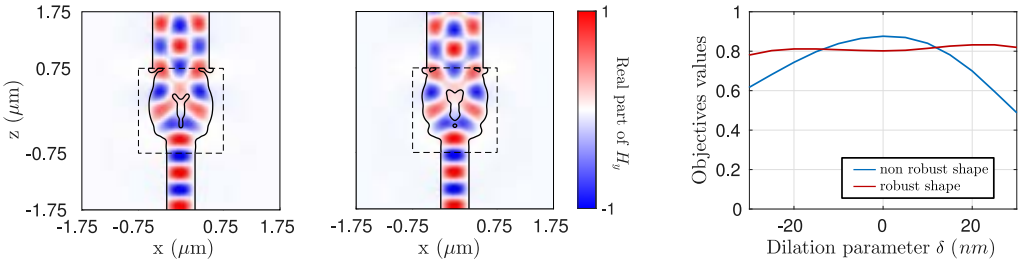

Figure 1: Two nanophotonic mode converters with one robust with respect to dilation or erosion.

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Sinkhorn Divergences for Unbalanced Optimal Transport

Thibault Séjourné, Jean Feydy, Francois-Xavier Vialard, Alain Trouvé, Gabriel Peyré

[1]DMA, ENS, France, {jean.feydy,thibault.sejourne,gabriel.peyre}@ens.fr
[2]CMLA, ENS Paris-Saclay, France, {trouve,feydy}@cmla.ens-cachan.fr
[2]LIGM, UPEM, France, francois-xavier.vialard@u-pem.fr

Keywords: optimal transport, entropic regularization, sinkhorn divergence, unbalanced OT

We will introduce in this presentation an extension the formulation of Sinkhorn divergences to the unbalanced setting of arbitrary positive measures, providing both theoretical and algorithmic advances. Sinkhorn divergences, introduced in [1], leverage the entropic regularization of Optimal Transport (OT) to define geometric loss functions. They are differentiable, cheap to compute and do not suffer from the curse of dimensionality, while maintaining the geometric properties of OT, in particular they metrize the weak* convergence. Extending these divergences to the unbalanced setting is of utmost importance since most applications in data sciences require to handle both transportation and creation/destruction of mass. This includes for instance problems as diverse as shape registration in medical imaging, density fitting in statistics, generative modeling in machine learning, and particles flows involving birth/death dynamics. Our first set of contributions is the definition and the theoretical analysis of the unbalanced Sinkhorn divergences. They enjoy the same properties as the balanced divergences (classical OT), which are obtained as a special case. Indeed, we show that they are convex, differentiable and metrize the weak* convergence. Our second set of contributions studies generalized Sinkhorn iterations, which enable a fast, stable and massively parallelizable algorithm to compute these divergences. We show, under mild assumptions, a linear rate of convergence, independent of the number of samples, i.e. which can cope with arbitrary input measures. We also highlight the versatility of this method, which takes benefit from the latest advances in term of GPU computing, for instance through the KeOps library for fast and scalable kernel operations.

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Newton-Conjugate Gradient Methods with Complexity Guarantees

Clément W. Royer[1] Michael O'Neill[2] Stephen J. Wright[2]

[1]Université Paris-Dauphine, France, clement.royer@dauphine.psl.eu
[2]University of Wisconsin-Madison, USA moneill@cs.wisc.edu, swright@cs.wisc.edu

Keywords: Nonconvex optimization, conjugate gradient, worst-case complexity.

There has been a recent surge of interest for finding local minima of nonconvex functions, mostly due to the outbreak of such instances in data science. In this setting, one aims at developing algorithms with suitable worst-case complexity properties. However, endowing an algorithm with a complexity analysis often requires to depart from the standard version of such a method. This can prevent from efficiently implementing or even testing these variants, in spite of their theoretical appeal.

In this talk, we consider a classical, practical approach in large-scale optimization, where the (linear) conjugate gradient algorithm is incorporated in a Newton-type method. To equip this scheme with a complexity analysis, we revisit the convergence theory of the conjugate gradient algorithm when applied to a nonconvex quadratic function. We also leverage randomized linear algebra techniques to allow for second-order complexity results at a suitable cost. By incorporating these tools within our Newton-type framework, we are able to match the guarantees of recently proposed algorithms based on accelerated gradient. Finally, we illustrate the performance of our strategies on several nonconvex problems.

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Interior point methods for logistic regression

Rubing Shen[1] François Pacaud[2]

[1]Ecole Polytechnique, France, rubing.shen@polytechnique.edu
[2]Artelys, France, francois.pacaud@artelys.com

Keywords: Non-linear programming, logistic regression, hyperparameters optimization

Logistic regression is a well known statistical model used to predict binary outcomes. Fitting logistic regression models reduces to the minimization of an empirical loss penalizing the gap between the values predicted by the statistical model and the observations. The corresponding optimization problem formulates naturally as a (unconstrained) non-linear problem. Then, the numerical resolution of the problem often fallbacks to a first order method. However, if the size of the dataset is not too large, second order methods also have proven to be effective [3]. In this talk, we study the resolution of logistic regression problems with a commercial interior point solver, Artelys Knitro [2]. We first provide numerical studies showing that Knitro behaves well to fit logistic regression models, both with ℓ_1 and ℓ_2 penalties. We compare Knitro with the solver L-BFGS-B [5], currently used in the library Scikit-Learn [4]. In the second part of the talk, we focus on the optimization of regularization hyperparameters. We suppose given a cross-validation evaluation function, based onto a validation dataset. By using the implicit function theorem, we derive the sensivity of the cross-validation loss function w.r.t. the penalty term [1], thus allowing to optimize it with a descent algorithm based on BFGS. The devised algorithm is faster than classical methods such as grid searches, and outperforms the finite-difference algorithm implemented inside Knitro. Eventually, we depict some ideas to improve interior point algorithms for the resolution of optimization problems arising in machine learning.

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An extended LP formulation for the water pump scheduling problem

Sophie Demassey Gratien Bonvin
CMA, Mines ParisTech, PSL Research University, France, sophie.demassey@mines-paristech.fr

Key words: Pump scheduling, Water distribution networks, Linear Programming.

Pump scheduling in drinking water distribution networks is the problem to plan, on the day-ahead typically, the operation of the pumps and the storage usage of the water tanks, in order to meet the dynamic demand in water at minimum costs. Solving this optimization problem is hard as it involves to model, for every time step of the discretized scheduling horizon, the hydraulic laws governing flows and pressures as non-convex relations, and the decision to activate pumps and valves as discrete variables. Global optimization using an on-the-shelf Mixed Integer NonLinear Programming (MINLP) solver can only be envisaged on toy instances with an overly-coarse time discretization. The two main options rely then either on a piecewise-linear approximation of the non-convex relations, or on an hydraulic simulator embedded in an optimization scheme. However, these approaches lead to suboptimal solutions, and they still rapidly become too time consuming as the problem size grows.

We present in this work an intermediate approach exploiting the strength of these two approaches and avoiding their pitfalls. The idea comes from the observation that the pressure variation at the tank nodes has a limited impact on the hydraulic balance of the network and thus can be neglected. Hence, by dualizing the time-coupling constraints of the compact MINLP formulation, we get an extended (continuous) LP formulation which can be quickly and entirely populated in a preprocessing step using a hydraulic simulator, and thanks to network partition and symmetry breaking arguments, after fixing arbitrarily the pressure at the tank nodes. Experimented on two benchmark instances of small-to-medium size, with fixed- or variable-speed pumps, the LP is built and solved in less than 3 seconds and provides approximated solutions which can be considered of practical use, as input of the network controller. A fast local search, inspired from the combinatorial Benders decomposition framework by [2] allows to derive then feasible near-optimal solutions in less than 1 minute where more specialized approaches reach comparable solutions in more than 30 minutes. [1]

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Evaluation of the Impact of the Power Production Function Approximation on Hydropower Maintenance Scheduling

Éloïse Edom[1] Miguel F. Anjos[2] Wim Van Ackooij[3] Claudia D'Ambrosio[4]
Pascal Côté[5] Sara Séguin[6]

[1]GERAD & Polytechnique Montréal, Canada, eloise.edom@polymtl.ca
[2]University of Edinburgh, UK, & Polytechnique Montréal, Canada, miguel.f.anjos@ed.ac.uk
[3]EDF R&D, Palaiseau, France, wim.van-ackooij@edf.fr
[4]LIX, CNRS & École Polytechnique, Palaiseau, France, dambrosio@lix.polytechnique.fr
[5]GERAD & Rio Tinto Aluminium, Québec, Canada, pascal.cote@riotinto.com
[6]GERAD & Université du Québec à Chicoutimi, Québec, Canada, sara_seguin@uqac.ca

Keywords: Hydroelectricity, maintenance scheduling, hydropower production function, mixed-integer linear optimization, nonlinear optimization.

Maintenance planning for hydropower plants is a crucial problem. In this paper, we evaluate the impact of the Hydropower Production Function formulation on the maintenance scheduling. Based on an existing model for Generator Maintenance Scheduling that uses a convex hull approximation for representing the Hydropower Production Function, we developed two additional models. The first one uses piecewise linear approximations and the second approach consists at using a polynomial function fitted on real data. We compare these three approximations using a real-world hydroelectric complex and two sets of data, one generated using the dynamic programming algorithm that simulate the power output, and the other produced by taking the convex envelope of the first set. The results show that changing the approximation used shifts the scheduling of some maintenance tasks, and hence that maintenance schedules may be noticeably impacted by the approximation of the production function. For the hydroelectric complex we consider, the differences between schedules can represent up to 8.3 GWh per month.

A Lagrangian Decomposition for Hydro Unit Commitment Problem With Two Reservoir

Wim van Ackooij[1] Claudia D'Ambrosio[2] Dimitri Thomopulos[2] Renan Spencer Trindade[2]

[1] OSIRIS, EdF R&D, Palaiseau, France, wim.van-ackooij@edf.fr

[2] LIX, CNRS, École Polytechnique, Institut Polytechnique de Paris, Palaiseau, France, dambrosio@lix.polytechnique.fr, thomopulos@lix.polytechnique.fr, renanspencer@gmail.com

Keywords: Hydro Unit Commitment Problem, Lagrangian Decomposition, Two reservoirs

Scheduling power production in water valleys is a critical problem solved daily by electrical power companies around the world. About 16.4% of the world's total energy comes from the hydropower production model, and represents 71% of all renewable electricity. It is necessary to define how to produce energy in each time-stamp, complying with the previously established demand, respecting the operational constraints and minimizing the operational cost. This is a large-scale problem that has strong non-linear and combinatorial characteristics. Also, many water valleys have cascading reservoirs, which increases the complexity of planning. In this work, we addressed the problem of optimizing short-term power generation planning, called the Hydro Unit Commitment Problem, considering two cascading reservoirs. We propose a Lagrangian Decomposition for the problem, which allows us to obtain the solution for each reservoir separately, as subproblems. This work is an extension of [1], which presents a study on the single-reservoir version of the problem and shows that this problem is reduced to the Constrained Shortest Path Problem. To deal with the difficulty of representing the flow rate curve and the energy generated, we used a *priori* discretization made by the operational team. This allows us to implement a deterministic price-taker model through the operational points and represent the problem through a time expanded graph representation, under some considerations: i) we ignore the head effect on this problem, thus some non-linear impacts are not considered ii) the set of operational points for the generated production is discrete. A Directed Acyclic Graph is generated for each reservoir and includes all operational points at each time step, including a starting and ending node, both artificial. Arcs indicate whether you can move from one operating point to another without violating the physical constraints of the problem. In our decomposition, we use the monotone reformulation and apply a labeling algorithm to the subproblem of the first reservoir. We also simplified the subproblem of the second reservoir to the Shortest Path Problem. In this case, the water bounds constraints were relaxed in decomposition.

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Bayesian Multi-objective Optimization with Noisy Evaluations using the Knowledge Gradient

Bruno Barracosa[1,2] Julien Bect[2] Héloïse Baraffe[1]
Juliette Morin[1] Gilles Malarange[1] Emmanuel Vazquez[2]

[1]EDF R&D, France, bruno.tebbal-barracosa@edf.fr
heloise.baraffe@edf.fr, juliette.morin@edf.fr , gilles.malarange@edf.fr

[2]Laboratoire des Signaux et Systèmes (L2S)
CentraleSupélec, CNRS, Univ. Paris-Sud, Université Paris-Saclay, France,
julien.bect@centralesupelec.fr, emmanuel.vazquez@centralesupelec.fr

Keywords: Bayesian optimization, global optimization, multi-objective optimization, noisy optimization, simulation optimization

We consider the problem of multi-objective optimization in the case where each objective is a stochastic black box that provides noisy evaluation results. More precisely, let $f_1, \dots f_q$ be q real-valued objective functions defined on a search domain $\mathbb{X} \subset \mathbb{R}^d$, and assume that, for each $x \in \mathbb{X}$, we can observe a noisy version of the objectives: $Z_1 = f_1(x) + \varepsilon_1, \dots, Z_q = f_q(x) + \varepsilon_q$, where the ε_is are zero-mean random variables. Our objective is to estimate the Pareto-optimal solutions of the problem:

$$\min f_1, \dots, f_q \,. \tag{1}$$

We adopt a Bayesian optimization approach, which is a classical approach when the affordable number of evaluations is severely limited—see, e.g., [1], in the context of multi-objective optimization. In essence, Bayesian optimization consists in choosing a probabilistic model for the outputs Z_i and defining a sampling criterion to select evaluation points in the search domain $\mathbb{X}$.

Here, we propose to discuss the extension of the Knowledge Gradient approach [2] for solving the multi-objective problem (1). For instance, such an extension has been recently proposed by Astudillo and Frazier [3].

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New Containers Scheduling Strategy based on a Multi-Criteria Decision Algorithm

Tarek Menouer Patrice Darmon

Umanis, Levallois Perret, France, {tmenouer,pdarmon}@umanis.com

Keywords: Container Technology, Scheduling Strategy, Multi-criteria Optimization.

This paper presents a new scheduling strategy proposed to optimize the scheduling of several containers submitted online by users in a private infrastructure of nodes i.e. a cloud platform.

In the literature, there are several frameworks proposed to schedule containers on cloud computing such as Google Kubernetes, Docker SwarmKit and Apache Mesos. However, the majority of scheduling frameworks use strategies based on only one criterion. For example, the Docker SwarmKit (version v1.12) is based on Spread strategy. This strategy executes a container on the node having the least number of running containers. The goal is to ensure a good load balancing of containers between all nodes of the infrastructure. The Bin Packing strategy is also used as a scheduling strategy in the previous Docker SwarmKit version and on the study presented in [2]. The principle of the Bin packing scheduling strategy consists in choosing the most compacted node regarding resources in order to reduce the total number of used nodes.

In our context, the submitted containers are defined in multi-criteria mode, such as the number of used CPUs and the used memory size. The state of each node is also defined in multi-criteria mode, such as the number of executed containers, the number of available CPUs and the size of available memory.

The novelty of our scheduling strategy is to choose the node that executes a container by combining the Spread and the Bin Packing principles using the Technique for the Order of Prioritisation by Similarity to Ideal Solution (TOPSIS) algorithm [1]. TOPSIS is a multi-criteria decision analysis algorithm used with success to solve several problems. Our proposed strategy is implemented in Docker SwarmKit. Docker swarmKit is an important container scheduler framework developed by Docker. Our strategy is presented in [3] and the experiments demonstrate the potential of our strategy in terms of performance gains under different scenarios.

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Bayesian Optimization in Reduced Eigenbases

David Gaudrie[1] Rodolphe Le Riche[2] Victor Picheny[3]

[1]Groupe PSA, France, david.gaudrie@mpsa.com
[2]CNRS LIMOS, Mines Saint-Étienne, France
[3]Prowler.io, United Kingdom

Keywords: Dimension Reduction, Principal Component Analysis, Gaussian Processes, Bayesian Optimization

Parametric shape optimization aims at minimizing a function $f(\mathbf{x})$ where $\mathbf{x} \in X \subset \mathbb{R}^d$ is a vector of d Computer Aided Design parameters, representing diverse characteristics of the shape $\Omega_{\mathbf{x}}$. It is common for d to be large, $d \gtrsim 50$, making the optimization difficult, especially when f is an expensive black-box and the use of surrogate-based approaches [1] is mandatory.

Most often, the set of considered CAD shapes resides in a manifold of lower dimension where it is preferable to perform the optimization. We uncover it through the Principal Component Analysis of a dataset of n designs, mapped to a high-dimensional shape space via $\phi : X \to \Phi \subset \mathbb{R}^D$, $D \gg d$. With a proper choice of ϕ, few *eigenshapes* allow to accurately describe the sample of CAD shapes through their principal components $\boldsymbol{\alpha}$ in the eigenbasis $\mathbf{V} = [\mathbf{v}^1, \dots, \mathbf{v}^D]$.

A Gaussian Process is fitted to the principal components $\boldsymbol{\alpha}^{(1)}, \dots, \boldsymbol{\alpha}^{(n)} \in \mathbb{R}^D$ instead of $\mathbf{x}^{(1)}, \dots, \mathbf{x}^{(n)} \in X$. The δ most important eigenshapes are selected by maximizing a likelihood with a L_1 regularization. These δ active dimensions with components $\boldsymbol{\alpha}^a$ are emphasized without entirely neglecting the $D - \delta$ remaining dimensions by constructing an additive GP [3]: $Y(\boldsymbol{\alpha}) = Y^a(\boldsymbol{\alpha}^a) + Y^{\overline{a}}(\boldsymbol{\alpha}^{\overline{a}})$. Y^a is the main-effect δ-dimensional anisotropic GP and $Y^{\overline{a}}$ is a coarse, isotropic high $(D - \delta)$ dimensional GP which only requires 2 hyperparameters.

A redefinition of the Expected Improvement [1] is proposed to take advantage of the space reduction and to carry out the maximization in the smaller space of important eigenshapes, completed by a cheap maximization with regard to $\boldsymbol{\alpha}^{\overline{a}}$ through an embedding strategy [4], $\boldsymbol{\alpha}^{(n+1)} = \arg\max \mathrm{EI}([\boldsymbol{\alpha}^a, \boldsymbol{\alpha}^{\overline{a}}])$. Its pre-image, $\mathbf{x}^{(n+1)} = \underset{\mathbf{x} \in X}{\arg\min} \, \|\mathbf{V}^\top \phi(\mathbf{x}) - \boldsymbol{\alpha}^{(n+1)}\|^2$, is the next evaluated design. A new replication strategy is described that guides the optimization to the manifold of the observed $\boldsymbol{\alpha}^{(i)}$, $i = 1, \dots, n$. It is based on the repelling property of EI and the addition of both $\boldsymbol{\alpha}^{(n+1)}$ and $\mathbf{V}^\top \phi(\mathbf{x}^{(n+1)})$ to the pool of components conditioning the GP.

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Optimal Resource Allocation in Micro-organisms: the Dynamics of Photoacclimation in Microalgae as a Case Study (Oracle Project)

Térence Bayen[1] Olivier Bernard[2] Piernicola Bettiol[3] Jean-Luc Gouzé[2]
Francis Mairet[4] Tangi Migot[5] Julien Salomon[6]

[1] Université d'Avignon
[2] Inria Biocore, Sophia Antipolis
[3] Université de Bretagne Occidentale
[4] Ifremer PBA, Nantes, francis.mairet@ifremer.fr
[5] University of Guelph, Canada
[6] Inria Ange, Paris

Keywords: Bi-level optimization, Pontryagin's maximum principle, Microbial growth

Given their key role in almost all ecosystems and in several industries, understanding and predicting microorganism growth is of utmost importance. In compliance with evolutionary principles, coarse-grained models of microbial growth can be used to determine optimal resource allocation scheme under dynamic environmental conditions. The key idea is to represent microorganism growth as an optimal control problem (OCP). In a previous work, we have determined using Pontryagin's maximum principle and numerical simulations the optimal strategy (involving a chattering arc) for a bacterial population facing a nutrient up-shift [1, 2].

This approach must now be validated with experiments. But fitting these models with data results in a bi-level optimization problem, whose numerical resolution involves complex optimization issues. As a toy example, we present here a model describing how microalgae acclimate to a change in light intensity. After the analytical investigation of the OCP by Pontryagin's maximum principle, we fit the model with experimental data. To do so, we use a classical parameter identification routine, calling at each iteration the bocop solver [3] to solve the OCP.

When dealing with more realistic model (*i.e.*, when increasing the numbers of states, controls, and parameters), the aforementioned fitting procedure will become too heavy. As a future work in the framework of the Oracle project, we aim to develop numerical tools to tackle such a complex bi-level optimization problem.

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Quasi-Variational Inequality problems over product sets and applications to GNEPs

Didier Aussel[1] Kien Cao Van[1] David Salas[2]

[1] Université de Perpignan Via Domitia, France aussel@univ-perp.fr, kien.van@promes.cnrs.fr
[2]CMM - Universidad de Chile, Chile dsalas@dim.uchile.cl

Keywords:Quasi-variational inequalities, Generalized Nash equilibrium, net-lower sign-continuity, quasimonotone operators, electricity contract problem

Quasi-variational inequalities are variational inequalities in which the constraint map depends on the current point. Due to this characteristic, specific proofs have been built to prove adapted existence results. Semicontinuity and generalized monotonicity are assumed and many efforts have been made in the last decades to use the weakest concepts. In the case of quasi-variational inequalities defined on a product of spaces, the existence statements in the literature require pseudomonotonicity of the operator, an hypothesis that is too strong for many applications, in particular in economics. On the other hand, the current minimal hypotheses for existence results for general quasi-variational inequalities are quasimonotonicity and locally upper sign- continuity. But since the product of quasimonotone (respectively locally upper sign-continuous) operators is not in general quasimonotone (respectively locally upper sign-continuous) it is thus quite difficult to use these general-type existence result in the quasi-variational inequalities defined on a product of spaces.

Our aim in this work is to develop some specific existence results for Generalized Nash Equilibrium Problems (GNEP), first introduced by Debreu as early as 1952. The GNEP is an extension of the classical Nash equilibrium problem in which the payoff function and strategy set of each player depend on the decision of the other players. These results are based on recent developments for quasi-variational inequalities defined on products of spaces and allows to tackle GNEP involving a bilevel structure, that is Multi-Leader-Follower Games. Applications to an energy management problem will be considered, thanks to the concept of Multi-Leader-Disjoint-Follower game.

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Solving Perfect Information Mean Payoff Zero-sum Stochastic Games by Variance Reduced Deflated Value Iteration

Marianne Akian[1] Stéphane Gaubert[1] Zheng Qu[2] Omar Saadi[3]

[1]INRIA and CMAP, École polytechnique, France, stephane.gaubert@inria.fr, marianne.akian@inria.fr
[2]Dep. Math., The University of Hong Kong, China, zhengqu@hku.hk
[3]CMAP, École polytechnique and INRIA, France, omar.saadi@polytechnique.edu,

Keywords: Deflated value iteration, stochastic games, mean payoff problems, first hitting times, variance reduction.

We introduce a deflated version of value iteration, which allows one to solve mean-payoff problems, including both Markov decision processes and perfect information zero-sum stochastic games. This method requires the existence of a distinguished state which is accessible from all initial states and for all policies; it differs from the classical relative value iteration algorithm for mean payoff problems in that it does not need any primitivity or geometric ergodicity condition. Our method is based on a reduction from the mean payoff problem to a discounted problem by a Doob h-transform, combined with a deflation technique and non-linear spectral theory results (Collatz-Wielandt characterization of the eigenvalue), inspired by [1]. In this way, we provide a new method *Deflated Value Iteration* that allows to extend complexity results from the discounted to the mean payoff case. In particular, Sidford, Wang, Wu and Ye [2] developed recently an algorithm combining value iteration with variance reduction techniques to solve discounted Markov decision processes in sublinear time when the discount factor is fixed. We combine deflated value iteration with variance reduction techniques to obtain sublinear algorithms for mean payoff stochastic games in which the first hitting times of a distinguished state are bounded a priori.

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There's No Free Lunch: On the Hardness of Choosing a Correct Big-M in Bilevel Optimization

Thomas Kleinert[1,2] Martine Labbé[3,4] Fränk Plein[3,4] Martin Schmidt[5]

[1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany;
[2]Energie Campus Nürnberg, Nürnberg, Germany;
thomas.kleinert@fau.de
[3]Université Libre de Bruxelles, Brussels, Belgium;
[4]Inria Lille - Nord Europe, Villeneuve d'Ascq, France;
{martine.labbe,frank.plein}@ulb.ac.be
[5]Trier University, Trier, Germany;
martin.schmidt@uni-trier.de

Keywords: Bilevel optimization, MPCC, Bounding polyhedra, Big-M, Hardness

One of the most frequently used approaches to solve linear bilevel optimization problems consists in replacing the lower-level problem with its Karush–Kuhn–Tucker (KKT) conditions and by reformulating the KKT complementarity conditions using techniques from mixed-integer linear optimization. The latter step requires to determine some big-M constant in order to bound the lower level's dual feasible set such that no bilevel-optimal solution is cut off. In practice, heuristics are often used to find a big-M although it is known that these approaches may fail. In this paper, we consider the hardness of two proxies for the above mentioned concept of a bilevel-correct big-M. First, we prove that verifying that a given big-M does not cut off any feasible vertex of the lower level's dual polyhedron cannot be done in polynomial time unless $\mathsf{P} = \mathsf{NP}$. Second, we show that verifying that a given big-M does not cut off any optimal point of the lower level's dual problem (for any point in the projection of the high-point relaxation onto the leader's decision space) is as hard as solving the original bilevel problem.

Near-Optimal Robust Bilevel Optimization

Mathieu Besançon[1,2] Miguel F. Anjos[3] Luce Brotcorne[2]

[1] Department of Mathematics & Industrial Engineering, Polytechnique Montréal, Canada.
mathieu.besancon@polymtl.ca
[2] INRIA Lille Nord-Europe, INOCS.
luce.brotcorne@inria.fr
[3] School of Mathematics, University of Edinburgh, Edinburgh, Scotland.
anjos@stanfordalumni.org

Keywords: bilevel optimization, robust optimization, game theory, bounded rationality, duality, bilinear constraints, extended formulation

Bilevel optimization problems embed the optimality conditions of a sub-problem into the constraints of a decision-making process. Such structure arises in a variety of decision-making problems in areas such as market equilibria, policy design or product pricing.

We introduce near-optimal robustness for bilevel problems, protecting the upper-level decision-maker from bounded rationality at the lower level and show it is a restriction of the corresponding pessimistic bilevel problem and of the constraint-based pessimistic formulation developed in [1]. Essential properties are derived in generic and specific settings. This model finds a corresponding and intuitive interpretation in various situations cast as bilevel optimization problems.

We develop a duality-based solution method for cases where the lower level is convex, leveraging the methodology from robust and bilevel literature. The models obtained are tested numerically using different solvers and formulations, showing the successful implementation of the near-optimal robust bilevel problem.

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The Rank Pricing Problem with Ties

Concepción Domínguez[1,2] Martine Labbé[1] Alfredo Marín[2]

[1]Université Libre de Bruxelles, Belgium, mlabbe@ulb.ac.be

[2]Universidad de Murcia, Spain, concepcion.dominguez@um.es, amarin@um.es

Keywords: Bilevel Programming, Mixed-integer programming, Pricing Problems

Pricing optimization problems are widely present in the economic literature, and their aim is to determine the prices of a series of products in order to maximize the revenue of a company. They have a bilevel structure with a first optimization problem given by the company, which aims at maximizing its profit, and part of the constraints that force the solution to be optimal to another optimization problem, which is modeling the customers' behavior.

The Rank Pricing Problem (RPP), introduced in [3], is an optimization problem which aims at setting the prices of a series of products of a company so as to maximize its revenue. In this pricing problem, customers are unit-demand, that is, they intend to buy at most one unit of a product among the ones offered by the company. To do so, they own a positive budget and they rank the products of their interest. Once the prices are established by the company, they will purchase their highest-ranked product among the ones they can afford (if any). The first bilevel and mixed-integer formulations and an in-depth analysis of its structure can be found in [1].

We present a generalization of the RPP, namely the Rank Pricing Problem with Ties (RPPT), in which we consider that ties in the preferences of the customers may occur. To model the RPPT, we present a formulation based on class representatives, an idea already used for the vertex coloring problem in Campêlo et al. [2]. To tackle its resolution, we also thoroughly introduce a reformulation of the problem based on Benders Decomposition.

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Handling correlated and repeated measurements with the smoothed Multivariate square-root Lasso

Quentin Bertrand[1] Mathurin Massias[1] Alexandre Gramfort[1] Joseph Salmon[2]

[1]Université Paris-Saclay, Inria, CEA, Palaiseau, 91120, France first.lastname@inria.fr
[2]IMAG, Univ. Montpellier, CNRS, Montpellier, France

Keywords: Optimization, Sparsity, Lasso, Neuroimaging Applications

Sparsity promoting norms are frequently used in high dimensional regression. A limitation of such Lasso-type estimators is that the optimal regularization parameter depends on the unknown noise level. Estimators such as the concomitant Lasso address this dependence by jointly estimating the noise level and the regression coefficients. Additionally, in many applications, the data is obtained by averaging multiple measurements: this reduces the noise variance, but it dramatically reduces sample sizes and prevents refined noise modeling. In this work, we propose a concomitant estimator that can cope with complex noise structure by using non-averaged measurements. The resulting optimization problem is convex and amenable, thanks to smoothing theory, to state-of-the-art optimization techniques that leverage the sparsity of the solutions. Practical benefits are demonstrated on toy datasets, realistic simulated data and real neuroimaging data.

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The Geometry of Sparse Analysis Regularization

X. Dupuis[1] S. Vaiter[2]

[1]Institut de Mathématiques de Bourgogne, France, xavier.dupuis@u-bourgogne.fr
[2]CNRS & Institut de Mathématiques de Bourgogne, France, samuel.vaiter@u-bourgogne.fr

Keywords: analysis ℓ_1-regularization, extreme solutions, maximal solutions

Analysis sparsity is a common prior in inverse problem or linear regression. We study the geometry of the solution set (a polyhedron) of the analysis ℓ_1-regularization when it is not reduced to a singleton. Leveraging a fine analysis of the sublevel sets of the regularizer, we derive a connection between the sign pattern of a solution and the dimension of the smallest face containing it. Particularizing this result, we get on the hand an algebraic test to check whether a solution is extreme (that is an extreme point of the solution set). Such solutions are of interest in the theory of representer theorems [1]. On the other hand, it gives the dimension of the solution set from the sign a maximal solution (that is a solution in the relative interior of the solution set), which can be determined numerically [2]. We provide numerical examples on how to use these results [3].

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Variational Formulations for the l_0 Pseudonorm and Applications to Sparse Optimization

Jean-Philippe Chancelier [1] Michel De Lara[1]

[1]École des Ponts ParisTech

Keywords: sparse optimization, ℓ_0 pseudonorm, orthant-strictly monotonic norms, generalized k-support norms, Fenchel-Moreau conjugacy

In sparse optimization problems, one looks for solution that have few nonzero components. We consider problems where sparsity is exactly measured by the ℓ_0 pseudonorm. In this case, the Fenchel conjugacy fails to provide relevant analysis: the Fenchel conjugate of the characteristic function of the level sets of the ℓ_0 pseudonorm is minus infinity; the Fenchel biconjugate of the ℓ_0 pseudonorm is zero. In this talk, we display a new conjugacy, induced by a so-called coupling Capra (constant along primal rays), which depends on a general source norm, and we show that it is suitable for the ℓ_0 pseudonorm and for sparse optimization, in three points.

First, we show that the Capra conjugate of the characteristic function of the level sets of the ℓ_0 pseudonorm is a new norm, the generalized top-k norm. With this, we display a lower bound convex program for the original (nonconvex) exact sparse optimization problem, which is a convex minimization program over the unit ball of a so-called generalized k-support norm.

Second, we show that the Capra biconjugate of the ℓ_0 pseudonorm is equal to the ℓ_0 pseudonorm, when the source norm of the coupling Capra has some properties — like orthant-strictly monotonic, rotundity. As a corollary, we obtain that the (nonconvex) ℓ_0 pseudonorm coincides, on the sphere, with a convex lower semi continuous function that we characterize. From this, we deduce variational formulas for the ℓ_0 pseudonorm. With these novel expressions for the ℓ_0 pseudonorm, we provide reformulations for exact sparse optimization problems, that contain convex parts, even if the original problem had no convex parts.

Third, we hint at how the above machinery extends to generalized sparse optimization, where the solution is searched among a finite union of subsets.

Polyhedral Newton-Min Algorithms for Complementarity Problems

Jean-Pierre Dussault[1] Mathieu Frappier[2] Jean Charles Gilbert[3]

[1]Université de Sherbrooke, Canada, Jean-Pierre.Dussault@Usherbrooke.ca
[2]Université de Sherbrooke, Canada, Mathieu.Frappier@usherbrooke.ca
[3]INRIA Paris, Jean-Charles.Gilbert@inria.fr

Keywords: complementarity problem, finite convergence, global convergence, least-square merit function, linesearch, minimum function, nonsmooth reformulation, P-matrix, polyhedral Newton-min algorithm, semismooth Newton.

The semismooth Newton method is a very efficient approach for computing a zero of a large class of nonsmooth equations. When the initial iterate is sufficiently close to a regular zero and the function is strongly semismooth, the generated sequence converges quadratically to that zero, while the iteration only requires to solve a linear system.

If the first iterate is far away from a zero, however, it is difficult to force its convergence using linesearch or trust regions because a semismooth Newton direction may not be a descent direction of the associated least-square merit function, unlike when the function is differentiable. We explore this question in the particular case of a nonsmooth equational reformulation of the nonlinear complementarity problem, using the minimum function. We propose a globally convergent algorithm using a modification of a semismooth Newton direction definition that makes it a descent direction of the least-square function. Instead of requiring that the direction satisfies a linear system, it must be a feasible point of a convex polyhedron; hence, it can be computed in polynomial time. This polyhedron is defined by the often very few inequalities, obtained by linearizing pairs of functions that have close negative values at the current iterate. Somehow, the algorithm feels the proximity of a "wrong kink" of the minimum function and acts accordingly.

In order to avoid as often as possible the extra cost of having to find a feasible point of a polyhedron, a hybrid algorithm is proposed, in which the Newton-min direction is accepted if a sufficient-descent-like criterion is satisfied. Global convergence to regular points is proved. The notion of regularity is associated with the algorithm and is analysed with care. For linear complementarity problems, this regularity condition has a subtle link with the nonsingularity of some principal submatrices and the **P**-matricity of Schur complements of other principal submatrices.

The design of the algorithm has been oriented by an intensive numerical exploration, which has shown that the proposed method is competitive with other solvers on some applications and on randomly generated problems.

A new strategy for solving nonlinear complementarity problems arising in thermodynamics of compositional multiphase mixtures

Duc Thach Son VU[1] Ibtihel BEN GHARBIA[1] Mounir HADDOU[2] Quang Huy TRAN[1]

[1]IFP Energies nouvelles, Rueil-Malmaison, France, duc-thach-son.vu@ifpen.fr,
[2]IRMAR, INSA-Rennes, Rennes, France, Mounir.Haddou@insa-rennes.fr

Keywords: Interior point methods, Multiphase flow, Newton method, Nonlinear complementarity problem

In this work, we propose a new method to solve difficult nonlinear complementarity problems [5, 3] arising in realistic applications.

Indeed, unified formulations [1, 2] using complementarity conditions have recently emerged as a promising way for the handling of the appearance and disappearance of phases in porous media multiphase compositional flows.

From a mathematical point of view and after discretization, this leads to systems of equations combining algebraic equations and nonlinear complementarity conditions. Such systems gives rise to major convergence difficulties for standard smooth or semi-smooth Newton-like methods [3].

This led us to design a new approach inspired by optimization interior point methods [4]. We propose a technique avoiding any parameter management while ensuring good theoretical convergence results validated by numerous numerical tests [7]. We present extensive numerical tests and several comparisons to classical methods [6].

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Error estimate for TV denoising

Antonin Chambolle[1] Corentin Caillaud[1]

[1]CMAP, Ecole Polytechnique, France

antonin.chambolle@cmap.polytechnique.fr, corentin.caillaud@polytechnique.edu

Keywords: Image denoising, Discrete total variations, Error estimates

We consider the ROF denoising problem

$$\overline{u} = \operatorname*{arg\,min}_{u\in BV(\Omega)} \frac{1}{2\lambda}||u-g||^2 + TV(u) =: E(u)$$

and we discretize it on a grid Ω^h of square pixels of size h, meaning that we look for a piece-wise constant ($P0$) function u^h and solve:

$$\overline{u}^h = \operatorname*{arg\,min}_{u^h\in P0(\Omega^h)} \frac{1}{2\lambda}||u^h-g^h||^2 + TV_d(u^h) =: E_h(u^h)$$

where g^h is the discretized version of the noisy image g. To do so, one can chose several discretizations TV_d of the continuous total variation TV. It has been observed frequently that the classical so called isotropic total variation $TV_d = TV_d^i$ given by

$$TV_d^i(u^h) = h\sum_{i,j}\sqrt{(u^h_{i+1,j}-u^h_{i,j})^2 + (u^h_{i,j+1}-u^h_{i,j})^2}$$

over-weights the 45 degrees diagonal leading to an exaggerate blur in that direction (that is when g is the characteristic function of this diagonal). We propose an estimation of the order of this blur. When defined on a cylinder, the problem reduces to a 1D denoising problem where the usual total variation term $\sum_n |u_{n+1}-u_n|$ is replaced by $\sum_n \sqrt{(u_{n+1}-u_n)^2+(u_n-u_{n-1})^2}$. We show that $|E_h(\overline{u}^h) - E(\overline{u})| \geq ch^{2/3}$ for a constant c depending only on λ and given by the positive value of the continuous optimization problem

$$\max_{\substack{\sigma,\rho \text{ s.t.}\\ \sigma(0)=\rho(0)=0\\ 2\sigma+\rho^2\leq 0}} \rho'(0) - \frac{\lambda}{2}\int_0^\infty (2\sigma'+\rho'')^2$$

As a comparison, we re-establish in our context of a square pixels grid, the result obtained in [1] with a total variation based on Raviart-Thomas fields. Taking $TV_d = TV_d^{RT}$ given by

$$TV_d^{RT}(u^h) = \sup\{-\int_{\Omega^h} u^h \operatorname{div}\phi^h,\ \phi^h\in RT0_0(\Omega^h) \text{ s.t. } \forall x\in\Omega,\ |\phi^h(x)|\leq 1\}$$

we obtain, under some reasonable hypothesis, the rate $|E_h(\overline{u}^h) - E(\overline{u})| \leq ch$.

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A Graph-based Heuristic for Variable Selection in Mixed Integer Linear Programming

Marc Etheve[1,2] Zacharie Ales[2,3] Côme Bissuel[1] Olivier Juan[1] Safia Kedad-Sidhoum[2]

[1]EDF R&D, France, marc.etheve@edf.fr, come.bissuel@edf.fr, olivier.juan@edf.fr
[2]CNAM, CEDRIC, safia.kedad_sidhoum@cnam.fr
[3]UMA, ENSTA Paris, Institut Polytechnique de Paris, zacharie.ales@ensta-paris.fr

Keywords: MILP, Branching Heuristic, Influence Maximization

Over the past decades, Branch and Bound (B&B) and its variants have become the most commonly used algorithms to solve Mixed Integer Linear Programming (MILP). Despite the efficiency of such methods, state-of-the-art solvers still rely on generic heuristics due to a lack of mathematical understanding of the underlying mechanics of the B&B algorithm. Amongst all the decisions made heuristically in a B&B tree, the most elementary are variable selection (branching) and node selection. As pointed out in [1], branching is crucial in controlling the size of a B&B tree and a plethora of heuristics has been put forward in the literature.

In this work, we propose a new branching heuristic, based on a graph representation of a MILP. Unlike many LP-based branching heuristics (e.g. Strong Branching and its variants), we propose an Influence Maximization scheme to target influential variables in the system of constraints. Indeed, the modifications of the polyhedron induced by branching in a B&B tree can be seen as local and guided by the links between variables through the set of constraints. This led us to the definition of a class of Influence Graphs for MILP dedicated to the proposed heuristic. As Influence Maximization in graphs is an NP-hard problem [2], we opt for using an approximation based on Spectral Clustering, allowing us to target multiple candidates for branching. We show that the proposed heuristic is equivalent in a specific case to clustering variables in a low-dimensional space when considering a MILP problem as a scatter of points.

We run some experiments with various Influence Graphs on EDF's energy planning problems, showing promising results in terms of size of the generated tree. The proposed heuristic seems to make structural branching decisions when used close to root node. However, the efficiency of this approach depends on the formulation as the notion of Influence is not invariant to reformulation.

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Mixed Integer Optimization Using Piecewise Linear Function Fitting and JULIA-based library

Julien Codsi[1,2] Bernard Gendron[1,2] Sandra Ulrich Ngueveu[3]

[1]CIRRELT and Département d'informatique et de recherche opérationnelle,
[2] Université de Montréal, Canada, julien.codsi@umontreal.ca, gendron@iro.umontreal.ca
[3]Université de Toulouse, CNRS, INP, LAAS, Toulouse, France, ngueveu@laas.fr

Keywords: piecewise linear functions, guaranteed tolerance, MINLP, MILP

We present an efficient algorithm able to over-estimate/under-estimate/approximate any arbitrary univariate nonlinear derivable function by a non necessarily continuous piecewise linear function that minimizes the number of linear segments with a guaranteed tolerance. The algorithm is based on the piecewise linear bounding method recently proposed by [Ngueveu 2018]. The two main methodological contributions of this paper are (i) a generalization of the approach to a larger class of tolerance types than the absolute and relative tolerances from Ngueveu, and (ii) a reformulation technique allowing any approximation problem of convex or concave function with any tolerance type that preserves concavity, to be reduced to fitting a piecewise linear function within a bounded corridor. The core of the JULIA library proposed is an efficient implementation of such piecewise linear function fitting. The resulting software is used to solve certain classes of MINLP problems with linear constraints and a non-linear objective function. Computational results on nonlinear functions approximation benchmark [Rebennack and Krasko, 2019] and on network design problems with congestion [Paraskevopoulos et al, 2016] show that state-of-the-art MINLP solvers and other MILP-based solution methods from the literature are outperformed.

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Optimality of a multi-variable fuzzy function

U. M. Pirzada[1]

[1]School of Engineering and Technology, Navrachana University of Vadodara-391410, India.
salmapirzada@yahoo.com

Keywords: Fuzzy functions , Fuzzy differentiability , Fuzzy Optimization , Optimality conditions

This article introduces a new idea of differentiability for fuzzy functions of fuzzy variables. Specifically, we define a first and second order derivative of a fuzzy function $\tilde{f} : (F(\mathbb{R}))^n \to F(\mathbb{R})$, where $(F(\mathbb{R}))^n$, is the set of all vectors of fuzzy numbers. In the process, we analyze algebra of derivatives of the considered fuzzy functions. Using the proposed differentiability notion, we prove a necessary and sufficient condition for optimality to obtain a non-dominated solution of a fuzzy optimization problem. Several illustrative examples are given to support the introduced ideas.

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