# A Reinforcement-Learning-Based 3-D Estimation of Distribution Algorithm for Fuzzy Distributed Hybrid Flow-Shop Scheduling Considering On-Time-Delivery

Deng, Libao Di, Yuanzhu Wang, Ling

With the increasing level of mass-customization and globalization of competition, environmentally friendly production scheduling for distributed manufacturing considering customer satisfaction has received growing attention. Meanwhile, uncertain scheduling is becoming a force to be considered within intelligent manufacturing industries. However, little research has been found that surveyed the uncertain distributed scheduling considering both energy consumption and customer satisfaction. In this article, the fuzzy distributed hybrid flow-shop scheduling problem considering on-time delivery (FDHFSP-OTD) is addressed, and a 3-D estimation of distribution algorithm (EDA) with reinforcement learning (RL) is proposed to minimize the makespan and total energy consumption while maximizing delivery accuracy. First, two heuristics and a random method are designed and used cooperatively for initialization. Next, an EDA with a 3-D probability matrix is innovated to generate offspring. Then, a biased decoding method based on Q-learning is proposed to adjust the direction of evolution self-adaptively. Moreover, a local intensification strategy is employed for further enhancement of elite solutions. The effect of major parameters is analyzed and the best combination of values is determined through extensive experiments. The numerical results prove the effectiveness of each specially designed strategy and method, and the comparisons with existing algorithms demonstrate the high-potential of the 3D-EDA/RL in solving the FDHFSP-OTD.

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# An Estimation of Distribution Algorithm With Resampling and Local Improvement for an Operation Optimization Problem in Steelmaking Process

Tang, Lixin Liu, Chang Liu, Jiyin Wang, Xianpeng

This article studies an operation optimization problem in a steelmaking process. Shortly before the tapping of molten steel from the basic oxygen furnace (BOF), end-point control measures are applied to achieve the required final molten steel quality. While it is difficult to build an exact mathematical model for this process, the control inputs and the corresponding outputs are available by collecting production data. We build a data-driven model for the process. To optimize the control parameters, an improved estimation of distribution algorithm (EDA) is developed using a probabilistic model comprising different distributions. A resampling mechanism is incorporated into the EDA to guide the new population to a broader and more promising area when the search becomes ineffective. To further enhance the solution quality, we add a local improvement to update the current best individual through simplified gravitational search and information learning. Experiments are conducted using real data from a BOF steelmaking process. The results show that the algorithm can help to achieve the specified molten steel quality. To evaluate the proposed algorithm as a general optimization algorithm, we test it on some complex benchmark functions. The results illustrate that it outperforms other state-of-the-art algorithms across a wide range of problems.

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# Minimizing the resource consumption of heterogeneous batch-processing machines using a copula-based estimation of distribution algorithm

Liu, Chuang Chen, Huaping Xu, Rui Wang, Yu

The two-stage flow-shop scheduling problem investigated in this work aims minimize the resource consumption of non-identical job sizes. The flow shop consists of two batch-processing machines (BPMs): a parallel batch BPM and a sequential BPM. The makespan and resource consumption are considered together in this study, the makespan is the constraint condition, and the resource consumption is the objective. A copula-based Estimation of Distribution Algorithm (cEDA) is used to solve the problem. In this study, the individuals are coded by the allocated resource sequences of all jobs in two machines, and the convex resource consumption function is adopted to simulate the relationship between the processing time of the jobs and the resources allocated to the jobs. A Gaussian distribution is adopted as the marginal probabilistic distribution of all the components. The proposed copula function C-1 assumes independence among the components, whereas the Clayton copula function C-2 assumes that all components are interrelated and introduced for comparison. The computational experiments and comparisons verify the effectiveness of the proposed cEDA. In addition, the copula functions C-1 and C-2 adopted in the proposed cEDA approach are compared. (C) 2018 Elsevier B.V. All rights reserved.

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# Exploring the probabilistic graphic model of a hybrid multi-objective Bayesian estimation of distribution algorithm

Martins, Marcella S. R. Delgado, Myriam Luders, Ricardo Santana, Roberto Goncalves, Richard A. de Almeida, Carolina P.

The Hybrid Multi-objective Bayesian Estimation of Distribution Algorithm (HMOBEDA) has shown to be very competitive for Many Objective Optimization Problems (MaOPs). The Probabilistic Graphic Model (PGM) of HMOBEDA expands the possibilities for exploration as it provides the joint probability of decision variables, objectives, and configuration parameters of an embedded local search. This work investigates different sampling mechanisms of HMOBEDA, applying the considered approaches to two different combinatorial MaOPs. Moreover, the paper provides a broad set of statistical analyses on its PGM model. These analyses have been carried out to evaluate how the interactions among variables, objectives and local search parameters are captured by the model and how information collected from different runs can be aggregated and explored in a Probabilistic Pareto Front. In experiments, two variants of HMOBEDA are compared with the original version, each one with a different set of evidences fixed during the sampling process. Results for instances of multi-objective knapsack problem with 2-5 and 8 objectives show that the best variant outperforms the original HMOBEDA in terms of convergence and diversity in the solution set. This best variant is then compared with five state-of-the-art evolutionary algorithms using the knapsack problem instances as well as a set of MNK-landscape instances with 2, 3, 5 and 8 objectives. HMOBEDA outperforms all of them.

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# A meta-heuristic for topology optimization using probabilistic learning

Ivvan Valdez, S. Marroquin, Jose L. Botello, Salvador Faurrieta, Noe

Topological shape optimization consists in finding the optimal shape of a mechanical structure by means of a process for removing or inserting new holes and structural elements, that is to say, using a process which produces topological changes. This article introduces a method for automated topological optimization via an Estimation of Distribution Algorithm (EDA), a global optimization meta-heuristic based on probabilistic learning, which requires of neither user initialization, nor a priori information or design bias in the algorithm. We propose a representation and solution mapping which favors feasible structures and requires a, relatively, low dimensionality (some hundreds), the probabilistic model learns from finite element evaluations to generate well-performed structures. The EDA for topology optimization (EDATOP) is compared with an algorithm, in the state of the art, specially designed to address this problem, demonstrating that our approach is useful for solving real-world problems, escapes from local optima, and delivers better solutions than the comparing algorithm which uses problem knowledge, with a payoff on the computational cost.

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# Hierarchical Energy Management for Power-Split Plug-In HEVs Using Distance-Based Optimized Speed and SOC Profiles

Lim, Hansang Su, Wencong

This paper proposes a distance-based two-stage energy management strategy for power-split plug-in hybrid electric vehicles (PHEVs). One stage is for long-term optimization and the other is for short-term adaptation to actual traffic conditions. Energy consumption in PHEVs depends on the characteristics of the drivetrain as well as the operating conditions such as power demands and their split. Thus, prior to departure, the operating conditions for a whole trip are optimized for the drivetrain characteristics and trip information, which generates optimal speed and state-of-charge profiles. While driving, the operating conditions are adapted to current traffic conditions for a short horizon on the basis of long-term optimization results. In consideration of the changeability of traffic conditions, the proposed energy management strategy is performed in a distance domain, which localizes the effects of changes in traffic conditions on the long-term optimization results. Therefore, this distance-based two-stage strategy improves the balance between the optimality and the real-time computing time, which is suitable for online management. A model for the propulsion system in a PHEV and the energy management strategy were formulated in a distance domain. An estimation of distribution algorithm was used for long-term optimization and local adaptation.

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# Level-Based Analysis of Genetic Algorithms and Other Search Processes

Corus, Dogan Duc-Cuong Dang Eremeev, Anton V. Lehre, Per Kristian

Understanding how the time complexity of evolutionary algorithms (EAs) depend on their parameter settings and characteristics of fitness landscapes is a fundamental problem in evolutionary computation. Most rigorous results were derived using a handful of key analytic techniques, including drift analysis. However, since few of these techniques apply effortlessly to population-based EAs, most time complexity results concern simple EAs, such as the (1+1) EA. We present the level-based theorem, a new technique tailored to population-based processes. It applies to any nonelitist process where offspring are sampled independently from a distribution depending only on the current population. Given conditions on this distribution, our technique provides upper bounds on the expected time until the process reaches a target state. The technique is demonstrated on pseudo-Boolean functions, the sorting problem, and approximation of optimal solutions in combinatorial optimization. The conditions of the theorem are often straightforward to verify, even for genetic algorithms and estimation of distribution algorithms which were considered highly nontrivial to analyze. The proofs for the example applications are available in the supplementary materials. Finally, we prove that the theorem is nearly optimal for the processes considered. Given the information the theorem requires about the process, a much tighter bound cannot be proved.

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# Improved Regularity Model-Based EDA for Many-Objective Optimization

Sun, Yanan Yen, Gary G. Yi, Zhang

The performance of multiobjective evolutionary algorithms deteriorates appreciably in solving many-objective optimization problems (MaOPs) which encompass more than three objectives. One of the known rationales is the loss of selection pressure which leads to the selected parents not generating promising offspring toward Pareto-optimal front (PF) with diversity. Estimation of distribution algorithms sample new solutions with a probabilistic model built from the statistics extracting over the existing solutions so as to mitigate the adverse impact of genetic operators. In this paper, an improved regularity-based estimation of distribution algorithm is proposed to effectively tackle unconstrained MaOPs. In the proposed algorithm, diversity repairing mechanism is utilized to mend the areas, where need nondominated solutions with a closer proximity to the PF. Then favorable solutions are generated by the model built from the regularity of the solutions surrounding a group of representatives. These two steps collectively enhance the selection pressure which gives rise to the superior convergence of the proposed algorithm. In addition, dimension reduction technique is employed in the decision space to speed up the estimation search of the proposed algorithm. Finally, by assigning the Pareto-optimal solutions to the uniformly distributed reference vectors, a set of solutions with excellent diversity and convergence is obtained. To measure the performance, NSGA-III, GrEA, MOEA/D, HypE, MBN-EDA, and RM-MEDA are selected to perform comparison experiments over DTLZ and DTLZ(-) test suites with 3-, 5-, 8-, 10-, and 15-objective. Experimental results quantified by the selected performance metrics reveal that the proposed algorithm shows considerable competitiveness in addressing unconstrained MaOPs.

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# Information fusion in offspring generation: A case study in DE and EDA

Fang, Hui Zhou, Aimin Zhang, Hu

Both differential evolution (DE) and estimation of distribution algorithm (EDA) are popular and effective evolutionary algorithms (EM) in solving global optimization problems. The two algorithms utilize different kinds of information for generating offspring solutions. In the former, the mutation and crossover operators use the individual information to create trial solutions, while in the later, a probabilistic model is built for sampling new trial solutions, which extracts the population distribution information. It is therefore natural to make use of both kinds of information for generating solutions. In this paper, we propose an algorithm that hybridizes DE and EDA, named as DE/GM, which utilizes both DE crossover/mutation operators and a Gaussian probabilistic model based operator for offspring generation. The basic idea is to generate some of trial solutions by the EDA operator, and to generate the rest by the DE operator. To validate the performance of DE/GM, a test suite of 13 benchmark functions is employed, and the experimental results suggest that DE/GM is promising.

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# A full variate Gaussian model-based RM-MEDA without clustering process

Shi, Meifeng He, Zhongshi Chen, Ziyu Liu, Xin

A regularity model-based multi-objective estimation of distribution algorithm (RM-MEDA) is an excellent multi-objective estimation of distribution algorithm proposed in recent years. However, the performance of RM-MEDA is seriously affected by its clustering process. In order to avoid the influence of the clustering process, this paper presents a novel full variate Gaussian model-based (FGM-based) RM-MEDA without clustering process, named FRM-MEDA. In FRM-MEDA, the clustering process is removed from the original algorithm and the full variate Gaussian model (FGM) is introduced to keep the population diversity and make up the loss of the performance caused by removing the clustering process. Meanwhile, the introduction of FGM makes the FRM-MEDA faster and more stable when solving all the test instances. In addition, variable variance of FGM is presented to enhance the exploring ability of FRM-MEDA. The experiments demonstrate that the proposed algorithm significantly outperforms the RM-MEDA without clustering process and the RM-MEDA with K equal to AVE(K).

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# A hybrid estimation of distribution algorithm for flexible job-shop scheduling problems with process plan flexibility

Perez-Rodriguez, Ricardo Hernandez-Aguirre, Arturo

The flexible job-shop environments have become increasingly significant because of rapid improvements on shop floors such as production technologies, manufacturing processes and systems. Several real manufacturing and service companies have had to use alternative machines or processes for each operation and the availability of alternative process plans for each job in order to achieve good performance on the shop floor where conflicting objectives are common, e.g. the overall completion time for all jobs and the workload of the most loaded machine. In this paper, we propose a Pareto approach based on the hybridization of an estimation of distribution algorithm and the Mallows distribution in order to build better sequences for flexible job-shop scheduling problems with process plan flexibility and to solve conflicting objectives. This hybrid approach exploits the Pareto-front information used as an input parameter in the Mallows distribution. Various instances and numerical experiments are presented to illustrate that shop floor performance can be noticeably improved using the proposed approach. In addition, statistical tests are executed to validate this novel research.

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# Applied Research on Distributed Generation Optimal Allocation Based on Improved Estimation of Distribution Algorithm

Yang, Lei Yang, Xiaohui Wu, Yue Liu, Xiaoping

Most of the current algorithms used to solve the optimal configuration problem in the distributed generation (DG) of electricity depend heavily on control parameters, which may lead to local optimal solutions. To achieve a rapid and effective algorithm of optimized configuration for distributed generation, a hybrid approach combined with Bayesian statistical-inference and distribution estimation is proposed. Specifically, a probability distribution estimation model based on the theory of Bayesian inference is established, then a posteriori probability model with the prior distribution and the conditional distribution is generated, and new individual generators are formed into a dominant group. The information of each individual of this dominant group is used to update the probability model and the updated posteriori probability is used for sampling until the optimal solution is obtained. Finally, the 12 bus, 34 bus and 69 bus radial distribution system is used as an example and comparison is performed to show the effectiveness of the proposed algorithm.

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# Exploiting Linkage Information and Problem-Specific Knowledge in Evolutionary Distribution Network Expansion Planning

Ngoc Hoang Luong La Poutre, Han Bosman, Peter A. N.

This article tackles the Distribution Network Expansion Planning (DNEP) problem that has to be solved by distribution network operators to decide which, where, and/or when enhancements to electricity networks should be introduced to satisfy the future power demands. Because of many real-world details involved, the structure of the problem is not exploited easily using mathematical programming techniques, for which reason we consider solving this problem with evolutionary algorithms (EAs). We compare three types of EAs for optimizing expansion plans: the classic genetic algorithm (GA), the estimation-of-distribution algorithm (EDA), and the Gene-pool Optimal Mixing Evolutionary Algorithm (GOMEA). Not fully knowing the structure of the problem, we study the effect of linkage learning through the use of three linkage models: univariate, marginal product, and linkage tree. We furthermore experiment with the impact of incorporating different levels of problem-specific knowledge in the variation operators. Experiments show that the use of problem-specific variation operators is far more important for the classic GA to find high-quality solutions. In all EAs, the marginal product model and its linkage learning procedure have difficulty in capturing and exploiting the DNEP problem structure. GOMEA, especially when combined with the linkage tree structure, is found to have the most robust performance by far, even when an out-of-the-box variant is used that does not exploit problem-specific knowledge. Based on experiments, we suggest that when selecting optimization algorithms for power system expansion planning problems, EAs that have the ability to effectively model and efficiently exploit problem structures, such as GOMEA, should be given priority, especially in the case of black-box or grey-box optimization.

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# Transfer Learning-Based Dynamic Multiobjective Optimization Algorithms

Jiang, Min Huang, Zhongqiang Qiu, Liming Huang, Wenzhen Yen, Gary G.

One of the major distinguishing features of the dynamic multiobjective optimization problems (DMOPs) is that optimization objectives will change over time, thus tracking the varying Pareto-optimal front becomes a challenge. One of the promising solutions is reusing "experiences" to construct a prediction model via statistical machine learning approaches. However, most existing methods neglect the nonindependent and identically distributed nature of data to construct the prediction model. In this paper, we propose an algorithmic framework, called transfer learning-based dynamic multiobjective evolutionary algorithm (EA), which integrates transfer learning and population-based EAs to solve the DMOPs. This approach exploits the transfer learning technique as a tool to generate an effective initial population pool via reusing past experience to speed up the evolutionary process, and at the same time any population-based multiobjective algorithms can benefit from this integration without any extensive modifications. To verify this idea, we incorporate the proposed approach into the development of three well-known EAs, non-dominated sorting genetic algorithm II, multiobjective particle swarm optimization, and the regularity model-based multiobjective estimation of distribution algorithm. We employ 12 benchmark functions to test these algorithms as well as compare them with some chosen state-of-the-art designs. The experimental results confirm the effectiveness of the proposed design for DMOPs.

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# Identifying DNA Methylation Modules Associated with a Cancer by Probabilistic Evolutionary Learning

Rhee, Je-Keun Kim, Soo-Jin Zhang, Byoung-Tak

DNA methylation leads to inhibition of downstream gene expression. Recently, considerable studies have been made to determine the effects of DNA methylation on complex disease. However, further studies are necessary to find the multiple interactions of many DNA methylation sites and their association with cancer. Here, to assess DNA methylation modules potentially relevant to disease, we use an Estimation of Distribution Algorithm (EDA) to identify high-order interaction of DNA methylated sites (or modules) that are potentially relevant to disease. The method builds a probabilistic dependency model to produce a solution that is a set of discriminative methylation sites. The algorithm is applied to array- and sequencing-based high-throughput DNA methylation profiling datasets. The experimental results show that it is able to identify DNA methylation modules for cancer.

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# Model-Based Position and Reflectivity Estimation of Fiber Bragg Grating Sensor Arrays

Werzinger, Stefan Zibar, Darko Koepel, Max Schmauss, Bernhard

We propose an efficient model-based signal processing approach for optical fiber sensing with fiber Bragg grating (FBG) arrays. A position estimation based on an estimation of distribution algorithm (EDA) and a reflectivity estimation method using a parametric transfer matrix model (TMM) are outlined in detail. The estimation algorithms are evaluated with Monte Carlo simulations and measurement data from an incoherent optical frequency domain reflectometer (iOFDR). The model-based approach outperforms conventional Fourier transform processing, especially near the spatial resolution limit, saving electrical bandwidth and measurement time. The models provide great flexibility and can be easily expanded in complexity to meet different topologies and to include prior knowledge of the sensors. Systematic errors due to crosstalk between gratings caused by multiple reflections and spectral shadowing could be further considered with the TMM to improve the performance of large-scale FBG array sensor systems.

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# A hybrid differential evolution algorithm with estimation of distribution algorithm for reentrant hybrid flow shop scheduling problem

Zhou, Bing-hai Hu, Li-man Zhong, Zhen-yi

This paper proposes a reentrant hybrid flow shop scheduling problem where inspection and repair operations are carried out as soon as a layer has completed fabrication. Firstly, a scheduling problem domain of reentrant hybrid flow shop is described, and then, a mathematical programming model is constructed with an objective of minimizing total weighted completion time. Then, a hybrid differential evolution (DE) algorithm with estimation of distribution algorithm using an ensemble model (eEDA), named DE-eEDA, is proposed to solve the problem. DE-eEDA incorporates the global statistical information collected from an ensemble probability model into DE. Finally, simulation experiments of different problem scales are carried out to analyze the proposed algorithm. Results indicate that the proposed algorithm can obtain satisfactory solutions within a short time.

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# A multi-model estimation of distribution algorithm for energy efficient scheduling under cloud computing system

Wu, Chu-ge Wang, Ling

How to manage the applications under computing systems such as a cloud computing system in a more efficient way is a focus problem. The primary performance goal is to reduce the execution time (makespan) of the application. As the need to cloud computing grows, the environmental influence of data centers attracts much attention. This paper aims at the scheduling of the precedence-constrained parallel application to minimize time and energy consumption efficiently. A multi-model estimation of distribution (mEDA) algorithm is adopted to determine both task processing permutation and voltage supply levels (VSLs). Specific operators to decrease execution time and energy consumption are designed. An improvement operator is also designed to enhance the diversity of the non-dominated solutions. The proposed algorithm is compared with the standard heuristic methods and a parallel bi-objective genetic algorithm (bGA). The comparative results show the Pareto solution set by the proposed algorithm is able to dominate a large proportion of those solutions by both the heuristic methods and the bGA. (C) 2018 Elsevier Inc. All rights reserved.

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# Trade-offs in PMU and IED Deployment for Active Distribution State Estimation Using Multi-objective Evolutionary Algorithm

Prasad, Sachidananda Kumar, D. M. Vinod

This paper proposes a new multi-objective optimization problem to find trade-offs in deployment of phasor measurement units (PMUs) and intelligent electronic devices (IEDs) for state estimation in active distribution networks. A new hybrid estimation of distribution algorithm (EDA) has been used to find the optimal number and location of measurement devices, such as PMU and IED, for accurate state estimation. The objective functions to be minimized in this optimization problem are the total cost of PMUs and IEDs, and the root mean square value of state estimation error. As the objectives are conflicting in nature, a multi-objective Pareto-based nondominated sorting (NDS) EDA algorithm is proposed. Moreover, to improve the local searching capability of the traditional EDA algorithm, the interior point method (IPM) is hybridized with EDA to get a near-global optimal solution. The hybridization of EDA with IPM brings a higher degree of balance between the exploration and exploitation capability of the traditional EDA during the search process. Furthermore, the random variation in loads and generations is also considered to check the reliability of the proposed meter placement technique. The viability of the proposed algorithm has been tested on the IEEE 69-bus system and Indian 85-bus system to validate the results. The obtained results have been compared with those of the conventional EDA algorithm, NDS genetic algorithm, and hybrid EDA-simulated annealing algorithm existing in the literature.

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# Experimental comparisons with respect to the usage of the promising relations in EDA-based causal discovery

Ko, Song Lim, Hyunki Ko, Hoon Kim, Dae-Won

A Bayesian network is a promising probabilistic model to represent causal relations between nodes (random variables). One of the major research issue in a Bayesian network is how to infer causal relations from a dataset by constructing better heuristic learning algorithms. Many kinds of approaches were so far introduced, and estimation of distribution algorithms (EDAs) are one of the promising causal discovery algorithms. However, the performance of EDAs is considerably dependent on the quality of the first population because new individuals are reproduced from the previous populations. In this paper, we introduce a new initialization method for EDAs that extracts promising candidate causal relations based on causal scores. Then, we used the promising relations to construct a better first population and to reproduce better individuals until the learning algorithm is terminated. Experimental results show that EDAs infer a more number of correct causal relations when promising relations were used in EDA based structure learning. It means that the performance of EDAs can be improved by providing better local search space, and it was the promising relations in this paper.

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# Non-Gaussian Systems Control Performance Assessment Based on Rational Entropy

Zhou, Jinglin Jia, Yiqing Jiang, Huixia Fan, Shuyi

Control loop Performance Assessment (CPA) plays an important role in system operations. Stochastic statistical CPA index, such as a minimum variance controller (MVC)-based CPA index, is one of the most widely used CPA indices. In this paper, a new minimum entropy controller (MEC)-based CPA method of linear non-Gaussian systems is proposed. In this method, probability density function (PDF) and rational entropy (RE) are respectively used to describe the characteristics and the uncertainty of random variables. To better estimate the performance benchmark, an improved EDA algorithm, which is used to estimate the system parameters and noise PDF, is given. The effectiveness of the proposed method is illustrated through case studies on an ARMAX system.

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# Multi-mode resource leveling in projects with mode-dependent generalized precedence relations

Li, Hongbo Dong, Xuebing

In real-life project management, resource leveling is an important technique to ensure the effective use of resources, in which activities (a) can often be executed in alternative modes and (b) are constrained by precedence relations with minimum and maximum time lags that can be modeled using generalized precedence relations (GPRs). In addition, the values of the time lags tend to depend on activity modes. The resource leveling problem with multiple modes and mode-dependent GPRs (MRLP-GPR) is a generalization of the classic NP-hard resource leveling problem. To our knowledge, no literature exists regarding the MRLP-GPR.

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# Anisotropic adaptive variance scaling for Gaussian estimation of distribution algorithm

Ren, Zhigang Liang, Yongsheng Wang, Lin Zhang, Aimin Pang, Bei Li, Biying

Traditional Gaussian estimation of distribution algorithms (EDAs) are confronted with issues that the variable variances decrease fast and the main search direction tends to become perpendicular to the improvement direction of the fitness function, which reduces the search efficiency of Gaussian EDAs (GEDAs) and makes them subject to premature convergence. In this paper, a novel anisotropic adaptive variance scaling (AAVS) technique is proposed to improve the performance of traditional GEDAs and a new GEDA variant named AAVS-EDA is developed. The advantages of AAVS over the existing variance scaling strategies lie in its ability for tuning the variances and main search direction of GEDA simultaneously, which are achieved by anisotropically scaling the variances along different eigendirections based on corresponding landscape characteristics captured by a simple topology -based detection method. Besides, AAVS-EDA also adopts an auxiliary global monitor to ensure its convergence by shrinking all the variances if no improvement is achieved in a generation. The evaluation results on 30 benchmark functions of CEC2014 test suite demonstrate that AAVS-EDA possesses stronger global optimization efficiency than traditional GEDAs. The comparison with other state-of-the-art evolutionary algorithms also shows that AAVS-EDA is efficient and competitive. (C) 2018 Elsevier B.V. All rights reserved.

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# An insight to the performance of estimation of distribution algorithm for multiple line outage identification

Ahmed, A. Khan, Q. Naeem, M. Iqbal, M. Anpalagan, A. Awais, M.

Realtime information relating to line outages has significant importance to pre-empt against the power system blackouts. Realtime information can be obtained by using phasor measurement units (PMUs) facilitating the realtime synchronized observations of voltage and current phasors at buses being monitored. Different optimization formulations including but not limited to linear, integer, stochastic, mixed integer and NP hard combinatorial optimization have been used to manipulate these phasor measurements for the detection of line outages. Single and double line outages can be addressed using combinatorial optimization but these are infeasible to apply for the detection of multiple line outages as the increased number of lines increases computational complexity. To alleviate the exponentially increased complexities of these combinatorial optimization problems, while investigating for multiple line outage, evolutionary, Estimation of Distribution Algorithm is used. This method gives near optimal solution in which computational complexity and time is reduced efficiently. In this paper we scrutinize the use of phasor angle measurements to detect multiple power line outages. The proposed EDA is compared with binary particle swarm optimization (BPSO) algorithm, adaptive BPSO and genetic algorithm (GA) in terms of line outage detection performance, fitness convergence w.r.t. iterations and time consumption. The simulation results depict that the proposed EDA outperforms the other state of the art algorithms.

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# Dynamic Multi-objective Estimation of Distribution Algorithm based on Domain Adaptation and Nonparametric Estimation

Jiang, Min Qiu, Liming Huang, Zhongqiang Yen, Gary G.

Although dynamic optimization and multi-objective optimization have made considerable progress individually, solving dynamic multi-objective optimization problems remains a monumental challenge since their multiple, conflicting objectives could change over time. In this paper, we propose a Domain Adaptation and Nonparametric Estimation-based Estimation of Distribution Algorithm, called DANE-EDA, to solve dynamic multi-objective optimization problems. Notable features of the proposed algorithm include the importance sampling, nonparametric density estimation, probabilistic prediction, and a domain adaptation technique seamlessly unified under an innovative framework. The design takes full advantage of the powerful Monte-Carlo method and transfer learning technique. This kind of combination will help the proposed algorithm to maintain a delicate exploration exploitation trade-off from temporal and spatial perspectives. At the same time, it will help the proposed algorithm to overcome the shortcomings caused by transfer learning, specifically, the loss of the diversity. After proving convergence and analyzing the computational complexity of the DANE-EDA, we compare the proposed method with nine EDAs or dynamic multi-objective optimization algorithms on twelve different test instances. The experimental results affirm the effectiveness of the proposed method in addressing dynamic multi-objective optimization problems. (C) 2018 Elsevier Inc. All rights reserved.

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# An estimation of distribution algorithm for scheduling problem of flexible manufacturing systems using Petri nets

Wang, XinNian Xing, KeYi Li, XiaoLing Luo, JianChao

Based on the place-timed Petri net models of flexible manufacturing systems (FMSs), this paper proposes a novel effective estimation of distribution algorithm (EDA) for solving the scheduling problem of FMSs. A candidate solution is represented as an individual with two sections: the first contains the route information while the second is a permutation with repetition for parts. The feasibility of individuals is checked and guaranteed by a highly permissiveness deadlock controller. A feasible individual is interpreted into a deadlock-free schedule while the infeasible ones are amended. The probabilistic model in EDA is constructed via a voting procedure. An offspring individual is then produced based on the model from a seed individual, and the set of seed individuals is extracted by a roulette method from the current population. The longest common subsequence is also embedded into the probabilistic model for mining good genes. A modified variable neighborhood search is applied on offspring individuals to obtain better solutions in their neighbors and hence to improve EDA's performance. Computational results show that our proposed algorithm outperforms all the existing ones on benchmark examples for the studied problem. It is of important practice significance for the manufacturing of time-critical and multi-type products. (C) 2017 Elsevier Inc. All rights reserved.

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# Multi-objective hybrid estimation of distribution algorithm-interior point method-based meter placement for active distribution state estimation

Prasad, Sachidananda Mallesham, Vinod Kumar Dulla

This study proposes a new multi-objective hybrid estimation of distribution algorithm (EDA)-interior point method (IPM) algorithm to obtain the optimal location of measuring devices for state estimation (SE) in active distribution networks. The objective functions to be minimised are, the total network configuration cost, the average relative percentage error of bus voltage magnitude and angle estimates. As the objectives are conflicting in nature, a multi-objective Pareto-based non-dominated sorting EDA has been proposed in this study. Moreover, due to poor exploitation capability of the EDA, it is hybridised with IPM to improve its local searching ability in the search space. The hybridisation of EDA and IPM brings a higher degree of balance between the exploration and exploitation capability of the algorithm during the search process. Furthermore, the loads and generators are treated as stochastic variable and the impact of different type of distributed generations on SE performance has also been investigated. The efficiency of the proposed algorithm is tested on PG&amp;E 69-bus system and Indian 85-bus radial distribution network. The obtained results are compared with conventional EDA, particle swarm optimisation, non-dominated sorting genetic algorithm and also with existing techniques in the literature such as dynamic programming and ordinal optimisation algorithm.

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# Hybrid multi-objective Bayesian estimation of distribution algorithm: a comparative analysis for the multi-objective knapsack problem

Martins, Marcella S. R. Delgado, Myriam R. B. S. Luders, Ricardo Santana, Roberto Goncalves, Richard A. de Almeida, Carolina P.

Nowadays, a number of metaheuristics have been developed for efficiently solving multi-objective optimization problems. Estimation of distribution algorithms are a special class of metaheuristic that intensively apply probabilistic modeling and, as well as local search methods, are widely used to make the search more efficient. In this paper, we apply a Hybrid Multi-objective Bayesian Estimation of Distribution Algorithm (HMOBEDA) in multi and many objective scenarios by modeling the joint probability of decision variables, objectives, and the configuration parameters of an embedded local search (LS). We analyze the benefits of the online configuration of LS parameters by comparing the proposed approach with LS off-line versions using instances of the multi-objective knapsack problem with two to five and eight objectives. HMOBEDA is also compared with five advanced evolutionary methods using the same instances. Results show that HMOBEDA outperforms the other approaches including those with off-line configuration. HMOBEDA not only provides the best value for hypervolume indicator and IGD metric in most of the cases, but it also computes a very diverse solutions set close to the estimated Pareto front.

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# A multi-objective optimization model and its evolution-based solutions for the fingertip localization problem

Gong, Dunwei Liu, Ke

Exact fingertip positions are of particular importance to the fingertip-based human–computer interaction. We build a multi-objective optimization model for the problem of fingertip localization, and present a method to solve the above model based on [evolutionary algorithms](https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/evolutionary-algorithms). When building the model, we take the positions of a series of pixels as the decision variable, the shape of the hand-edge curve corresponding to each of the pixels as one objective function, and the distance between each of the pixels and the [gravity center of](https://www.sciencedirect.com/topics/mathematics/center-of-gravity) the palm as the other objective function. In addition, based on the correlation among the positions of pixels of the fingertip regions, we present a multi-objective [estimation of distribution algorithm](https://www.sciencedirect.com/topics/computer-science/estimation-of-distribution-algorithms) to solve the model so as to obtain the best pixel set, thus gaining the fingertip positions. The experimental results demonstrate the effectiveness of the proposed model and algorithm.

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# A new Algorithm based on the Gbest of Particle Swarm Optimization algorithm to improve Estimation of Distribution Algorithm

Zhao, Qiuyue Gao, Ying

In recent years, with the rise of artificial intelligence and deep learning, as an evolutionary algorithm based on probability model, estimation of distribution algorithm has been widely research and development. The estimation of distribution algorithm without the traditional genetic operation such as crossover and mutation, is a new kind of evolution model. As an algorithm based on probabilistic mode, the estimation of distribution algorithm establishes a probabilistic model describing the solution space of optimization problems. With the emergence for big data, the convergence of the algorithm and the requirements for solving precision are also increasing. This paper attempts to improve the distribution estimation algorithm. The optimal population of each iteration is found through the location update of each iteration of the Particle Swarm Optimization (PSO) algorithm. The simulation test was carried out with ten benchmark test function. The proposed algorithm was compared with the GA\_EDA9improved genetic algorithm) and the basic distribution estimation (EDA) algorithm. Experimental results show that the new algorithm is superior to GA\_EDA and basic EDA in terms of convergence and accuracy.

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# An Analysis of the Bias of Variation Operators of Estimation of Distribution Programming

Schweim, Dirk Rothlauf, Franz

Estimation of distribution programming (EDP) replaces standard GP variation operators with sampling from a learned probability model. To ensure a minimum amount of variation in a population, EDP adds random noise to the probabilities of random variables. This paper studies the bias of EDP's variation operator by performing random walks. The results indicate that the complexity of the EDP model is high since the model is overfitting the parent solutions when no additional noise is being used. Adding only a low amount of noise leads to a strong bias towards small trees. The bias gets stronger with an increased amount of noise. Our findings do not support the hypothesis that sampling drift is the reason for the loss of diversity.

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# The Improved Estimation of Distribution Algorithms for Community Detection

Zhou Ben-Da Pan, Zhao Zhang Jinbo

Based on the analysis of local monotonic of modularity function, this paper designs a fast and effective mutation operator, and then proposes an improved Estimation of Distribution Algorithm (EDA) for solving community detection problem. The proposed algorithm is tested on basic network and big scale complex network. Experimental results show that this algorithm can get 0.419 8 for the average Q function while running 100 times, has better performance than Girvan-Newman(GN) algorithm, Fast Newman (FN) algorithm and Tasgin Genetic Algorithm (TGA).

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# NSGA-II/EDA Hybrid Evolutionary Algorithm for Solving Multi-objective Economic/Emission Dispatch Problem

Alawode, Kehinde Olukunmi Adegboyega, Gabriel Adebayo Muhideen, Jubril Abimbola

In this study, a hybrid algorithm which combines the NSGA-II with a modified form of the marginal histogram model Estimation of Distribution Algorithm (EDA), herein called the NSGA-II/EDA is proposed for solving the multi-objective economic/emission power dispatch problem. The goal is to improve the convergence while preserving the diversity properties of the obtained solution set. The effect of variable interaction on the marginal histogram EDA model is reduced by performing multi-scale Principal Component Analysis on the population of solutions. Also, the concepts of non-domination and elitism have been introduced into the marginal histogram model in order for it to handle multiple objectives. Several optimization runs were carried out on the standard multi-objective test problems, including the IEEE 30- and the 118-bus test systems. Standard metrics are used to compare the performance of the developed hybrid approach with that of other multi-objective evolutionary algorithms. The effectiveness of the proposed approach in improved convergence, with good diversity is demonstrated.

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# Expanding variational autoencoders for learning and exploiting latent representations in search distributions

Garciarena, Unai Santana, Roberto Mendiburu, Alexander

In the past, evolutionary algorithms (EAs) that use probabilistic modeling of the best solutions incorporated latent or hidden variables to the models as a more accurate way to represent the search distributions. Recently, a number of neural-network models that compute approximations of posterior (latent variable) distributions have been introduced. In this paper, we investigate the use of the variational autoencoder (VAE), a class of neural-network based generative model, for modeling and sampling search distributions as part of an estimation of distribution algorithm. We show that VAE can capture dependencies between decision variables and objectives. This feature is proven to improve the sampling capacity of model based EAs. Furthermore, we extend the original VAE model by adding a new, fitness-approximating network component. We show that it is possible to adapt the architecture of these models and we present evidence of how to extend VAEs to better fulfill the requirements of probabilistic modeling in EAs. While our results are not yet competitive with state of the art probabilistic-based optimizers, they represent a promising direction for the application of generative models within EDAs.

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# Significance-based Estimation-of-Distribution Algorithms

Doerr, Benjamin Krejca, Martin S.

Estimation-of-distribution algorithms (EDAs) are randomized search heuristics that maintain a stochastic model of the solution space. This model is updated from iteration to iteration based on the quality of the solutions sampled according to the model. As previous works show, this short-term perspective can lead to erratic updates of the model, in particular, to bit-frequencies approaching a random boundary value. This can lead to significant performance losses.

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# Optimization of Contract Distribution Based on Multi-objective Estimation of Distribution Algorithm

Hu, Laihong Yang, Xiaogang Fan, Hongdong

Contract distribution is widely exists in modem commercial society, which mainly depends on qualitative analysis, and there still lack studies of quantitative analysis. Based on multi-objective estimation of distribution algorithm (MOEDA), quantitative research idea on contract distribution is explored in this article. First of all, Multi-objective optimization model is built for contract distribution. Then, the algorithm flow base on MOEDA is designed. At last, simulations are carried out and compare with multi-objective genetic algorithm (MOGA). The simulation results show that the MOEDA performs better than MOGA, and verify the effectiveness and robustness of the proposed method in optimization of contract distribution.

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# An Estimation of Distribution Algorithm for Multi-robot Multi-point Dynamic Aggregation Problem

Xin, Bin Liu, Shiqing Peng, Zhihong Gao, Guanqiang

Multi-Point Dynamic Aggregation (MPDA) is a novel task model for describing the process of multiple robots performing time-variant tasks. In the MPDA problem, several task points are located in different places and their states change over time. Multiple robots aggregate to these task points and execute the tasks cooperatively to make the states of all the task points change to zero. The task planning of MPDA is a typical NP-hard combinatorial optimization problem. Estimation of Distribution Algorithms (EDA) are evolutionary techniques based on probabilistic models. In this paper, a permutation-based EDA is proposed to solve the task planning problems in MPDA. The algorithm uses K-means clustering to update its probabilistic model which follows the multi-modal Gaussian distribution. Experimental results show that the proposed algorithm outperforms other compared methods in solving the task planning problems of MPDA.

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# Hybrid estimation of distribution algorithms for solving a keyboard layout problem

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

The use of smartphones and handheld devices in our daily activities has sharply increased. The added features of wireless technology and related applications on these devices make it possible to write emails, notes, and long text. Even though the most commonly used electronic input device is a keyboard, very little work has been dedicated for finding an optimal layout for this device. In this research, the aim is to propose a better layout for the single-finger keyboard in terms of rapid typing. The keyboard layout problem can be formulated as a quadratic assignment problem, which is one of the hardest combinatorial optimization problems. Some well-known literary works in English are chosen for estimating the keying-in-time. A variant of genetic algorithm, namely, the estimation of distribution algorithms is used to find a better layout. The new layout is found to be efficient compared with some of the existing prominent keyboard layouts.

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# Towards Fully Automated Semantic Web Service Composition Based on Estimation of Distribution Algorithm

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

Web service composition has been a challenging research area, where many researchers have been working on a composition problem that optimizes Quality of service and/or Quality of semantic matchmaking of composite solutions. This NP-hard problem has been successfully handled by many Evolutionary Computation techniques with promising results. Estimation of Distribution has shown its initial promise in solving fully automated service composition, and its success strongly relies on distribution models and sampling techniques. Our recently published work proposed a Node Histogram-Based approach to fully automated service composition. However, many services presented in sampled optimized queues does not contribute to decoded solutions of the queue. Therefore, efforts should be made to focus on learning distributions of component services in solutions. Consequently, we aim to learn more suitable distributions considering services satisfying service dependency in the solutions and use the Edge Histogram Matrix to learn restricted sampled outcomes satisfying the dependency. Besides that, we proposed effective sampling techniques with high efficiency in a straightforward implementation. Our experimental evaluation using benchmark datasets shows our proposed EDA-based approach outperforms two recent approaches regarding both efficiency and effectiveness.

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# An Estimation of Distribution Algorithm for Large-Scale Optimization with Cooperative Co-evolution and Local Search

Lin, Jia-Ying Chen, Wei-Neng Zhang, Jun

Cooperative co-evolution (CC) is an effective framework for evolutionary algorithms (EAs) to solve large-scale optimization problems. By combining a divide-and-conquer strategy and the classic evolutionary algorithms (EA) like genetic algorithm (GA), CC has shown promising performance in many fields. As a family of EAs, the estimation of distribution algorithm (EDA) is good at search diversity maintenance, but its capability in solving large-scale problems has not been fully explored. In this paper, we aim to propose a new estimation of distribution algorithm with the cooperative co-evolution framework (EDACC). The proposed EDACC has the following features. (1) The differential grouping (DG) strategy is applied for variable decomposition. (2) A combination of the Gaussian and Cauchy distributions are adopted to generate offspring. (3) A local search method is performed in promising domains to accelerate the search. To verify the performance of EDACC, experiments are conducted on 20 single-objective functions in the CEC 2010 benchmarks. The experimental results show that EDACC can still achieve competitive performance in spite of the weakness of the original EDAs like the low accuracy in global optima searching compared with classical EAs.

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# SELF-CALIBRATION OF TRAFFIC SURVEILLANCE CAMERAS BASED ON MOVING VEHICLE APPEARANCE AND 3-D VEHICLE MODELING

Wang, Na Du, Haiqing Liu, Yong Tang, Zheng Hwang, Jenq-Neng

This paper proposes an effective and practical method for self-calibration of traffic surveillance cameras. Based on analyzing multiple moving vehicles across multiple frames, the Canny edge detector and Hough transform are first adopted to obtain orthogonal horizontal vanishing points pairs, from which corresponding vertical vanishing points are derived. Next, mean shift clustering and Laplace linear regression are employed to deal with noise and outliers during estimation of vanishing points. To overcome the unreliable estimation issues of orthogonal vanishing points pairs, we further utilize the projective line segments obtained from 3-D vehicle model to create more reliable pairs and iteratively improve the calibration results. Finally, the estimation of distribution algorithm (EDA) is also applied to relax the assumptions made on camera parameters and the moving trajectories of vehicles during the iterations. Experimental results on different datasets prove the feasibility of our proposed scheme.

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# The N-Tuple Bandit Evolutionary Algorithm for Game Agent Optimisation

Lucas, Simon M. Liu, Jialin Perez-Liebana, Diego

This paper describes the N-Tuple Bandit Evolutionary Algorithm (NTBEA), an optimisation algorithm developed for noisy and expensive discrete (combinatorial) optimisation problems. The algorithm is applied to two game-based hyperparameter optimisation problems. The N-Tuple system directly models the statistics, approximating the fitness and number of evaluations of each modelled combination of parameters. The model is simple, efficient and informative. Results show that the NTBEA significantly outperforms grid search and an estimation of distribution algorithm.

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# Increasing Boosting Effectiveness with Estimation of Distribution Algorithms

Cagnini, Henry E. L. Basgalupp, Marcio Porto Barros, Rodrigo C.

Ensemble learning is the machine learning paradigm that aims at integrating several base learners into a single system under the assumption that the collective consensus outperforms a single strong learner, be it regarding effectiveness, efficiency, or any other problem-specific metric. Ensemble learning comprises three main phases: generation, selection, and integration, and there are several possible (deterministic or stochastic) strategies for executing one or more of those phases. In this paper, our focus is on improving the predictive accuracy of the well-known AdaBoost algorithm. By using its former voting weights as starting point in a global search carried by an Estimation of Distribution Algorithm, we are capable of improving AdaBoost up to approximate to 11% regarding predictive accuracy in a thorough experimental analysis with multiple public datasets.

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# Computational Intelligence for Parameter Estimation of Biochemical Systems

Nobile, Marco S. Tangherloni, Andrea Rundo, Leonardo Spolaor, Simone Besozzi, Daniela Mauri, Giancarlo Cazzaniga, Paolo

In the field of Systems Biology, simulating the dynamics of biochemical models represents one of the most effective methodologies to understand the functioning of cellular processes in normal or altered conditions. However, the lack of kinetic rates, necessary to perform accurate simulations, strongly limits the scope of these analyses. Parameter Estimation (PE), which consists in identifying a proper model parameterization, is a non-linear, non-convex and multi-modal optimization problem, typically tackled by means of Computational Intelligence techniques, such as Evolutionary Computation and Swarm Intelligence. In this work, we perform a thorough investigation of the most widespread methods for PE-namely, Artificial Bee Colony (ABC), Covariance Matrix Adaptation Evolution Strategy (CMA-ES), Differential Evolution (DE), Estimation of Distribution Algorithm (EDA), Genetic Algorithms (GAs), Particle Swarm Optimization (PSO), and Fuzzy Self-Tuning PSO (FST-PSO)-comparing their performances on a set of synthetic (yet realistic) biochemical models of increasing size and complexity. Our results show that a variant of the settings-free FST-PSO algorithm can consistently outperform all other methods; ABC and GAs represent the most performing alternatives, while methods based on multivariate normal distributions (e.g., CMA-ES, EDA) struggle to keep pace with the other approaches.

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# Multi-objective Job Shop Rescheduling with Estimation of Distribution Algorithm

Hao, Xinchang Sun, Lu Gen, Mitsuo

To solve the moJSRP model, with the framework of proposed MoEDA, the probability model of the operation sequence is estimated firstly. For sampling the processing time of each operation with the Monte Carlo methods, allocation method is used to decide the operation sequence, and then the expected makespan and total tardiness of each sampling are evaluated. Subsequently, updating mechanism of the probability models is proposed according to the best solutions to obtain. Finally, for comparing with some existing algorithms by numerical experiments on the benchmark problems, we demonstrate the proposed effective estimation of distribution algorithm can obtain an acceptable solution in the aspects of schedule quality and computational efficiency.

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# Restricted Boltzmann Machine-Assisted Estimation of Distribution Algorithm for Complex Problems

Bao, Lin Sun, Xiaoyan Chen, Yang Man, Guangyi Shao, Hui

A novel algorithm, called restricted Boltzmann machine-assisted estimation of distribution algorithm, is proposed for solving computationally expensive optimization problems with discrete variables. First, the individuals are evaluated using expensive fitness functions of the complex problems, and some dominant solutions are selected to construct the surrogate model. The restricted Boltzmann machine (RBM) is built and trained with the dominant solutions to implicitly extract the distributed representative information of the decision variables in the promising subset. The visible layer's probability of the RBM is designed as the sampling probability model of the estimation of distribution algorithm (EDA) and is updated dynamically along with the update of the dominant subsets. Second, according to the energy function of the RBM, a fitness surrogate is developed to approximate the expensive individual fitness evaluations and participates in the evolutionary process to reduce the computational cost. Finally, model management is developed to train and update the RBM model with newly dominant solutions. A comparison of the proposed algorithm with several state-of-the-art surrogate-assisted evolutionary algorithms demonstrates that the proposed algorithm effectively and efficiently solves complex optimization problems with smaller computational cost.

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# Distance-Based Exponential Probability Models for Constrained Combinatorial Problems

Ceberio, Josu Mendiburu, Alexander Lozano, Jose A.

Estimation of Distribution Algorithms (EDAs) have already demonstrated their utility when solving a broad range of combinatorial problems. However, there is still room for methodological improvement when approaching problems with constraints. The great majority of works in the literature implement repairing or penalty schemes, or use ad-hoc sampling methods in order to guarantee the feasibility of solutions. In any of the previous cases, the behavior of the EDA is somehow denaturalized, since the sampled set does not follow the probability distribution estimated at that step. In this work, we present a general method to approach constrained combinatorial optimization problems by means of EDAs. This consists of developing distance-based exponential probability models defined exclusively on the set of feasible solutions. In order to illustrate this procedure, we take the 2-partition balanced Graph Partitioning Problem as a case of study, and design efficient learning and sampling methods to use distance-based exponential probability models in EDAs.

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# Knowledge-Driven Automated Web Service Composition-An EDA-Based Approach

Wang, Chen Ma, Hui Chen, Aaron Hartmann, Sven

Service Oriented Architecture starts with the concept of web services, which give birth to an application of web service composition that selects and combines web services to accommodate users' complex requirements. These requirements often cover functional parts (i.e., semantic matchmaking of services' inputs and outputs) and nonfunctional parts (i.e., Quality of Service). Service composition is an NP-hard problem. Evolutionary Computation (EC) techniques have been successfully proposed for finding solutions with near-optimal Quality of Semantic Matchmaking (QoSM) and/or Quality of Service (QoS) using knowledge of promising solutions. Estimation of Distribution Algorithm (EDA) has been applied to semi-automated QoS-aware service composition, since it is capable of extracting knowledge of good solutions into a explicit probabilistic model. However, existing works do not support extracting knowledge for fully automated service composition that does not obeying a given workflow. In this paper, we proposed an EDA-based fully automated service composition approach to jointly optimize Quality of Semantic Matchmaking and Quality of Services. This approach is compared with a PSO-based approach that was recently proposed to solve the same problem.

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# Evaluating the Max-Min Hill-Climbing Estimation of Distribution Algorithm on B-Functions

Madera, Julio Ochoa, Alberto

In this paper we evaluate a new Estimation of Distribution Algorithm (EDA) constructed on top of a very successful Bayesian network learning procedure, Max-Min Hill-Climbing (MMHC). The aim of this paper is to check whether the excellent properties reported for this algorithm in machine learning papers, have some impact on the efficiency and efficacy of EDA based optimization. Our experiments show that the proposed algorithm outperform wellknown state of the art EDA like BOA and EBNA in a test bed based on B-functions. On the basis of these results we conclude that the proposed scheme is a promising candidate for challenging real-world applications, specifically, problems related to the areas of Data Mining, Patter Recognition and Artificial Intelligence.

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# CSA-DE/EDA: A Clonal Selection Algorithm Using Differential Evolution and Estimation of Distribution Algorithm

Li, Zhe Xia, Yong Sahli, Hichem

The clonal selection algorithm (CSA), which describes the basic features of an immune response to an antigenic stimulus, has drawn a lot of research attention in the bio-inspired computing community, due to its highly-adaptive and easy-to-implement nature. However, despite many successful applications, this optimization technique still suffers from limited ability to explore the solution space. In this paper, we incorporate the differential evolution (DE) and estimation of distribution algorithm (EDA) into CSA, and thus propose a novel bio-inspired computing algorithm called CSA-DE/EDA. In this algorithm, the hypermutaion and receptor editing processes are implemented based on DE and EDA, which provide improved local and global search ability, respectively. We have applied this algorithm to brain image segmentation. Our comparative experimental results suggest that the proposed CSA-DE/EDA algorithm outperforms several bio-inspired computing techniques on the segmentation problem.

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# A Multi-model Estimation of Distribution Algorithm for Agent Routing Problem in Multi-point Dynamic Task

Lu, Sai Xin, Bin Dou, Lihua Wang, Ling

The agent routing problem in multi-point dynamic task (ARP-MPDT) is a multi-task routing problem of a mobile agent. In this problem, there are multiple tasks to be carried out in different locations. As time goes on, the state of each task will change nonlinearly. The agent must go to the task points in turn to perform the tasks, and the execution time of each task is related to the state of the task point when the agent arrives at the point. ARP-MPDT is a typical NP-hard optimization problem. In this paper, we establish the nonlinear ARP-MPDT model. A multi-model estimation of distribution algorithm (EDA) employing node histogram models (NHM) and edge histogram models (EHM) in probability modeling is used to solve the ARP-MPDT. The selection ratio of NHM and EHM probability models is adjusted adaptively. Finally, performance of the algorithm for solving the ARP-MPDT problem is verified by the computational experiments.

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# Hybrid Estimation of Distribution Algorithm for Blocking Flow-Shop Scheduling Problem with Sequence-Dependent Setup Times

Zhang, Zi-Qi Qian, Bin Liu, Bo Hu, Rong Zhang, Chang-Sheng

This paper presents an innovative hybrid estimation of distribution algorithm, named HEDA, for blocking flow-shop scheduling problem (BFSP) with sequence-dependent setup times (SDSTs) to minimize the makespan criterion, which has been proved to be typically NP-hard combinatorial optimization problem with strong engineering background. Firstly, several efficient heuristics are proposed according to the property of BFSP with SDSTs. Secondly, the genetic information of both the order of jobs and the promising blocks of jobs are concerned to generate the guided probabilistic model. Thirdly, after the HEDA-based global exploration, a reference sequence-based local search with path relinking technique is developed and incorporated into local exploitation to escape from local optima and improve the convergence property. Due to the reasonable balance between EDA-based global exploration and sequence dependent local exploitation as well as comprehensive utilization of the speedup evaluation method, the BFSP with SDSTs can be solved effectively and efficiently. Finally, computational results and comparisons with the existing state-of-the-art algorithms are carried out, which demonstrate the superiority of the proposed HEDA in terms of searching quality, robustness, and efficiency.

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# An Improved Discrete Migrating Birds Optimization for Lot-Streaming Flow Shop Scheduling Problem with Blocking

Han, Yuyan Li, Junqing Sang, Hongyan Tian, Tian Bao, Yun Sun, Qun

Blocking lot-streaming flow shop (BLSFS) scheduling problems have considerable applications in various industrial systems, however, they have not yet been well studied. In this paper, an optimization model of BLSFS scheduling problems is formulated, and an improved migrating birds optimization (iMBO) algorithm is proposed to solve the above optimization problem with the objective of minimizing makespan. The proposed algorithm utilizes discrete job permutations to represent solutions, and applies multiple neighborhoods based on insert and swap operators to improve the leading solution. An estimation of distribution algorithm (EDA) is employed to obtain solutions for the rest migrating birds. A local search based on the insert neighborhood is embedded to improve the algorithm's local exploitation ability. iMBO is compared with the existing discrete invasive weed optimization, estimation of distribution algorithm and modified MBO algorithms based on the well-known lotstreaming flow shop benchmark. The computational results and comparison demonstrate the superiority of the proposed iMBO algorithm for the BLSFS scheduling problems with makespan criterion.

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# Decentralized Optimization Algorithms for Variable Speed Pumps Operation Based on Local Interaction Game

Wang, Shi-Qiang Xing, Jian-Chun Jiang, Zi-Yan Dai, Yun-Chuang

A fully distributed optimal control strategy for the parallel variable speed pumps in heating, ventilation, and air-conditioning (HVAC) systems is proposed. Compared with the traditional centralized method, the efficient control and coordination are scattered to every updated smart pump without the need for a monitoring host. Similar to the structure, mechanism, and characteristics of biological communities, a smart pump can communicate with adjacent nodes and operate collaboratively to complete pumps group operation with the least total power consumption under load demand and system constraints. And a decentralized optimization method that is decentralized estimation of distribution algorithm (DEDA) under local interaction games framework has been transplanted to the proposed structure to optimize the pumps working in parallel mode. Besides, convergence property of the two novel mechanisms is analyzed theoretically. Finally, simulation studies have been conducted based on the models of a physical pumps system, and the performance of the proposed algorithm is compared with centralized algorithms in terms of both effectiveness and stability. The results provide support for the validity of the proposed algorithms and control structure.

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# Modelling and solving a cost-oriented resource-constrained multi-model assembly line balancing problem

Pereira, Jordi

A line balancing problem considers the assignment of operations to workstations in an assembly line. While assembly lines are usually associated to mass production of standardised goods, their advantages have led to their widespread use whenever a product-oriented production system is applicable and the benefits of the labour division and specialisation are significant, even when some of its characteristics may deviate from classical assembly lines. In this work, we study a line balancing problem found in the textile industry in which the line must be balanced for multiple types of goods taking into account resource requirements. In order to solve the problem, a hybrid method that combines classical methods for line balancing with an Estimation of Distribution Algorithm is proposed. Computational experiments show that the new procedure improves upon the state of the art when compared using a benchmark set derived from the literature, as well as when compared using data from the manufacturer that originated this research work.

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# Multimodal Estimation of Distribution Algorithm Based on Cooperative Clustering Strategy

Huang, Shanshan Jiang, Houming

Multimodal optimization is becoming more and more important. Among all the optimization algorithms, estimation of distribution algorithm (EDA) attracts more attention because of its simple principle and special mechanism. Unfortunately, it loses feasibility and effectiveness in multimodal problems because of premature convergence and the missing of multimodality-specific mechanism. So niching is adopted to help EDA to locate diverse promising solution regions in multimodal optimization. However, many of the niching techniques are either sensitive to parameters or cost a number of fitness evaluations. In this paper a new proposed fast cooperative clustering strategy is adopted to offer improved assistance for locating multiple optima based on both decision and target space information. Taking the advantage of EDA in preserving high diversity, this paper proposes a cooperative clustering based multimodal EDA (CMEDA). Integrated with new proposed cooperative clustering strategy, multimodal problems are divided into certain promising regions automatically. Then each cluster independently runs a separate optimizer in parallel to search promising regions carefully, which can avoid premature convergence greatly. Based on the results of clustering, the value of key parameter is determined by statistic information but not artificial setting. Then a balance between exploration and exploitation is achieved. Experimental results indicate that the proposed technique is an effective and efficient algorithm which can not only explores and exploits the promising regions in the search space effectively but also obtain the global optima superior to the typical multimodal EDA (MEDA).

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# Estimation of Distribution Algorithm for Autonomous Underwater Vehicles Path Planning

Liu, Run-Dong Zhan, Zhi-Hui Chen, Wei-Neng Yu, Zhiwen Zhang, Jun

Path planning is that given the start point and target point, finding out a shortest or smallest cost path. In recent years, more and more researchers use evolutionary algorithms (EAs) to solve path planning problems, such as genetic algorithms (GAs) and particle swarm optimization (PSO). Estimation of distribution algorithms (EDAs) belong to a kind of EAs that can make good use of global statistic information of the population. However, EDAs are seldom used to solve path planning problems. In this paper, we propose an EDA variant named adaptive fixed-height histogram (AFHH) algorithm to make path planning for autonomous underwater vehicles (AUVs). The proposed AFHH algorithm can adaptively shrink its search space to make good use of computational resource. We use a regenerate approach to avoid getting stuck in local optimum. We also measure the ability of fixed-height histogram (FHH) algorithm for path planning. We simulate a 3-D environment to measure the ability of the proposed AFHH algorithm. The results show that AFHH has a good convergence rate and can also get better performance.

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# An Improved Estimation of Distribution Algorithm for Cloud Computing Resource Scheduling

Sun, Haisheng Liu, Chuang Xu, Rui Chen, Huaping

This paper focuses on cloud computing resource scheduling on the Soft as a Service layer and aims at minimizing the user costs by regarding the deadline as a constraint for scheduling independent tasks. Existing works with evolutionary computation approaches fail to describe the interactions among independent tasks. To overcome this problem, an improved Markov-chain-based estimation of distribution algorithm is proposed, and the concept of virtual machine selection diversity is created to construct the probabilistic model rationally. Moreover, one heuristic rule related to the investigated problem is created to keep the population maintaining a high diversity in the evolution process. The experiment results show that the proposed algorithm not only obtains the best solution quality but also has competitive convergence among all compared algorithms.

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# Improving Estimation of Distribution Algorithms with Heavy-Tailed Student's t Distributions

Liu, Bin Cheng, Shi Shi, Yuhui

As a derivative-free optimization method, the estimation of distribution algorithm (EDA) usually leverages a Gaussian or a Gaussian mixture model to represent the distribution of promising solutions that have been found so far. This paper investigates the application of an alternative model, namely the heavier-tailed Student's t distribution, to implement EDA. Two corresponding algorithms, termed ESTDA and EMSTDA, are developed, respectively. The ESTDA employs a single Student's t model to represent the distribution of the promising solutions. The EMSTDA uses a mixture of Student's t models to take account of hard multimodal cases. These methods are evaluated through extensive and in-depth numerical experiments using over a dozen of benchmark objective functions. Empirical results show that they provide remarkably better performance than their Gaussian counterparts in most cases under consideration.

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# Independent Tasks Scheduling in Cloud Computing via Improved Estimation of Distribution Algorithm

Sun, Haisheng Xu, Rui Chen, Huaping

To minimize makespan for scheduling independent tasks in cloud computing, an improved estimation of distribution algorithm (IEDA) is proposed to tackle the investigated problem in this paper. Considering that the problem is concerned with multi-dimensional discrete problems, an Unproved population-based incremental learning (PBIL) algorithm is applied, which the parameter for each component is independent with other components in PBIL. In order to improve the performance of PBIL, on the one hand, the integer encoding scheme is used and the method of probability calculation of PBIL is improved by using the task average processing time; on the other hand, an effective adaptive learning rate function that related to the number of iterations is constructed to trade off the exploration and exploitation of IEDA. in addition, both enhanced Max-Min and Min-Min algorithms are properly introduced to form two initial individuals. In the proposed IEDA, an improved genetic algorithm (IGA) is applied to generate partial initial population by evolving two initial individuals and the rest of initial individuals are generated at random. Finally, the sampling process is divided into two parts including sampling by probabilistic model and IGA respectively. The experiment results show that the proposed IEDA not only gets better solution, but also has faster convergence speed.

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# An Improved Shuffled Frog Leaping Algorithm and Its Application in Dynamic Emergency Vehicle Dispatching

Duan, Xiaohong Niu, Tianyong Huang, Qi

The traditional method for solving the dynamic emergency vehicle dispatching problem can only get a local optimal strategy in each horizon. In order to obtain the dispatching strategy that can better respond to changes in road conditions during the whole dispatching process, the real-time and time-dependent link travel speeds are fused, and a time-dependent polygonal-shaped link travel speed function is set up to simulate the predictable changes in road conditions. Response times, accident severity, and accident time windows are taken as key factors to build an emergency vehicle dispatching model integrating dynamic emergency vehicle routing and selection. For the unpredictable changes in road conditions caused by accidents, the dispatching strategy is adjusted based on the real-time link travel speed. In order to solve the dynamic emergency vehicle dispatching model, an improved shuffled frog leaping algorithm (ISFLA) is proposed. The global search of the improved algorithm uses the probability model of estimation of distribution algorithm to avoid the partial optimal solution. Based on the Beijing expressway network, the efficacy of the model and the improved algorithm were tested from three aspects. The results have shown the following: (1) Compared with SFLA, the optimization performance of ISFLA is getting better and better with the increase of the number of decision variables. When the possible emergency vehicle selection strategies are 815, the objective function value of optimal selection strategies obtained by the base algorithm is 210.10% larger than that of ISFLA. (2) The prediction error of the travel speed affects the accuracy of the initial emergency vehicle dispatching. The prediction error of +/- 10 can basically meet the requirements of the initial dispatching. (3) The adjustment of emergency vehicle dispatching strategy can successfully bypassed road sections affected by accidents and shorten the response time.

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# Improved Alopex-based evolutionary algorithm by Gaussian copula estimation of distribution algorithm and its application to the Butterworth filter design

Yang, Yihang Cheng, Xiang Cheng, Junrui Jiang, Da Li, Shaojun

The application of evolutionary algorithms (EAs) is becoming widespread in engineering optimisation problems because of their simplicity and effectiveness. The Alopex-based evolutionary algorithm (AEA) possesses the basic characteristics of heuristic search algorithms but is lacking in adequate information about the fitness landscape of the input domain, reducing the convergence speed. To improve the performance of AEA, the Gaussian copula estimation of distribution algorithm (EDA) is embedded into the original AEA in this paper. With the help of Gaussian copula EDA, precise probability models are built utilising the best solutions, which can increase the convergence speed, and at the same time, keep the population diversity as much as possible. The simulation results on the benchmark functions and the application to the Butterworth filter design demonstrate the efficiency and effectiveness of the proposed algorithm, compared with several other EAs.

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# Multiple Power Line Outage Detection in Smart Grids: Probabilistic Bayesian Approach

Ahmed, Ashfaq Awais, Muhammad Naeem, Muhammad Iqbal, Muhammad Ejaz, Waleed Anpalagan, Alagan Kim, Hongseok

Efficient power line outage identification is an important step which ensures reliable and smooth operation of smart grids. The problem of multiple line outage detection (MLOD) is formulated as a combinatorial optimization problem and known to be NP-hard. Such a problem is optimally solvable with the help of an exhaustive evaluation of all possible combinations of lines in outage. However, the size of search space is exponential with the number of power lines in the grid, which makes exhaustive search infeasible for practical sized smart grids. A number of published works on MLOD are limited to identify a small, constant number of lines outages, usually known to the algorithm in advanced. This paper applies the Bayesian approach to solve the MLOD problem in linear time. In particular, this paper proposes a low complexity estimation of outage detection algorithm, based on the classical estimation of distribution algorithm. Thanks to an efficient thresholding routine, the proposed solution avoids the premature convergence and is able to identify any arbitrary number (combination) of line outages. The proposed solution is validated against the IEEE-14 and 57 bus systems with several random line outage combinations. Two performance metrics, namely, success generation ratio and percentage improvement have been introduced in this paper, which quantify the accuracy as well as convergence speed of proposed solution. The comparison results demonstrate that the proposed solution is computationally efficient and outperforms a number of classical meta-heuristics.

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# Analysing a Hybrid Model-Based Evolutionary Algorithm for a Hard Grouping Problem

Raggl, Sebastian Beham, Andreas Wagner, Stefan Affenzeller, Michael

We present a new hybrid model-based algorithm called Memetic Path Relinking (MemPR). MemPR incorporates ideas of memetic, evolutionary, model-based algorithms and path relinking. It uses different operators that compete to fill a small population of high quality solutions. We present a new hard grouping problem derived from a real world transport lot building problem. In order to better understand the algorithm as well as the problem we analyse the impact of the different operators on solution quality and which operators perform best at which stage of optimisation. Finally we compare MemPR to other state-of-the-art algorithms and find that MemPR outperforms them on real-world problem instances.

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# Estimation of distribution algorithm with path relinking for the blocking flow-shop scheduling problem

Shao, Zhongshi Pi, Dechang Shao, Weishi

This article presents an effective estimation of distribution algorithm, named P-EDA, to solve the blocking flow-shop scheduling problem (BFSP) with the makespan criterion. In the P-EDA, a Nawaz-Enscore-Ham (NEH)-based heuristic and the random method are combined to generate the initial population. Based on several superior individuals provided by a modified linear rank selection, a probabilistic model is constructed to describe the probabilistic distribution of the promising solution space. The path relinking technique is incorporated into EDA to avoid blindness of the search and improve the convergence property. A modified referenced local search is designed to enhance the local exploitation. Moreover, a diversity-maintaining scheme is introduced into EDA to avoid deterioration of the population. Finally, the parameters of the proposed P-EDA are calibrated using a design of experiments approach. Simulation results and comparisons with some well-performing algorithms demonstrate the effectiveness of the P-EDA for solving BFSP.

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# Optimization of buffer allocation in unreliable production lines based on availability evaluation

Zhou, Bing-hai Liu, Yu-Wang Yu, Jia-di Tao, Da

The buffer allocation problem is an important issue in production lines design. In this paper, we present new evaluation and optimization methods to optimally allocate buffers in unreliable production lines. Through analyzing different states of the machines and buffers by Markov process and incorporating the aggregation method, we make an evaluation on the system availability, instead of the throughput rate of the line. The optimization method is proposed by combining particle swarm optimization and estimation of distribution algorithm to maximize the system availability. It generates the new populations by estimation of distribution algorithm and particle swarm optimization to take their respective advantages in global and local optimization. Numerical tests and simulations are performed to validate the performance of the evaluation and optimization methods. The results indicate the effectiveness and efficiency of the proposed methods.

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# Determining the inspection intervals for one-shot systems with support equipment

Zhao, Qian Qian Yun, Won Young

This paper considers systems that comprise one-shot devices and support equipment. One-shot devices are stored for long periods of time, and failures are detected only upon inspection. The support equipment needed to operate one-shot devices is maintained immediately upon failure. This paper addresses the inspection schedule problem for such systems with limited maintenance resources. The interval availability and life cycle cost are used as optimization criteria. The aim is to determine near-optimal inspection intervals for one-shot systems to minimize the expected life cycle cost and satisfy the target interval availability between inspection periods. An estimation of distribution algorithm (EDA) and a heuristic method are proposed to find the near-optimal solutions, and numerical examples are given to demonstrate the effects of the various model parameters to the near-optimal inspection intervals. (C) 2017 Elsevier Ltd. All rights reserved.

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# Deadlock-Free Scheduling of Flexible Assembly Systems Based on Petri Nets and Local Search

Luo, JianChao Liu, ZhiQiang Zhou, MengChu Xing, KeYi

Deadlock-free scheduling and control is critical for optimizing the performance of flexible assembly systems (FASs). Based on the Petri net models of FASs, this paper integrates a deadlock prevention policy with local search and develops a novel deadlock-free scheduling algorithm. A solution of the scheduling problem is coded as a chromosome representation that is a permutation with repetition of parts. By using the deadlock prevention policy, a repairing algorithm (RA) is developed to repair unfeasible chromosomes. A perturbation strategy based on estimation of distribution algorithm is developed to escape from local optima. Moreover, to improve population diversity, an acceptance criterion (AC) based on Pareto dominance is proposed. The chromosome representation, RA, perturbation strategy, and AC together support the cooperative aspect of local search for scheduling problems strongly.

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