# An Adaptive Covariance Scaling Estimation of Distribution Algorithm

Yang, Qiang Li, Yong Gao, Xu-Dong Ma, Yuan-Yuan Lu, Zhen-Yu Jeon, Sang-Woon Zhang, Jun

Optimization problems are ubiquitous in every field, and they are becoming more and more complex, which greatly challenges the effectiveness of existing optimization methods. To solve the increasingly complicated optimization problems with high effectiveness, this paper proposes an adaptive covariance scaling estimation of distribution algorithm (ACSEDA) based on the Gaussian distribution model. Unlike traditional EDAs, which estimate the covariance and the mean vector, based on the same selected promising individuals, ACSEDA calculates the covariance according to an enlarged number of promising individuals (compared with those for the mean vector). To alleviate the sensitivity of the parameters in promising individual selections, this paper further devises an adaptive promising individual selection strategy for the estimation of the mean vector and an adaptive covariance scaling strategy for the covariance estimation. These two adaptive strategies dynamically adjust the associated numbers of promising individuals as the evolution continues. In addition, we further devise a cross-generation individual selection strategy for the parent population, used to estimate the probability distribution by combing the sampled offspring in the last generation and the one in the current generation. With the above mechanisms, ACSEDA is expected to compromise intensification and diversification of the search process to explore and exploit the solution space and thus could achieve promising performance. To verify the effectiveness of ACSEDA, extensive experiments are conducted on 30 widely used benchmark optimization problems with different dimension sizes. Experimental results demonstrate that the proposed ACSEDA presents significant superiority to several state-of-the-art EDA variants, and it preserves good scalability in solving optimization problems.

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# The Univariate Marginal Distribution Algorithm Copes Well with Deception and Epistasis

Doerr, Benjamin Krejca, Martin S.

In their recent work, Lehre and Nguyen (2019) show that the univariate marginal distribution algorithm (UMDA) needs time exponential in the parent populations size to optimize the DeceptiveLeadingBlocks (DLB) problem. They conclude from this result that univariate EDAs have difficulties with deception and epistasis. In this work, we show that this negative finding is caused by the choice of the parameters of the UMDA. When the population sizes are chosen large enough to prevent genetic drift, then the UMDA optimizes the DLB problem with high probability with at most lambda(n/2+2e ln n) fitness evaluations. Since an offspring population size lambda of order nlogn can prevent genetic drift, the UMDA can solve the DLB problem with O(n(2) log n) fitness evaluations. In contrast, for classic evolutionary algorithms no better runtime guarantee than O(n(3)) is known (which we prove to be tight for the (1+1) EA), so our result rather suggests that the UMDA can cope well with deception and epistatis. From a broader perspective, our result shows that the UMDA can cope better with local optima than many classic evolutionary algorithms; such a result was previously known only for the compact genetic algorithm. Together with the lower bound of Lehre and Nguyen, our result for the first time rigorously proves that running EDAs in the regime with genetic drift can lead to drastic performance losses.

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# Acceleration Control Design of HEVs with Comfortability Evaluation based on IRL

Narita, Shohei Zhang, Jiangyan Zhang, Weidong Shen, Tielong

For passenger cars, comfortability is an important issue to consider in powertrain control. However, it is not easy to take comfortability into account when designing a powertrain control strategy because of its subjective nature and difficulty in being quantified. This paper presents a solution by using the inverse reinforcement learning (IRL) method. An acceleration scenario of a hybrid electric powertrain is considered to show this design approach. With a sample acceleration profile scored by an expert evaluating module, a reward function is obtained by training an extreme learning machine. Using the analytical representation of comfortability, an estimation of distribution algorithm (EDA) is used to seek the optimal acceleration reference. Given the reference acceleration signal, the control law for the electric motors that provide power assistance during the acceleration phase is obtained by solving a optimal tracking control problem. A numerical example is shown to evaluate the design approach. Copyright (C) 2021 The Authors.

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# Maximizing Lifetime of Range-Adjustable Wireless Sensor Networks: A Neighborhood-Based Estimation of Distribution Algorithm

Chen, Zong-Gan Lin, Ying Gong, Yue-Jiao Zhan, Zhi-Hui Zhang, Jun

Sensor activity scheduling is critical for prolonging the lifetime of wireless sensor networks (WSNs). However, most existing methods assume sensors to have one fixed sensing range. Prevalence of sensors with adjustable sensing ranges posts two new challenges to the topic: 1) expanded search space, due to the rise in the number of possible activation modes and 2) more complex energy allocation, as the sensors differ in the energy consumption rate when using different sensing ranges. These two challenges make it hard to directly solve the lifetime maximization problem of WSNs with range-adjustable sensors (LM-RASs). This article proposes a neighborhood-based estimation of distribution algorithm (NEDA) to address it in a recursive manner. In NEDA, each individual represents a coverage scheme in which the sensors are selectively activated to monitor all the targets. A linear programming (LP) model is built to assign activation time to the schemes in the population so that their sum, the network lifetime, can be maximized conditioned on the current population. Using the activation time derived from LP as individual fitness, the NEDA is driven to seek coverage schemes promising for prolonging the network lifetime. The network lifetime is thus optimized by repeating the steps of the coverage scheme evolution and LP model solving. To encourage the search for diverse coverage schemes, a neighborhood sampling strategy is introduced. Besides, a heuristic repair strategy is designed to fine-tune the existing schemes for further improving the search efficiency. Experimental results on WSNs of different scales show that NEDA outperforms state-of-the-art approaches. It is also expected that NEDA can serve as a potential framework for solving other flexible LP problems that share the same structure with LM-RAS.

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# Surrogate-assisted cooperative signal optimization for large-scale traffic networks

Liang, Yongsheng Ren, Zhigang Wang, Lin Liu, Hanqing Du, Wenhao

Reasonable setting of traffic signals can be very helpful in alleviating congestion in urban traffic networks. Meta-heuristic optimization algorithms have proved themselves to be able to find high quality signal timing plans. However, they generally suffer from performance deterioration when solving large-scale traffic signal optimization problems due to the huge search space and limited computational budget. Directing against this issue, this study proposes a surrogate-assisted cooperative signal optimization (SCSO) method. Different from existing methods that directly deal with the entire traffic network, SCSO first decomposes it into a set of tractable sub-networks, and then achieves signal setting by cooperatively optimizing these sub-networks with a surrogate-assisted optimizer. The decomposition operation significantly narrows the search space of the whole traffic network, and the surrogate-assisted optimizer greatly lowers the computational burden by reducing the number of expensive traffic simulations. By taking Newman fast algorithm, radial basis function and a modified estimation of distribution algorithm as decomposer, surrogate model and optimizer, respectively, this study develops a concrete SCSO algorithm. To evaluate its effectiveness and efficiency, a large-scale traffic network involving crossroads and T-junctions is generated based on a real traffic network. Comparison with several existing meta-heuristic algorithms specially designed for traffic signal optimization demonstrates the superiority of SCSO in reducing the average delay time of vehicles. (c) 2021 Elsevier B.V. All rights reserved.

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# ~~Surrogate-Assisted Hybrid-Model Estimation of Distribution Algorithm for Mixed-Variable Hyperparameters Optimization in Convolutional Neural Networks~~

~~Li, Jian-Yu Zhan, Zhi-Hui Xu, Jin Kwong, Sam Zhang, Jun~~

~~The performance of a convolutional neural network (CNN) heavily depends on its hyperparameters. However, finding a suitable hyperparameters configuration is difficult, challenging, and computationally expensive due to three issues, which are 1) the mixed-variable problem of different types of hyperparameters; 2) the large-scale search space of finding optimal hyperparameters; and 3) the expensive computational cost for evaluating candidate hyperparameters configuration. Therefore, this article focuses on these three issues and proposes a novel estimation of distribution algorithm (EDA) for efficient hyperparameters optimization, with three major contributions in the algorithm design. First, a hybrid-model EDA is proposed to efficiently deal with the mixed-variable difficulty. The proposed algorithm uses a mixed-variable encoding scheme to encode the mixed-variable hyperparameters and adopts an adaptive hybrid-model learning (AHL) strategy to efficiently optimize the mixed-variables. Second, an orthogonal initialization (OI) strategy is proposed to efficiently deal with the challenge of large-scale search space. Third, a surrogate-assisted multi-level evaluation (SME) method is proposed to reduce the expensive computational cost. Based on the above, the proposed algorithm is named surrogate-assisted hybrid-model EDA (SHEDA). For experimental studies, the proposed SHEDA is verified on widely used classification benchmark problems, and is compared with various state-of-the-art methods. Moreover, a case study on aortic dissection (AD) diagnosis is carried out to evaluate its performance. Experimental results show that the proposed SHEDA is very effective and efficient for hyperparameters optimization, which can find a satisfactory hyperparameters configuration for the CIFAR10, CIFAR100, and AD diagnosis with only 0.58, 0.97, and 1.18 GPU days, respectively.~~

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# A Hybrid Estimation of Distribution Algorithm for the Quay Crane Scheduling Problem

Perez-Rodriguez, Ricardo

The aim of the quay crane scheduling problem (QCSP) is to identify the best sequence of discharging and loading operations for a set of quay cranes. This problem is solved with a new hybrid estimation of distribution algorithm (EDA). The approach is proposed to tackle the drawbacks of the EDAs, i.e., the lack of diversity of solutions and poor ability of exploitation. The hybridization approach, used in this investigation, uses a distance based ranking model and the moth-flame algorithm. The distance based ranking model is in charge of modelling the solution space distribution, through an exponential function, by measuring the distance between solutions; meanwhile, the heuristic moth-flame determines who would be the offspring, with a spiral function that identifies the new locations for the new solutions. Based on the results, the proposed scheme, called QCEDA, works to enhance the performance of those other EDAs that use complex probability models. The dispersion results of the QCEDA scheme are less than the other algorithms used in the comparison section. This means that the solutions found by the QCEDA are more concentrated around the best value than other algorithms, i.e., the average of the solutions of the QCEDA converges better than other approaches to the best found value. Finally, as a conclusion, the hybrid EDAs have a better performance, or equal in effectiveness, than the so called pure EDAs.

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# Differential Evolution with Estimation of Distribution for Worst-Case Scenario Optimization

Antoniou, Margarita Papa, Gregor

Worst-case scenario optimization deals with the minimization of the maximum output in all scenarios of a problem, and it is usually formulated as a min-max problem. Employing nested evolutionary algorithms to solve the problem requires numerous function evaluations. This work proposes a differential evolution with an estimation of distribution algorithm. The algorithm has a nested form, where a differential evolution is applied for both the design and scenario space optimization. To reduce the computational cost, we estimate the distribution of the best worst solution for the best solutions found so far. The probabilistic model is used to sample part of the initial population of the scenario space differential evolution, using a priori knowledge of the previous generations. The method is compared with a state-of-the-art algorithm on both benchmark problems and an engineering application, and the related results are reported.

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# A two-stage approach for multicast-oriented virtual network function placement

Wang, Xinhan Xing, Huanlai Zhan, Dawei Luo, Shouxi Dai, Penglin Iqbal, Muhammad Azhar

Network function virtualization (NFV) is an emerging network paradigm that decouples softwarized network functions from proprietary hardware. Nowadays, resource allocation has become one of the hot topics in the NFV domain. In this paper, we formulate a service function chain (SFC) mapping problem in the context of multicast, which is also referred to as the multicast-oriented virtual network function placement (MVNFP) problem. The objective function considers end-to-end delay as well as compute resource consumption, with bandwidth requirements met. A two-stage approach is proposed to address this problem. In the first stage, Dijkstra's algorithm is adopted to construct a multicast tree. In the second stage, a novel estimation of distribution algorithm (nEDA) is developed to map a given SFC over the multicast tree. Simulation results show that the proposed two-stage approach outperforms a number of state-of-the-art evolutionary, approximation, and heuristic algorithms, in terms of the solution quality. (C) 2021 Elsevier B.V. All rights reserved.

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# Solving slot allocation problem with multiple ATFM measures by using enhanced meta-heuristic algorithm

Tian, Jing Hao, Xinchang Huang, Jibo Huang, Jinglei Gen, Mitsuo

In Air Traffic Flow Management (ATFM), one key issue is to determine the Calculated Take Off Time (CTOT) for each flight. Due to the limited slot time resources, one single flight's slot decision could be influenced by plenty of other flights.

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# Solving dynamic multi-objective problems with a new prediction-based optimization algorithm

Zhang, Qingyang Jiang, Shouyong Yang, Shengxiang Song, Hui

This paper proposes a new dynamic multi-objective optimization algorithm by integrating a new fitting-based prediction (FBP) mechanism with regularity model-based multi-objective estimation of distribution algorithm (RM-MEDA) for multi-objective optimization in changing environments. The prediction-based reaction mechanism aims to generate high-quality population when changes occur, which includes three subpopulations for tracking the moving Pareto-optimal set effectively. The first subpopulation is created by a simple linear prediction model with two different stepsizes. The second subpopulation consists of some new sampling individuals generated by the fitting-based prediction strategy. The third subpopulation is created by employing a recent sampling strategy, generating some effective search individuals for improving population convergence and diversity. Experimental results on a set of benchmark functions with a variety of different dynamic characteristics and difficulties illustrate that the proposed algorithm has competitive effectiveness compared with some state-of-the-art algorithms.

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# GA-EDA: Hybrid Design Space Exploration Engine for Multicore Architecture

Waris, Hira Ahmad, Ayaz Qadri, Muhammad Yasir Raja, Gulistan Malik, Tahir Nadeem

Emergence of modern multicore architectures has made runtime reconfiguration of system resources possible. All reconfigurable system resources constitute a design space and the proper selection of configuration of these resources to improve the system performance is known as Design Space Exploration (DSE). This reconfiguration feature helps in appropriate allocation of system resources to improve the efficiency in terms of performance, energy consumption, throughput, etc. Different techniques like exhaustive search of design space, architect's experience, etc. are used for optimization of system resources to achieve desired goals. In this work, we hybridized two optimization algorithms, i.e., Genetic Algorithm (GA) and Estimation of Distribution Algorithm (EDA) for DSE of computer architecture. This hybrid algorithm achieved optimal balance between two objectives (minimal energy consumption and maximal throughput) by using decision variables such as number of cores, cache size and operating frequency. The final set of optimal solutions proposed by this GA-EDA hybrid algorithm is explored and verified by running different benchmark applications derived from SPLASH-2 benchmark suite on a cycle level simulator. The significant reduction in energy consumption without extensive impact on throughput in simulation results validate the use of this GA-EDA hybrid algorithm for DSE of multicore architecture. Moreover, the simulation results are compared with that of standalone GA, EDA and fuzzy logic to show the efficiency of GA-EDA hybrid algorithm.

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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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# Using Markov Chain Based Estimation of Distribution Algorithm for Model-Based Safety Analysis of Graph Transformation

Pira, Einollah

The ability to assess the reliability of safety-critical systems is one of the most crucial requirements in the design of modern safety-critical systems where even a minor failure can result in loss of life or irreparable damage to the environment. Model checking is an automatic technique that verifies or refutes system properties by exploring all reachable states (state space) of a model. In large and complex systems, it is probable that the state space explosion problem occurs. In exploring the state space of systems modeled by graph transformations, the rule applied on the current state specifies the rule that can perform on the next state. In other words, the allowed rule on the current state depends only on the applied rule on the previous state, not the ones on earlier states. This fact motivates us to use a Markov chain (MC) to capture this type of dependencies and applies the Estimation of Distribution Algorithm (EDA) to improve the quality of the MC. EDA is an evolutionary algorithm directing the search for the optimal solution by learning and sampling probabilistic models through the best individuals of a population at each generation. To show the effectiveness of the proposed approach, we implement it in GROOVE, an open source toolset for designing and model checking graph transformation systems. Experimental results confirm that the proposed approach has a high speed and accuracy in comparison with the existing meta-heuristic and evolutionary techniques in safety analysis of systems specified formally through graph transformations.

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# An Estimation of Distribution Algorithm With Filtering and Learning

Tang, Lixin Song, Xiangman Liu, Jiyin Liu, Chang

Estimation of distribution algorithm (EDA) is an efficient population-based stochastic search technique. Since it was proposed, many attempts have been made to improve its performance in the context of nonlinear continuous optimization. However, the success of EDA depends on the accuracy of modeling, the effectiveness of sampling, and the ability of exploration. An effective EDA often needs to take some measures to adjust the model and to guide sampling. In this article, we propose a novel EDA which applies the idea of Kalman filtering to revise the modeling data and a learning strategy to improve sampling. The filtering scheme modifies the modeling data set using an estimation error matrix based on historic solution data. During the sampling process, the learning strategy determines the region to sample next based on the sampling outcomes so far, instead of completely random sampling. The proposed EDA also employs a multivariate probabilistic model based on copula function and can quickly reach the promising area in which the optimal solution is likely to be located. A collection of general benchmark functions are used to test the performance of the proposed algorithm. Computational experiments show that the EDA is effective. Note to Practitioners-In many process industries, there exist black-box operation optimization problems and large-scale nonlinear optimization problems with variable coupling. For these problems, it is difficult to establish mechanism models between input and output. However, real-time data can be measured from the system through sensors. We can utilize this process information to optimize the system so as to attain the desired objective. In this article, we propose a novel estimation of distribution algorithm (EDA) which applies a filtering scheme to revise the modeling data and a learning strategy to improve sampling, which can solve the problems with the characteristics of nonlinearity, variable coupling, and large scale. Computational experiments show that the EDA is effective. In the future, the proposed algorithm can be applied to some practical optimization problems such as operation optimization in blast furnace, which is considered as a continuous production process with variable coupling. The algorithm has the potential to help optimizing the process control parameters.

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# A path relinking enhanced estimation of distribution algorithm for direct acyclic graph task scheduling problem

Wu, Chu-ge Wang, Ling Wang, Jing-jing

Superior task scheduling scheme is able to improve the performance in achieving shorter task completion time in multi-processor computing system. Large scale applications are generally modelled as direct acyclic graph (DAG) to be processed efficiently in parallel. To solve DAG task scheduling problem (DAG-SP) with the criterion of minimizing makespan, this paper proposes an estimation of distribution algorithm (EDA) enhanced by the path relinking. An efficient hybrid scheme integrating list scheduling heuristics is designed to take advantage of the knowledge of existing works. In addition, to describe the relative position relationships between the task pairs, a specific probability model is built and the task processing permutations are produced by sampling such a model. To enhance the exploitation of EDA, a path relinking based knowledge is used to design the local search method. Simulation experiments are carried out with both benchmark datasets and real-world graphs, where the comparative results show that the above designs can improve the performance effectively. Moreover, the numerical comparisons show that the proposed algorithm performs significantly better than the existing heuristics and evolutionary algorithms. (C) 2021 Elsevier B.V. All rights reserved.

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# Data-driven topology design using a deep generative model

Yamasaki, Shintaro Yaji, Kentaro Fujita, Kikuo

In this paper, we propose a sensitivity-free and multi-objective structural design methodology called data-driven topology design. It is schemed to obtain high-performance material distributions from initially given material distributions in a given design domain. Its basic idea is to iterate the following processes: (i) selecting material distributions from a dataset of material distributions according to eliteness, (ii) generating new material distributions using a deep generative model trained with the selected elite material distributions, and (iii) merging the generated material distributions with the dataset. Because of the nature of a deep generative model, the generated material distributions are diverse and inherit features of the training data, that is, the elite material distributions. Therefore, it is expected that some of the generated material distributions are superior to the current elite material distributions, and by merging the generated material distributions with the dataset, the performances of the newly selected elite material distributions are improved. The performances are further improved by iterating the above processes. The usefulness of data-driven topology design is demonstrated through numerical examples.

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# A cooperative coevolution algorithm for complex hybrid seru-system scheduling optimization

Wu, Yuting Wang, Ling Chen, Jing-fang

Under the current volatile business environment, the requirement of flexible production is becoming increasingly urgent. As an innovative production mode, seru-system with reconfigurability can overcome the lack of flexibility in traditional flow lines. Compared with pure seru-system, the hybrid seru-system composed of both serus and production lines is more practical for adapting to many production processes. This paper addresses a specific hybrid seru-system scheduling optimization problem (HSSOP), which includes three strongly coupled sub-problems, i.e., hybrid seru formation, seru scheduling and flow line scheduling. To minimize the makespan of the whole hybrid seru-system, we propose an efficient cooperative coevolution algorithm (CCA). To tackle three sub-problems, specific sub-algorithms are designed based on the characteristic of each sub-problem, i.e., a sub-space exploitation algorithm for hybrid seru formation, an estimation of distribution algorithm for seru scheduling, and a first-arrive-first-process heuristic for flow line scheduling. Since three sub-problems are coupled, a cooperation coevolution mechanism is proposed for the integrated algorithm by information sharing. Moreover, a batch reassign rule is designed to overcome the mismatch of partial solutions during cooperative coevolution. To enhance the exploitation ability, problem-specific local search methods are designed and embedded in the CCA. In addition to the investigation about the effect of parameter setting, extensive computational tests and comparisons are carried out which demonstrate the effectiveness and efficiency of the CCA in solving the HSSOP.

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# Optimal model parameter estimation of solar and fuel cells using improved estimation of distribution algorithm

Chandran, Benin Pratap Selvakumar, A. Immanuel Let, G. Shine Sathiyan, S. Paul

Renewable energy through the use of fuel cells and solar cells is one of the popular developments in recent days that produce electricity. Accurate modelling of fuel cell and solar cells are essential in simulation and analysis of energy systems with these sources. However, the systems are extremely nonlinear and complicated. The model needs to be optimized under distinct operating circumstances. Enhanced and streamlined Improved Estimation of Distribution (IED) Algorithm is suggested in this paper to estimate the parameter through optimization for solar cell models and fuel cell models. This is accomplished through the introduction of an ideal approach to improve population quality and the use of a local search to improve the efficiency of the finest global solution further. The design of an IED algorithm is much more straightforward and search efficiency is greatly improved compared with the fundamental optimization techniques from the literature. (C) 2020 The Authors. Published by Elsevier B.V. on behalf of Faculty of Engineering, Ain Shams University.

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# A Radial Hybrid Estimation of Distribution Algorithm for the Vehicle Routing Problem with Time Windows

Perez-Rodriguez, Ricardo

The vehicle routing environment has been widely studied under different approaches. It is due to its practical characteristic that makes its research interesting. Therefore, the vehicle-scheduling problem continues being attracted to develop new evolutionary algorithms. In this paper, we propose a new estimation of distribution algorithm coupled with a radial probability function. The aforementioned radial function comes from the hydrogen element. Continuous values, for the solution representation, are used in this research. Each value represents the distance, in picometers, between the electron and the core of the hydrogen atom. The representation, elected in this research, is suitable to integrate the radial probability distribution as a probability model. This approach is proposed in order to build a competitive estimation of distribution algorithm for the vehicle routing problem with time windows. The key point is to exploit the radial probability distribution to construct offspring, and to tackle the inconvenient of the estimation of distribution algorithms, i.e., lack of diversity of the solutions and poor ability of exploitation. In addition, this paper omits to use permutation-based representation as other recent estimation of distribution algorithms. Various instances and numerical experiments are presented to illustrate, and to validate this novel research. The results, obtained from this research, permits to conclude that using radial probability distributions is an emerging field to develop new and efficient EDAs.

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# Hybrid Estimation of Distribution Algorithm for Solving Three-Stage Multiobjective Integrated Scheduling Problem

Deng, Chao Hu, Rong Qian, Bin Jin, Huai P.

Aiming at reducing the total energy consumption of three stages processing-transportation-assembly in the assembly manufacturing industry, a three-stage multiobjective integrated scheduling problem with job batch transportation considering the energy consumption (3sMISP\_JBTEC) is proposed, and a comprehensive energy consumption model of multistage of 3sMISP\_JBTEC with an improved turn off/on strategy in the processing stage and considering speed in the transportation stage is formulated. Then, a hybrid estimation of distribution algorithm with variable neighborhood search (HEDA\_VNS) is developed to solve the scheduling problem. In the HEDA\_VNS, the reasonable coding/decoding rules and speed scheduling scheme (SSS) are designed. Moreover, two local search strategies are designed to further enhance the performance of HEDA\_VNS. Among them, three types of neighborhood search strategies are devised in Local Search I to improve the search efficiency while retaining the structure of the original high-quality solution. A variable neighborhood hybrid operation based on the speed scheduling set is designed in Local Search II to further improve the quality of the solution while balancing the optimization goals. Finally, simulations and comparisons show the efficiency of the proposed HEDA\_VNS.

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# Random mask-based estimation of the distribution algorithm for stacked auto-encoder one-step pre-training

Xu, Qingyang Liu, Anbang Yuan, Xianfeng Song, Yong Zhang, Chengjin Li, Yibin

The deep learning techniques have received great achievements in computer vision, natural language processing, etc. The success of deep neural networks depends on the sufficient training of parameters. The traditional way of neural network training is a gradient-based algorithm, which suffers the disadvantage of gradient disappearing, especially for the deeper neural network. Recently, a heuristic algorithm has been proposed for deeper neural network optimization. In this paper, a random mask and elitism univariate continuous estimation of distribution algorithm based on the Gaussian model is proposed to pre-train staked auto-encoder, and then a Stochastic Gradient Descent (SGD) based fine-tuning process is carried out for local searching. In the improved estimation of the distribution algorithm, two individual update strategies are defined; one group of individuals is generated according to the constructed probabilistic model, and another is updated according to the statistics of advanced individuals that aim to reduce the probability of combination explosion and time consumption according to the mask information. In the simulations, different architectures, different mask ratios and different promising individual ratios are adopted to testify the effectiveness of the improved algorithm. According to simulation results, the estimation of thr distribution algorithm has a steady optimization ability for the shallow and stacked autoencoder by one-step pre-training combining SGD based fine-tuning for the MNIST dataset. The proposed model will achieve a state-of-the-art performance on Fashion-MNIST.

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# Stochastic resource-constrained project scheduling problem with time varying weather conditions and an improved estimation of distribution algorithm

Zhou, Yifan Miao, Jindan Yan, Bin Zhang, Zhisheng

Construction projects with outdoor operations are affected by time-varying weather conditions. However, most existing research on stochastic resource-constrained project scheduling problems (SRCPSPs) considers activity duration as a random variable from a time-independent distribution. To address this issue, this study investigates SRCPSP under time-varying weather conditions; an improved estimation of distribution algorithm (EDA) including a ranking and selection method using common random numbers is proposed for enhancing the performance of project scheduling. The benchmark J120 dataset from PSPLIB and a practical case of windfarm construction are used to validate the improved EDA. For three randomly selected cases from the J120 dataset, the improved EDA can reduce the expected makespan by 17.0, 29.4, and 12.5 days when compared with deterministic scheduling. The corresponding makespan reductions obtained by the original EDA are 10.8, 22.7, and 7.1 days. Similarly, the improved EDA obtains 23% higher expected makespan reduction for the practical case.

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# An incremental-learning model-based multiobjective estimation of distribution algorithm

Liu, Tingrui Li, Xin Tan, Liguo Song, Shenmin

Knowledge obtained from the properties of a Pareto-optimal set can guide an evolutionary search. Learning models for multiobjective estimation of distributions have led to improved search efficiency, but they incur a high computational cost owing to their use of a repetitive learning or iterative strategy. To overcome this drawback, we propose an algorithm for incremental-learning model-based multiobjective estimation of distribu-tions. A learning mechanism based on an incremental Gaussian mixture model is embed-ded within the search procedure. In the proposed algorithm, all new solutions generated during the evolution are passed to a data stream, which is fed incrementally into the learn-ing model to adaptively discover the structure of the Pareto-optimal set. The parameters of the model are updated continually as each newly generated datum is collected. Each datum is learned only once for the model, regardless of whether it has been preserved or deleted. Moreover, a sampling strategy based on the learned model is designed to balance the exploration/exploitation dilemma in the evolutionary search. The proposed algorithm is compared with six state-of-the-art algorithms for several benchmarks. The experimental results show that there is a significant improvement over the representative algorithms. (c) 2021 Elsevier Inc. All rights reserved.

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# Hybrid optimization for charge planning problem in twin strands continuous casting production

Yi, Jian Jia, Shu-jin Du, Bin

Charge planning is one of batching problems for steelmaking and continuous casting production, and its optimization will be conducive to subsequent cast planning. Charge planning problem in the twin strands continuous casting production was studied, where casting width of the odd strand might be different from that of the even strand. Considering the different widths in the twin strands, the resulting counterweights and the constraints of steelmaking and continuous casting, a multi-objective optimization model was established to minimize the number of charges, the number of scale pairs, the surplus and the upgrading costs of steel grades. Furthermore, a hybrid optimization algorithm combined with heuristic and mutation-based estimation of distribution algorithm was proposed to solve the model. Experiments were conducted on several groups of test data collected from practical production orders of Baosteel. The computational results demonstrate that the proposed algorithm can generate better solutions than the manual method. The proposed model and algorithm proved to be effective and practical.

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# An improved estimation of distribution algorithm for multi-compartment electric vehicle routing problem

Shen Yindong Peng Liwen Li Jingpeng

The multi-compartment electric vehicle routing problem (EVRP) with soft time window and multiple charging types (MCEVRP-STW&amp;MCT) is studied, in which electric multi-compartment vehicles that are environmentally friendly but need to be recharged in course of transport process, are employed. A mathematical model for this optimization problem is established with the objective of minimizing the function composed of vehicle cost, distribution cost, time window penalty cost and charging service cost. To solve the problem, an estimation of the distribution algorithm based on Levy flight (EDA-LF) is proposed to perform a local search at each iteration to prevent the algorithm from falling into local optimum. Experimental results demonstrate that the EDA-LF algorithm can find better solutions and has stronger robustness than the basic EDA algorithm. In addition, when comparing with existing algorithms, the result shows that the EDA-LF can often get better solutions in a relatively short time when solving medium and large-scale instances. Further experiments show that using electric multi-compartment vehicles to deliver incompatible products can produce better results than using traditional fuel vehicles.

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# Optimal Design of Continuum Robots With Reachability Constraints

Cheong, Hyunmin Ebrahimi, Mehran Duggan, Timothy

While multi-joint continuum robots are highly dexterous and flexible, designing an optimal robot can be challenging due to its kinematics involving curvatures. Hence, the current work presents a computational method developed to find optimal designs of continuum robots, given reachability constraints. First, we leverage both forward and inverse kinematic computations to perform reachability analysis in an efficient yet accurate manner. While implementing inverse kinematics, we also integrate torque minimization at joints such that robot configurations with the minimum actuator torque required to reach a given workspace could be found. Lastly, we apply an estimation of distribution algorithm (EDA) to find optimal robot dimensions while considering reachability, where the objective function could be the total length of the robot or the actuator torque required to operate the robot. Through three application problems, we show that the EDA is superior to a genetic algorithm (GA) in finding better solutions within a given number of iterations, as the objective values of the best solutions found by the EDA are 4-15% lower than those found by the GA.

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# Hybrid Evolutionary Scheduling for Energy-Efficient Fog-Enhanced Internet of Things

Wu, Chu-ge Li, Wei Wang, Ling Zomaya, Albert Y.

In recent years, the rapid development of the Internet of Things (IoT) has produced a large amount of data that needs to be processed in a timely manner. Traditional cloud computing systems can provide us with plentiful resources to process such data. However, the increasing requirements of IoT applications on data privacy, energy consumption savings and location-aware data processing pushes the emergence and the interplay of fog computing and cloud computing. This paper examines the resource scheduling issue under such a system to minimize makespan and energy consumption. A multi-objective estimation of distribution algorithm (EDA) as well as a partition operator is adopted to divide the graph and determine the task processing permutation and processor assignment. Single and multiple application simulation were both conducted. The comparative results show that the Pareto set produced by our proposed algorithm is able to dominate a large proportion of those solutions by the heuristic method and the simple EDA under single application simulation. When it comes to multi-application simulation, IoT devices can have a much longer lifetime with our proposed scheduling algorithm as well having similar performance to the other algorithms on fog node energy consumption and much better on makespan.

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# Cellular estimation of distribution algorithm designed to solve the energy resource management problem under uncertainty

Martinez-Lopez, Yoan Rodriguez-Gonzalez, Ansel Y. Madera, Julio Bethencourt Mayedo, Miguel Lezama, Fernando

The Energy Resource Management (ERM) can be modeled as a Mixed-Integer Non-Linear Problem whose aim is to maximize profits generally using smart grid capabilities more than importing energy from external markets. Due to this, many resources and customers are involved in optimization, making ERM a complex problem. Moreover, when the inherent uncertainty of weather conditions, load forecast, electric vehicles planned trips, or market prices is considered, deterministic approaches might fail in obtaining optimal solutions to the problem. In this context, evolutionary algorithms are a useful tool to find effective near-optimal solutions. In fact, to design and test evolutionary algorithms to solve the ERM problem under uncertainty, the research community has developed a simulation framework. In this paper, we propose the Cellular Univariate Marginal Distribution Algorithm with Normal-Cauchy distribution (CUMDANCauchy) to address the ERM problem in uncertain environments. CUMDANCauchy uses a univariate estimation of the product of Normal and Cauchy distributions over each feature, and produces new individuals not only by the sampling of the learned distributions but also using neighborhoods of individuals from a ring cellular structure. The experiments performed over two case studies show that: CUMDANCauchy is as competitive as the previous dominant class of algorithms in terms of the global fitness achieved; its convergence behavior is among the best in comparison with the other tested algorithms; its running time is similar to the algorithm with the best global fitness achieved in the first case study, and it is the fastest algorithm in the second one.

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# Cooperative Path Planning of UAVs & UGVs for a Persistent Surveillance Task in Urban Environments

Wu, Yu Wu, Shaobo Hu, Xinting

There have been many applications of drones in urban environments, such as delivery, rescue, and surveillance. In a persistent surveillance task, the drones sometimes cannot complete it independently when some regions are required to be covered on the ground. For this purpose, unmanned aerial vehicles and unmanned ground vehicles (UAVs &amp; UGVs) system is introduced to perform such a task in this article, and the goal is to generate the circular paths for the drones and the UGVs, respectively, to minimize their travel time of realizing a complete coverage. First, the cooperative path planning problem of UAVs &amp; UGVs is formulated into a large-scale 0-1 optimization problem, in which the on-off states of the discrete points are to be optimized. Second, a hybrid algorithm integrating the estimation of distribution algorithm (EDA) and the genetic algorithm (GA) algorithm is proposed to solve the problem. The advantages of EDA and GA in the global and local search are fully taken considering the demands in different phases of the iterative process. A simple sweep-based approach is employed to determine the optimal sequence of passing the open points. Then, an online local adjustment strategy is also applied to address the changes of the requirements on covering the ground area. Simulation results demonstrate that the UAVs &amp; UGVs system can enhance the efficiency of the task. The hybrid EDA-GA algorithm can greatly improve the performance of EDA and GA in terms of the quality and the stability of solutions. The online adjustment strategy is effective to maintain a complete coverage while minimizing the impact on the circular paths.

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# Achieving Highly Scalable Evolutionary Real-Valued Optimization by Exploiting Partial Evaluations

Bouter, Anton Alderliesten, Tanja Bosman, Peter A. N.

It is known that to achieve efficient scalability of an Evolutionary Algorithm (EA), dependencies (also known as linkage) must be properly taken into account during variation. In a Gray-Box Optimization (GBO) setting, exploiting prior knowledge regarding these dependencies can greatly benefit optimization. We specifically consider the setting where partial evaluations are possible, meaning that the partial modification of a solution can be efficiently evaluated. Such problems are potentially very difficult, for example, non-separable, multimodal, and multiobjective. The Gene-pool Optimal Mixing Evolutionary Algorithm (GOMEA) can effectively exploit partial evaluations, leading to a substantial improvement in performance and scalability. GOMEA was recently shown to be extendable to real-valued optimization through a combination with the real-valued estimation of distribution algorithm AMaLGaM. In this article, we definitively introduce the Real-Valued GOMEA (RV-GOMEA), and introduce a new variant, constructed by combining GOMEA with what is arguably the best-known real-valued EA, the Covariance Matrix Adaptation Evolution Strategies (CMA-ES). Both variants of GOMEA are compared to L-BFGS and the Limited Memory CMA-ES (LM-CMA-ES). We show that both variants of RV-GOMEA achieve excellent performance and scalability in a GBO setting, which can be orders of magnitude better than that of EAs unable to efficiently exploit the GBO setting.

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# A hybrid estimation of distribution algorithm for distributed flexible job shop scheduling with crane transportations

Du, Yu Li, Jun-qing Luo, Chao Meng, Lei-lei

Distributed flexible job shop scheduling has attracted research interest due to the development of global man-ufacturing. However, constraints including crane transportation and energy consumption should be considered with the realistic requirements. To address this issue, first, we modeled the problem by utilizing an integer programming method, wherein the makespan and energy consumptions during the machine process and crane transportation are optimized simultaneously. Afterward, a hybrid algorithm consisting of estimation of distri-bution algorithm (EDA) and variable neighborhood search (VNS) was proposed to solve the problem, where an identification rule of four crane conditions was designed to make fitness calculation feasible. In EDA compo-nent, the parameters in probability matrices are set to be self-adaptive for stable convergence to obtain better output. Moreover, a probability mechanism was applied to control the activity of the EDA component. In VNS component, five problem-specific neighborhood structures including global and local strategies are employed to enhance exploitation ability. The simulation tests results confirmed that the proposed hybrid EDA-VNS algo-rithm can solve the considered problem with high efficiency compared with other competitive algorithms, and the proposed improving strategies are verified to have significance in better performance.

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# A scheduling decision support model for minimizing the number of drones with dynamic package arrivals and personalized deadlines

Liu, Chuang Chen, Huaping Li, Xueping Liu, Zeyu

Unmanned Aerial Vehicles (UAVs, commonly known as drones) hold great potential to reduce operational costs and guarantee on-time delivery of packages. This paper aims to minimize the number of drones used in a depot, in which each package has its own customized release time, distance to the depot, and personalized deadline. For decision-makers, it is difficult to determine the optimal number of drones to ensure that all packages can be delivered before the corresponding deadline. We propose a mixed integer programming model formulate the problem. Due to the NP-hardness of the problem, a scheduling decision support model with a genetic algorithm (SDSMGA) is developed to address the problem. A fitness function that can determine the minimum number of drones required by a package delivery sequence is proposed. We develop a swap-based correction algorithm to correct unqualified individuals in SDSMGA. Experimental results show that compared with CPLEX for small instances, SDSMGA can obtain solutions of the same quality or sub-optimal solutions. Computational results among SDSMGA, Estimation of Distribution Algorithm (EDA), and Particle Swarm Optimization (PSO) indicate that SDSMGA can effectively and efficiently address the problem. As the number of packages increases, SDSMGA outperforms the other two algorithms. Sensitivity analysis shows that the smaller the dense factor, or the more extensive the service radius, the more drones are needed.

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# Analysis of Bayesian Network Learning Techniques for a Hybrid Multi-objective Bayesian Estimation of Distribution Algorithm: a case study on MNK Landscape

Martins, Marcella S. R. Yafrani, Mohamed El Delgado, Myriam Luders, Ricardo Santana, Roberto Siqueira, Hugo V. Akcay, Huseyin G. Ahiod, Belaid

This work investigates different Bayesian network structure learning techniques by thoroughly studying several variants ofHybrid Multi-objectiveBayesian Estimation of Distribution Algorithm (HMOBEDA), applied to the MNK Landscape combinatorial problem. In the experiments, we evaluate the performance considering three different aspects: optimization abilities, robustness and learning efficiency. Results for instances of multi- and many-objective MNK-landscape show that, score-based structure learning algorithms appear to be the best choice. In particular, HMOBEDA(k2) was capable of producing results comparable with the other variants in terms of the runtime of convergence and the coverage of the final Pareto front, with the additional advantage of providing solutions that are less sensible to noise while the variability of the corresponding Bayesian network models is reduced.

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# Handling Uncertainty in Financial Decision Making: A Clustering Estimation of Distribution Algorithm With Simplified Simulation

Shi, Wen Chen, Wei-Neng Gu, Tianlong Jin, Hu Zhang, Jun

In financial decision making models, parameters are usually obtained based on historical data, which involve strong uncertainties. In some cases, the fluctuation caused by environmental uncertainty may even be more significant than that caused by utilizing different strategies. Such phenomenon makes the optimization and uncertainty handling in finical optimization a great challenge. In this article, a group insurance portfolio problem is considered as an instance of financial optimization with strong uncertainty. To handle uncertainty, we first analyze the feature of the problem and discover that in such kind of optimization problem with strong uncertainty, the solutions are strongly relative to the scenario. In view of the scenario-relevant feature, a simplified simulation approach is designed. Only one scenario is simulated for each generation in the evolution process to deal with the uncertainties. Combining this approach with a clustering estimation of distribution algorithm, a new algorithm (CEDA-SS) is proposed. Estimation of current profit is made by Monte Carlo (MC) simulation based on historical data. Solutions in each generation are evaluated in the same scenario. Two kinds of clustering mechanisms are applied to further improve the performance of the algorithm. Moreover, a comparison mechanism based on the Wilcoxon rank sum test is proposed to evaluate the performance of the algorithms. Experimental results show that the proposed CEDA-SS is suitable for the group insurance portfolio problem and it outperforms other uncertain evolutionary algorithms.

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

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

The distributed assembly permutation flow-shop scheduling problem (DAPFSP) is a typical NP-hard combinatorial optimization problem that has wide applications in advanced manufacturing systems and modern supply chains. In this work, an innovative three-dimensional matrix-cube-based estimation of distribution algorithm (MCEDA) is first proposed for the DAPFSP to minimize the maximum completion time. Firstly, a matrix cube is designed to learn the valuable information from elites. Secondly, a matrix-cube-based probabilistic model with an effective sampling mechanism is developed to estimate the probability distribution of superior solutions and to perform the global exploration for finding promising regions. Thirdly, a problem-dependent variable neighborhood descent method is proposed to perform the local exploitation around these promising regions, and several speedup strategies for evaluating neighboring solutions are utilized to enhance the computational efficiency. Furthermore, the influence of the parameters setting is analyzed by using design-of-experiment technique, and the suitable parameters are suggested for different scale problems. Finally, a comprehensive computational campaign against the state-of-the-art algorithms in the literature, together with statistical analyses, demonstrates that the proposed MCEDA produces better results than the existing algorithms by a significant margin. Moreover, the new best-known solutions for 214 instances are improved.

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# EDA-based optimized global control for PV inverters in distribution grids

Canadillas, David Valizadeh, Hamed Kleissl, Jan Gonzalez-Diaz, Benjamin Guerrero-Lemus, Ricardo

Operating distribution grids is increasingly challenging due to the increasing penetration of photovoltaic systems. To address these challenges, modern photovoltaic inverters include features for local control, which sometimes lead to suboptimal results. Improved communication infrastructure and photovoltaic inverters favour global control strategies, which receive information from all the systems in the grid. An estimation of distribution algorithm is used to optimize a global control strategy that minimizes active power curtailment and use of reactive power of the photovoltaic inverters, while maintaining voltage stability. Optimized global control outperforms every other local control evaluated in terms of apparent energy used for control (9.9% less usage compared to the second best alternative in all scenarios studied) and ranks second in terms of voltage stability (with a 0.14% of total time outside the voltage limits). Two new indicators to compare control strategies are proposed, and optimized global control strategy ranks best for both efficiency index (0.98) and average apparent power use (0.48 kVA).

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# Robust parameter estimation of a PEMFC via optimization based on probabilistic model building

Blanco-Cocom, Luis Botello-Rionda, Salvador Ordonez, L. C. Valdez, S. Ivvan

In this work, we approximated a set of unknown physical parameters for a semi-empirical mathematical model of a PEMFC. We used an Estimation of Distribution Algorithm (EDA) known as UMDA(G) to find the tuple that best reproduces the experimental polarization curve. We tackled non-derivable objective functions to perform robust parameter estimation. We compared the sum of the squared error with published results, and the sum and the median of the absolute error values were used to diminish or remove the effect of possible noise or outliers. Since the UMDA(G) requires a single user-given parameter (the population size) and presents a natural reduction of the variance, it was possible to introduce a variance-based stopping criterion. The obtained results were compared with the most up-to-date evolutionary algorithms, demonstrating that this proposal is competitive. We used four previously reported experimental datasets to get the parameters or validate them. Two of them were used to test the method and to compare it with reported results of recent bio-inspired metaheuristics. Then, we used the identified parameters to simulate the cases of the remaining data sets validating the correct estimation. Finally, we introduced a posterior statistical analysis (hypothesis test), which provided further information about dependencies and the impact of each parameter on the cell performance. (C) 2020 International Association for Mathematics and Computers in Simulation (IMACS). Published by ElsevierB.V. All rights reserved.

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# A simplified run time analysis of the univariate marginal distribution algorithm on LeadingOnes

Doerr, Benjamin Krejca, Martin S.

With elementary means, we prove a stronger run time guarantee for the univariate marginal distribution algorithm (UMDA) optimizing the LEADINGONES benchmark function in the desirable regime with low genetic drift. If the population size is at least quasilinear, then, with high probability, the UMDA samples the optimum in a number of iterations that is linear in the problem size divided by the logarithm of the UMDA's selection rate. This improves over the previous guarantee, obtained by Dang and Lehre (2015) via the deep level-based population method, both in terms of the run time and by demonstrating further run time gains from small selection rates. Under similar assumptions, we prove a lower bound that matches our upper bound up to constant factors. (C) 2020 Elsevier B.V. All rights reserved.

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# An evolutionary fuzzy scheduler for multi-objective resource allocation in fog computing

Wu, Chu-ge Li, Wei Wang, Ling Zomaya, Albert Y.

With rapid development of the Internet of Things (IoT), a vast amount of raw data produced by IoT devices needs to be processed promptly. Compared to cloud computing, fog computing nodes are closer to data resource for decreasing the end-to-end transmission latency. Considering the limited resource of IoT devices, offloading computationally-intensive tasks to the servers with high computing capability is essential in the IoT-fog-cloud system to complete those tasks on time. In this work, we propose a fuzzy logical offloading strategy for IoT applications characterized by uncertain parameters to optimize both agreement index and robustness. A multi-objective Estimation of Distribution Algorithm (EDA) is designed to learn and optimize the fuzzy offloading strategy from a diversity of the applications. The algorithm partitions applications into independent clusters, so that each cluster can be allocated to the corresponding tier for further processing. Thus, system resources are saved by making scheduling decisions in a reduced search space. Simulation studies on benchmark problems and real-world cases are carried out to verify the efficiency of our proposed algorithm. Pareto sets produced by our algorithm outperformed classic heuristic solutions for 88.3% benchmark cases and dominated Pareto sets of two state-of-art multi-objective algorithms for 92.7% and 94.4% cases correspondingly. (C) 2020 Elsevier B.V. All rights reserved.

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# Cooperative hybrid evolutionary algorithm for large scale multi-stage multi-product batch plants scheduling problem

Han, Yuxin Gu, Xingsheng

As an important part of batch chemical industry scheduling problems, the multi-stage multi-product batch plant scheduling problem (MMSP) has been widely studied for decades. This problem is character-ized by multiple stages with non-identical parallel units and operate based on customer orders. In this paper, we focus on the large scale MMSP and treat the minimization of make-span as the objective function. An efficient cooperative hybrid evolutionary algorithm is proposed based on the framework of cooperative co-evolution. First, a novel two-line encoding scheme is developed to represent the unit assignment and sequencing for orders respectively. Second, modified estimation of distribution algorithm (EDA) and differential evolutionary (DE) operations are proposed according to the feature of MMSP. EDA operation with a novel population-based incremental learning strategy is applied to handle the unit assignment variables. And novel DE operation based on a novel encoding method is adopted to deal with sequence variables. Then, two selection strategies are applied to preserve optimal and sub-optimal solutions for the proposed algorithm. The critical path based local search algorithm is adopted to further improve the efficiency of local optimization. The proposed algorithm has been tested by several instances with different sizes and characteristics. The numerical results and comparisons show that the proposed work is very competitive in solving large scale MMSP. (c) 2020 Elsevier B.V. All rights reserved.

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# Metaheuristics for Optimal Scheduling of Appliances in Energy Efficient Neighbourhoods

Alfageme, Amaia Esnaola-Gonzalez, Iker Javier Diez, Francisco Gilabert, Eduardo

As a consequence of the continuous growth in the worldwide electricity consumption, supplying all customer electrical requests is becoming increasingly difficult for electricity companies. That is why, they encourage their clients to actively manage their own demand, providing several resources such us their Optimal Demand Profile (ODP). This profile provides to users a summary of the demand they should consume during the day. However, this profile needs to be translated into specific control actions first, such as the when each appliance should be used. In this article a comparison of the performance of two metaheuristic optimisation algorithms (Tabu Search and Estimation of Distribution Algorithm (EDA)) and their variants for the calculation of optimal appliance scheduling is presented. Results show that Tabu Search algorithm can reach better feasible solutions at faster execution times than EDA does.

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# Towards Explainable Metaheuristics: PCA for Trajectory Mining in Evolutionary Algorithms

Fyvie, Martin McCall, John A. W. Christie, Lee A.

The generation of explanations regarding decisions made by population-based meta-heuristics is often a difficult task due to the nature of the mechanisms employed by these approaches. With the increase in use of these methods for optimisation in industries that require end-user confirmation, the need for explanations has also grown. We present a novel approach to the extraction of features capable of supporting an explanation through the use of trajectory mining - extracting key features from the populations of NDAs. We apply Principal Components Analysis techniques to identify new methods of population diversity tracking post-runtime after projection into a lower dimensional space. These methods are applied to a set of benchmark problems solved by a Genetic Algorithm and a Univariate Estimation of Distribution Algorithm. We show that the new sub-space derived metrics can capture key learning steps in the algorithm run and how solution variable patterns that explain the fitness function may be captured in the principal component coefficients.

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# PREEMPTIVE RESOURCE LEVELING IN PROJECTS

Li, Hongbo Hu, Ziyi Zhu, Hanyu Liu, Yinbin

As a well-known NP-hard problem in project scheduling, the resource leveling problem (RLP) has attracted many researchers' attentions. In the RLP, a typical assumption is that activities are non-preemptive during project execution, which means that activities cannot be interrupted once they have been started. However, preemption is not uncommon in project management practice and existing studies already show that it is beneficial to consider preemption when leveling resource usage. Therefore, we investigate the preemptive resource leveling problem and design a genetic estimation of distribution algorithm (GEDA). To analyze the performance of the GEDA, we conduct extensively computational experiments on 2160 randomly generated instances. We also examine the impacts of various factors on the GEDA. Comparative experimental results show that the GEDA outperforms the existing meta-heuristic algorithm.

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# Automated Dimensional Synthesis of a Portable Sky Scanner for Measuring Light Pollution

Rios, Alejandra Hernandez, Eusebio E. Lamphar, Hector Valdez, S. Ivvan

Light pollution is often measured by a photometric sensor network distributed in the area of interest. However, photometric sensors usually have a narrow view angle, making difficult to perform measurements at low elevation angles. Furthermore, short-term variations are not significant; hence, a low-cost solution is to displace a portable device, able to scan the sky in a range of azimuth and zenith angles, to different locations of interest. The device should be designed with the aim of characterizing the emission function from ground based light sources, which is decreasing in intensity with respect to the zenith. In this manuscript, we propose to find the dimensions of a four-bar linkage mechanism that best fits the scanning task via an optimization problem, solved with an estimation of distribution algorithm. The optimization algorithm proposes configurations with different lengths and reference positions of four-bar linkage mechanisms; then, it measures the distance between points in the actual path and points in the desired path for each configuration. The objective function value is the sum of such distances; thus, the optimal design produces the minimum distance to the desired path. This proposal for automated design reduces the working time and experience requirements of a human designer, and trial-and-error design intends, by determining adequate dimensions for the mechatronic system. A CAD model and a simulation demonstrate the design feasibility and the high accuracy of the resulting device.

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

Yu, Hui Li, Jun-qing Han, Yu-yan Sang, Hong-yan

In recent years, outpatient scheduling problem has attracted much attention. This paper considers the outpatient scheduling problem as an extension of the flexible job shop scheduling problem (FJSP), where the patient is considered as a job. Then, to solve the outpatient scheduling problem, a hybrid imperialist competitive algorithm (HICA) is proposed. In the proposed algorithm, the simulated annealing (SA) algorithm and estimation of distribution algorithm (EDA) are embedded to improve the quality of the solution. Furthermore, the two realistic constraints, i.e., switching time and preparation time of patients are also considered to make the problem closer to the reality. Finally, to verify the performance of the proposed HICA, different outpatient scheduling problem instances are randomly generated and used for simulation tests. Four efficient algorithms, including imperialist competitive algorithm (ICA), improved genetic algorithm (IGA), EDA, and modified artificial immune algorithm (MAIA), 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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# Multi-task Allocation of Multi-UAV Coalition Based on Improved Quantum Genetic Algorithm

Liu, Pengfei Wang, Bing Liu, Wenjie Zhang, Lan

In the multi-UAV task allocation problem, one task may need several UAVs with specific capabilities to form a coalition to execute cooperatively. In this paper, considering the UAV coalition loss cost and time cost, an improved quantum genetic algorithm is proposed to solve the task allocation problem of multi-UAV coalition. On the basis of quantum genetic algorithm, the historical optimal solution retention mechanism and estimation of distribution algorithm are introduced to speed up the convergence speed and reduce the probability falling into the local optimum of the algorithm, respectively. Then, a gene repair strategy is used to improve the efficiency of the algorithm according to the problem background. Finally, the simulation results show that the proposed algorithm has more advantages than other comparison algorithms in terms of search ability and convergence speed in solving the task allocation problem of multi-UAV coalition.

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# Parameter Calibration of the Patch Growing Algorithm for Urban Land Change Simulations

Lopez-Farias, Rodrigo Valdez, S. Ivvan Garcia-Robledo, A.

Urban growth modelling is a current trend in geocomputation due to its impact on the local living environment and the quality of life. The FUTure Urban-Regional Environment Simulation (FUTURES) model produces projections of landscape patterns by coupling land suitability, per-capita demand, and patch growing algorithm (PGA) sub-models. In particular, the PGA is the urban growing simulator component that takes into account the stochastic nature of urban development. It requires a set of parameters, namely compactness mean, compactness range, and discount factor to approximate the general characteristics of the urban development structure. The fitness of the parameters is measured by computing the difference between the area and compactness histograms of the observed and simulated urban growths. On the one hand, the authors find these parameters via an exhaustive grid search; nevertheless, this requires evaluating all the points in the grid, which implies a high computational cost because each point is associated with several PGA simulations. In addition, the approximation is limited to be one of the points in the grid. Thus, the better the precision is, the higher the required computational cost. On the other hand, evolutionary algorithms have been widely used for the automatic calibration of parameters but, in general, they are not designed to use a low number of evaluations, require expert tuning, and to define the stop criteria. Therefore, we propose an algorithm to find the adequate parameters, with minimum expert intervention, using an Estimation of Distribution Algorithm designed to use a low number of function evaluations (EDALNFE) when compared to the grid search. EDALNFE provides several assets: it delivers competitive results, it requires a low number of function evaluations, it does not require expert settings, and it is equipped with an automatic stop criterion. The proposed algorithm is compared to exhaustive grid search (the only method readily available in the FUTURES package) and differential evolution to demonstrate its superior performance.

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# On Crossing Fitness Valleys with Majority-Vote Crossover and Estimation-of-Distribution Algorithms

Witt, Carsten

The benefits of using crossover in crossing fitness gaps have been studied extensively in evolutionary computation. Recent runtime results show that majority-vote crossover is particularly efficient at optimizing the well-known JUMP benchmark function that includes a fitness gap next to the global optimum. Also estimation-of-distribution algorithms (EDAs), which use an implicit crossover, are much more efficient on JUMP than typical mutation-based algorithms. However, the allowed gap size for polynomial runtimes with EDAs is at most logarithmic in the problem dimension n.

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# Quantum-Inspired Estimation Of Distribution Algorithm To Solve The Travelling Salesman Problem

Soloviev, Vicente P. Bielza, Concha Larranaga, Pedro

A novel Quantum-Inspired Estimation of Distribution Algorithm (QIEDA) is proposed to solve the Travelling Salesman Problem (TSP). The QIEDA uses a modified version of the W state quantum circuits to sample new solutions during the algorithm runtime. The algorithm behaviour is compared with other state-of-the-art population-based algorithms. QIEDA convergence is faster than other algorithms, and the obtained solutions improve as the size of the problem increases. Moreover, we show that quantum noise enhances the search of an optimal solution. Because quantum computers differ from each other, partly due to the topology that distributes the qubits, the computational cost of executing the QIEDA in different topologies is analyzed and an ideal topology is proposed for the TSP solved with the QIEDA.

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# Power Aware Data Center Placement in WDM Optical Networks

Zeb, Sanwal Ahmad, Arsalan Ahmed, Ashfaq Bianco, Andrea

Due to the increasing trend in IP traffic, the placement of Data Centers (DCs) at network nodes has become a hot research topic. A proper DCs placement translates in reduced power consumption of overall network. The paper scope is to find the best placement of "k" DCs nodes out of "N" total nodes to reduce power consumption. To solve the problem, we propose two heuristics: EoDCP, based on Estimation of Distribution Algorithm (EDA), and MaxN-MinL. An exhaustive search based ESDCP algorithm is used as a lower bound to compare the performance of EoDCP and MaxN-MinL. Moreover, electronic traffic grooming technique is employed to further reduce the total network power consumption. A 20-Node Random network and a 17-Node German network are used to perform comparison of proposed heuristics. Performance of EoDCP algorithm is far better than those of MaxN-MinL, and is similar to the optimal solution obtained via ESDCP. Finally, using electronic traffic grooming improves power savings up-to 15% in the two considered topologies.

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# Smart grid planning method based on multi-objective particle swarm optimisation algorithm

Zhang, Jianguang

Smart grid refers to a modern electric energy supply system to tackle a lot of problems in grid management, such as, resource shortage, environment pollution and so on. In this paper, we propose a novel smart grid planning method using multi-objective particle swarm optimisation algorithm. The goal of smart grid plan is to calculate the minimum investment and annual operating costs, when we obtain the planning level of load distribution, substation capacity and power supply area to satisfy the load requirement and optimised substation location. Afterwards, we propose a multi-objective particle swarm optimisation algorithm which integrates the estimation of distribution algorithm. Furthermore, the propose approach divides the particle population into a lot of sub-populations and then build probability models for each population. Finally, experimental results demonstrate that the proposed method can effectively arrange new substation, which is able to make up for deficiencies of current existing substations.

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# Collaborative Optimization Design for Centralized Networked Control System

Yan, Xiang Li, Jun Mei, Bizhou

This paper proposes a collaborative optimization design for a kind of centralized networked control system based on jitter. After the analysis of the network delay and jitter on the performance of the Train Networked Control System (TNCS) based on the MVB (Multifunction Vehicle Bus) network, the proposed strategy modifies the media allocating model of MVB directly related to the performance of the control system. Under the premise of ensuring the stability of the control system, and taking into account the impact of transmission jitter on the dynamic performance of the closed-loop control, this collaborative design method can minimize the network resource occupancy rate of the subsystem. Thus, it can overcome schedule failure in the traditional algorithm that excessively occupies network resources in order to reduce jitter. Finally, the authors present an algorithm based on EDA to find the optimal solution of the proposed strategy and illustrate the effectiveness of the strategy through numerical simulation and experimental tests.

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# Neural Architecture Search by Estimation of Network Structure Distributions

Muravev, Anton Raitoharju, Jenni Gabbouj, Moncef

The influence of deep learning is continuously expanding across different domains, and its new applications are ubiquitous. The question of neural network design thus increases in importance, as traditional empirical approaches are reaching their limits. Manual design of network architectures from scratch relies heavily on trial and error, while using existing pretrained models can introduce redundancies or vulnerabilities. Automated neural architecture design is able to overcome these problems, but the most successful algorithms operate on significantly constrained design spaces, assuming the target network to consist of identical repeating blocks. While such approach allows for faster search, it does so at the cost of expressivity. We instead propose an alternative probabilistic representation of a whole neural network structure under the assumption of independence between layer types. Our matrix of probabilities is equivalent to the population of models, but allows for discovery of structural irregularities, while being simple to interpret and analyze. We construct an architecture search algorithm, inspired by the estimation of distribution algorithms, to take advantage of this representation. The probability matrix is tuned towards generating high-performance models by repeatedly sampling the architectures and evaluating the corresponding networks, while gradually increasing the model depth. Our algorithm is shown to discover non-regular models which cannot be expressed via blocks, but are competitive both in accuracy and computational cost, while not utilizing complex dataflows or advanced training techniques, as well as remaining conceptually simple and highly extensible.

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# The Runtime of the Compact Genetic Algorithm on Jump Functions

Doerr, Benjamin

In the first and so far only mathematical runtime analysis of an estimation-of-distribution algorithm (EDA) on a multimodal problem, Hasenohrl and Sutton (GECCO 2018) showed for any k = o(n) that the compact genetic algorithm (cGA) with any hypothetical population size mu = Omega(ne(4k) + n(3.5+epsilon)) with high probability finds the optimum of the n-dimensional jump function with jump size k in time O(mu n(1.5) log n). We significantly improve this result for small jump sizes k &lt;= 1/20 ln n - 1. In this case, already for mu = Omega(root n log n) boolean AND poly (n) the runtime of the cGA with high probability is only O(mu root n). For the smallest admissible values of mu, our result gives a runtime of O(n log n), whereas the previous one only shows O(n(5+epsilon)). Since it is known that the cGA with high probability needs at least Omega(mu root n) iterations to optimize the unimodal ONEMAX function, our result shows that the cGA in contrast to most classic evolutionary algorithms here is able to cross moderate-sized valleys of low fitness at no extra cost. For large k, we show that the exponential (in k) runtime guarantee of Hasenohrl and Sutton is tight and cannot be improved, also not by using a smaller hypothetical population size. We prove that any choice of the hypothetical population size leads to a runtime that, with high probability, is at least exponential in the jump size k. This result might be the first non-trivial exponential lower bound for EDAs that holds for arbitrary parameter settings. To complete the picture, we show that the cGA with hypothetical population size mu = Omega(log n) with high probability needs Omega(mu root n + n log n) iterations to optimize any n-dimensional jump function. This bound was known for ONEMAX, but, as we also show, the usual domination arguments do not allow to extend lower bounds on the performance of the cGA on ONEMAX to arbitrary functions with unique optimum. As a side result, we provide a simple general method based on parallel runs that, under mild conditions, (1) overcomes the need to specify a suitable population size and still gives a performance close to the one stemming from the best-possible population size, and (2) transforms EDAs with high-probability performance guarantees into EDAs with similar bounds on the expected runtime.

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# NMIEDA: Estimation of distribution algorithm based on normalized mutual information

Lin, Zhiyi Su, Qing Xie, Guobo

A new estimation of distribution algorithm based on normalized mutual information (NMIEDA) is proposed for overcoming the premature convergence of bivariate estimation of distribution algorithms. NMIEDA first uses normalized mutual information to measure the interaction between two variables and then generate a dependency forest model. Second, based on the concept of sporadic model building and a reward and punishment scheme in Selfish Gene, NMIEDA provides a new updating mechanism that accelerates the convergence speed. Finally, a new sampling mechanism is adopted in NMIEDA to improve the efficiency of sampling, which combines stochastic sampling, the opposition-based learning scheme and the mutation operator. The simulation results on benchmark problems and real-world problems demonstrate that NMIEDA often outperforms several other bivariate algorithms.

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# Probabilistic distribution learning algorithm based transmit antenna selection and precoding for millimeter wave massive MIMO systems

Khalid, Salman Mehmood, Rashid bin Abbas, Waqas Khalid, Farhan Naeem, Muhammad

In modern day communication systems, the massive MIMO architecture plays a pivotal role in enhancing the spatial multiplexing gain, but vice versa the system energy efficiency is compromised. Consequently, resource allocation in-terms of antenna selection becomes inevitable to increase energy efficiency without having any obvious effect or compromising the system spectral efficiency. Optimal antenna selection can be performed using exhaustive search. However, for a massive MIMO architecture, exhaustive search is not a feasible option due to the exponential growth in computational complexity with an increase in the number of antennas. We have proposed a computationally efficient and optimum algorithm based on the probability distribution learning for transmit antenna selection. An estimation of the distribution algorithm is a learning algorithm which learns from the probability distribution of best possible solutions. The proposed solution is computationally efficient and can obtain an optimum solution for the real time antenna selection problem. Since precoding and beamforming are also considered essential techniques to combat path loss incurred due to high frequency communications, so after antenna selection, successive interference cancellation algorithm is adopted for precoding with selected antennas. Simulation results verify that the proposed joint antenna selection and precoding solution is computationally efficient and near optimal in terms of spectral efficiency with respect to exhaustive search scheme. Furthermore, the energy efficiency of the system is also optimized by the proposed algorithm, resulting in performance enhancement of massive MIMO systems.

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# A variable neighbourhood search enhanced estimation of distribution algorithm for quadratic assignment problems

Pradeepmon, T. G. Panicker, Vinay V. Sridharan, R.

Quadratic Assignment Problem (QAP) is one of the most complex combinatorial optimization problems. Many real-world problems such as printed circuit board design, facility location problems, assigning gates to airplanes can be modelled as QAP. Problems of size greater than 35 is not able to solve optimally using conventional optimization methods. This warrants the use of evolutionary optimization methods for obtaining optimal or near optimal solutions for QAPs. This work proposes a hybridization on a univariate Estimation of Distribution Algorithm, namely the Population Based Incremental Learning Algorithm (PBILA), with Variable Neighbourhood Search (VNS) for solving QAPs. The proposed algorithm is employed to solve benchmark instances of QAP and the results are reported. The results of this work reveals that PBILA on its own is not efficient for solving the QAPs. However, when hybridised with VNS, the algorithm performs well providing best known solutions for 95 test instances out of the 101 instances considered. For most of the test instances, the percentage deviation is less than one percentage. The overall average percentage deviation of the obtained solutions from the best-known solutions is 0.037%, which is a significant improvement when compared with state-of-the-art algorithms.

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# An improved gravitational search algorithm to the hybrid flowshop with unrelated parallel machines scheduling problem

Cao, Cuiwen Zhang, Yao Gu, Xingsheng Li, Dan Li, Jie

The hybrid flowshop scheduling problem with unrelated parallel machines exists in many industrial manufacturers, which is an NP-hard combinatorial optimisation problem. To solve this problem more effectively, an improved gravitational search (IGS) algorithm is proposed which combines three strategies: generate new individuals using the mutation strategy of the standard differential evolution (DE) algorithm and preserve the optimal solution via a greedy strategy; substitute the exponential gravitational constant of the standard gravitational search (GS) algorithm with a linear function; improve the velocity update formula of the standard GS algorithm by mixing an adaptive weight and the global search strategy of the standard particle swarm optimisation (PSO) algorithm. Benchmark examples are solved to demonstrate the proposed IGS algorithm is superior to the standard genetic algorithm, DE, GS, DE with local search, estimation of distribution algorithm and artificial bee colony algorithms. Two more examples from a real-world water-meter manufacturing enterprise are effectively solved.

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# An estimation of distribution algorithm with branch-and-bound based knowledge for robotic assembly line balancing

Sun, Bin-qi Wang, Ling

Robotic assembly lines are widely used in manufacturing industries. The robotic assembly line balancing (RALB) problem aims to balance the workloads among different workstations and optimize the assembly line efficiency. This paper addresses a particular type of RALB problem, which minimizes the assembly line cycle time by determining the task and robot assignment in each workstation under precedence constraints. To solve the problem, we present an effective hybrid algorithm fusing the estimation of distribution algorithm and branch-and-bound (B&amp;B) based knowledge. A problem-specific probability model is designed to describe the probabilities of each task being assigned to different workstations. Based on the probability model, an incremental learning method is developed and a sampling mechanism with B&amp;B based knowledge is proposed to generate new feasible solutions. The fuse of B&amp;B based knowledge is able to reduce the search space of EDA while focusing the search on the promising area. To enhance the exploitation ability, a problem-specific local search is developed based on the critical workstation to further improve the quality of elite solutions. The computational complexity of the proposed algorithm is analyzed, and the effectiveness of the B&amp;B based knowledge and the problem-specific local search is demonstrated through numerical experiments. Moreover, the performance of the proposed algorithm is compared with existing algorithms on a set of widely-used benchmark instances. Comparative results demonstrate the effectiveness and efficiency of the proposed algorithm.

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