

# Thematic Talk 1

## The Control Parametrization Technique for Numerically Solving Fractal-fractional Optimal Control Problems Involving Caputo-Fabrizio Derivatives

Chongyang Liu, Shandong Technology and Business University

**Abstract:** Fractal-fractional derivatives open new opportunities for modelling complex processes. In this talk, we develop a novel numerical computation approach for solving optimal control problems with Caputo-Fabrizio derivatives. Firstly, we propose a general class of fractal-fractional optimal control problems with Caputo-Fabrizio derivatives and subject to state constraints of equality and inequality. Then, by using control parametrization technique, the fractal-fractional optimal control problem is approximated by a series of finite-dimensional optimization problems. Furthermore, the gradients of the cost and constraint functions in regard to decision variables are derived, which can be obtained by solving auxiliary fractal-fractional systems. A 3<sup>rd</sup>-order numerical scheme is also presented to solve the involved fractal-fractional systems. On the basis of this result, we develop a gradient-based optimization algorithm to solve the resulting optimization problem. Finally, numerical examples are provided to demonstrate the applicability and effectiveness of the developed algorithm.

**Keywords:** Fractal-fractional optimal control; Caputo-Fabrizio derivative; Numerical scheme; Numerical optimization

## Linear and Nonlinear Scalarization Methods for Vector Optimization Problems with Variable Ordering Structures

Jianwen Peng, Chongqing Normal University

**Abstract:** This paper investigates linear and nonlinear scalarization methods for vector optimization problems (VOP) with variable ordering structures (VOS). Firstly, we introduce the concepts of  $\epsilon$ -efficient elements and weakly  $\epsilon$ -efficient elements of a set with VOSs given by coradiant sets. Secondly we derive characterization theorems for weakly  $\epsilon$ -efficient solutions in the sense of linear scalarization. Then, we establish characterization theorems for weakly  $\epsilon$ -efficient solutions in the sense of nonlinear scalarization via the Hirriart-Urruty nonlinear functions and the functions defined via the Kasimbeyli's augmented dual cones. Finally, we establish nonlinear scalarization theorems for the weakly  $\epsilon$ -efficient elements of a set via the augmented dual cones approach. The results of this paper generalize the corresponding results in the literature.

**Keywords:** Vector optimization; Coradiant set; Variable ordering structure; Linear scalarization; Nonlinear scalarization

## Semi-Orthogonal Matrix Factorization with Sparse Constraint in Topic Modeling

Yong Kheng Goh, University Tunku Abdul Rahman

**Abstract:** This study introduces a novel method for topic modeling by combining semi-orthogonal matrix factorization with sparse constraints to improve interpretability, coherence, and scalability. Traditional techniques such as Latent Dirichlet Allocation (LDA) and Nonnegative Matrix Factorization (NMF) often face challenges in maintaining these qualities, especially with high-dimensional data. To address these issues, we propose the Spectral Proximal Method (SPM), an optimization approach that uses proximal variable metric updates with spectral diagonal scaling. SPM enforces both  $l_1$ -norm sparsity and semi-orthogonality to generate diverse and interpretable topics. The algorithm uses SPM, with initialization based on NMF to enhance computational efficiency. Experiments conducted on the 20 Newsgroups dataset demonstrate that SPM outperforms the Proximal Steepest

Descent (PSD) method in terms of topic coherence, sparsity of the topic-term matrix, and reduced computation time. These results highlight the scalability and effectiveness of SPM in text analysis, clustering, and recommendation systems. This research contributes a practical, interpretable, and scalable solution to existing limitations in traditional topic modeling techniques.

**Keywords:** Proximal variable metric; Matrix factorisation; Orthogonal matrix; Sparse optimization; Topic modelling

## Optimal Quality Supervision Control Model Based on Internet Plus Agricultural Product Quality Traceability System

Ying Zhang, Zhejiang Normal University

**Abstract:** Quality traceability is a guarantee to reduce agricultural product safety risks, since it allows problems to be traced to all stages of production and distribution. Most of the research in this field is about system design or qualitative nature. This paper focuses on the quantitative approach to broaden the scope of current study. By supposing the enforcement of quality supervision as control variables, and taking selling price and sales volume as states variables, this paper presents a optimal quality supervision control (OQSC) model in the form of a discrete-time optimal control problem. The aim is to optimize an overall profit. Based on the gradient formulae for the cost and canonical constraint functions, the optimal control problem can be solved by any existing constraint optimization technique. A case study arising from Suichang's agricultural product traceability system reveals a better solution of effective optimal quality supervision.

**Keywords:** Discrete-time optimal control; Quality traceability; Gradient formulae; Case study

## Fast Online $\ell_0$ Elastic Net Subspace Clustering via a Novel Dictionary Update Strategy

Wentao Qu, Jiangsu Normal University

**Abstract:** Driven by rapidly growing data volumes and increasing demands for real-time analysis, online subspace clustering has emerged as a valuable tool for processing dynamic data streams. However, existing online subspace clustering methods struggle to capture the complex and evolving distribution of such data due to rigid dictionary learning frameworks. In this work, we propose a novel  $\ell_0$  elastic net subspace clustering model that integrates the  $\ell_0$  norm and the Frobenius norm to achieve the desirable block diagonal property. To enable dynamic adaptation, we further design a fast online alternating direction method of multipliers featuring an innovative dictionary update strategy based on support points--a compact set capturing the underlying data distribution. By selectively updating dictionary atoms guided by the support points, the proposed method dynamically adapts to shifting data characteristics, thereby enhancing adaptability and computational efficiency. Moreover, we provide rigorous convergence guarantees for the algorithm. Extensive numerical experiments demonstrate superior clustering accuracy and computational efficiency of our method, confirming its suitability for real-time and large-scale data processing tasks.

**Keywords:** Sparse optimization; Subspace clustering; Online algorithm; Support points

## Integral Sliding Mode Control with a Double Closed Loop Based on Intelligent Optimization for Speed Control of PMSM

Shenping Xiao, Hunan University of Technology

**Abstract:** Surface-mounted Permanent Magnet Synchronous Motor (SPMSM) has the advantages of compact structure, low energy consumption, high power density and high operational reliability. Due to its nonlinear dynamic characteristics and sensitivity to disturbances, advanced speed regulation strategies are required. Integral

Sliding Mode Control (ISMC) can effectively meet the above control requirements owing to its fast response, easy implementation and strong robustness.

When integral sliding mode control is applied to such motors, problems such as large initial speed error and difficulty in parameter selection arise. Traditional integral sliding mode control adopts a fixed integral limit to solve this problem. However, the fixed limit cannot accurately deal with the dynamic changes of the system, resulting in the integral term being restricted too early or too late, and its control performance cannot be fully exerted.

To address the above problems, this paper proposes a speed-current dual-loop coordinated optimization control strategy combining an improved integral oversaturation-based sliding mode control method and an intelligent optimization algorithm. Among them, the intelligent optimization algorithm trains and optimizes the controller parameters through adaptive iteration to realize intelligent self-tuning of controller parameters.

Finally, to verify the superiority of the proposed control strategy, simulations and experiments are carried out on the MATLAB/Simulink platform and hardware physical platform. The results lead to the following conclusions:

- 1) Applying the intelligent optimization algorithm to PI parameter optimization makes parameter selection more intelligent, which fully demonstrates the superiority of intelligent optimization algorithms in the field of traditional control.
- 2) Compared with PID, ERLSMC and ISMC-PI control strategies, the control strategy proposed in this paper can reach the given speed faster and more stably, providing the optimal control performance for the motor.

**Keywords:** Surface-mounted permanent magnet synchronous motor; Intelligent optimization algorithm; Integral sliding mode control; Self-tuning of control parameter; Control system optimization

## Thematic Talk 2

# A DC-Based Optimization Method for Solving Reverse Convex Programming Problems

Adil. M. Bagirov, Federation University Australia

**Abstract:** In this talk, we consider reverse convex programming problems. A novel solution approach that integrates the difference-of-convex (DC) optimization with the concept of sharp augmented Lagrangians is introduced. Sharp Lagrangians are first employed to formulate the dual problem, and subgradients of the resulting dual function are computed to determine ascent directions. The sharp Lagrangians are represented as DC functions with respect to the primal variables, and a new scheme based on the  $\varepsilon$ -subdifferentials of the DC components is developed to approximate these functions. The proposed method comprises two interrelated components: an  $\varepsilon$ -subdifferential-based procedure for approximating global minimizers in the primal space, and a subgradient method for solving the corresponding dual problem. To further improve the solution accuracy, a local refinement step is applied to the final approximation. The effectiveness of the proposed method is validated through a series of academic benchmark problems and comparative analyses with an existing algorithm.

**Keywords:** Reverse convex programming; DC programming; Sharp augmented Lagrangians;  $\varepsilon$ -subdifferential

## Directionally Variational Analysis and Second-Order Optimality Conditions of Optimization with SC

Jiawei Chen, Southwest University

**Abstract:** This presentation focus on directionally variational analysis and the second-order optimality conditions for mathematical programs with switching constraints (MPSC) originated from optimal control theory. Developing the variational analysis associated with switching constraints, we present explicit formulas of radial cone, (directional) tangent cones, (directional) normal cones, outer (inner) second-order tangent set as well as geometrically

derivability and parabolically derivability of the cross set. The relations among the (directional) tangent cones and normal cones, and second-order tangent set are established. The decompositions of normal cones, tangent cones and second-order tangent sets associated with Cartesian product of the cross set and a nonempty closed set are also obtained. We derive the characterizations, such as the non-emptiness, uniqueness, convexity and compactness, of the multiplier sets and directional multiplier sets associated with the stationary points and directional stationary points of MPSC. Then the second-order necessary conditions and the second-order growth conditions of MPSC are established by the second-order tangent sets. Besides, the second-order optimality conditions of MPSC are also established by using the Fréchet second-order subdifferentials, where the involved functions are lack of the twice-differentiability.

**Keywords:** Second-order necessary conditions; Constraint qualifications; Directionally variational analysis

## Existence and Relaxation in Nonconvex Optimal Control Problems Governed by Sweeping Processes with Composed Perturbations

Sergey A. Timoshin, Xi'an Jiaotong-Liverpool University

**Abstract:** We study optimal control problems governed by sweeping processes with composed perturbations of different structural types. The perturbations may include control-dependent multivalued mappings, upper semicontinuous operators, and additional nonsmooth components. We establish existence of trajectories using fixed-point techniques and derive relaxation results for nonconvex optimal control problems. In particular, we prove existence of optimal relaxed solutions and establish the fundamental relaxation equality. The results provide a unified framework combining existence theory for sweeping processes with relaxation methods in optimal control.

**Keywords:** Sweeping process; Optimal control; Relaxation; Nonconvex control; Composed perturbations.

## High-Order Finite-Difference Methods for Hyperbolic Nonconservative Systems of Partial Differential Equations

Baifen Ren, Shandong Technology and Business University

**Abstract:** This work aims to extend the well-known high-order WENO finite-difference methods for systems of conservation laws to nonconservative hyperbolic systems. The main difficulty of these systems both from the theoretical and the numerical points of view comes from the fact that the definition of weak solution is not unique: according to the theory developed by Dal Maso, LeFloch, and Murat in 1995, it depends on the choice of a family of paths. A new strategy is introduced here that allows non-conservative products to be written as the derivative of a generalized flux function that is defined locally on the basis of the selected family of paths. WENO reconstructions are then applied to this generalized flux. Moreover, if a Roe linearization is available, the generalized flux function can be evaluated through matrix-vector operations instead of path-integrals. Two different known techniques are used to extend the methods to problems with source terms and the well-balanced properties of the resulting schemes are studied. These numerical schemes are applied to a coupled Burgers' system and to the two-layer shallow water equations in one- and two- dimensions to obtain high-order methods that preserve water-at-rest steady states.

**Keywords:** WENO finite difference scheme; High order accuracy; Well-balanced scheme; Nonconservative equations; Path-conservative method

# A Control Parameterization Method for Solving Combined Fractional Optimal Parameter Selection and Optimal Control Problems

Xiaopeng Yi, Shandong Technology and Business University

**Abstract:** In this paper, we consider a class of combined fractional optimal parameter selection and optimal control problems involving nonlinear fractional systems with Caputo fractional derivatives and subject to canonical equality and inequality constraints. We first approximate this problem by a set of finite-dimensional optimization problems using the control parameterization method, where both the heights of parameterized controls and system parameters are taken as decision variables. We then show that the gradients of the cost and constraint functions with respect to the decision variables can be expressed as the solutions of a series of auxiliary fractional systems, which can be solved together with the original fractional system forward in time, simultaneously. Furthermore, we present a third-order numerical scheme for solving both the original and auxiliary fractional systems. On this basis, a gradient-based optimization algorithm is developed to solve the resulting optimization problems. Finally, we demonstrate the effectiveness and applicability of the developed algorithm through two non-trivial examples.

**Keywords:** Fractional parameter selection; Fractional optimal control; Control parameterization; Numerical scheme; Numerical optimization

## Fractional Optimal Control in Cancer Chemotherapy

Meijia Han, Shandong Technology and Business University

**Abstract:** In this paper, considering the memory effect and non-local characteristic in biological systems, we propose a nonlinear fractional system with free terminal time to describe the tumor dynamics in cancer chemotherapy process. Based on this, we present a fractional optimal control problem subject to safety threshold constraints on cell counts, where the cost function aims to minimize the tumor cell population and

the drug usage in an average sense. Then, we apply time-scaling transformation and constraint transcription to convert the problem into a sequence of optimal control problems with fixed terminal time and canonical constraints. Furthermore, an optimization algorithm, which combines a discretization scheme and gradients of the cost and canonical constraint functions, is developed to solve the resulting problems. Finally, numerical results show that the proposed algorithm is highly effective.

**Keywords:** Fractional optimal control; Free terminal time; Time-scaling transformation; Numerical optimization; Cancer chemotherapy.

## Thematic Talk 3

### Data-Driven Discovery of a Refined Dynamical Model for Ocean Internal Solitary Waves

B. Saheya, Inner Mongolia Normal University

**Abstract:** Internal solitary waves (ISWs) are a typical form of nonlinear wave phenomena in the ocean, characterized by large amplitudes and high energy, and they play a critical role in both marine engineering safety and ecosystem stability. Accurately characterizing their propagation properties and evolutionary mechanisms is essential for understanding ocean dynamic processes. Although traditional theoretical models have yielded certain achievements, their applicability in complex marine environments is limited due to reliance on numerous idealized assumptions. At present, constrained by the scarcity of in-situ observational data, it remains challenging to directly identify and validate the governing equations under realistic oceanic conditions. In light of the above considerations, this preliminary study proposes a data-driven modeling approach that employs sparse regression techniques to automatically discover the structural form of the governing equations for ISWs, while ensuring physical interpretability. Additionally, the Levenberg-Marquardt (LM) algorithm is introduced to optimize model parameters, thereby enhancing prediction

accuracy and stability. The governing equations derived through this method are further solved numerically to enable high-precision simulation of the propagation process of ISWs. This study synthesizes laboratory observations and numerical simulations spanning a wide range of ocean stratification regimes and ISW generation scenarios. By imposing multiple physical constraints, this paper establish a comprehensive ISW dynamics database that enables systematic investigation of wave evolution characteristics and the associated dynamical mechanisms under diverse environmental conditions. The results show that, when multi-source data and physical constraints are jointly incorporated, the proposed method significantly outperforms traditional models in both equation identification accuracy and propagation-process prediction. Compared with traditional models, the proposed method improves the overall amplitude-prediction accuracy in numerical simulations by approximately 0.3 m. For physical experimental data, when the prediction horizon exceeds 10 steps, the proposed method achieves at least a 0.02 m improvement in amplitude-prediction accuracy over theoretical models such as KdV and mKdV. While conventional approaches require selecting an appropriate model based on the specific physical setting, the proposed method relies solely on data and thus enables dynamical-process prediction without presupposing physical conditions.

**Keywords:** Internal solitary wave(ISW); Data-driven modeling; Machine learning; Levenberg-Marquardt (LM); System identification

## Optimization of Beamspace Blind Signal Separation Method

Cedric Yiu, The Hong Kong Polytechnic University

**Abstract:** For speech extraction, multi-sensors are often deployed in order to pick up and enhance multi-source speech signals. This is the typical cocktail party problem. In general, there are two popular techniques, namely blind signal separation (BSS) and beamforming. BSS exploits the statistical properties of the signals while beamforming capitalizes on spatial information. One possible method, which combines the strength of both techniques, to carry out BSS under a pre-designed

beam-space. However, in a dynamic environment, a fixed beam-space is not practical and more dynamic approach is required. Here, we discuss different optimization formulations and propose an optimization method which optimizes on both beamforming and BSS techniques. We demonstrate the performance of the method via several examples.

**Keywords:** Signal processing; Beamforming; Blind signal separation (BSS)

## A Fast Block Coordinate Descent Method for Orthogonal Nonnegative Matrix Factorization

Liangshao Hou, Sun Yat-sen University

**Abstract:** Orthogonal nonnegative matrix factorization (ONMF) extends traditional matrix factorization by incorporating nonnegativity and orthogonality constraints. It has gained significant attention for applications in dimension reduction and data clustering. This paper proposes a novel algorithm for solving ONMF within the block coordinate descent (BCD) framework. Both subsequence and whole sequence convergence of the algorithm are rigorously established, representing a major advancement in ONMF research. Extensive experiments on real-world datasets demonstrate the method's effectiveness and efficiency. Compared with several state-of-the-art ONMF techniques, the proposed algorithm achieves superior performance in terms of computational efficiency, relative error, and optimality gap.

**Keywords:** Orthogonal nonnegative matrix factorization; Block coordinate descent method; Kurdyka-Lojasiewicz property

## Sum of Radii Clustering with Concave Power Costs

Yicheng Xu, Chinese Academy of Sciences

**Abstract:** We study a covering problem in Euclidean and general metric spaces: given a set of clients and a prescribed set of admissible centers  $S$ , assign a radius to

each so that every client in is covered by at least one ball  $B(s, r_s)$ . The objective is to minimize the concave power cost  $\sum_{s \in S} r_s^\alpha$  for a fixed exponent  $0 < \alpha < 1$ . This concave regime complements the classical linear sum-of-radii objective and the extensively studied convex power cover objective ( $\alpha > 1$ ). Our main contribution is a PTAS in Euclidean space: for any fixed dimension and  $\varepsilon > 0$ , we compute a  $(1 + \varepsilon)$ -approximate solution in time polynomial in  $|P| + |S|$ . The analysis turns concavity into structure: a merging inequality induces an uncrossing principle that limits how large-radius balls can interact locally within a hierarchical geometric decomposition, enabling a dynamic program with constant-size boundary information per cell. In general metrics, we additionally obtain a  $3^\alpha$ -approximation via a primal–dual (radius-inflation) framework, consistent with the best-known constant-factor approximations for the linear case [Buchem et al., SODA’24] and with  $3^\alpha$ -type guarantees in the convex regime [Bar-Yehuda and Rawitz, CGTA’13].

**Keywords:** Clustering; Sum of radii; Power Cover; Approximation Algorithm; Concave Function

## Optimal Microphone Subset Selection for Beamforming

Yuhan Zhang, The Hong Kong Polytechnic University

**Abstract:** Microphone arrays are widely utilized in speech-related applications, where selecting an optimal subset of microphones is crucial for minimizing computational burden without degrading beamformer performance. This subset selection is inherently a challenging combinatorial problem, conventionally addressed by greedy-based heuristics that cannot guarantee optimality. In this paper, we propose a novel exact formulation for microphone subset selection. By rigorously reformulating the combinatorial conditions into continuous algebraic constraints, we transform the problem into a novel mixed-integer linear programming (MILP) model. The optimal subset is derived from a multi-objective optimization problem that maximizes beamforming performance while minimizing the number of selected microphones. A branch-and-bound algorithm is employed to find the global optimum.

Numerical experiments demonstrate that our proposed MILP approach achieves competitive beamforming performance compared to greedy and genetic algorithms (GA), while strictly minimizing the active microphone count, making it highly effective for hardware-constrained applications.

**Keywords:** Microphone selection; Beamformer design; Mixed integer linear programming; Branch-and-bound

## Convergence Analysis of The Transformed Gradient Projection Algorithms on Compact Matrix Manifolds

Wentao Ding, The Chinese University of Hong Kong

**Abstract:** Existing algorithms for Riemannian optimization can be classified into retraction-based and projection-based methods. While retraction-based algorithms admit a unified comprehensive convergence theory, projection-based line-search methods with possibly non-tangent search directions remain less understood. To address this gap, we propose a unified framework called the Transformed Gradient Projection (TGP) algorithm, where the search direction is defined as a transformed Riemannian (or Euclidean) gradient augmented with a normal component. This construction generalizes various existing methods, including the classical Euclidean gradient projection algorithm, the shifted power method, and certain retraction-based algorithms, while also producing new variants on Stiefel and Grassmann manifolds. Within this framework, we establish weak convergence, global convergence, and iteration complexity under Armijo, Zhang - Hager type nonmonotone Armijo, and fixed stepsizes. A key ingredient of our analysis is the development of new geometric properties of projections onto compact matrix manifolds, which may be of independent interest. Numerical experiments further demonstrate that different choices of scaling matrices and normal components significantly affect performance, implying the flexibility of the TGP framework enables it to outperform classical methods in several scenarios.

**Keywords:** Optimization on manifold; Transformed gradient projection algorithm; Euclidean gradient projection algorithm; Convergence analysis

## Thematic Talk 4

### A Hybrid Direct Method for Fractional Optimal Control Problems

Yu Wang, Shanghai University

**Abstract:** With the growing interest in fractional optimal control problems, developing robust numerical methods to solve general multi-dimensional cases efficiently and accurately remains a challenge. This paper proposes a hybrid direct method for solving fractional optimal control problems governed by the Caputo and Atangana - Baleanu - Caputo fractional derivatives. The approach employs a collocation scheme to discretize the state and control variables, while approximating the fractional dynamics using a second-order one-point quadrature rule. Inspired by the principle of control parameterization, we further partition the control values at the collocation points into subsets, each governed by a single decision variable. Compared with standard collocation methods, this strategy reduces the dimensionality of the control input without compromising solution accuracy. Numerical experiments on three benchmark problems demonstrate the superior computational efficiency and robustness of the proposed methods.

**Keywords:** Fractional optimal control; Caputo derivative; Numerical approaches; Collocation method; Second-order one-point quadrature rule

### Research on Direct Optimization of Switching Time Based on Control Parameterization Method

Weidong Lu, Shanghai University

**Abstract:** Traditional control parameterization methods are effective for solving general constrained optimal control problems, but the predefined control switching

times limit their flexibility. The sequential time-scaling transformation technique addresses this by introducing a new control function to indirectly optimize switching times. However, as the number of controls increases, this method becomes increasingly complex and significantly alters the problem structure. To overcome these challenges, we propose a group-adaptive direct optimization method for switching times. Our results show that the previously perceived shortcomings of direct optimization can be effectively mitigated, leading to higher computational efficiency compared to the sequential time-scaling transformation. We derive gradient calculation formulas using the variational and co-state methods and validate the effectiveness of our approach through numerical examples.

**Keywords:** Control parameterization; Optimization algorithm; Optimal control; Switching-time optimization; Sequential time-scaling transformation

## From the Helmholtz equation to Caustic: High-Frequency Analysis of Aberration-Induced Breakdown in Lithography Imaging

Rui Da, Shanghai University

**Abstract:** Lithography imaging plays an important role in semiconductor manufacturing. This paper studies mathematical problems motivated by optical lithography. We show that the ideal plane wave in the Abbe imaging model can be realized in a bounded two-dimensional domain as a solution to the Helmholtz equation with a Dirichlet-to-Neumann boundary condition and an appropriate source term. We also investigate wave propagation from the collimating lens system to the mask in the presence of lens aberrations. We show that lens aberrations alter the propagation structure of the field, leading to the breakdown of the single-stationary-point approximation and eventually to caustic formation.

**Keywords:** Helmholtz equation, plane wave, Dirichlet-to-Neumann operator, aberration, caustic

## Thematic Talk 5

### An Inexact ADMM for Nonconvex and Nonsmooth Optimization Problems

Jianchao Bai, Northwestern Polytechnical University

**Abstract:** In this talk, an Inexact Alternating Direction Method of Multipliers (I-ADMM) with an expansion linesearch step will be presented for solving a family of separable minimization problems subject to linear constraints, where the objective function is the sum of a smooth but possibly nonconvex function and a possibly nonsmooth nonconvex function. A unified proximal gradient method with momentum acceleration is also proposed for solving the smooth but possibly nonconvex subproblem. Numerical experiments on testing nonconvex quadratic programming problems and sparse optimization problems show that the proposed I-ADMM performs faster than some state-of-the-art algorithms in the literature.

**Keywords:** Nonconvex optimization; Inexact ADMM; Proximal gradient method; Convergence

### Dynamic Filtering-Based False Data Injection Attacks Detection for IEC 61850 Architecture

Yanyan Yin, Curtin University

**Abstract:** With the continuous development of digital substations based on the IEC 61850 standard, it significantly improves the real-time communication capabilities for power system protection, control, and measurement. However, the open and high-speed nature of sampled values (SV), GOOSE messages, and MMS-based station control layer communication makes the system vulnerable to False Data Injection Attacks (FDIA). The injection of false data will threaten power system

stability and cause huge losses. Malicious attackers can bypass traditional static residual-based detection mechanisms by carefully designing attack vectors, thereby undermining the security and stability of power systems. Therefore, to address this issue, a dynamic filtering based FDIA suppression strategy is proposed for the IEC-61850 architecture. Specifically, it is a multi-source measurement verification mechanism based on unscented Kalman filtering (UKF) and integrates it into the dynamic state estimation layer. The strategy integrates synchronous data streams from IEC-61850 SV and PMU, embeds an anomaly detection module based on innovative sequence, and incorporates it into the filtering process. By calculating the normalized innovation square (NIS) in real time and comparing it with the chi-square distribution threshold, real-time verification of anomalous measurement data can be achieved. When the system detects an anomaly in the innovation data sequence, it triggers an adaptive data weighting mechanism to dynamically reduce the weight of suspicious data while not completely discarding suspicious measurements data, thereby effectively resisting covert fake data injection attacks. This protection strategy fully leverages the dynamic constraints, time consistency characteristics, and data cross-validation mechanisms of the power system, which is significantly different from traditional static residual detection methods. By deploying the filtering layer on a ruggedized communication infrastructure secured under IEC 62351-6 communication security mechanisms and placing it below the protection decision logic, a layered defense system is formed, improving the operational security of the power system while ensuring system performance.

**Keywords:** Digital substation; IEC 61850 standard; False Data Injection Attacks; Unscented Kalman filtering

## A Relaxation Method for Nonsmooth Nonlinear Optimization with Binary Constraints

Lianghai Xiao, Jinan University

**Abstract:** We study binary optimization problems of the form  $\min_{x \in \{-1,1\}^n} f(Ax-b)$  with possibly nonsmooth loss  $f$ . Following the lifted rank-one

semidefinite programming (SDP) approach\cite{qian2023matrix}, we develop a majorization-minimization algorithm by using the difference-of-convexity (DC) reformulation for the rank-one constraint and the Moreau envelop for the nonsmooth loss. We provide global complexity guarantees for the proposed Difference of Convex Relaxation Algorithm (DCRA) and show that it produces an approximately feasible binary solution with an explicit bound on the optimality gap. Numerical experiments on synthetic and real datasets confirm that our method achieves superior accuracy and scalability compared with existing approaches.

**Keywords:** Binary orthogonal optimization problems; Global exact penalty; Relaxation methods; Semantic hashing

## An inexact $q$ -order regularized proximal Newton method for nonconvex composite optimization

Ruyu Liu, South China University of Technology

**Abstract:** This paper concerns the composite problem of minimizing the sum of a twice continuously differentiable function  $f$  and a nonsmooth convex function. For this class of nonconvex and nonsmooth problems, by leveraging a practical inexactness criterion and a novel selection strategy for iterates, we propose an inexact  $q$ -order regularized proximal Newton method for  $q \in [2, 3]$ , which becomes an inexact cubic regularization (CR) method for  $q=3$ . We prove that the whole iterate sequence converges to a stationary point for the KL objective function; and when the objective function has the KL property of exponent  $\theta \in (0, \frac{q-1}{q})$ , the convergence has a local  $Q$ -superlinear rate of order  $\frac{q-1}{\theta q}$ . In particular, under a local H\"olderian error bound of order  $\gamma \in (\frac{1}{q-1}, 1]$  on a second-order stationary point set, we show that the iterate and objective value sequences converge to a second-order stationary point and a second-order stationary value, respectively, with a local  $Q$ -superlinear rate of order  $\gamma(q-1)$ , specified as the  $Q$ -quadratic rate for  $q=3$  and  $\gamma=1$ . This is the first practical inexact CR method with  $Q$ -quadratic convergence rate for nonconvex composite optimization. We validate the efficiency of

the CR method with ZeroFPR as the inner solver by applying it to composite optimization problems with highly nonlinear  $f$ .

**Keywords:** Nonconvex composite optimization; Inexact  $q$ -order regularized proximal Newton method; Cubic regularization method; KL property; Local Hölderian error bound

## A New Class of Adaptive Collocation Method for Optimal Control Problems

Mengzhen Shao, Shanghai University

**Abstract:** Local collocation and control parameterization are two widely used direct methods for solving optimal control problems. The former approximates the state and control variables using polynomial basis functions and enforces system dynamics at discrete collocation points, whereas the latter discretizes only the control variables, with the state trajectories obtained via numerical integration. To leverage the properties of both approaches, this paper introduces a class of hybrid direct methods that integrate local collocation with control parameterization. Specifically, control values at collocation points are assigned to predefined groups, and each group shares a single decision variable. This substantially reduces the number of control variables compared to standard collocation, while maintaining solution accuracy and improving computational efficiency. Moreover, we introduce auxiliary variables to control the number of collocation points within each group, thus allowing better flexibility in control design. Numerical results validate the effectiveness and computational advantages of the proposed method.

**Keywords:** Optimal control; Local collocation method; Control parameterization; Hybrid direct methods

**Thematic Talk 6**

# Accelerated Proximal Gradient Algorithms For Nonsmooth Multiobjective Optimization

Chengzhi Huang, sichuan university

**Abstract:** Many practical problems can be modeled as nonsmooth multiobjective optimization problems; however, subgradient methods suffer from slow convergence and the lack of explicit convergence rate guarantees. To address these issues, this paper proposes two improved algorithms. First, based on a backtracking strategy, we develop a backtracking accelerated proximal gradient method, which achieves a convergence rate of  $O(1/k^2)$  under relatively mild assumptions. By further incorporating smoothing techniques, the method is extended to the nonsmooth setting, attaining a convergence rate of  $O(\ln k / k)$ , and outperforming classical subgradient methods in both iteration complexity and computational time. Second, to avoid the additional overhead introduced by backtracking, we propose an adaptive accelerated proximal gradient method by modifying the inertial term, under the assumption that an upper bound on the initial estimate of the Lipschitz constant of the gradient is available. Combining this approach with smoothing techniques extends it to the nonsmooth case. The resulting method enjoys the same convergence rate as the aforementioned algorithm while requiring less computational time. Finally, we analyze the influence of the inertial parameter on convergence behavior, providing theoretical guidance for subsequent algorithm design.

**Keywords:** Nonsmooth multiobjective optimization; Accelerated proximal gradient method; Backtracking; Adaptive updating scheme;

## New Algorithms via Multiobjective Damped Inertial Gradient-like Systems with Asymptotic Vanishing Normalized Gradient

Yingdong Yin, Chongqing Normal university

**Abstract:** For unconstrained convex smooth multiobjective optimization, we propose a novel inertial gradient-like system that incorporates the asymptotic vanishing normalized gradient. In the scalar case, this system reduces to a first-order method with strong empirical performance, as introduced by Wang et al. [SIAM J. Sci. Comput., 2021]. We prove the existence of a trajectory solution and, using Lyapunov analysis, establish convergence rates of  $O(1/t^2)$  and  $O(\ln^2 t / t^2)$  under two distinct parameter choices. Under certain assumptions, we employ new techniques to establish the convergence of solution trajectories to weakly Pareto optimal solutions. Based on this system, we designed a new multiobjective accelerated algorithm. Numerical experiments demonstrate the effectiveness of the proposed algorithm.

**Keywords:** Multiobjective optimization; Inertial Gradient-like system; Accelerated gradient method; Direction correction; Lyapunov analysis

## Riemannian Bilevel Optimization with Gradient Aggregation

Zhuo Chen, Shanghai University

**Abstract:** Bilevel optimization (BLO) provides a powerful framework for hierarchical decision-making and is widely used in machine learning tasks like hyperparameter optimization and meta-learning. Traditional BLO methods mainly operate in Euclidean spaces, yet many real-world problems have structural constraints. We propose a novel Riemannian bilevel optimization (RBLO) algorithm incorporating a bilevel descent aggregation (BDA) scheme to coordinate updates at both levels efficiently. Our approach abstracts constraints as manifold structures and reformulates the constrained BLO into an unconstrained RBLO problem. To overcome convergence limitations of existing methods, we leverage smooth manifold mappings and offer convergence guarantees under geodesic convexity and Lipschitz smoothness assumptions. Finally, we demonstrate our method on multi-view hypergraph spectral clustering with the 3sources dataset, showing superior performance compared to Euclidean and manifold-based baselines.

**Keywords:** Riemannian Optimization; Bilevel Optimization; Gradient Aggregation; Convergence Analysis; Hypergraph Spectral Clustering;

# Multi-Objective Online Convex Optimization from Metric Theory to Discrete Representations

Jieyuan Guo, University of Science and Technology Beijing

**Abstract:** Multi-Objective Online Convex Optimization (MO-OCO) has garnered significant attention for its ability to simultaneously address conflicting objectives and dynamic environmental changes in streaming data-driven decision-making scenarios. However, existing studies remain limited in two key aspects: on one hand, the geometric implications and theoretical properties of the metrics employed require further refinement; on the other hand, the continuous Pareto front generates an infinite number of potential solutions during the online process, imposing substantial computational and cognitive burdens on practical decision-making. To address these challenges, in this talk, we first propose a multi-objective regret metric based on  $\epsilon$ -nondominance, providing a novel perspective for evaluating the convergence performance of online decision sequences for MO-OCO problems. Theoretical analysis demonstrates that this metric is a natural extension of the regret concept in traditional single-objective online convex optimization. Furthermore, to address the practical demand for finite yet high-quality solution sets in decision-making, this paper proposes an Online Discrete Representation (ODR) algorithm. Theoretical proofs first demonstrate that each online decision sequence generated by the ODR algorithm achieves sublinear multi-objective regret. On this basis, this paper analyzes the uniformity of distribution and coverage accuracy of the entire discrete representation solution set in the objective space, revealing the intrinsic connection between the convergence of individual sequences and the representativeness of the overall solution set. Finally, this paper applies the proposed multi-objective regret and the ODR algorithm to several classic convex machine learning tasks. Experimental results demonstrate that compared to existing baseline methods, the ODR algorithm achieves a more uniformly distributed and broader non-dominated solution set while maintaining the fastest convergence rate. In summary, this paper not only theoretically

unifies the measurement criteria for single-objective and multi-objective regret but also proposes the ODR algorithm for multi-objective decision-making in online settings, which simultaneously guarantees convergence and representativeness.

**Keywords:** Multi-objective online convex optimization; Pareto front;  $\epsilon$ -nondominance; Discrete representation; Convergence analysis

## A Multi-Strategy Improved Kepler Optimization Algorithm for Feature Selection

Qihang Guo, Liaoning Technical University

**Abstract:** Kepler Optimization Algorithm (KOA) is a metaheuristic inspired by the laws of planetary motion. Although KOA has demonstrated superior performance in several benchmark test sets, it still faces challenges such as susceptibility to local optima and imbalances between exploration and exploitation. To address these issues, we developed an improved version of the algorithm, named the Improved Kepler Optimization Algorithm (IKOA), designed for both global optimization and feature selection problems (FS). IKOA incorporates three key enhancements: Adaptive Sine-Cosine Heliocentric Motion (AHM), Extreme-guided Exponential Exploration (EGEE), and Elite Opposition-based Levy Flight (EOLF). The effectiveness of IKOA was validated using the CEC2022 benchmark function. Additionally, IKOA was applied to ten real-world datasets from the UCI repository. The numerical results demonstrate that IKOA outperforms other methods in the field of feature selection (FS). Overall, this study confirms that IKOA exhibits exceptional robustness, practicality, and effectiveness in feature vector reduction.

**Keywords:** Kepler optimization algorithm; Adaptive sine-cosine heliocentric motion; Extreme-guided exponential exploration; Elite opposition-based levy flight; Feature selection

## The Multi-Objective Portfolio Model for Oil and Gas Exploration Drilling Projects Selection and Its

# Operator-Enhanced Non-Dominated Sorting Genetic Algorithm Based Solution

Junyi Cui, Southwest Petroleum University

**Abstract:** Drilling investment is a critical component of oil and gas exploration planning. Conventional drilling deployment relies heavily on fragmented expert assessments of geological and economic factors, resulting in limited capability for information integration. Motivated by portfolio theory as a parsimonious yet effective framework for asset allocation, we develop a multi-objective mean-variance portfolio model that explicitly accounts for uncertainty in geological parameters to enable an effective risk-return trade-off and optimal selection. First, probabilistic distributions of key geological parameters are constructed for the candidate exploration projects using expert-elicited priors. Second, drilling project screening is formulated as a portfolio selection problem, and an optimization model is established to characterize the return and risk of short-term plans under multiple constraints. Third, we propose an operator-enhanced non-dominated sorting genetic algorithm tailored to the model. Specifically, (i) a directional crossover operator is designed to embed improving directions in objective space-derived from dominance and objective differences-into recombination, and (ii) a structure-aware mutation operator is designed to prioritize high-utility bit flips via probabilistic sampling with feasibility repair, thus improving the search ability for superior Pareto solutions. Finally, the proposed framework is validated using the 2023 exploration drilling deployment as a case study. The results indicate that the proposed method provides a reusable solution for drilling portfolio optimization in oil and gas exploration.

**Keywords:** Multiple objective programming; Optimal drilling; Portfolio; Meta-Heuristic; Non-dominated sorting genetic algorithm

## Thematic Talk 7

### A Behavior-Aware Influence Maximization Model with Informed Users: A Hybrid Optimization Approach Based on RIS and DQN

Yifan Gu, Wuhan University

**Abstract:** With the rapid growth of social networks, the scale and speed of information spread have increased significantly, making viral marketing and online advertising key application areas for combinatorial optimization. The Influence Maximization (IM) problem, a well-known discrete combinatorial optimization challenge in network analysis, aims to select a limited set of seed nodes within a social network to maximize overall information diffusion, which holds great practical importance in optimization tasks. However, traditional IM models mainly depend on network topology and typically focus only on the number of activated nodes. This approach makes it difficult to account for behavioral factors involved in real-world diffusion processes, such as user interests, content quality, and differences in user value, often resulting in suboptimal optimization outcomes.

To address this limitation, this paper introduces a behavior-aware influence maximization model from the perspective of optimization modeling. Based on the Independent Cascade (IC) model, we refine the propagation probability by incorporating multiple behavioral factors, including the influence of the propagator, user interests, and the relevance between users and information topics, to enhance the rationality of the optimization model. Additionally, an informed state is introduced, extending the traditional two-state diffusion process (active and inactive) to a three-state model (active, informed, and inactive). In this model, informed users are those who receive information but do not propagate it further, which makes the diffusion process more aligned with real-world scenarios and provides a solid foundation for accurate optimization. Simultaneously, a user-value weighting

mechanism is integrated into the optimization objective function, enabling the model to focus on the economic value generated by information diffusion among target user groups and facilitating multi-objective optimization of both diffusion effectiveness and economic value.

Regarding algorithm design, we develop a hybrid optimization framework that combines Reverse Influence Sampling (RIS) with a Deep Q-Network (DQN) to efficiently solve the IM optimization problem. RIS is initially used to estimate influence spread and generate an initial seed set through a greedy approach; DQN then further refines the seed selection policy, effectively overcoming the limitations of traditional greedy methods in local optimization. Since the objective function is submodular, the greedy approach provides theoretical approximation guarantees, which are essential for evaluating optimization algorithms. Experimental results show that, compared to models that overlook user heterogeneity and refined propagation probabilities, the proposed method achieves a higher diffusion value while maintaining efficient dissemination, confirming the effectiveness and superiority of the proposed model and algorithm in solving the IM optimization problem.

**Keywords:** Targeted Influence Maximization; Information Diffusion; Reverse Influence Sampling; Deep Reinforcement Learning; Social Network Analysis

## Matrix Splitting-based Optimizer: A Novel metaheuristic Algorithm Inspired by Mathematics

Yanzhe Ji, Liaoning Technical University

**Abstract:** The Matrix Splitting-based Optimizer (MSBO) is a novel metaheuristic algorithm inspired by the mathematical concept of matrix splitting. MSBO introduces several search operators derived from classical matrix splitting methods, such as Jacobi, Gauss – Seidel, and successive over-relaxation (SOR), to guide the population toward optimal solutions while balancing exploration and exploitation. This approach, presented for the first time, integrates these techniques to enhance convergence speed and avoid local optima. The effectiveness of MSBO is validated through three sets of

experiments: the CEC2017 benchmark functions, four real-world constrained engineering problems, and an unmanned aerial vehicle (UAV) path planning problem. Comparative experiments with nine state-of-the-art optimization algorithms, supported by Wilcoxon rank-sum tests, demonstrate that MSBO consistently outperforms its competitors in terms of solution quality and convergence rate. The findings confirm that MSBO is robust, efficient, and well-suited for both continuous and constrained optimization tasks.

**Keywords:** Optimization algorithm; Metaheuristic; Matrix Splitting; Constrained optimization

## A Machine Learning-Based Fast and Robust Operational Reliability Assessment Method for Power Systems

Tao Xie, Chongqing Normal University

**Abstract:** The strong stochasticity and volatility of wind power generation pose new challenges to the operational reliability of power systems. Traditional reliability assessment often struggles to balance economic efficiency and robustness under high-penetration wind power integration, yielding either optimistic or overly conservative results. We develop a data-driven distributionally robust optimization (DRO) model for operational risk assessment, which computes state-conditioned reliability indices while hedging probability misspecification and distribution shifts. To meet real-time needs, we propose a CNN-DRO method that predicts the worst-case probability distribution (WPD) and thereby collapses the tri-level "min-max-min" DRO model to a single-level OPF-consistent optimization problem solved per operating state. This preserves physical feasibility and enables minute-level updates. A hybrid CNN Classifier-Regressor design first screens secure states (no load shedding needed) and then predicts the WPD for insecure states, so only the latter invokes the single-level optimization solve. The CNN inference is negligible relative to the solver. Numerical simulations are conducted on the RTS-79 and IEEE 118-bus systems under varying wind power penetration levels, with comparisons against stochastic optimization (SO) and robust optimization (RO)

methods. The results validate the superior robustness and economic benefits of the proposed DRO model in operational risk assessment for high-penetration wind power systems. Additionally, experiments demonstrate that the proposed method has much higher computational speed and accuracy when compared with the classical column and constraint generation (CCG) algorithm.

**Keywords:** Distributionally robust optimization; Convolutional neural network; Power system with high wind power penetration; Risk assessment; uncertainty

## Twin SSLM for Imbalanced Data Classification and Its Optimization Algorithm

Zhenxia Xue, North Minzu University

**Abstract:** Imbalanced data classification has always been a significant challenging in machine learning. Support Vector Data Description (SVDD) and Small Sphere and Large Margin (SSLM) approach can adapt to address this problem by finding a minimum-volume hypersphere that encloses the majority of training data while excluding the minority of training data outside the hypersphere. And the SSLM approach also maximize the margin between the two class samples. However, the SVDD and SSLM both employs a large scale optimization and Hinge loss function, which is sensitive to noise or outliers. In this paper, inspired by Twin support vector machine (TSVM) which solves two smaller scale optimization problems, we first proposed a bilateral truncated pinball loss function, which is bounded, asymmetric and more suitable for dealing with imbalanced data classification problem. Then based on the idea of SVDD, SSLM and TSVM, we propose a Twin SVDD-SSLM (TSVDD-SSLM) model which seeks to solve two smaller scale optimization problems to integrate noise insensitivity and sparsity simultaneously. Furthermore, some properties of parameters is also analyzed. Concerning the non-convexity of TSVDD-SSLM, we employ the Concave-Convex Procedure (CCCP) to transform the two optimization problems of TSVDD-SSLM into a series of convex quadratic and

linear programming subproblems, respectively and then utilize the Operator Splitting Quadratic Program (OSQP) and Linear programming (LP ) algorithm to solve these two subproblems in the dual formulation. Thus, the framework CCCP-OSQP and CCCP-LP algorithms is proposed. The CCCP-OSQP and CCCP-LP algorithms offer fast convergence and low memory requirements. Moreover, we provide a comprehensive analysis of the computational complexity and convergence properties of our proposed model. To order to validate the efficiency of TSVDD-SSLM model, we have conducted extensive experiments on multiple imbalanced datasets including UCI benchmark datasets, and real world credit card fraud detection Dataset with different noises to demonstrate that the effectiveness of our proposed models compared to several state-of-the-art algorithms.

**Keywords:** Imbalanced data classification; SVDD; SSLM; CCCP; OSQP

## Parameter Coordinated Optimization Design for Event-Triggered Delayed Power System Load Frequency Control

Yiming Zhou, Hunan University of Technology

**Abstract:** For the load frequency control (LFC) problem in multi-region interconnected power systems where communication resources are limited and there is communication delay, this paper proposes a collaborative optimization design method based on event-triggering mechanism and output feedback. Firstly, considering the impact of communication delay on the system dynamics, a discrete state space model of delay LFC with event-triggering mechanism is established, and the communication transmission strategy and controller parameters are unified into the optimization framework. On this basis, to reduce the conservatism of the stability criterion and minimize communication redundancy, the multi-sum inequality method is introduced to accurately estimate the Lyapunov-Krasovskii functional, and a less conservative delay-related stability criterion is derived. Furthermore, the solution problem of the controller gain matrix and the event-triggering matrix is transformed

into a multivariable optimization problem under linear matrix inequality (LMI) constraints, and the variable substitution method and Finsler lemma are used to achieve the collaborative parameter optimization of the two. Under the premise of ensuring the stability of the closed-loop system, the delay tolerance ability is maximized and the data transmission frequency is minimized. Simulation results show that the proposed optimization method can effectively suppress frequency and tie-line power oscillations in a three-region interconnected system, ensure the stability of the system with delay, and significantly reduce redundant communication in the network.

**Keywords:** Collaborative optimization design; Event-triggered control; Load frequency control; LMI; Delay system

## Two-Stage Wasserstein Distributionally Robust Optimization for Risk-Averse Two-Machine Flow-Shop Scheduling

Xudong Gao, Shanghai University of Finance and Economics

**Abstract:** This article considers a data-driven two-stage 1-Wasserstein distributionally robust optimization (DRO) model for two-machine flow-shop scheduling with uncertain processing times. The model minimizes a risk-averse composite objective of the expected makespan and its Conditional Value-at-Risk (CVaR). To address the bilinear coupling between binary sequencing variables and continuous worst-case dual variables, explicit bounds for the dual variables are derived and integrated with McCormick inequalities to establish an exact mixed-integer linear programming reformulation. Such a theoretical contribution offers a general framework for tackling nonlinear scheduling problems under the

DRO setting. The proposed reformulation entirely eliminates the reliance on heuristic big-M coefficients. Computational experiments demonstrate improved out-of-sample stability and robustness, together with favorable computational performance compared with standard stochastic models.

**Keywords:** Two-machine Flow-shop scheduling; Distributionally robust optimization; Wasserstein ambiguity set; McCormick inequalities; Conditional value-at-risk

## Thematic Talk 8

### A Deep Learning-Standard Quadratic Programming Approach to Intensity-Modulated Radiation Therapy Beam Angle Optimization

Can Li, Beijing University of Technology

**Abstract:** Beam angle optimization constitutes a core and highly challenging problem in the formulation of intensity-modulated radiation therapy treatment plans, and its essence is recognized as a typical NP-hard non-convex optimization problem. Existing conventional optimization schemes either rely on oversimplified assumptions that deviate significantly from real-world clinical scenarios, or adopt overly complex models that suffer from extremely slow solution speeds. In contrast, current artificial intelligence-based approaches, while offering high computational efficiency, are plagued by two critical limitations: an exorbitant demand for large-scale labeled datasets and poor interpretability. Moreover, all existing methods universally require the beam number or its upper limit as a hyperparameter input. To address these drawbacks, this study proposes a novel two-stage integrated optimization framework for beam angle optimization, which seamlessly integrates the high-efficiency solution advantages of deep learning with the rigorous interpretability merits of traditional mathematical optimization methods. In the first stage, a deep learning-based beam number selection strategy is designed: three-dimensional feature information is

extracted from computed tomography images and anatomical structure data, and then fused with two-dimensional feature information encompassing tumor-organ-at-risk geometric parameters and beam attenuation factors. The fused multi-dimensional features are fed into the model to accurately predict the optimal beam number. In the second stage, upon determining the optimal beam number, a novel standard quadratic programming solution framework is constructed for the beam angle optimization subproblem, coupled with a tailored optimization algorithm to achieve efficient and stable angle solving. The effectiveness of the proposed framework is validated on a clinically realistic lung cancer dataset by comparing the optimized beam angles with those manually designed by medical physicists.

**Keywords:** intensity-modulated radiation therapy; beam angle optimization; artificial intelligence-enhanced optimization

## Exact Algorithms for Partially Disjoint Paths under Shared Resource Constraints

Fengjuan Wang, Beijing University of Technology

**Abstract:** As internet reliance grows with technologies like IoT and 5G, network failures pose greater challenge. Employing primary and backup paths can improve network fault tolerance; however, requiring multiple paths to be completely disjoint often leads to higher routing costs or lower resource utilization. Therefore, allowing paths to share a limited number of nodes or links in a controlled manner helps improve network stability and fault tolerance while reducing cost. To address complex network failure scenarios, we are the first to propose and systematically define the  $(k, \delta, \sigma)$ -PNLSP model. Given a network with a source node and a sink node, the problem aims to find  $k$  paths with minimum total weight such that at most  $\delta$  nodes and at most  $\sigma$  links are shared by at least two paths. To solve this problem, we develop two exact algorithms: one for general directed graphs with time complexity  $O(mn \log_{(1+m/n)} n + \delta \sigma n^2)$ , and the other for directed acyclic graphs with time complexity  $O(\delta \sigma^k n^{k+1})$ . Extensive experiments on both synthetic datasets and

real-world networks, such as P2P and Email-EuAll, verify the effectiveness of the proposed algorithms.

**Keywords:** Partially disjoint paths; Exact algorithm; Restricted shortest path; Network fault tolerance; Directed acyclic graph

## Joint Optimization of FPGA Routing and TDM Ratio Assignment Based on Min-Max Resource Sharing

Guihao Wang, Beijing University of Technology

**Abstract:** System-level field-programmable gate array prototyping is widely used in the verification of modern very large scale integration circuits. However, because the available interconnection resources between FPGAs are limited, routing failures are likely to occur when the number of inter-FPGA signals becomes large. Time-division multiplexing improves interconnect resource utilization by allowing multiple signals to share physical wires, but it also significantly increases the transmission delay of inter-FPGA signals. Existing approaches mostly adopt a two-stage framework that treats routing and TDM ratio assignment separately, making it difficult to fully capture their coupling and thereby limiting the overall optimization performance. To address this issue, we study the joint optimization of system-level FPGA routing and TDM ratio assignment, and propose a four-step solution framework. First, the original problem is relaxed. Second, the relaxed problem is transformed into a min-max resource sharing problem. Third, the resulting resource sharing problem is solved. Finally, randomized rounding, legalization, and post-processing are applied to obtain a feasible solution satisfying practical constraints. Experimental results show that the proposed method effectively coordinates FPGA routing and TDM ratio assignment, and achieves better overall performance than the compared methods.

**Keywords:** FPGA routing; Time-division multiplexing; Joint optimization; Min-max resource sharing; Randomized rounding

# Online Parallel-Batch Scheduling with Deterioration for Sustainable Battery Electrode Drying

Jiahe Wang, Beijing University of Technology

**Abstract:** The rapid growth of electric vehicles demands energy-efficient lithium-ion battery manufacturing. In electrode production, the drying oven is a key energy-intensive bottleneck where scheduling directly impacts both throughput and energy consumption. This paper studies an online parallel-batch scheduling problem on a single bounded-capacity drying oven with simple linear deterioration: the processing time of job  $J_j$  is  $p_j = \alpha_j S_j$ , where  $\alpha_j > 0$  is a material-dependent deterioration rate and  $S_j$  is the batch start time. Jobs arrive online in non-increasing order of deterioration rates. We consider two sustainability-related objectives: the makespan  $C_{\max}$ , which governs line throughput and overall energy usage, and the maximum processing time  $P_{\max}$ , which determines peak energy demand. For both objectives, we prove a tight competitive ratio of  $1 + \alpha_{\max}$  and design a best possible online algorithm  $H_1$ . Notably, this single algorithm simultaneously optimizes both throughput and peak energy without any trade-off. Numerical experiments on 10,000 randomly generated instances confirm the theoretical bounds and demonstrate that  $H_1$  significantly outperforms the greedy strategy, reducing energy waste by up to 66% under clustered arrival patterns typical of real production lines.

**Keywords:** Online scheduling; Parallel-batch processing; Deterioration effect; Competitive analysis; Sustainable battery manufacturing

## On Competitive Ratio for Online Uniform Facility Location Problem in Random-Order Model

Mengzhen Li, Beijing University of Technology

**Abstract:** We study the online facility location problem, where clients arrive sequentially in a random order and must be assigned to an open facility immediately and irrevocably upon arrival. At the initial stage, the set of facilities is fully known. We present an 8-competitive online algorithm for the uniform facility cost case,

providing the first competitive ratio result for this setting. Our algorithm reduces the competitive ratio by 75% compared to the previously known 33-competitive ratio for the nonuniform case. The analysis offers new theoretical insights into online algorithms for the nonuniform case and establishes a foundation for practical applications in decision-making contexts.

**Keywords:** Facility location; Online algorithm; Competitive ratio; Random order; Randomized algorithm

## Balancing Traffic and Profitability: Assortment and Ranking in Live-Streaming under Bounded Rationality

Xiaoyu Shao, Beijing University of Technology

**Abstract:** In live-streaming commerce, streamers sequentially present a curated subset of products within a limited session duration, while consumers make purchase decisions under severe attention constraints. This challenges traditional assortment models based on the standard Multinomial Logit (MNL) framework, which assume simultaneous display and fully rational evaluation. However, live-stream viewers exhibit bounded rationality: a highly attractive anchor product can dominate attention and endogenously shrink the consideration set by crowding out regular items. To address the joint assortment and ranking optimization under such endogenous consideration sets, we adapt the Threshold Multinomial Logit (TMNL) model to the live-streaming context. We formulate a model where consumers consider only products whose utilities fall within a tolerance threshold relative to the highest presented utility. By employing a conditional decoupling and iterate-over-anchor approach to resolve the non-convexity induced by the endogenous anchor, we analytically derive global optimal policies. Unlike the standard MNL model's unconstrained revenue-ordered assortment strategy, the optimal live-streaming assortment follows a threshold-constrained revenue-ordered policy: high-margin products are strictly excluded if their perceived utility falls below the endogenous consideration set by the anchor. Furthermore, the optimal ranking strategy assigns

products to heterogeneous traffic positions based on a weighted marginal contribution index. These findings suggest that overly salient anchor products may attract traffic at the cost of suppressing the visibility and profitability of regular and long-tail items. This study extends assortment planning theory to a sequential selling environment with bounded rationality and endogenous consideration sets. It also offers managerial implications for live-streaming operations by highlighting the importance of threshold management in balancing traffic generation and overall assortment profitability.

**Keywords:** Assortment optimization; Live-streaming commerce; Consideration sets; Choice models; Ranking