mathematics

MDPI

Editorial

Preface to the Special Issue "Mathematical Optimization and Evolutionary Algorithms with Applications"

Antonin Ponsich [1,*], Bruno Domenech [1] and Mariona Vilà [2]

[1] Management Department, Universitat Politècnica de Catalunya—BarcelonaTech, 08028 Barcelona, Spain; bruno.domenech@upc.edu
[2] Academic Department, EAE Business School, 08015 Barcelona, Spain; mariona.vila.bonilla@upc.edu
* Correspondence: antonin.sebastien.ponsich@upc.edu

It is recognized that many real-world problems can be interpreted and formulated as optimization problems. This feature has fostered the development of research studies aiming to design and implement efficient optimization methods, able to address the increasing complexity of the applications that are intended to be solved. These research studies have mostly followed two main axes.

The first one focuses on the theoretical development of advanced solution strategies through the perspective of tackling problems of increasing complexity. For instance, multimodal objective functions, highly constrained search spaces, single vs. multi-objective problems, optimization of stochastic systems, among others. In this matter, thanks to both cutting-edge mathematical tools and the increasing power of computational hardware, exact solution methods (in general based on mathematical programming) now enable solving large-size intricate problems. However, many problems have also required the implementation of approximated, heuristic or metaheuristic techniques, which are not affected by the mathematical properties of the tackled problem but, on the other hand, are unable to guarantee result optimality. Within this class of approximated optimization methods, evolutionary algorithms occupy a relevant part of the devoted literature.

On the other hand, a great effort has also been made towards developing problem-devoted techniques that aim to efficiently find high-quality solutions to specific applications drawn from a wide spectrum of areas (engineering, social sciences, biotechnologies, finances, etc.). The corresponding studies do not usually start designing a new solution strategy from scratch, but rather reuse techniques developed in general frameworks and adapt their working mode to the specific feature of the problem that is being tackled. As a consequence, it is necessary to take advantage of the problem structure, conditioning factors or particular characteristics of the considered application for an efficient solution technique to be built.

The Special Issue proposed here illustrates both types of studies. Indeed, as shown in Table 1, 5 out of the 16 published articles tackle the issue of the theoretical development of optimization techniques or the formulation of academic operations research problems. Among these theoretical papers, two of them propose novel mathematical formulations for academic problems, while the other three focus on the development of evolutionary algorithms as a solution technique. The remaining 11 papers propose original and ad hoc solution strategies for different applications. Table 1 provides an overview of the topics addressed in these papers. It is worth highlighting that among these 11 studies, a majority of them use evolutionary algorithms, while four are based on mathematical programming.

The papers will be explained in detail, beginning with the theoretical studies. Yuraszeck et al. [1] propose a novel heuristic procedure to solve the fixed group shop scheduling problem, in which the tasks corresponding to each job have been assigned to stages, and the tasks of each stage share a set of machines. The authors introduce an algorithm that uses both a decomposition-based approach, as well as a constraint programming solver,

check for updates

Citation: Ponsich, A.; Domenech, B.; Vilà, M. Preface to the Special Issue "Mathematical Optimization and Evolutionary Algorithms with Applications". *Mathematics* **2023**, *11*, 2229. https://doi.org/10.3390/math11102229

Received: 27 April 2023
Accepted: 4 May 2023
Published: 10 May 2023

Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

allowing for the inclusion of extra constraints found in real-life instances. To test the performance of the proposed approach, computational tests are carried out to compare the algorithm with some available solvers; the former obtained the best solution in most instances. The heuristic procedure is also used in a Colombian automotive company case study, in which not only is the scheduling of jobs optimized, but also information about bottlenecks is easily obtained.

Table 1. Classification of the papers included in the Special Issue.

Type	Application	Mathematical Modelling	Evolutionary Algorithms
Theory	Scheduling	[1]	[2]
	Mathematics	[3]	[4,5]
Application	Distribution and Commerce	[6]	[7,8]
	Energy	[9,10]	[11–14]
	Physics and Materials	[15]	[16]

In Zapotecas et al. [4], the authors focus on one of the main paradigms employed for handling multi-objective optimization problems (MOPs) with evolutionary algorithms, which use hypervolume as a performance indicator governing the selection operator. A well-known drawback of this strategy is the complexity of the hypervolume computation when the number of objectives increases. This paper uses the property regularity of continuous MOPs, as well as the locality property of the hypervolume in order to reduce the number of computations of this indicator within a novel and efficient multi-objective evolutionary algorithm (MOEA). Three academic applications, with a number of objectives ranging from 4 to 7, are solved with the new algorithm, and the numerical experiments highlight the benefits of the proposed methodology for identifying efficiently better approximations of the Pareto front (when compared with classical MOEAs based on the hypervolume indicator).

In Ambrosino and Cerrone [3], a variant of the shortest path problem is proposed, considering both negative and positive costs at the edges of a graph. The aim consists of obtaining the Hamiltonian cycle such that the sum of the costs associated with each edge on the chosen path is close to 0. The resulting problem, called the cost-balanced path problem, is proved to be NP-hard since it can be reduced to the Hamiltonian path problem, which is NP-hard. Different versions of this problem are also introduced, so that practical conditions can be included through the appropriate constraints, and their complexity is also studied. Finally, computational experiments empirically confirm the problem complexity and suggest the need for heuristic or metaheuristic solution techniques to address large-size instances.

Belazi et al. [5] introduce an improved version of the sine–cosine algorithm (SCA), which is a population-based metaheuristic recently developed in the area of continuous optimization. The modifications proposed consist of the introduction of a new equation within the algorithm's variation operator, leading to an enhanced intensification effect, which promotes convergence towards the best solutions found. In addition, several parallelization strategies are implemented and tested in order to identify the best performing one. Finally, the new technique proves to significantly outperform the original SCA when both versions are compared over a benchmark, including 30 classical unconstrained text functions and several constrained engineering problems. Additionally, the enhanced SCA obtains very good results when its performance levels are compared with those of a set of state-of-the-art algorithms, such as differential evolution or grey wolf optimizer.

In the last theoretical work of this Special Issue, Wang et al. [2] address the multi-skilled resource-constrained project scheduling problem, which combines a typical scheduling of activities with the skill assignment of resources, taking into account uncertainty in resource availability. The authors formulate the corresponding mathematical model and, given its complexity, propose a genetic algorithm combined with priority rules. A computational

experiment is performed comparing dynamic, random and static scheduling, showing the effectiveness of the first option. These results can help project managers in the selection of resources at the beginning of a project and the reinforcement of resources during the execution, especially under uncertain contexts such as COVID-19.

Regarding the 11 studies devoted to the solution of specific applications, Wu et al. [6] present a novel approach for algorithms devoted to community commerce recommendation for repeated purchases. The authors attempt to fill in the perceived gap in these types of purchase recommendation algorithms by accounting not just for past customer behaviors, but also for the repeat purchase behavior of different types of customers. The method uses a divide-and-conquer strategy, separating users into four categories: active users with stable interest, active users with unstable interest, inactive users with stable interest and inactive users with unstable interest. The proposed algorithm is tested on a real dataset and outperforms well-known recommendation algorithms by at least 13.6% in all categories, showing an even greater performance among active users.

Abdelhamid et al. [11] propose an adaptive protection scheme, used to overcome the coordination problems presented by protection relays. The adaptive protection scheme presented is based on both original and modified heap-based optimization. The algorithm proposed is tested using the IEEE 8-bus and the IEEE 14-bus test systems, obtaining better results than the existing algorithms. Specifically, the adaptive protection scheme is able to more reliably investigate the benefits of both directional overcurrent relays and distance relays. Additionally, the modified heap-based optimization makes the algorithm more effective at solving relay coordination.

Reyes-Barquet et al. [12] present a multi-objective genetic algorithm, which, combined with a TOPSIS analysis for multi-criteria decision making, is applied in the design stage of hydrogen supply chain networks. A specific case study is selected, where the hydrogen is obtained using energy generated by the biomass waste produced by Mexican sugar factories. The algorithm uses both the maximization of profit and the minimization of greenhouse gas emissions as optimization objectives. The results of the study highlight the benefits that could be obtained from this unorthodox energy source, as the case study was validated by several economic metrics, such as an internal rate of return of 21.5%, while remaining environmentally respectful.

In Chesalin and Pishchalnikov [15], the optical properties of pigment–protein complexes (PPCs) are investigated due to their major relevance in the study of photosynthetic mechanisms of living species. These properties and, in particular, the spectral response of PPC can be assessed either experimentally or through a simulation. However, the simulation process uses a set of input parameters that should be appropriately tuned in order to produce valid results. In this study, the differences between the experimental and simulated spectral responses of different PPCs are minimized through an evolutionary algorithm, differential evolution (DE), which has proved to perform very well for real-parameter optimization problems. Ten different DE strategies are implemented and their performance levels are compared, showing that the DE/rand-to-best/1/exp version consistently obtains the best results, although the authors recommend the use of self-adaptive implementations to improve the convergence rate.

Domenech et al. [9] deals with the design of autonomous electrification systems in Ecuador's amazon region (RAE), which is an isolated area with communities scattered across the rainforest. This situation involves great practical and economic difficulties for the development of electrification systems promoting the access to power for rural and indigenous local populations. This work introduces a mathematical model for the design of stand-alone rural electrification systems based on photovoltaic technologies, including both microgrid or individual supply configurations. The corresponding mixed integer linear programming (MILP) problem considers economic, technical and social aspects, and it is used to design electrification systems (equipment location and sizing and microgrid configurations) in three real communities, providing relevant insights regarding RAE electrification.

Another original application is presented in Qin et al. [7], which tackles the management of a high-speed railway in China. In particular, the problems of ticket pricing, train stop planning and seat allocation are all addressed in this study. A mathematical model is formulated, with the aim of maximizing the total revenue of the railway company while minimizing passengers' time loss. Due to the complexity of the resulting MILP problem, a simulated annealing algorithm is adopted as a solution technique, with two nested neighborhood structures; the first one deals with the stop plan, and the second focuses on ticket pricing and seat allocation. A solution using the proposed methodology is provided for the case study that is presented in this study, allowing for significant improvements of the chosen performance criteria when compared with those observed in the real system operation mode.

Galleguillos-Pozo et al. [10] develop a fuzzy MILP model to design wind–PV–battery electricity access projects for remote communities of developing countries. It is hard to estimate the electricity needs of the population in those areas, so fuzziness is introduced to balance the project cost vs. the demand supplied within a range of predefined values. Two approaches are considered: maximizing the general satisfaction of the whole community and maximizing the satisfaction of the least satisfied consumption point. The model is used to design electricity access projects in Ecuador, Mexico and Peru. The results achieve a generally better balance between the project cost and the electricity supplied than those that would have been obtained without using a fuzzy MILP model.

In Martínez et al. [16], a multi-objective and multi-scale optimization procedure is designed to improve the structure performance of eco-composites. As objectives, the shelf stiffness and the material cost and weight are optimized by modifying the configuration of the structure at macro and micro levels. The results highlight the importance of considering both the micro and macro structure when designing composite materials. An illustrative example is shown for the design of the cabin stowage bin located above the seats in airplanes. This procedure can be helpful for optimizing the design of eco-composites in many engineering structures, reducing the environmental impact.

Grisales-Noreña et al. [13] propose a mixed integer non-linear programming model to minimize the yearly operation costs of PV generators integrated into DC grids. The problem is solved through a primary—secondary methodology. First, the primary problem is addressed to locate and size the PV modules using a discrete-continuous version of the crow search algorithm. Second, the secondary problem searches the objective function value through the successive approximation power flow method. Test instances are used to validate the proposed methodology, which better performs in terms of applicability and effectiveness in comparison to other literature approaches; lower operation costs of the solution and computation times to solve the problem are achieved.

Park et al. [14] focus on the energy disaggregation problem, which consists of estimating the energy consumption of each device given the aggregated measure from the smart meter. In this perspective, the authors develop a multi-objective model that optimizes sparsity and disaggregation, subject to constraints related to equipment operational characteristics. The model is solved by means of an evolutionary algorithm. The results are compared to those obtained using different formulations from the literature, achieving better performance either on the appliance level or on the disaggregation accuracy.

Finally, Gutiérrez-Bahamontes et al. [8] identify the complexity of designing pump stations in real-size water distribution networks. To address this gap, they propose reducing the problem size through a preprocess where the range of flows that every pump station can manage is calculated, which leads to the construction of infeasibility maps. Then, the problem is optimized by means of a pseudo-genetic algorithm. They later perform a computational experiment showing that the preprocess effectively reduces the solution space, significantly improving the computation time and achieving better solutions in terms of the objective function value obtained.

Finally, it is worth providing a general overview of the Special Issue in terms of the geographical origin of the institutions of the papers' authors in this Special Issue. Figure 1

illustrates the fact that the most represented institutions are from Spain, followed by China and Latin American countries (20, including Mexico, Chile and Colombia). Additionally, it can be mentioned that the mean number of authors per paper is 4.3.

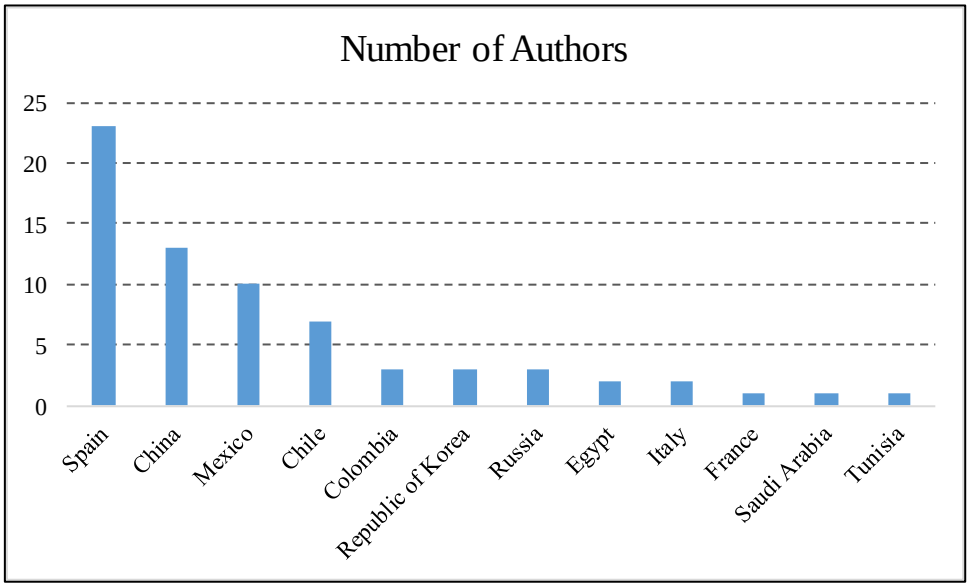


Figure 1. Geographical distribution of the institutions of accepted papers' authors.

In conclusion, the resulting mixture of methods, algorithms and applications for the treatment of complex optimization problems presented in this Special Issue, either through mathematical tools or metaheuristic algorithms, is expected to contribute to the development of research in this area. We also believe that the new knowledge acquired here, as well as the applied results are attractive and useful for young scientists, doctoral students and researchers from various scientific specialties.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Yuraszeck, F.; Mejía, G.; Pereira, J.; Vilà, M. A Novel Constraint Programming Decomposition Approach for the Total Flow Time Fixed Group Shop Scheduling Problem. *Mathematics* **2022**, *10*, 329. [CrossRef]
2. Wang, M.; Liu, G.; Lin, X. Dynamic Optimization of the Multi-Skilled Resource-Constrained Project Scheduling Problem with Uncertainty in Resource Availability. *Mathematics* **2022**, *10*, 3070. [CrossRef]
3. Ambrosino, D.; Cerrone, C. The Cost-Balanced Path Problem: A Mathematical Formulation and Complexity Analysis. *Mathematics* **2022**, *10*, 804. [CrossRef]
4. Zapotecas-Martínez, S.; García-Nájera, A.; Menchaca-Méndez, A. Improved Lebesgue Indicator-Based Evolutionary Algorithm: Reducing Hypervolume Computations. *Mathematics* **2022**, *10*, 19. [CrossRef]
5. Belazi, A.; Migallón, H.; Gónzalez-Sánchez, D.; Gónzalez-García, J.; Jimeno-Morenilla, A.; Sánchez-Romero, J.L. Enhanced Parallel Sine Cosine Algorithm for Constrained and Unconstrained Optimization. *Mathematics* **2022**, *10*, 1166. [CrossRef]
6. Wu, J.; Li, Y.; Shi, L.; Yang, L.; Niu, X.; Zhang, W. ReRec: A Divide-and-Conquer Approach to Recommendation Based on Repeat Purchase Behaviors of Users in Community E-Commerce. *Mathematics* **2022**, *10*, 208. [CrossRef]
7. Qin, J.; Li, X.; Yang, K.; Xu, G. Joint Optimization of Ticket Pricing Strategy and Train Stop Plan for High-Speed Railway: A Case Study. *Mathematics* **2022**, *10*, 1679. [CrossRef]
8. Gutiérrez-Bahamondes, J.H.; Mora-Melia, D.; Valdivia-Muñoz, B.; Silva-Aravena, F.; Iglesias-Rey, P.L. Infeasibility Maps: Application to the Optimization of the Design of Pumping Stations in Water Distribution Networks. *Mathematics* **2023**, *11*, 1582. [CrossRef]
9. Domenech, B.; Ferrer-Martí, L.; García, F.; Hidalgo, G.; Pastor, R.; Ponsich, A. Optimizing PV Microgrid Isolated Electrification Projects—A Case Study in Ecuador. *Mathematics* **2022**, *10*, 1226. [CrossRef]
10. Galleguillos-Pozo, R.; Domenech, B.; Ferrer-Martí, L.; Pastor, R. Balancing Cost and Demand in Electricity Access Projects: Case Studies in Ecuador, Mexico and Peru. *Mathematics* **2022**, *10*, 1995. [CrossRef]

11. Abdelhamid, M.; Kamel, S.; Ahmed, E.M.; Bonah Agyekum, E. An Adaptive Protection Scheme Based on a Modified Heap-Based Optimizer for Distance and Directional Overcurrent Relays Coordination in Distribution Systems. *Mathematics* **2022**, *10*, 419. [CrossRef]
12. Reyes-Barquet, L.M.; Rico-Contreras, J.O.; Azzaro-Pantel, C.; Moras-Sánchez, C.G.; González-Huerta, M.A.; Villanueva-Vásquez, D.; Aguilar-Lasserre, A.A. Multi-Objective Optimal Design of a Hydrogen Supply Chain Powered with Agro-Industrial Wastes from the Sugarcane Industry: A Mexican Case Study. *Mathematics* **2022**, *10*, 437. [CrossRef]
13. Grisales-Noreña, L.F.; Cortés-Caicedo, B.; Alcalá, G.; Danilo Montoya, O. Applying the Crow Search Algorithm for the Optimal Integration of PV Generation Units in DC Networks. *Mathematics* **2023**, *11*, 387. [CrossRef]
14. Park, J.; Ajani, O.S.; Mallipeddi, R. Optimization-Based Energy Disaggregation: A Constrained Multi-Objective Approach. *Mathematics* **2023**, *11*, 563. [CrossRef]
15. Chesalin, D.D.; Pishchalnikov, R.Y. Searching for a Unique Exciton Model of Photosynthetic Pigment–Protein Complexes: Photosystem II Reaction Center Study by Differential Evolution. *Mathematics* **2022**, *10*, 959. [CrossRef]
16. Martínez, X.; Pons-Prats, J.; Turon, F.; Coma, M.; Gratiela Barbu, L.; Bugeda, G. Multi-Objective Multi-Scale Optimization of Composite Structures, Application to an Aircraft Overhead Locker Made with Bio-Composites. *Mathematics* **2023**, *11*, 165. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.