# A memetic based on-state for max-cut

Zeng, Zhi-zhong Lue, Zhi-peng Yu, Xin-guo Wu, Qing-hua Wang, Yang Zhou, Zhou

Max-cut is one of the most classic NP-hard combinatorial optimization problems. The symmetry nature of it leads to special difficulty in extracting meaningful configuration information for learning; none of the state-of-the-art algorithms has employed any learning operators. This paper proposes an original learning method for max-cut, namely post-flip edge-state learning (PF-ESL). Different from previous algorithms, PF-ESL regards edge-states (cut or not cut) rather than vertex-positions as the critical information of a configuration, and extracts their statistics over a population for learning. It is based on following observations. 1) Edges are the only factors considered by the objective function. 2) Edge-states keep invariant when rotating a local configuration to its symmetry position, but vertex-positions do not. These suggest that edge-states contain more meaningful information about a configuration than vertex-positions do. It is impossible to set the state of an edge without influencing some other edges' states due to their dependencies. Therefore, instead of setting edge-states directly, PF-ESL samples the flips on vertices. Flips on vertices are sampled according to their capacities in increasing the similarity on edge-states between the given solution and a population. PF-ESL is employed in an EDA (Estimation of Distribution Algorithm) perturbation operator and a path-relinking operator. Experimental results show that our algorithm is competitive, and show that edge-state learning is value-added for both the two operators.The main contributions of this paper are as follows. Firstly, previous state-of-the-art evolutionary algorithms for max-cut focus on vertex positions in their evolutionary operation, this paper proposes a new and more reasonable perspective suggesting that edge-states are the critical information of divided graphs rather than vertex positions, and introduces a novel method to measure and utilize their similarities based on it. Such a perspective is fundamental to learning based algorithms design for max-cut and other graph partitioning problems, and can shed lights on future researches. Furthermore, since max-cut is one of the most classic and fundamental NP hard problems, many real-world problems involve dividing graph data into different parts to optimize certain functions, this new perspective may inspire related or similar problems. Secondly, besides the original edge-states based perspective, and the post-flip edge-states learning (PFESL) operator based on it, our memetic algorithm also incorporates a novel evolutionary framework which alternates between EDA based Iterated Tabu search (ITS) and path relinking based genetic algorithm. Finally, the proposed algorithm provides competitive results on two mostly used benchmark sets and improves the best-known results of 6 most challenging instances.

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# Influence of GEOTRACES data distribution and misfit function choice on objective parameter retrieval in a marine zinc cycle model

Eisenring, Claudia Oliver, Sophy E. Khatiwala, Samar de Souza, Gregory F.

Biogeochemical model behaviour for micronutrients is typically hard to constrain because of the sparsity of observational data, the difficulty of determining parameters in situ, and uncertainties in observations and models. Here, we assess the influence of data distribution, model uncertainty, and the misfit function on objective parameter optimisation in a model of the oceanic cycle of zinc (Zn), an essential micronutrient for marine phytoplankton with a long whole-ocean residence time. We aim to investigate whether observational constraints are sufficient for reconstruction of biogeochemical model behaviour, given that the Zn data coverage provided by the GEOTRACES Intermediate Data Product 2017 is sparse. Furthermore, we aim to assess how optimisation results are affected by the choice of the misfit function and by confounding factors such as analytical uncertainty in the data or biases in the model related to either seasonal variability or the larger-scale circulation. The model framework applied herein combines a marine Zn cycling model with a state-of-the-art estimation of distribution algorithm (Covariance Matrix Adaption Evolution Strategy, CMA-ES) to optimise the model towards synthetic data in an ensemble of 26 optimisations. Provided with a target field that can be perfectly reproduced by the model, optimisation retrieves parameter values perfectly regardless of data coverage. As differences between the model and the system underlying the target field increase, the choice of the misfit function can greatly impact optimisation results, while limitation of data coverage is in most cases of subordinate significance. In cases where optimisation to full or limited data coverage produces relatively distinct model behaviours, we find that applying a misfit metric that compensates for differences in data coverage between ocean basins considerably improves agreement between optimisation results obtained with the two data situations.

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# Resilience-Based Surrogate Robustness Measure and Optimization Method for Robust Job-Shop Scheduling

Xiao, Shichang Wu, Zigao Dui, Hongyan

This paper addresses the robust job-shop scheduling problems (RJSSP) with stochastic deteriorating processing times by considering the resilience of the production schedule. To deal with the disturbances caused by the processing time variations, the expected deviation between the realized makespan and the initial makespan is adopted to measure the robustness of a schedule. A surrogate model for robust scheduling is proposed, which can optimize both the schedule performance and robustness of RJSSP. Specifically, the computational burden of simulation is considered a deficiency for robustness evaluation under the disturbance of stochastic processing times. Therefore, a resilience-based surrogate robustness measure (SRM-R) is provided for the robustness estimation in the surrogate model. The proposed SRM-R considers the production resilience and can utilize the available information on stochastic deteriorating processing times and slack times in the schedule structure by analyzing the disturbance propagation of the correlated operations in the schedule. Finally, a multi-objective hybrid estimation of distribution algorithm is employed to obtain the Pareto optimal solutions of RJSSP. The simulation experiment results show that the presented SRM-R is effective and can provide the Pareto solutions with a lower computational burden. Furthermore, an RJSSP case derived from the manufacturing environment demonstrates that the proposed approach can generate satisfactory robust solutions with significantly improved computational efficiency.

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Trajectory optimization of space vehicle in rendezvous proximity operation with evolutionary feasibility conserving techniques

Shirazi, Abolfazl Ceberio, Josu Lozano, Jose A.

In this paper, a direct approach is developed for discovering optimal transfer trajectories of close-range rendezvous of satellites considering disturbances in elliptical orbits. The control vector representing the inputs is parameterized via different interpolation methods, and an Estimation of Distribution Algorithm (EDA) that implements mixtures of probability models is presented. To satisfy the terminal conditions, which are represented as non-linear inequality constraints, several feasibility conserving mechanisms associated with learning and sampling methods of the EDAs are proposed, which guarantee the feasibility of the explored solutions. They include a particular implementation of a clustering algorithm, outlier detection, and several heuristic mapping methods. The combination of the proposed operators guides the optimization process in achieving the optimal solution by surfing the regions of the search domain associated with feasible solutions. Numerical simulations confirm that space transfer trajectories with minimum-fuel consumption for the chaser spacecraft can be obtained with terminal condition satisfaction in rendezvous proximity operation.

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# The Low-Carbon Scheduling Optimization of Integrated Multispeed Flexible Manufacturing and Multi-AGV Transportation

Liu, Zhengchao Luo, Qiang Wang, Lei Tang, Hongtao Li, Yibing

As low-carbon and sustainable manufacturing becomes the mainstream development direction of the current manufacturing industry, the traditional heavy industry manufacturing enterprises in China urgently need to transform. For the heavy cement equipment manufacturing enterprise investigated here, there is a large amount of energy waste during the manufacturing operation due to scheduling confusion. In particular, the multispeed, multi-function machining and the transportation of multiple automated guided vehicles (multi-AGV) are the main influencing factors. Therefore, this paper addresses a novel low-carbon scheduling optimization problem that integrated multispeed flexible manufacturing and multi-AGV transportation (LCSP-MSFM &amp; MAGVT). First, a mixed-integer programming (MIP) model is established to minimize the comprehensive energy consumption and makespan in this problem. In the MIP model, a time-node model is built to describe the completion time per workpiece, and a comprehensive energy consumption model based on the operation process of the machine and the AGV is established. Then, a distribution algorithm with a low-carbon scheduling heuristic strategy (EDA-LSHS) is estimated to solve the proposed MIP model. In EDA-LSHS, the EDA with a novel probability model is used as the main algorithm, and the LSHS is presented to guide the search direction of the EDA. Finally, the optimization effect and actual performance of the proposed method are verified in a case study. The experimental results show that the application of the proposed method in actual production can save an average of 43.52% comprehensive energy consumption and 64.43% makespan, which effectively expands the low-carbon manufacturing capacity of the investigated enterprise.

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# An Estimation of Distribution Algorithm Based on Variational Bayesian for Point-Set Registration

Cao, Hualong He, Qiqi Wang, Haifeng Xiong, Zenghui Zhang, Ni Yang, Yang

Point-set registration is widely used in computer vision and pattern recognition. However, it has become a challenging problem since the current registration algorithms suffer from the complexities of the point-set distributions. To solve this problem, we propose a robust registration algorithm based on the estimation of distribution algorithm (EDA) to optimize the complex distributions from a global search mechanism. We propose an EDA probability model based on the asymmetric generalized Gaussian mixture model, which describes the area in the solution space as comprehensively as possible and constructs a probability model of complex distribution points, especially for missing and outliers. We propose a transformation and a Gaussian evolution strategy in the selection mechanism of EDA to process the deformation, rotation, and denoising of selected dominant individuals. Considering the complexity of the model, we choose to optimize from the perspective of variational Bayesian, and introduce a prior probability distribution through local variation to reinforce the convergence of the algorithm in dealing with complex point sets. In addition, a local search mechanism based on the simulated annealing algorithm is added to realize the coarse-to-fine registration. Experimental results show that our method has the best robustness compared with the state-of-the-art registration algorithms.

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# Multisource Heterogeneous User-Generated Contents-Driven Interactive Estimation of Distribution Algorithms for Personalized Search

Bao, Lin Sun, Xiaoyan Gong, Dunwei Zhang, Yong

Personalized search is essentially a complex qualitative optimization problem, and interactive evolutionary algorithms (EAs) have been extended from EAs to adapt to solving it. However, the multisource user-generated contents (UGCs) in the personalized services have not been concerned on in the adaptation. Accordingly, we here present an enhanced restricted Boltzmann machine (RBM)-driven interactive estimation of distribution algorithms (IEDAs) with multisource heterogeneous data from the viewpoint of effectively extracting users' preferences and requirements from UGCs to strengthen the performance of IEDA for personalized search. The multisource heterogeneous UGCs, including users' ratings and reviews, items' category tags, social networks, and other available information, are sufficiently collected and represented to construct an RBM-based model to extract users' comprehensive preferences. With this RBM, the probability model for conducting the reproduction operator of estimation of distribution algorithms (EDAs) and the surrogate for quantitatively evaluating an individual (item) fitness are further developed to enhance the EDA-based personalized search. The UGCs-driven IEDA is applied to various publicly released Amazon datasets, e.g., recommendation of Digital Music, Apps for Android, Movies, and TV, to experimentally demonstrate its performance in efficiently improving the IEDA in personalized search with less interactions and higher satisfaction.

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# A practical regularity model based evolutionary algorithm for multiobjective optimization

Zhang, Wanpeng Wang, Shuai Zhou, Aimin Zhang, Hu

It is well known that domain knowledge helps design efficient problem solvers. The regularity model based multiobjective estimation of distribution algorithm (RM-MEDA) is such a method that uses the regularity property of continuous multiobjective optimization problems (MOPs). However, RM-MEDA may fail to work when dealing with complicated MOPs. This paper aims to propose some practical strategies to improve the performance of RM-MEDA. We empirically study the modeling and sampling components of RM-MEDA that influence its performance. After that, some new components, including the population partition, modeling, and offspring generation procedures, are designed and embedded in the regularity model. The experimental study suggests that the new components are more efficient than those in RM-MEDA when using the regularity model. The improved version has also been verified on various complicated benchmark problems, and the experimental results have shown that the new version outperforms five state-of-the-art multiobjective evolutionary algorithms. (c) 2022 Elsevier B.V. All rights reserved.

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# An improved estimation of distribution algorithm for multi-objective optimization problems with mixed-variable

Wang, Wenxiang Li, Kangshun Jalil, Hassan Wang, Hui

Multi-objective evolutionary algorithms face many challenges in optimizing mixed-variable multi-objective problems, such as quantization error, low search efficiency of discontinuous discrete variables, and difficulty in coding non-integer discrete variables. To overcome these challenges, this paper proposes a mixed-variable multi-objective evolutionary algorithm based on estimation of distribution algorithm (MVMO-EDA). Compared with traditional multi-objective evolutionary algorithms, MVMO-EDA has the following improvements: (1) instead of crossover and mutation, statistics and sampling are used to generate offspring, which can avoid the quantization error caused by crossover and mutation operations; (2) using index coding for discrete variables to improve the search efficiency; and (3) a scalable histogram probability distribution model and two crowding distance-based diversity maintenance strategies are used to improve the global optimization ability. The performance of the proposed MVMO-EDA is evaluated on the modified ZDT and DTLZ benchmark sets with mixed-variable, and the results show that MVMO-EDA has a competitive performance both in convergence and diversity.

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# An evolutionary correlation-aware feature selection method for classification problems

Namakin, Motahare Rouhani, Modjtaba Sabzekar, Mostafa

As global search techniques, population-based optimization algorithms have provided promising results in feature selection (FS) problems. However, their major challenge is high time complexity associated with the exploration of a large search space and consequently a large number of fitness function evaluations. Moreover, the interaction between features is another key issue in FS problems, directly affecting the classification per-formance through selecting correlated features. In this paper, an estimation of distribution algorithm (EDA)-based method is proposed with three important contributions. Firstly, as an extension of EDA, the proposed method in each iteration generates only two individuals competing based on a fitness function, evolving during the algorithm using our proposed update procedure. Secondly, we provide a guiding technique to determine the number of features to be selected for individuals in each iteration. As a result, the number of selected features in the final solution would be optimized during the evolution process. These two would lead to increasing the convergence speed of the algorithm. Thirdly, as the main contribution of the paper, in addition to considering the importance of each feature alone, the proposed method can consider the interaction between features, being able to deal with complementary features and consequently increase classification performance. To do this, we provide a conditional probability scheme that considers the joint probability distribution of selecting two fea-tures. The introduced probabilities successfully detect correlated features. Experimental results on a synthetic dataset with correlated features proved the performance of our proposed approach facing these types of features. Furthermore, the results on 13 real-world datasets obtained from the UCI repository showed the superiority of the proposed method in comparison with some state-of-the-art approaches. To evaluate the effectiveness of each feature subset, support vector machines are used as classifier. The efficiency analysis of the experimental results using two non-parametric statistical tests proved that the proposed method had significant advantages in com-parison to other approaches.

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# Solving dynamic multi-objective problems using polynomial fitting-based prediction algorithm

Zhang, Qingyang He, Xiangyu Yang, Shengxiang Dong, Yongquan Song, Hui Jiang, Shouyong

Recently, dynamic multi-objective optimization has received growing attention due to its popularity in real-world applications. Inspired by polynomial fitting, this paper proposes a polynomial fitting-based prediction algorithm (PFPA) and incorporates it into the model -based multi-objective estimation of distribution algorithm (RM-MEDA) for solving dynamic multi-objective optimization problems. When an environment change is detected, the main mission of PFPA is to predict high-quality search populations for track-ing the moving Pareto-optimal set effectively. Firstly, the non-dominated solutions obtained in past environments are utilized to predict high-quality solutions based on a multi-step movement strategy. Secondly, a polynomial fitting-based strategy is designed to fit the distribution of variables according to the obtained search populations, and cap-ture the relationship between variables in the new search environment. Thirdly, some effective search agents are generated for improving population convergence and diversity based on characteristics of variables. To evaluate the performance of the proposed algo-rithm, experimental results on a set of benchmark functions, with a variety of different dynamic characteristics and difficulties, and two classical dynamic engineering design problems show that PFPA is competitive with some state-of-the-art algorithms.(c) 2022 Elsevier Inc. All rights reserved.

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# A Composite Service Provisioning Mechanism in Edge Computing

Zhang, Junna Zhao, Xiaoyan Wang, Yali Yuan, Peiyan Zhang, Xinglin

Users can invoke various composite services in Edge Computing (EC) with the development of Service Computing. Generally, users cannot invoke the optimal composite service due to the migration of component service or failure in the edge device. In this study, a Composite Service Provisioning mechanism in EC (CSP-EC) is proposed. It starts when the location of component service changes and terminates when the optimal composite service is obtained. CSP-EC employs dynamic optimization process to meet the real-time requirements. It first caches m optimized intermediate solutions from the first m users, which can be reused by other users to get the final optimal solution. Moreover, a multipopulation Estimation of Distribution Algorithm is used to reduce the probability of falling into a local optimum, and the roulette mechanism is used to accelerate the optimization process. Extensive simulations are conducted based on the real-world dataset. The results show that the proposed mechanism achieves higher quality, better stability, and shorter execution time compared with other schemes.

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# An EDA-based method for solving electric vehicle charging scheduling problem under limited power and maximum imbalance constraints

Shahmoradi, Hadi Esmaelian, Majid Karshenas, Hossein

Electronic vehicles (EVs) are receiving increasing attention to addressing global warming challenges since fossil fuel is replaced with fuel cell technology. Hence, new challenges arise as demands have increased for using EVs. One of these challenges is the long waiting time of charging EVs spent in queues, especially during peak hours. So, in this study, we aim to propose an efficient method for the electric vehicle charging scheduling problem (EVCSP), which an actual charging station inspires. The most important constraint in this problem is balancing power consumption between charging lines, leading to a limited number of devices that can be charged simultaneously. Also, in this problem, EVs may have interrelationships with each other during the scheduling procedure. So, the estimation of distribution algorithm (EDA) as a competent method in handling the possible relations among decision variables is applied in our proposed hybrid EDA-based solving method. Our proposed method comprises two EDAs, a Markov network-based EDA and a Mallows model-based EDA. It achieves an appropriate schedule and charging line assignment simultaneously while minimizing the total tardiness considering problem constraints. We compared our method with a constraint programming (CP) model and the state-of-art meta-heuristic methods in terms of the objective function value by simulation on a benchmark dataset. Results from the experimental study show significant improvement in solving the introduced EVCSPs.

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# An offline learning co-evolutionary algorithm with problem-specific knowledge

Zhao, Fuqing Zhu, Bo Wang, Ling Xu, Tianpeng Zhu, Ningning Jonrinaldi, Jonrinaldi

The meta-heuristics is an effective way to solve the complex optimization problems. However, the applicability of meta-heuristic is restricted in real applications due to the various characteristics of the corresponding problems. An offline learning co-evolutionary algorithm (OLCA) based on the fitness landscape analysis that introduces the Gaussian estimation of distribution algorithm (EDA) and a variant of differential evolution (DE) for enhancing the search ability, is proposed for complex continuous real-valued problems. The relationship between strategies and fitness landscapes is established by using offline learning of a random forest. The suitable strategy is determined based on the properties of the fitness landscape trained by a random forest before the beginning of the evolutionary process. The proposed OLCA is tested by using the CEC 2017 benchmark test suite and is compared with several state-of-the-art algorithms. The results show that the proposed OLCA is efficient and competitive for solving complex continuous optimization problems. In addition, the effectiveness of the proposed OLCA is also verified by using 19 IEEE CEC 2011 benchmark problems for tackling real-world problems.

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# Using estimation of distribution algorithm for procedural content generation in video games

Karkaj, Arash Moradi Lotfi, Shahriar

Content generation is one of the major challenges in the modern age. The video game industry is no exception and the ever-increasing demand for bigger titles containing vast volumes of content has become one of the vital challenges for the content generation domain. Conventional game development as a human product is not cost efficient and the need for more intelligent, advanced and procedural methods is evident in this field. In a sense, procedural content generation (PCG) is a Non-deterministic Polynomial-Hard optimization problem in which specific metrics should be optimized. In this paper, we use the Estimation of Distribution Algorithm (EDA) to optimize the task of PCG in digital video games. EDA is an evolutionary stochastic optimization method and the introduction of probabilistic modeling as one of the main features of EDA into this problem domain is a reliable way to mathematically apply human knowledge to the challenging field of content generation. Acceptable performance of the proposed method is reflected in the results, which can inform the academia of PCG and contribute to the game industry.

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# An efficient mixture sampling model for gaussian estimation of distribution algorithm

Dang, Qianlong Gao, Weifeng Gong, Maoguo

Estimation of distribution algorithm (EDA) is a stochastic optimization algorithm based on probability distribution model and has been widely applied in global optimization. However, the random sampling of Gaussian EDA (GEDA) usually suffers from the poor diversity and the premature convergence, which severely limits its performance. This paper analyzes the shortcomings of the random sampling and develops an efficient mixture sampling model (EMSM). EMSM can explore more promising regions and utilize the unsuccessful mutation vectors, which achieves a good tradeoff between the diversity and the convergence. Moreover, the feasibility analysis of EMSM is studied. A new GEDA variant named EMSM-EDA is developed, which combines EMSM with enhancing Gaussian estimation of distribution algorithm (EDA(2)). The experimental results on IEEE CEC2013 and IEEE CEC2014 test suites demonstrate that EMSM-EDA is efficient and competitive. (C) 2022 Elsevier Inc. All rights reserved.

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# Estimation of distribution algorithms using Gaussian Bayesian networks to solve industrial optimization problems constrained by environment variables

Soloviev, Vicente P. Larranaga, Pedro Bielza, Concha

Many real-world optimization problems involve two different subsets of variables: decision variables, and those variables which are not present in the cost function but constrain the solutions, and thus, must be considered during optimization. Thus, dependencies between and within both subsets of variables must be considered. In this paper, an estimation of distribution algorithm (EDA) is implemented to solve this type of complex optimization problems. A Gaussian Bayesian network is used to build an abstraction model of the search space in each iteration to identify patterns among the variables. As the algorithm is initialized from data, we introduce a new hyper-parameter to control the influence of the initial data in the decisions made during the EDA execution. The results show that our algorithm improves the cost function more than the expert knowledge does.

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# A matrix-cube-based estimation of distribution algorithm for blocking flow-shop scheduling problem with sequence-dependent setup times

Zhang, Zi-Qi Qian, Bin Hu, Rong Jin, Huai-Ping Wang, Ling Yang, Jian-Bo

The blocking flow-shop scheduling problem with sequence-dependent setup times (BFSP\_SDST) is a strong NP- hard problem that exists widely in practice. However, research on this issue is still quite limited. Hence, this paper presents a novel matrix-cube-based estimation of distribution algorithm (MCEDA) to minimize the makespan criterion of the BFSP\_SDST. In MCEDA's global search, a matrix cube is devised to reasonably learn the promising patterns in excellent solutions or individuals, and then a matrix-cube-based probabilistic model is developed to quickly guide global search toward the potential promising regions in solution space. A diversity controlling mechanism is also added to avoid the stagnation of global search. In MCEDA's local search, an iterated multi-neighborhood local search controlled by the probabilistic model in global search is designed to execute deeper exploitation from those promising regions. Additionally, two constructive heuristics for generating high-quality initial individuals and one fast Insert-based neighbor evaluation method for accelerating the efficiency of local search are presented based on an analysis of the problem's features. MCEDA's efficacy and superiority in solving the BFSP SDST are demonstrated through comprehensive comparisons with 22 state-of-the- art algorithms.

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# Memetic EDA-Based Approaches to QoS-Aware Fully Automated Semantic Web Service Composition

Wang, Chen Ma, Hui Chen, Gang Hartmann, Sven

Quality-of-service (QoS)-aware automated semantic Web service composition aims to find a composite service with optimized or near-optimized QoS and quality of semantic matchmaking within polynomial time. To cope with this NP-hard problem with high complexity, a variety of evolutionary computation (EC) techniques has been developed. To improve the effectiveness and efficiency of these techniques, in this article, we proposed a novel memetic estimation of the distribution algorithm-based approach, namely, MEEDA, to tackle this problem. In particular, MEEDA explores four different domain-dependent local search methods that search for effective composite services by utilizing several neighborhood structures. Apart from that, to significantly reduce the computational time of MEEDA, an efficient local search strategy is introduced by combining a uniform fitness distribution scheme for selecting suitable solutions and stochastic local search operators for effectively and efficiently exploiting neighbors. To better demonstrate MEEDA's effectiveness and scalability, we create a more challenging, augmented version of the service composition benchmark dataset. Experimental results on this benchmark show that MEEDA with newly developed domain-dependent local search operator, i.e., layer-based constrained one-point swaps, significantly outperforms existing state-of-the-art algorithms in finding high-quality composite services.

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# Bearing Fault Classification Using Improved Antlion Optimizer and Extreme Learning Machine

Zhao, Zhuanzhe Zhang, Yu Ma, Qiang Rui, Yujian Ye, Guowen Wang, Mengxian Liu, Yongming Zhang, Zhen Wei, Neng Tu, Zhijian

Bearing is an important part of rotating machinery, and its early fault diagnosis and accurate classification have always been difficult in engineering application. At present, the models based on the fusion of various optimization algorithms and neural networks have become one of the emerging techniques for accurate fault identification. Firstly, an improved antlion optimizer (ALO) algorithm based on estimation of distribution algorithm (EDA) and variable-step Levy flight strategy, abbreviated as ELALO, is proposed as a new bionic intelligence. During the initialization of population, the individuals with poor fitness are redistributed by the Gaussian probability model. In view of the stagnation of iteration, Levy flight strategy is introduced and the adaptive change of disturbance step length is controlled. Experimental results on 4 benchmark functions show that the novel ELALO can effectively improve the solution accuracy and convergence speed, compared with the original ALO. Secondly, in order to solve the disadvantage that extreme learning machine (ELM) network is easy to fall into local optimization, this ELALO algorithm is used to initialize the weights and thresholds of its network and to form the new pattern recognition model, ELALO-ELM. Finally, the bearing data of 8 patterns from Western Reserve University are decomposed by local mean decomposition (LMD), and then the symbolic entropy (SE) of the first three product function (PF) components signals is extracted and used as the input eigenvectors. Compared with the standard ELM and ALO-ELM models, the ELALO-ELM model has better generalization and stronger robustness and it can effectively improve the efficiency of network training and the accuracy of early fault pattern classification in bearing fault diagnosis. The new ELALO-ELM model can also be used for other difficult classification problems.

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# Drought prediction in the Yunnan-Guizhou Plateau of China by coupling the estimation of distribution algorithm and the extreme learning machine

Li, Qiongfang Du, Yao Liu, Zhennan Zhou, Zhengmo Lu, Guobin Chen, Qihui

Drought prediction is a critical non-engineering approach to mitigate their significant threats to water availability, food safety, and ecosystem health. Therefore, to improve the efficiency and accuracy of drought prediction, a novel drought prediction model was proposed by optimizing the extreme learning machine (ELM) using the estimation of distribution algorithm (EDA) (EDA-ELM) and evaluated by the comparison with the genetic algorithm-optimized ELM (GA-ELM) model, standard ELM model, and adaptive network-based fuzzy inference system (ANFIS) in drought prediction for Yunnan-Guizhou Plateau (YGP). The standardized precipitation evapotranspiration index (SPEI) in 3/6/12-month time scales was treated as the dependent variable and the primary drought driving factors as predictor variables. The results revealed that the EDA-ELM model performed best in multiscalar SPEI prediction, followed by GA-ELM, ANFIS, and standard ELM models, while the model execution time was descended by EDA-ELM, GA-ELM, ANFIS, and standard ELM models, varying from 100 to 700 s. The outputs could provide a novel approach to drought prediction and benefit drought prevention and mitigation.

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# A vector-to-sequence based multilayer recurrent network surrogate model for history matching of large-scale reservoir

Ma, Xiaopeng Zhang, Kai Zhao, Hanjun Zhang, Liming Wang, Jian Zhang, Huaqing Liu, Piyang Yan, Xia Yang, Yongfei

History matching can estimate the parameter of spatially varying geological properties and provide reliable numerical models for reservoir development and management. However, in practice, high-dimension, multiple-solutions and computational cost are key issues that restrict the application of history matching methods. Recently, the combination of deep-learning-based surrogate model and sampling algorithm has been widely studied in history matching to overcome the limitations. Considering that real-world large-scale reservoirs often have hundreds of thousands or even millions of grid-based uncertain parameters, extracting spatial features using convolutional neural networks requires a lot of computational cost and storage requirements. Therefore, in this work, we mainly study how to use the recurrent neural network (RNN) to construct the surrogate model for history matching. Specifically, we propose a multilayer RNN surrogate model based on a vector-to-sequence modeling framework. The multilayer RNN surrogate model with gated recurrent unit (GRU), termed MLGRU, is developed to approximate the mapping from feature vector of geological realizations to the production data. The feature vector is the low-dimensional representation of geological parameter fields after using the re-parameterization method, while production data are the simulation results of historical period. In addition, we design a log-transformation-based windowed normalization (LTWN) method for the production data, which can enhance the learnability and features of production data. The MLGRU model is incorporated into a multi -modal estimation of distribution algorithm (MEDA) to formulate a history matching workflow. The hyper-parameters and performance of the proposed MLGRU model are analyzed by numerical experiments on a 2D reservoir model. Furthermore, numerical experiments performed on the Brugge benchmark model, a large-scale 3D reservoir model, demonstrated the performance of the proposed surrogate model and history matching method.

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# Modeling stochastic service time for complex on-demand food delivery

Zheng, Jie Wang, Ling Wang, Shengyao Chen, Jing-fang Wang, Xing Duan, Haining Liang, Yile Ding, Xuetao

Uncertainty is everywhere in the food delivery process, which significantly influences decision-making for complex on-demand food delivery problems, affecting delivery efficiency and customer satisfaction. Especially, the service time is an indispensable part of the delivery process impacted by various uncertain factors. Due to the simplicity and high accuracy requirement, we model the uncertain service time as a Gaussian mixture model (GMM). In detail, we transform the distribution estimation problem into a clustering problem by determining the probability of each data belonging to each component (each cluster as well). A hybrid estimation of distribution algorithm is proposed to intelligently solve the clustering problem with the criterion to optimize quality and simplicity simultaneously. First, to optimize the simplicity, problem-specific encoding and decoding methods are designed. Second, to generate initial solutions with good clustering results, a Chinese restaurant process-based initialization mechanism is presented. Third, a weighted-learning mechanism is proposed to effectively guide the update of the probability model. Fourth, a local intensification based on maximum likelihood is used to exploit better solutions. The effect of critical parameters on the performances of the proposed algorithm is investigated by the Taguchi design of the experimental method. To demonstrate the effectiveness of the proposed algorithm, we carry out extensive offline experiments on real-world historical data. Besides, we employ the GMMs obtained by our algorithm in a real-world on-demand food delivery platform, Meituan, to assist decision-making for order dispatching. The results of rigorous online A/B tests verify the practical value of introducing the uncertainty model into the real-life application.

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# Scheduling of energy-efficient distributed blocking flowshop using pareto-based estimation of distribution algorithm

Zhang, Xiaohui Liu, Xinhua Cichon, Andrzej Krolczyk, Grzegorz Li, Zhixiong

This study investigates the impact of production scheduling decisions aims at improving productive and energy- efficient performances simultaneously in distributed blocking flowshops (EDBFSP). To reach a compromise be-tween the conflicting objectives, a Pareto multi-objective optimization model based on the estimation of dis-tribution algorithm (MOEDA) is proposed. Firstly, an initialization method based on the problem-specific characteristics is designed to create a promising population with quality and diversity; secondly, a probabilistic model based on a Bayesian network is constructed to predict position relationships between jobs. Two neigh-borhood operators with modified insertion technique are proposed to realize the adjustments of both job sequence and processing speed; thirdly, two operators are developed to execute multi-objective local searches on the elite solutions. Aiming at efficient utilization of the resulted blocking and idle time, an energy-saving method is designed for EDBFSP. In the experimental parts, to gain the best performance, the key parameters of MOEDA have been calibrated. The validation is conducted to assess the performances of the designed initialization method, neighborhood search, local search, and energy-saving strategies. The proposed MOEDA is also compared with mainstream metaheuristics for solving green scheduling problems. The experiment results show that the optimization and search ability of MOEDA have gained prominent advantages over other metaheuristics in both precision and distributivity.

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# Precision Analysis for an Optimal Parallel IIR Filter's Implementation

Zelmat, Mohammed Lamini, El-Sedik Tagzout, Samir Belbachir, Hacene Belouchrani, Adel

This paper addresses the precision analysis of filters in the parallel form framework. The precision analysis consists of determining suitable fractional bit-widths to set a tradeoff between resource consumption and computational accuracy. Although the stability of the parallel form is relatively better controlled than the related direct form, its bit-width optimization did not receive much consideration in the literature, despite its significant contribution to the optimization of the filter's physical implementation. To carry out the needed bit-width optimization, we present two heuristics based on the Estimation of Distribution Algorithm, which falls within the category of probabilistic model-building genetic algorithm. The performance of the proposed approach is discussed, and compared to chosen benchmarks, the results show that our hardware implementations reduce the cost of the resulted circuits up to 37%.

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# A Novel Energy Management Strategy for Plug-in Hybrid Electric Buses Based on Model Predictive Control and Estimation of Distribution Algorithm

Tian, Xiang Cai, Yingfeng Sun, Xiaodong Zhu, Zhen Xu, Yiqiang

Energy management strategies determine how much energy is consumed by the engine and electric motor of plug-in hybrid electric buses (PHEBs), which represent critical fuel-saving technologies. In this study, a model predictive control (MPC) method with the estimation of distribution algorithm (EDA) as the solver is proposed to optimize the energy flow of PHEBs. Inspired by the recursive mechanism, short-term velocity prediction is achieved based on a Markov chain model with online updates to greatly improve prediction accuracy. Then, the energy-flow control problem of PHEBs is formulated as a discrete-time nonlinear optimization problem. Due to its strong nonlinear multivariable and constrained nature, the control algorithm is implemented by using MPC. To obtain an optimal solution efficiently, the EDA algorithm is incorporated into the MPC-based control framework, in which the Gaussian distribution is selected as a probabilistic model to characterize the candidate solutions and make full use of the statistical information extracted from the search experience. All performance verifications were conducted by theoretical simulation and hardware-in-the-loop. The verification results show that the proposed strategy can greatly improve the fuel economy and the shorten computational time over cycle-based driving.

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# An estimation of distribution algorithm with clustering for scenario-based robust financial optimization

Shi, Wen Hu, Xiao-Min Chen, Wei-Neng

One important problem in financial optimization is to search for robust investment plans that can maximize return while minimizing risk. The market environment, namely the scenario of the problem in optimization, always affects the return and risk of an investment plan. Those financial optimization problems that the performance of the investment plans largely depends on the scenarios are defined as scenario-based optimization problems. This kind of uncertainty is called scenario-based uncertainty. The consideration of scenario-based uncertainty in multi-objective optimization problem is a largely under explored domain. In this paper, a nondominated sorting estimation of distribution algorithm with clustering (NSEDA-C) is proposed to deal with scenario-based robust financial problems. A robust group insurance portfolio problem is taken as an instance to study the features of scenario-based robust financial problems. A simplified simulation method is applied to measure the return while an estimation model is devised to measure the risk. Applications of the NSEDA-C on the group insurance portfolio problem for real-world insurance products have validated the effectiveness of the proposed algorithm.

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# UAV path optimization with an integrated cost assessment model considering third-party risks in metropolitan environments

Pang, Bizhao Hu, Xinting Dai, Wei Low, Kin Huat

Various applications of unmanned aerial vehicles (UAVs) in urban environments facilitate our daily life and public services. However, UAV operations bring third party risk (TPR) issues, as UAV may crash to pedestrians and vehicles on the ground. It may also cause property damages to critical infrastructures and noise impacts to the public. Path planning is an effective method to mitigate these risks and impacts by avoiding high-risk areas before flight. However, most of the existing path planning methods focus on minimizing flight distance or energy cost, rarely considered risk cost. This paper develops a novel flight path optimization method that considers an integrated cost assessment model. The assessment model incorporates fatality risk, property damage risk, and noise impact, which is an extension of current TPR indicators at modeling and assessment levels. To solve the proposed integrated cost-based path optimization problem, a hybrid estimation of distribution algorithm (EDA) and CostA\* (named as EDA-CostA\*) algorithm is proposed, which provides both global and local heuristic information for path searching in cost-based environments. A downtown area in Singapore is selected for the case study. Simulation results demonstrate the effectiveness of the developed cost-based path optimization model in reducing the risk cost. The statistical analysis for 100 sampled environments also shows the reliability of the proposed method, which reduced the cost by [42.64%, 44.15%] at 95% confidence level.

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# Reliability evaluation of a composite power system in the presence of renewable generations

Firouzi, Mohsen Samimi, Abouzar Salami, Abolfazl

Power system reliability evaluation plays a vital role in the planning and operation studies by reflecting the system safety level. In this paper, a combination of a non-sequential Monte Carlo simulation (MCS)-based model and an improved Estimation of Distribution Algorithm (EDA) is exploited for evaluating the reliability of the composite power systems considering variability and uncertainty of wind farms (WFs) and Photovoltaic (PV) units. Variability of these resources is defined as the random fluctuation of wind speed and solar irradiation caused by changes in the atmosphere, while their uncertainty results from output power forecast errors. In the proposed model, the states of traditional generating units, transmission lines, WFs, and PV units are constructed using non-sequential MCS. These states can be achieved based on the component failure probability for dispatchable traditional generators and transmission lines along with the Probability Distribution Functions (PDFs) of renewable generations. To enhance the computational efficiency of the MCS in the sampling step, the improved EDA upgraded with the Population-Based Incremental Learning (PBIL) algorithm is employed. The proposed mathematical model for reliability evaluation of composite power system is applied to the IEEE RTS 24-bus system, and numerical studies are performed under several case studies. The simulation results confirm the proficiency of the proposed method to improve the computational efficiency, while the high accuracy of reliability evaluation of the composite power system is attained.

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# Combining a hybrid prediction strategy and a mutation strategy for dynamic multiobjective optimization

Chen, Ying Zou, Juan Liu, Yuan Yang, Shengxiang Zheng, Jinhua Huang, Weixiong

The environments of the dynamic multiobjective optimization problems (DMOPs), such as Pareto optimal front (POF) or Pareto optimal set (POS), usually frequently change with the evolution process. This kind of problem poses a higher challenge for evolutionary algorithms because it requires the population to quickly track (i.e., con -verge) to the position of a new environment and be widely distributed in the search space. The prediction-based response mechanism is a commonly used method to deal with environmental changes, but it's only suitable for predictable changes. Moreover, the imbalance of population diversity and convergence in the process of tracking the dynamically changing POF has aggravated. In this paper, we proposed a new change response mechanism that combines a hybrid prediction strategy and a precision controllable mutation strategy (HPPCM) to solve the DMOPs. Specifically, the hybrid prediction strategy coordinates the center point-based prediction and the guiding individual-based prediction to make accurate predictions. Thus, the population can quickly adapt to the predictable environmental changes. Additionally, the precision controllable mutation strategy handles un-predictable environmental changes. It improves the diversity exploration of the population by controlling the variation degree of solutions. In this way, our change response mechanism can adapt to various environmental changes of DMOPs, such as predictable and unpredictable changes. This paper integrates the HPPCM mecha-nism into a prevalent regularity model-based multiobjective estimation of distribution algorithm (RM-MEDA) to optimize DMOPs. The results of comparative experiments with some state-of-the-art algorithms on various test instances have demonstrated the effectiveness and competitiveness of the change response mechanism proposed in this paper.

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# A matrix cube-based estimation of distribution algorithm for the energy-efficient distributed assembly permutation flow-shop scheduling problem

Zhang, Zi-Qi Hu, Rong Qian, Bin Jin, Huai-Ping Wang, Ling Yang, Jian-Bo

In this paper, a matrix-cube-based estimation of distribution algorithm (MCEDA) is proposed to solve the energy-efficient distributed assembly permutation flow-shop scheduling problem (EE\_DAPFSP) that minimizes both the maximum completion time (C-max) and the total carbon emission (TCE) simultaneously. Firstly, a high-quality and diverse initial population is constructed via a hybrid initialization method. Secondly, a matrix-cube-based probabilistic model and its update mechanism are designed to appropriately accumulate the valuable pattern information from superior solutions. Thirdly, a suitable sampling strategy is developed to sample the probabilistic model to generate a new population per generation, so as to guide the search direction toward promising regions in solution space. Fourthly, a problem-dependent neighborhood search based on critical path is provided to perform an in-depth local search around the promising regions found by the global search. Fifthly, two types of speed adjustment strategies based on problem properties are also embedded to further improve the quality of the obtained solutions. Sixthly, the influence of the parameters is investigated based on the multi-factor analysis of variance of Design-of-Experiments. Finally, extensive experiments and comprehensive comparisons with several recent state-of-the-art multi-objective algorithms are carried out based on the well-known benchmark instances, and the statistical results demonstrate the efficiency and effectiveness of the proposed MCEDA in addressing the EE\_DAPFSP.

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# Competition-Driven Dandelion Algorithms With Historical Information Feedback

Han, Shoufei Zhu, Kun Zhou, MengChu

A Dandelion algorithm (DA) inspired by the seed dispersal process of dandelions has been proposed as a newly intelligent optimization algorithm. For improving its exploration ability as well as reducing the probability of its falling into a local optimum, this work proposes to add a novel competition mechanism with historical information feedback to current DA. Specifically, the fitness value of each dandelion in the next generation, which is calculated by linear prediction, is compared with the current best dandelion, and the loser is replaced by a new offspring. Current DA generates new offsprings without considering historical information. This work improves its offspring generation process by exploiting historical information with an estimation-of-distribution algorithm. Three historical information models are designed. They are best, worst, and hybrid historical information feedback models. The experimental results show that the proposed algorithms outperform DA and its variants, and the proposed algorithms are superior or competitive to nine participating algorithms benchmarked on 28 functions from CEC2013. Finally, the proposed algorithms demonstrate the effectiveness on four real-world problems, and the results indicate that the proposed algorithms have better performance than its peers.

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# Damage identification of single-layer cylindrical latticed shells based on the model updating technique

Xu, Ying Pan, Yongzhi Wang, Ying Deng, Dandan Han, Qinghua

Large-span spatial structures have closely spaced frequencies and complex vibration modes. The traditional methods based on static responses or dynamic parameters are difficult to identify the multi-damage locations and severities in large-span spatial structures. Moreover, with a large number of structural members and a limited number of sensors, finite element (FE) model updating is especially challenging for spatial structures. In this work, a structural damage identification (SDI) framework based on the estimation of distribution algorithm (EDA) is proposed and applied to the damage identification of a single-layer cylindrical latticed shell. Numerical simulations and laboratory tests are performed. The results demonstrate the effectiveness of the proposed damage identification algorithm. Only four accelerometer locations from 38 available points are used to identify the damage of the test structure with 83 members. The average identification accuracy using FE data reaches 90% by considering multiple damage conditions and noise interference. Based on the laboratory data, the average identification accuracy is over 82% considering different damage levels of a single member. The results demonstrate that the EDA-based framework can effectively improve the optimization process in the parameter identification problem, which is applicable to the damage identification of large-span spatial structures.

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# A novel hybrid recurrent convolutional network for surrogate modeling of history matching and uncertainty quantification

Ma, Xiaopeng Zhang, Kai Zhang, Jinding Wang, Yanzhong Zhang, Liming Liu, Piyang Yang, Yongfei Wang, Jian

Automatic history matching (AHM) has been widely studied in petroleum engineering due to it can provide reliable numerical models for reservoir development and management. However, AHM is still a challenging problem because it usually involves running a great deal of time-consuming numerical simulations during the solving process. To address this issue, this article studies a hybrid recurrent convolutional network (HRCN) model for surrogate modeling of numerical simulation used in AHM. The HRCN model is end-to-end trainable for predicting the well production data of high-dimensional parameter fields. In HRCN, a convolutional neural network (CNN) is first developed to learn the high-level spatial feature representations of the input parameter fields. Following that, a recurrent neural network (RNN) is constructed with the purpose of modeling complex temporal dynamics and predicting the production data. In addition, given that the fluctuations of production data are influenced by well control measures, the well control parameters are used as auxiliary inputs of RNN. Moreover, the proposed surrogate model is incorporated into a multimodal estimation of distribution algorithm (MEDA) to formulate a novel surrogate-based AHM workflow. The numerical studies performed on a 2D and a 3D reservoir model illustrate the performance of the proposed surrogate model and history matching workflow. Compared with the MEDA using only numerical simulations, the surrogate-based AHM workflow significantly reduces the computational cost.

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# Quantum Parametric Circuit Optimization with Estimation of Distribution Algorithms

Soloviev, Vicente P. Larranaga, Pedro Bielza, Concha

Variational quantum algorithms (VQAs) offer some promising characteristics for carrying out optimization tasks in noisy intermediate-scale quantum devices. These algorithms aim to minimize a cost function by optimizing the parameters of a quantum parametric circuit. Thus, the overall performance of these algorithms, heavily depends on the classical optimizer which sets the parameters. In the last years, some gradient-based and gradient-free approaches have been applied to optimize the parameters of the quantum circuit. In this work, we follow the second approach and propose the use of estimation of distribution algorithms for the parameter optimization in a specific case of VQAs, the quantum approximate optimization algorithm. Our results show an statistically significant improvement of the cost function minimization compared to traditional optimizers.

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# A Layered Learning Estimation of Distribution Algorithm

Li, Yong Yang, Qiang Gao, Xu-Dong Lu, Zhen-Yu Zhang, Jun

Though estimation of distribution algorithms (EDAs) have witnessed success in problem optimization, most of them suffer from sharp shrink of covariance, which may lead to premature convergence. To alleviate this issue, this paper proposes a layered learning estimation of distribution algorithm (LLEDA) by maintaining multiple probability distribution models. Specifically, LLEDA first separates the population into several layers based on fitness. Then, the mean position of each layer is computed. Subsequently, we let the estimated mean position in each lower layer randomly learn from the one of a randomly selected higher layer, so that the mean positions of lower layers could be promoted to be close to promising areas found in the current population. At last, the covariance of each layer is estimated based on the generated new mean position and the individuals in this layer. By this means, multiple probability models with high quality are maintained and then are used to sample promising and diversified offspring separately. Comparative experiments conducted on a widely used benchmark problem set demonstrate that the proposed LLEDA achieves competitive or even much better performance than several state-of-the-art and representative EDAs.

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# Introducing Generative adversarial networks on Estimation of distribution algorithm to solve permutation-based problems

Lemtenneche, Sami Cheriet, Abdelhakim Bensayah, Abdallah

As a subclass of evolutionary algorithms, estimation of distribution algorithms (EDAs) have found widespread use in a variety of optimization problems with impressive performance. In each generation, they build a probabilistic model representing the promising individuals, and the next generation constructs by sampling this model. Constructing and sampling the probabilistic model is a real challenge in developing such algorithms. Generative adversarial networks (GANs) are a popular kind of generative model that has been widely adopted due to their ability to generate new samples that closely match the distribution of training data. However, research on how GANs handle permutation spaces is lacking. We suggest a novel Estimation of Distribution Algorithm (EDA) that uses GANs as a probabilistic model estimator to advance this subject. in order to preserve the information captured from the selected individuals, those promising individuals were represented by a one-hot matrix, then used to train GANs. The proposed algorithm is tested to solve two permutation problems: The Travelling Salesman Problem (TSP) and Permutation Flowshop Scheduling Problem (PFSP). The Experimental results show that the proposed algorithm can obtain the optimal solution in some instances and a near-optimal in others.

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# Choosing the Right Algorithm With Hints From Complexity Theory (Hot-off-the-Press Track at GECCO 2022)

Wang, Shouda Zheng, Weijie Doerr, Benjamin

Choosing a suitable algorithm from the myriads of different search heuristics is difficult when faced with a novel optimization problem. In this work, we argue that the purely academic question of what could be the best possible algorithm in a certain broad class of black-box optimizers can give fruitful indications in which direction to search for good established optimization heuristics. We demonstrate this approach on the recently proposed DLB benchmark, for which the only known results are O (n(3)) runtimes for several classic evolutionary algorithms and an O (n(2) log n) runtime for an estimation-of-distribution algorithm. Our finding that the unary unbiased black-box complexity is only O (n(2)) suggests the Metropolis algorithm as an interesting candidate and we prove that it solves the DLB problem in quadratic time. Since we also prove that better runtimes cannot be obtained in the class of unary unbiased algorithms, we shift our attention to algorithms that use the information of more parents to generate new solutions. An artificial algorithm of this type having an O (n log n) runtime leads to the result that the significance-based compact genetic algorithm sig-cGA) can solve the DLB problem also in time O (n log n).

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# Evolving Robust Solutions to Uncertain Capacitated Arc Routing Problem with Time Window

Huang, Shuo Tian, Yinxi Duan, Xintong

The capacitated arc routing problem with time window has been studied for years, while uncertainties in real-world scenarios, such as uncertain demands and uncertain routing conditions, were rarely considered. In this paper, we formulate an uncertain capacitated arc routing problem with time window that takes into account the uncertain demand of tasks, the uncertain deadheading costs and the uncertain presence of tasks and paths. A number of problem instances are generated based on the benchmark instances of static capacitated arc routing problem with time window considering the aforementioned four uncertain factors. To tackle this new challenging problem, we adapt a state-of-the-art algorithm for solving uncertain capacitated arc routing problem, an estimation of distribution algorithm (EDA) with a stochastic local search, to find robust solutions. Another algorithm, a memetic algorithm with extended neighborhood search, is also adapted as a baseline solution algorithm to this challenging problems. Our experimental results indicate that our EDA-based algorithm is effective in finding robust solutions to uncertain capacitated arc routing problems with time window.

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# An Estimation of Distribution Algorithm for Puzzle Reconstruction Problem

Qin, Bin Tseng, Shih-Pang

Puzzle is a game to have a very long history for training the human logic thinking. In addition, the puzzle-solving methods can be used in various practical applications. In this paper, we proposed an EDA-based edge-matching puzzle solver. The proposed approach is based on the probability model. We have presented how to build the suitable probability model for puzzle solving. And we also provide the sampling method to construct a candidate solution. The experimental results show the proposed approach is available and effective.

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# A bi-level optimization method for integrated production scheduling between continuous casting and hot rolling processes

Tang, Wei Cao, Lingling Wen, Yaomin Jiang, Sheng-Long

To improve production efficiency and reduce energy costs in steel manufacturing, this paper investigates the integrated production scheduling problem between continuous casting and hot rolling (IPSP-CCHR) and formulates it as a bi-level optimization model. The upper-level one is the production planning match problem (PPMP) between continuous casting and hot rolling processes, which aims to maximize productivity. The lower-level one is the reheating furnace scheduling problem (RFSP), which aims to minimize the total residence time. Next, we propose a stratified sampling bi-level optimization (SSBLO) algorithm to solve the IPSP-CCHR, which applies Latin Hypercube sampling (LHS) for solving the upper-level problem and estimation of distribution algorithm (EDA) for solving the lower-level problem. In the experiments, computational results via well-synthetic data show the bi-level optimization model and the proposed algorithm is effective and is expected to apply in realistic industrial cases.

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# General Univariate Estimation-of-Distribution Algorithms

Doerr, Benjamin Dufay, Marc

We propose a general formulation of a univariate estimation-of-distribution algorithm (EDA). It naturally incorporates the three classic univariate EDAs compact genetic algorithm, univariate marginal distribution algorithm and population-based incremental learning as well as the max-min ant system with iteration-best update. Our unified description of the existing algorithms allows a unified analysis of these; we demonstrate this by providing an analysis of genetic drift that immediately gives the existing results proven separately for the four algorithms named above. Our general model also includes EDAs that are more efficient than the existing ones and these may not be difficult to find as we demonstrate for the ONEMAX and LEADINGONES benchmarks.

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# An EDA-based Genetic Algorithm for EV Charging Scheduling under Surge Demand

Li, Tianyang Li, Xiaolong He, Ting Zhang, Yufeng

With continually increased Electric Vehicles (EVs), the EVs Charging Scheduling is of great importance to managing multiple charging demands for maximizing user satisfactions and minimizing adverse influences on the grid. However, it is challenging to effectively manage EVs charging schedules when a large number of (on-the-move) EVs are planning to charge at the same time. With this concern, we focus on Charging Station (CS)-selection decision making by the global aggregator that is taken as controller to implement charging management for EVs and CSs. An Estimation of Distribution Algorithm (EDA)-based genetic algorithm is proposed to find constrained charging scheduling plans to maximize the charging efficiency, which may improve user satisfaction and alleviate impacts on the grid. Experimental results under a city scenario with realistic EVs and CSs show the advantage of our proposal, in terms of minimized queuing time and maximized charging performance at both the EV and CS sides. The code and data are available at https://github.com/EV-charging-scheduling-algorithm.

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# An improved Estimation of Distribution Algorithm for Solving Constrained Mixed-Integer Nonlinear Programming Problems

Molina Perez, Daniel Alfredo Portilla-Flores, Edgar Mezura-Montes, Efren Vega-Alvarado, Eduardo

In a mixed-integer nonlinear programming problem, integer restrictions divide the feasible region into discontinuous feasible parts with different sizes. Evolutionary Algorithms (EAs) are usually vulnerable to being trapped in larger discontinuous feasible parts. In this work, an improved version of an Estimation of Distribution Algorithm (EDA) is developed, where two new operations are proposed. The first one establishes a link between the learning-based histogram model and the s-constrained method. Here, the constraint violation level of the s-constrained method is used to explore the smaller discontinuous parts and form a better statistical model. The second operation is the hybridization of the EDA with a mutation operator to generate offspring from both the global distribution information and the parent information. A benchmark is used to test the performance of the improved proposal. The results indicated that the proposed approach shows a better performance against other tested EAs. This new proposal solves to a great extent the influence of the larger discontinuous feasible parts, and improve the local refinement of the real variables.

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# A Surrogate Model Assisted Estimation of Distribution Algorithm with Mutil-acquisition Functions for Expensive Optimization

Hao, Hao Wang, Shuai Li, Bingdong Zhou, Aimin

The estimation of distribution algorithm (EDA) is an efficient heuristic method for handling black-box optimization problems since the ability for global population distribution modeling and gradient-free searching. However, the trial and error search mechanism relies on a large number of function evaluations, which is a considerable challenge under expensive black-box problems. Therefore, this article presents a surrogate assisted EDA with multi-acquisition functions. Firstly, a variable-width histogram is used as the global distribution model that focuses on promising areas. Next, the evaluated-free local search method improves the quality of new generation solutions. Finally, model management with multiple acquisitions maintains global and local exploration preferences. Several commonly used benchmark functions with 20 and 50 dimensions are adopted to evaluate the proposed algorithm compared with several state-of-the-art surrogate assisted evaluation algorithms (SAEAs) and Bayesian optimization method. In addition, a rover trajectories optimizing problem is used to verify the ability to solve complex problems. The experimental results demonstrate the superiority of the proposed algorithm over these comparison algorithms.

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# Combining Soft-Actor Critic with Cross-Entropy Method for Policy Search in Continuous Control

Hieu Trung Nguyen Khang Tran Ngoc Hoang Luong

In this paper, we propose CEM-SAC - a hybridization between the cross-entropy method (CEM), i.e., an estimation-of-distribution algorithm, and the soft-actor critic (SAC), i.e., a state-of-the-art policy gradient algorithm. Our work extends the evolutionary reinforcement learning (ERL) line of research on integrating the robustness of population-based stochastic black-box optimization, that typically assumes little to no problem-specific knowledge, into the training process of policy gradient algorithms, that exploits the sequential decision making nature for efficient gradient estimation. Our hybrid approach, CEM-SAC, exhibits both the stability of CEM and the efficiency of SAC in training policy neural networks of reinforcement learning agents for solving control problems. Experimental result comparisons with the three baselines CEM, SAC, and CEM-TD3, a recently-introduced ERL method that combines CEM and the twin-delayed deep deterministic policy gradient (TD3) algorithm, on a wide range of control tasks in the MuJoCo benchmarks confirm the enhanced performance of our proposed CEM-SAC. The source code is available at https://github.com/ELO-Lab/CEM-SAC.

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# The Compact Genetic Algorithm Struggles on Cliff Functions

Neumann, Frank Sudholt, Dirk Witt, Carsten

The compact genetic algorithm (cGA) is a non-elitist estimation of distribution algorithm which has shown to be able to deal with difficult multimodal fitness landscapes that are hard to solve by elitist algorithms. In this paper, we investigate the cGA on the Cliff function for which it has been shown recently that non-elitist evolutionary algorithms and artificial immune systems optimize it in expected polynomial time. We point out that the cGA faces major difficulties when solving the Cliff function and investigate its dynamics both experimentally and theoretically around the Cliff. Our experimental results indicate that the cGA requires exponential time for all values of the update strength... We show theoretically that, under sensible assumptions, there is a negative drift when sampling around the location of the cliff. Experiments further suggest that there is a phase transition for.. where the expected optimization time drops from n Theta((n)) to 2 Theta((n)).

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# The Asteroid Routing Problem: A Benchmark for Expensive Black-Box Permutation Optimization

Lopez-Ibanez, Manuel Chicano, Francisco Gil-Merino, Rodrigo

Inspired by the recent 11th Global Trajectory Optimisation Competition, this paper presents the asteroid routing problem (ARP) as a realistic benchmark of algorithms for expensive bound-constrained black-box optimization in permutation space. Given a set of asteroids' orbits and a departure epoch, the goal of the ARP is to find the optimal sequence for visiting the asteroids, starting from Earth's orbit, in order to minimize both the cost, measured as the sum of the magnitude of velocity changes required to complete the trip, and the time, measured as the time elapsed from the departure epoch until visiting the last asteroid. We provide open-source code for generating instances of arbitrary sizes and evaluating solutions to the problem. As a preliminary analysis, we compare the results of two methods for expensive blackbox optimization in permutation spaces, namely, Combinatorial Efficient Global Optimization (CEGO), a Bayesian optimizer based on Gaussian processes, and Unbalanced Mallows Model (UMM), an estimation-of-distribution algorithm based on probabilistic Mallows models. We investigate the best permutation representation for each algorithm, either rank-based or order-based. Moreover, we analyze the effect of providing a good initial solution, generated by a greedy nearest neighbor heuristic, on the performance of the algorithms. The results suggest directions for improvements in the algorithms being compared.

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# A Radial Estimation-of-Distribution Algorithm for the Job-Shop Scheduling Problem

Perez-Rodriguez, Ricardo

The job-shop environment has been widely studied under different approaches. Its practical characteristics make its research interesting. Therefore, the job-shop scheduling problem continues being attractive in developing new evolutionary algorithms. In this paper, the authors propose a new estimation of distribution algorithm coupled with a radial probability function. The aforementioned radial function comes from the hydrogen element. This approach is proposed in order to build a competitive evolutionary algorithm for the job-shop scheduling problem. The key point is to exploit the radial probability distribution to construct offspring and to tackle the inconvenient of the EDAs (i.e., lack of diversity of the solutions and poor ability of exploitation). Various instances and numerical experiments are presented to illustrate and to validate this novel research. The results, obtained from this research, permit the conclusion that using radial probability distributions is an emerging field to develop new and efficient EDAs.

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# Data-Enabled Reactive Power Control of Distributed Energy Resources via a Copula Estimation of Distribution Algorithm

Van der Meer, Dennis Haghi, Hamed Valizadeh Kleissl, Jan Widen, Joakim

The increase in the number of distributed energy resources (DERs) in the low-voltage grid causes reverse active power flow, which induces voltage regulation issues across the feeder. We employ the parameter-free copula estimation of distribution algorithm (EDA) that optimally controls the reactive power of DERs to minimize voltage deviations. EDAs iteratively learn from data and sample an explicit probability distribution that models the dependencies between variables, allowing for a more effective exploration of the optimal solution space with fewer iterations. A copula offers additional flexibility, since the dependence structure between the decision variables and the marginal distributions can be modeled independently. The effectiveness of the proposed method is illustrated on a modified IEEE 123 node test feeder with 10 smart photovoltaic inverters. The results show that the proposed method achieves improved voltage profiles and offers many opportunities for further adaptability.

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# Multi-Objective Deep Network-Based Estimation of Distribution Algorithm for Music Composition

Jeong, Jae-Hun Lee, Eunbin Lee, Jong-Hyun Ahn, Chang Wook

In the field of evolutionary algorithm music composition, most of the current researches focus on how to enhance environmental selection based on multi-objective evolutionary algorithms (MOEAs). However, the real music composition process defined as large-scale multi-optimization problems (LSMOP) involve the number of combinations, and the existing MOEA-based optimization process can be challenging to effectively explore the search space. To address this issue, we propose a new Multi-Objective Generative Deep network-based Estimation of Distribution Algorithm (MODEDA) based on dimensionality reduction in decision space. In order to alleviate the difficulties with dimensional transformation, we propose a novel solution search method that optimizes in the transformed space and ensures consistency between the pareto sets of the original problem. The proposed algorithm is tested on the knapsack problems and music composition experiments. The experimental results have demonstrated that the proposed algorithm has excellency in terms of its optimization performance and computational efficiency in LSMOP.

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# A hybrid imperialist competitive algorithm for the outpatient scheduling problem with switching and preparation times

Yu, Hui Li, Jun-qing Chen, Xiao-Long Zhang, Wei-meng

During recent years, the outpatient scheduling problem has attracted much attention from both academic and medical fields. This paper considers the outpatient scheduling problem as an extension of the flexible job shop scheduling problem (FJSP), where each patient is considered as one job. Two realistic constraints, i.e., switching and preparation times of patients are considered simultaneously. To solve the outpatient scheduling problem, a hybrid imperialist competitive algorithm (HICA) is proposed. In the proposed algorithm, first, the mutation strategy with different mutation probabilities is utilized to generate feasible and efficient solutions. Then, the diversified assimilation strategy is developed. The enhanced global search heuristic, which includes the simulated annealing (SA) algorithm and estimation of distribution algorithm (EDA), is adopted in the assimilation strategy to improve the global search ability of the algorithm. Moreover, four kinds of neighborhood search strategies are introduced to generate new promising solutions. Finally, the empires invasion strategy is proposed to increase the diversity of the population. To verify the performance of the proposed HICA, four efficient algorithms, including imperialist competitive algorithm, improved genetic algorithm, EDA, and modified artificial immune algorithm, are selected for detailed comparisons. The simulation results confirm that the proposed algorithm can solve the outpatient scheduling problem with high efficiency.

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# Optimization Techniques and Formal Verification for the Software Design of Boolean Algebra Based Safety-Critical Systems

Perez, Jon Flores, Jose Luis Blum, Christian Cerquides, Jesus Abuin, Alex

Artificial intelligence, and the ability to learn optimized solutions that comply with a set of safety rules, could facilitate the human-based design process of safety-critical systems. However, the reconciliation of state-of-the-art artificial intelligence technology with current safety standards and safety engineering processes is a challenge to be addressed. In this article, this publication describes a method based on optimization and on formal verification for the design of safety-critical systems that are defined by Boolean algebra. Several diverse optimization techniques and a hybrid of these approaches are used to find an optimized design that considers performance requirements, availability rules, and complies with all defined safety rules. Subsequently, this solution is translated into an alternative knowledge representation that can be formally verified and developed in compliance with currently considered safety standards. This method is evaluated with a simplified safety-critical case study.

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# A Coevolutionary Estimation of Distribution Algorithm for Group Insurance Portfolio

Shi, Wen Chen, Wei-Neng Kwong, Sam Zhang, Jie Wang, Hua Gu, Tianlong Yuan, Huaqiang Zhang, Jun

With the rapid development of the insurance industry, more diverse insurance products are produced for consumers. Insurance portfolio problems have received increasing attention. While most studies focus on insurance portfolio problem for a single insured, insurance portfolio problems for a specific group of insured are even more intricate but little attention has been paid to. In this article, we propose a group insurance portfolio model for investment allocation of several insurance policies so that the total payout of the whole group can be maximized. The statistical average value of each parameter is considered in the model to approximate the expectation payout of the group insurance portfolio problem. To solve this problem, a coevolutionary estimation of distribution algorithm (EDA) utilizing the divide-and-conquer strategy is proposed. First, as the payout of each insured under a certain portfolio plan can be calculated separately, the proposed approach decomposes the group insurance portfolio problem into several single-insured insurance portfolio problems. In this way, the dimension of the optimization problem becomes lower compared to the original problem. An adaptive EDA is proposed to optimize the portfolio plan of each insured independently. Second, the group insurance portfolio problem remains a nonseparable problem since the investment amount of each insured is limited by the total investable amount of the whole group. A particle swarm optimization algorithm is adopted to cooperate with the EDA to optimize the proportion of allocation to each insured. The proposed algorithm is verified on various scenarios. The experimental results validate that the proposed approach is effective for the group insurance portfolio problem.

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# Probabilistic calibration and short-term prediction of the prevalence herpes simplex type 2: A transmission dynamics modelling approach

Cortes, Juan-Carlos Martinez-Rodriguez, Pablo Morano, Jose-Antonio Romero, Jose-Vicente Rosello, Maria-Dolores Villanueva, Rafael-Jacinto

An epidemiological model is proposed to study the transmission dynamics of the herpes virus type 2, a sexually transmitted infectious disease. This model considers two states, susceptible and infected, divides the population into sexes, assumes only heterosexual contacts and includes different transmission rates depending on whether the transmission is woman-man or man-woman. Reported and prevalence series data are retrieved from several sources. We consider the inherent data survey errors and the sensitivity of the diagnosis tests (data uncertainty). To calibrate the model to the available data and their uncertainty, a novel technique is proposed in two steps: (1) the application of the estimation of distribution algorithm (EDA) to find sets of model parameter values close to the data uncertainty and (2) the application of a selection algorithm to get a reduced number of model parameter values whose model outputs capture accurately the data uncertainty. Then, we check its robustness, and we provide a prediction of the evolution of the infected over the next 4 years. From the technical point of view, we conclude that the proposed technique to calibrate probabilistically the model is reliable and robust. Also, it is able to provide confidence intervals for the model parameter values and the predictions. From the medical point of view, the model returns that the transmission woman-man is higher than the man-woman, according to recent literature, and there is a mild increasing trend in the number of infected people over the next years.

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# Vine copula-based EDA for dynamic multiobjective optimization

Cheriet, Abdelhakim

Dynamic Multiobjective Problems cover a set of real-world problems that have many conflicting objectives. These problems are challenging and well known by the dynamic nature of their objective functions, constraint functions, and problem parameters which often change over time. In fact, dealing with these problems has not been investigated in detail using the Estimation of Distribution Algorithms (EDAs). Thus, we propose in this paper an EDA-based on Vine Copulas algorithm to deal with Dynamic Multiobjective Problems (DMOPs). Vines Copulas are graphical models that represent multivariate dependence using bivariate copulas. The proposed Copula-based Estimation of Distribution Algorithm, labeled Dynamic Vine-Copula Estimation of Distribution Algorithm (DynVC-EDA), is used to implement two search strategies. The first strategy is an algorithm that uses the model as a memory to save the status of the best solutions obtained during the current generation. The second strategy is a prediction-based algorithm that uses the history of the best solutions to predict a new population when a change occurs. The proposed algorithms are tested using a set of benchmarks provided with CEC2015 and the Gee-Tan-Abbass. Statistical findings show that the DynVC-EDA is competitive to the state-of-the-art methods in dealing with dynamic multiobjective optimization.

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# A General Variable Neighborhood Search approach based on a p-median model for cellular manufacturing problems

Ibrahim, Saber Jarboui, Bassem

One of the practical application in cellular manufacturing systems is the cell formation problem (CFP). Its main idea is to group machines into cells and parts into part families in a way that the number of exceptional elements and the number of voids are minimized. In literature, it is proved that p-median is an efficient mathematical programming model for solving CF problems. In the present work, we develop a modified p-median based model dedicated to solve CFP respecting the objective of minimizing the sum of dissimilarities of machines. For this aim, we applied a General Variable Neighborhood Search algorithm and we collaborated it with an Estimation of Distribution Algorithm maximizing the group capability index and the grouping efficacy evaluation criteria. Thirty CF problems are taken from the literature and tested by our proposed algorithm and the experimental study demonstrated that the proposed method guided by p-median model provides high quality cells in speed running times and beats other state-of-the-art algorithms particularly for CF instances with large sizes.

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# Multiobjective meta-heuristic with iterative parameter distribution estimation for aeroelastic design of an aircraft wing

Wansasueb, Kittinan Pholdee, Nantiwat Panagant, Natee Bureerat, Sujin

This paper proposes a new self-adaptive meta-heuristic (MH) algorithm for multiobjective optimisation. The adaptation is accomplished by means of estimation of distribution. The differential evolution reproduction strategy is modified and used in this dominance-based multiobjective optimiser whereas population-based incremental learning is used to estimate the control parameters. The new method is employed to solve aeroelastic multiobjective optimisation of an aircraft wing which optimises structural weight and flutter speed. Design variables in the aeroelastic design problem include thicknesses of ribs, spars and composite layers. Also, the ply orientation of the upper and lower composite skins are assigned as the design variables. Additional benchmark test problems are also use to validate the search performance of the proposed algorithm. The performance validation reveals that the proposed optimiser is among the state-of-the-art multiobjective meta-heuristics. The concept of using estimation of distribution algorithm for tuning meta-heuristic control parameters is efficient and effective and becomes a new direction for improving MH performance.

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# An inverse model-based multiobjective estimation of distribution algorithm using Random-Forest variable importance methods

Gholamnezhad, Pezhman Broumandnia, Ali Seydi, Vahid

Most existing methods of multiobjective estimation of distributed algorithms apply the estimation of distribution of the Pareto-solution on the decision space during the search and little work has proposed on making a regression-model for representing the final solution set. Some inverse-model-based approaches were reported, such as inversed-model of multiobjective evolutionary algorithm (IM-MOEA), where an inverse functional mapping from Pareto-Front to Pareto-solution is constructed on nondominated solutions based on Gaussian process and random grouping technique. But some of the effective inverse models, during this process, may be removed. This paper proposes an inversed-model based on random forest framework. The main idea is to apply the process of random forest variable importance that determines some of the best assignment of decision variables (x(n)) to objective functions (f(m)) for constructing Gaussian process in inversed-models that map all nondominated solutions from the objective space to the decision space. In this work, three approaches have been used: classical permutation, Naive testing approach, and novel permutation variable importance. The proposed algorithm has been tested on the benchmark test suite for evolutionary algorithms [modified Deb K, Thiele L, Laumanns M, Zitzler E (DTLZ) and Walking Fish Group (WFG)] and indicates that the proposed method is a competitive and promising approach.

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