# Significance-Based Estimation-of-Distribution Algorithms

Doerr, Benjamin Krejca, Martin S.

Estimation-of-distribution algorithms (EDAs) are randomized search heuristics that create a probabilistic model of the solution space, which is updated iteratively, based on the quality of the solutions sampled according to the model. As previous works show, this iteration-based perspective can lead to erratic updates of the model, in particular, to bit-frequencies approaching a random boundary value. In order to overcome this problem, we propose a new EDA based on the classic compact genetic algorithm (cGA) that takes into account a longer history of samples and updates its model only with respect to information which it classifies as statistically significant. We prove that this significance-based cGA (sig-cGA) optimizes the commonly regarded benchmark functions OneMax (OM), LeadingOnes, and BinVal all in quasilinear time, a result shown for no other EDA or evolutionary algorithm so far. For the recently proposed stable compact genetic algorithm—an EDA that tries to prevent erratic model updates by imposing a bias to the uniformly distributed model—we prove that it optimizes OM only in a time exponential in its hypothetical population size. Similarly, we show that the convex search algorithm cannot optimize OM in polynomial time.

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A novel strategy for power sources management in connected plug-in hybrid electric vehicles based on mobile edge computation framework

Zhang, Yuanjian Guo, Chong Liu, Yonggang Ding, Fei Chen, Zheng Hao, Wanming

This paper proposes a novel control framework and the corresponding strategy for power sources management in connected plug-in hybrid electric vehicles (cPHEVs). A mobile edge computation (MEC) based control framework is developed first, evolving the conventional on-board vehicle control unit (VCU) into the hierarchically asynchronous controller that is partly located in cloud. Elaborately contrastive analysis on the performance of processing capacity, communication frequency and communication delay manifests dramatic potential of the proposed framework in sustaining development of the cooperative control strategy for cPHEVs. On the basis of MEC based control framework, a specific cooperative strategy is constructed. The novel strategy accomplishes energy flow management between different power sources with incorporation of the active energy consumption plan and adaptive energy consumption management. The method to generate the reference battery state-of-charge (SOC) trajectories in energy consumption plan stage is emphatically investigated, fast outputting reference trajectories that are tightly close to results by global optimization methods. The estimation of distribution algorithm (EDA) is employed to output reference control policies under the specific terminal conditions assigned via the machine learning based method. Finally, simulation results highlight that the novel strategy attains superior performance in real-time application that is close to the offline global optimization solutions.

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# Vine copula-based EDA for dynamic multiobjective optimization

Cheriet, Abdelhakim

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

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

Ibrahim, Saber Jarboui, Bassem

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

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# Multi-objective hybrid decomposition and local dominance based meter placement for distribution system state estimation

Chintala, Bhanu Prasad Vinod Kumar, D. M.

The study proposes a new hybrid multi-objective evolutionary optimisation algorithm based on decomposition and local dominance for meter placement in distribution system state estimation. The evenly distributed qualitative and diverse solutions on the Pareto front are required for a decision-maker for selecting a final optimal solution. Such a Pareto front can be achieved by obtaining the balance between convergence and diversity of multi-objective optimisation algorithm. Therefore, the proposed method combined dominance and decomposition techniques, modelled meter placement as a constrained combinatorial multi-objective optimisation. The meter placement is designed as a trade-off between three objectives that are minimising the cost of the meters, average relative percentage error (ARPE) of voltage magnitude and ARPE of voltage angle. As the meter placement problem is a combinatorial optimisation, the binomial distribution-based Monte Carlo method is utilised to initialise the population, which aims to improve the diversity, as a consequence it improves the convergence, which is a by-product of this method. The results of the proposed method are compared with multi-objective evolutionary algorithm based on decomposition, non-dominated sorting genetic algorithm-II and with multi-objective hybrid particle swarm optimisation-krill herd algorithm, multi-objective hybrid estimation of distribution algorithm-interior point method and demonstrated on PG&amp;E 69-bus distribution system and Practical Indian 85-bus distribution system.

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# Lower bounds on the run time of the Univariate Marginal Distribution Algorithm on OneMax

Krejca, Martin S. Witt, Carsten

The Univariate Marginal Distribution Algorithm (UMDA) - a popular estimation-of-distribution algorithm - is studied from a run time perspective. On the classical OneMax benchmark function on bit strings of length n, a lower bound of Omega(lambda + mu root n + n logn), where mu and lambda are algorithm-specific parameters, on its expected run time is proved. This is the first direct lower bound on the run time of UMDA. It is stronger than the bounds that follow from general black-box complexity theory and is matched by the run time of many evolutionary algorithms. The results are obtained through advanced analyses of the stochastic change of the frequencies of bit values maintained by the algorithm, including carefully designed potential functions. These techniques may prove useful in advancing the field of run time analysis for estimation-of-distribution algorithms in general. (C) 2018 Elsevier B.V. All rights reserved.

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# Bound-guided hybrid estimation of distribution algorithm for energy-efficient robotic assembly line balancing

Sun, Bin-qi Wang, Ling Peng, Zhi-ping

Under the pressure of climate change, energy-efficient manufacturing has attracted much attention. Robotic assembly lines are widely-used in automotive and electronic manufacturing. It is necessary to consider the energy saving and economic criteria simultaneously when robots are utilized to operate assembly tasks replacing human labor. This paper addresses an energy-efficient robotic assembly line balancing (EERALB) problem with the criteria to minimize both the cycle time and total energy consumption. We present a multi-objective mathematical model and propose a bound-guided hybrid estimation of distribution algorithm to solve the problem. When designing the optimization algorithm, we adopt estimation of distribution algorithm (EDA) to tackle the task assignment, and design a non-dominated robot allocation (NGRA) heuristic which is embedded into the EDA to allocate suitable robot to each workstation. Moreover, we propose a bound-guided sampling (BGS) method, which is able to reduce the search space of EDA and focus the search on the promising area. The computational complexity of the proposed algorithm is analyzed and the effectiveness of the proposed NGRA and BGS is tested. In addition, we compare the performances of the proposed mathematical model and the proposed algorithm with those of the existing model and algorithms on a set of widely-used benchmark instances. Comparative results demonstrate the effectiveness of the proposed model and algorithm.

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# Language model based interactive estimation of distribution algorithm

Chen, Yang Jin, Yaochu Sun, Xiaoyan

It is very hard, if not impossible to use analytical objective functions for optimization of personalized search due to the difficulties in mathematically describing qualitative problems. To solve such optimization problems, interactive evolutionary algorithms, which can make use of human preferences, are highly desirable. However, due to the lack of effective encoding methods, interactive evolutionary algorithms have been limited to numerically encoded optimization problems. In practice, however, linguistic terms (words) are the most natural expression of human preferences, and they are also commonly used to describe items in personalized search or E-commerce; therefore, language models better suit encoding, and the optimization of personalized search is converted into a dynamic document matching problem. To optimize word-described personalized search, we propose a novel interactive estimation of distribution algorithm. This algorithm combines a language model-based encoding approach, a Dirichlet-Multinomial compound distribution-based preference expression, and a Bayesian inference mechanism. The proposed algorithm is applied to two personalized search cases to demonstrate the capability of the algorithm in ensuring a more efficient and accurate search with less user fatigue. (C) 2020 Elsevier B.V. All rights reserved.

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# Restricted Boltzmann Machine-driven Interactive Estimation of Distribution Algorithm for personalized search

Bao, Lin Sun, Xiaoyan Chen, Yang Gong, Dunwei Zhang, Yongwei

Effective and efficient personalized search is one of the most pursued objectives in the era of big data. The challenge of this problem lies in its complex quantifying evaluations and dynamic user preferences. A user-involved interactive evolutionary algorithm is a good choice if it has reliable preference surrogate and powerful evolutionary strategies. A Restricted Boltzmann Machine (RBM) assisted Interactive Estimation of Distribution Algorithm (IEDA) is presented to enhance the IEDA in solving the personalized search. Specifically, a dual-RBM module is developed to simultaneously provide a preference surrogate and a probability model for conducting the individual selection and generation of the IEDA. Firstly, the positive and negative preferences of the currently involved user in IEDA are distinguished and combined to achieve a dual-RBM, and then the weighted energy functions of the RBM model together with social group information from users with similar preferences are designed as the preference surrogate. The probability of the trained positive RBM on the visible units is fetched as the reproduction model of EDA since it reflects the attribute distributions of more preferred items. Some benchmarks from the Movielens and Amazon datasets are applied to experimentally demonstrate the superiority of the proposed algorithm in improving the efficiency and effectiveness of the interactive evolutionary computations served personalized search. (C) 2020 Elsevier B.V. All rights reserved.

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# Support condition monitoring of offshore wind turbines using model updating techniques

Xu, Ying Nikitas, George Zhang, Tong Han, Qinghua Chryssanthopoulos, Marios Bhattacharya, Subhamoy Wang, Ying

The offshore wind turbines are dynamically sensitive, whose fundamental frequency can be very close to the forcing frequencies activated by the environmental and turbine loads. Minor changes of support conditions may lead to the shift of natural frequencies, and this could be disastrous if resonance happens. To monitor the support conditions and thus to enhance the safety of offshore wind turbines, a model updating method is developed in this study. A hybrid sensing system was fabricated and set up in the laboratory to investigate the long-term dynamic behaviour of the offshore wind turbine system with monopile foundation in sandy deposits. A finite element model was constructed to simulate structural behaviours of the offshore wind turbine system. Distributed nonlinear springs and a roller boundary condition are used to model the soil-structure interaction properties. The finite element model and the test results were used to analyse the variation of the support condition of the monopile, through an finite element model updating process using estimation of distribution algorithms. The results show that the fundamental frequency of the test model increases after a period under cyclic loading, which is attributed to the compaction of the surrounding sand instead of local damage of the structure. The hybrid sensing system is reliable to detect both the acceleration and strain responses of the offshore wind turbine model and can be potentially applied to the remote monitoring of real offshore wind turbines. The estimation of distribution algorithm-based model updating technique is demonstrated to be successful for the support condition monitoring of the offshore wind turbine system, which is potentially useful for other model updating and condition monitoring applications.

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# Multisource Selective Transfer Framework in Multiobjective Optimization Problems

Zhang, Jun Zhou, Weien Chen, Xianqi Yao, Wen Cao, Lu

For complex system design [e.g., satellite layout optimization design (SLOD)] in practical engineering, when launching a new optimization instance with another parameter configuration from the intuition of designers, it is always executed from scratch which wastes much time to repeat the similar search process. Inspired by transfer learning which can reuse past experiences to solve relevant tasks, many researchers pay more attention to explore how to learn from past optimization instances to accelerate the target one. In real-world applications, there have been numerous similar source instances stored in the database. The primary question is how to measure the transferability from numerous sources to avoid the notorious negative transferring. To obtain the relatedness between source and target instance, we develop an optimization instance representation method named centroid distribution, which is by the aid of the probabilistic model learned by elite candidate solutions in estimation of distribution algorithm (EDA) during the evolutionary process. Wasserstein distance is employed to evaluate the similarity between the centroid distributions of different optimization instances, based on which, we present a novel framework called multisource selective transfer optimization with three strategies to select sources reasonably. To choose the suitable strategy, four selection suggestions are summarized according to the similarity between the source and target centroid distribution. The framework is beneficial to choose the most suitable sources, which could improve the search efficiency in solving multiobjective optimization problems. To evaluate the effectiveness of the proposed framework and selection suggestions, we conduct two experiments: 1) comprehensive empirical studies on complex multiobjective optimization problem benchmarks and 2) a real-world SLOD problem. Suggestions for strategy selection coincide with the experiment results, based on which, we propose a mixed strategy to deal with the negative transfer in the experiments successfully. The results demonstrate that our proposed framework achieves competitive performance on most of the benchmark problems in convergence speed and hypervolume values and performs best on the real-world applications among all the comparison algorithms.

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# A novel approach to solve AI planning problems in graph transformations

Pira, Einollah

The aim of AI planning is to solve the problems with no exact solution available. These problems usually have a big search space, and planning may not find plans with the least actions and in the shortest time. Recent researches show that using suitable heuristics can help to find desired plans. In planning problems specified formally through graph transformation system (GTS), there are dependencies between applied rules (actions) in the search space. This fact motivates us to solve the planning problem for a small goal (instead of the main goal), extract dependencies from the searched space, and use these dependencies to solve the planning problem for the main goal. In GTS based systems, the nodes of a state (really is a graph) can be grouped due to their type. To create a small (refined) goal, we use a refinement technique to remove the predefined percent of nodes from each group of the main goal. Bayesian Optimization Algorithm (BOA) is then used to solve the planning problem for the refined goal. BOA is an Estimation of Distribution Algorithm (EDA) in which Bayesian networks are used to evolve the solution populations. Actually, a Bayesian network is learned from the current population, and then this network is employed to generate the next population. Since the last Bayesian network learned in BOA has the knowledge about dependencies between applied rules, this network can be used to solve the planning problem for the main goal. Experimental results on four well-known planning domains confirm that the proposed approach finds plans with the least actions and in the lower time compared with the state-of-the-art approaches.

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# An Estimation of Distribution Algorithm for Mixed-Variable Newsvendor Problems

Wang, Feng Li, Yixuan Zhou, Aimin Tang, Ke

As one of the classical problems in the economic market, the newsvendor problem aims to make maximal profit by determining the optimal order quantity of products. However, the previous newsvendor models assume that the selling price of a product is a predefined constant and only regard the order quantity as a decision variable, which may result in an unreasonable investment decision. In this article, a new newsvendor model is first proposed, which involves of both order quantity and selling price as decision variables. In this way, the newsvendor problem is reformulated as a mixed-variable nonlinear programming problem, rather than an integer linear programming problem as in previous investigations. In order to solve the mixed-variable newsvendor problem, a histogram model-based estimation of distribution algorithm (EDA) called EDA(mvn) is developed, in which an adaptive-width histogram model is used to deal with the continuous variables and a learning-based histogram model is applied to deal with the discrete variables. The performance of EDA(mvn) was assessed on a test suite with eight representative instances generated by the orthogonal experiment design method and a real-world instance generated from real market data of Alibaba. The experimental results show that, EDA(mvn) outperforms not only the state-of-the-art mixed-variable evolutionary algorithms, but also a commercial software, i.e., Lingo.

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# A Predictive-Reactive Approach with Genetic Programming and Cooperative Coevolution for the Uncertain Capacitated Arc Routing Problem

Liu, Yuxin Mei, Yi Zhang, Mengjie Zhang, Zili

The uncertain capacitated arc routing problem is of great significance for its wide applications in the real world. In the uncertain capacitated arc routing problem, variables such as task demands and travel costs are realised in real time. This may cause the predefined solution to become ineffective and/or infeasible. There are two main challenges in solving this problem. One is to obtain a high-quality and robust baseline task sequence, and the other is to design an effective recourse policy to adjust the baseline task sequence when it becomes infeasible and/or ineffective during the execution. Existing studies typically only tackle one challenge (the other being addressed using a naive strategy). No existing work optimises the baseline task sequence and recourse policy simultaneously. To fill this gap, we propose a novel proactive-reactive approach, which represents a solution as a baseline task sequence and a recourse policy. The two components are optimised under a cooperative coevolution framework, in which the baseline task sequence is evolved by an estimation of distribution algorithm, and the recourse policy is evolved by genetic programming. The experimental results show that the proposed algorithm, called Solution-Policy Coevolver, significantly outperforms the state-of-the-art algorithms to the uncertain capacitated arc routing problem for the ugdb and uval benchmark instances. Through further analysis, we discovered that route failure is not always detrimental. Instead, in certain cases (e.g., when the vehicle is on the way back to the depot) allowing route failure can lead to better solutions.

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# A GPU-Enabled Compact Genetic Algorithm for Very Large-Scale Optimization Problems

Ferigo, Andrea Iacca, Giovanni

The ever-increasing complexity of industrial and engineering problems poses nowadays a number of optimization problems characterized by thousands, if not millions, of variables. For instance, very large-scale problems can be found in chemical and material engineering, networked systems, logistics and scheduling. Recently, Deb and Myburgh proposed an evolutionary algorithm capable of handling a scheduling optimization problem with a staggering number of variables: one billion. However, one important limitation of this algorithm is its memory consumption, which is in the order of 120 GB. Here, we follow up on this research by applying to the same problem a GPU-enabled "compact" Genetic Algorithm, i.e., an Estimation of Distribution Algorithm that instead of using an actual population of candidate solutions only requires and adapts a probabilistic model of their distribution in the search space. We also introduce a smart initialization technique and custom operators to guide the search towards feasible solutions. Leveraging the compact optimization concept, we show how such an algorithm can optimize efficiently very large-scale problems with millions of variables, with limited memory and processing power. To complete our analysis, we report the results of the algorithm on very large-scale instances of the OneMax problem.

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# A self-adaptive estimation of distribution algorithm with differential evolution strategy for supermarket location problem

Zhou, Bing-Hai Tan, Fen

In modern production systems, an ever-rising product variety has imposed great challenges for in-plant part supply systems used to feed mixed-model assembly lines with required parts. In recent years, many automotive manufacturers have identified the supermarket concept as an efficient part feeding strategy to enable JIT (Just-in-time) deliveries at low costs. This paper studies a discrete supermarket location problem which considers the utilization rate and capacity constraint of the supermarkets simultaneously. Firstly, a mathematical model is developed with the objective of minimizing the total system cost consisting of operating cost and transportation cost. Then, a self-adaptive estimation of distribution algorithm with differential evolution strategy, named DE/AEDA, is proposed to solve the problem. Finally, computational experiments are carried out to analyze the performance of the proposed algorithm compared with the benchmark algorithm by using a non-parametric test method. The results indicate that the proposed algorithm is valid and efficient.

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# Local Parameter Optimization of LSSVM for Industrial Soft Sensing With Big Data and Cloud Implementation

Zhang, Xinyu Ge, Zhiqiang

Due to the advantages of high prediction accuracy, least squares support vector machine (LSSVM) has been widely utilized for soft sensor developments in industrial processes. The hyper-parameters of LSSVM are often determined by minimizing the predicted error of validation set based on the intelligent optimization algorithm, which may lead to excessive optimization and model overfitting when validation set are selected improperly. Meanwhile, online parameters optimization is difficult to implement, which results in poor effect of local modeling. This paper proposes UMDA-LOS-LSSVM that is a LSSVM with parameters optimization in local objective set (LOS-LSSVM) by univariate marginal distribution algorithm (UMDA) based on the idea of local modeling. First, the local objective set is extracted in the candidate set based on the testing samples. Then, UMDA is utilized for minimize the predicted error of the objective set and provides the optimized parameters. Finally, training and testing of LSSVM are carried out based on the optimal parameters. In addition, this paper provides the distributed parallel form of the proposed method, which can be used for big data modeling and soft sensor development. The proposed method is applied in a CO2 absorbing column unit to estimate the residual CO2 content, which is implemented through an industrial big data distributed analytics platform. The results show a significant improvement of proposed method based soft sensor, compared to traditional methods.

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# A cooperative coevolution algorithm for multi-objective fuzzy distributed hybrid flow shop

Zheng, Jie Wang, Ling Wang, Jing-jing

With consideration of uncertainty in the distributed manufacturing systems, this paper addresses a multi-objective fuzzy distributed hybrid flow shop scheduling problem with fuzzy processing times and fuzzy due dates. To optimize the fuzzy total tardiness and robustness simultaneously, a cooperative coevolution algorithm with problem-specific strategies is proposed by reasonably combining the estimation of distribution algorithm (EDA) and the iterated greedy (IG) search. In the EDA-mode search, a problem-specific probability model is established to reduce the solution space and a sample mechanism is proposed to generate new individuals. To enhance exploitation, a specific local search is designed to improve performance of non-dominated solutions. Moreover, destruction and reconstruction methods in the IG-mode search are employed for further exploiting better solutions. To balance exploration and exploitation capabilities, a cooperation scheme for mode switching is designed based on the information entropy and the diversity of elite solutions. The effect of the key parameters on the performances of the proposed algorithm is investigated by Taguchi design of experiment method. Comparative results and statistical analysis demonstrate the effectiveness of the proposed algorithm in solving the problem. (C) 2020 Elsevier B.V. All rights reserved.

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

Gholamnezhad, Pezhman Broumandnia, Ali Seydi, Vahid

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

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# Multi-objective green flowshop scheduling problem under uncertainty: Estimation of distribution algorithm

Amiri, M. Faraji Behnamian, J.

Flowshop scheduling is a well-known NP-hard problem. Sustainable scheduling problem has recently attracted the attention of researchers due to the importance of energy and environmental issues. Moreover, considering uncertainty in the real-world manufacturing environment makes the problem more realistic. Insufficient researches on energy issue under uncertainty were encouraging to conduct this study. In this paper, a mathematical formulation and a scenario-based estimation of distribution algorithm (EDA) are proposed to address the flowshop scheduling problem to optimize makespan and energy consumption under uncertainty. To the best of knowledge, scenario-based EDA has not been used to solve this problem. In this study, it is assumed that the processing times are stochastic and follow the normal distribution with known average and variance. In this problem, the machines have different processing speeds and reducing machine speeds increase makespan and decrease energy consumption and conversely. So, machine speeds affect the objective values which are conflicting. The proposed formulation assigns speeds to machines as well as decides about job sequencing. Different scenarios are used to consider stochastic processing times; so, the E-model approach is used for evaluation of objective functions. At the end, the computational experiment is presented and its results show promising performance of EDA in comparison to another algorithm. The proposed algorithm as practical method gives through insight about the problem and because of the suitable number of solutions in the Pareto set, the decision maker has more choice compared to the competing algorithm. (C) 2019 Elsevier Ltd. All rights reserved.

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# Novel Prediction Strategies for Dynamic Multiobjective Optimization

Zhang, Qingyang Yang, Shengxiang Jiang, Shouyong Wang, Ronggui Li, Xiaoli

This paper proposes a new prediction-based dynamic multiobjective optimization (PBDMO) method, which combines a new prediction-based reaction mechanism and a popular regularity model-based multiobjective estimation of distribution algorithm (RM-MEDA) for solving dynamic multiobjective optimization problems. Whenever a change is detected, PBDMO reacts effectively to it by generating three subpopulations based on different strategies. The first subpopulation is created by moving nondominated individuals using a simple linear prediction model with different step sizes. The second subpopulation consists of some individuals generated by a novel sampling strategy to improve population convergence as well as distribution. The third subpopulation comprises some individuals generated using a shrinking strategy based on the probability distribution of variables. These subpopulations are tailored to form a population for the new environment. The experimental results carried out on a variety of bi- and three-objective benchmark functions demonstrate that the proposed technique has competitive performance compared with some state-of-the-art algorithms.

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# Optimal chiller loading in HVAC System Using a Novel Algorithm Based on the distributed framework

Yu, Junqi Liu, Qite Zhao, Anjun Qian, Xuegen Zhang, Rui

Aimed at the optimal chiller loading (OCL) problem in heating, ventilation and air conditioning (HVAC) system, a distributed framework for HVAC control is introduced and discussed. And furthermore, the distributed chaotic estimation of distribution algorithm (DCEDA) based on this framework is proposed. Firstly, compared with the centralized framework, the distributed framework has the features of flexibility and expansibility. Therefore, the distributed framework can fit the development of HVAC control system better. Secondly, in the proposed algorithm, an initialization methodology based on logistic map is developed and the chaotic mutation mechanism is applied to increase the search capability of the algorithm. To testify the performance of DCEDA, two well-known cases based on the OCL problem are tested and the results are compared with other algorithms. The results show that DCEDA is an efficient distributed optimization algorithm with good robustness, stability and convergence, and it can achieve significant energy saving effect.

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# A patient flow scheduling problem in ophthalmology clinic solved by the hybrid EDA-VNS algorithm

Fan, Wenjuan Wang, Yi Liu, Tongzhu Tong, Guixian

This paper studies the patient flow scheduling problem in a multi-phase-multi-server system setting for a typical ophthalmology clinic, considering different patient flow processes and specific appointment time. In this problem, patients may go through the following processes, i.e., consultation, examination, re-consultation, and treatment, which form four patient flow paths according to different situations. The objective of this paper is to minimize the completion time of all the patients in the ophthalmology clinic. For solving this problem, we develop a hybrid meta-heuristic algorithm EDA-VNS combining estimation of distribution algorithm (EDA) and variable neighborhood search (VNS). We test the suitability of the approach for the ophthalmology clinic's problem. Computational results demonstrate that the proposed algorithm is capable of providing high-quality solutions within a reasonable computational time. In addition, the proposed algorithm is also compared with several high-performing algorithms to validate its efficiency. The results indicate the advantages of the proposed EDA-VNS algorithm.

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# An evolutionary algorithm for automated machine learning focusing on classifier ensembles: An improved algorithm and extended results

Xavier-Junior, Joao C. Freitas, Alex A. Ludermir, Teresa B. Feitosa-Neto, Antonino Barreto, Cephas A. S.

A large number of classification algorithms have been proposed in the machine learning literature. These algorithms have different pros and cons, and no algorithm is the best for all datasets. Hence, a challenging problem consists of choosing the best classification algorithm with its best hyper-parameter settings for a given input dataset. In the last few years, Automated Machine Learning (Auto-ML) has emerged as a promising approach for tackling this problem, by doing a heuristic search in a large space of candidate classification algorithms and their hyper-parameter settings. In this work we propose an improved version of our previous Evolutionary Algorithm (EA) - more precisely, an Estimation of Distribution Algorithm - for the Auto-ML task of automatically selecting the best classifier ensemble and its best hyper-parameter settings for an input dataset. The new version of this EA was compared against its previous version, as well as against a random forest algorithm (a strong ensemble algorithm) and a version of the well-known Auto-ML method Auto-WEKA adapted to search in the same space of classifier ensembles as the proposed EA. In general, in experiments with 21 datasets, the new EA version obtained the best results among all methods in terms of four popular predictive accuracy measures: error rate, precision, recall and F-measure. (C) 2019 Elsevier B.V. All rights reserved.

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# Harmless Overfitting: Using Denoising Autoencoders in Estimation of Distribution Algorithms

Probst, Malte Rothlauf, Franz

Estimation of Distribution Algorithms (EDAs) are metaheuristics where learning a model and sampling new solutions replaces the variation operators recombination and mutation used in standard Genetic Algorithms. The choice of these models as well as the corresponding training processes are subject to the bias/variance tradeoff, also known as under- and overfitting: simple models cannot capture complex interactions between problem variables, whereas complex models are susceptible to modeling random noise. This paper suggests using Denoising Autoencoders (DAEs) as generative models within EDAs (DAE-EDA). The resulting DAE-EDA is able to model complex probability distributions. Furthermore, overfitting is less harmful, since DAEs overfit by learning the identity function. This overfitting behavior introduces unbiased random noise into the samples, which is no major problem for the EDA but just leads to higher population diversity. As a result, DAE-EDA runs for more generations before convergence and searches promising parts of the solution space more thoroughly. We study the performance of DAE-EDA on several combinatorial single-objective optimization problems. In comparison to the Bayesian Optimization Algorithm, DAE-EDA requires a similar number of evaluations of the objective function but is much faster and can be parallelized efficiently, making it the preferred choice especially for large and difficult optimization problems.

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# Enhanced Interactive Estimation of Distribution Algorithms with Attention Mechanism and Restricted Boltzmann Machine

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

Interactive Estimation of Distribution Algorithm (IEDA), by integrating users interactions with Estimation of Distribution Algorithm, is powerful for efficient personalized search when the probability model and fitness function are well designed. We here propose an improved IEDA by using attention mechanism strengthened Restricted Boltzmann Machine (RBM). An attention mechanism assisted RBM model is constructed to approximate the user preferences by inputting item features and user generated contents. Then the attention-enhanced probability model of EDA and the fitness function are developed based on the RBM. In the evolutionary process, the attention-based RBM together with the probability model and fitness function are managed according to new interactions and corresponding information. The proposed algorithm is applied to real-world Amazon data sets usually used in the personalized search or recommendation, and its performance is experimentally demonstrated in better predicting the user preferences to improve the searching efficiency and accuracy.

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# Alternative Representations for Codifying Solutions in Permutation-Based Problems

Malagon, Mikel Irurozki, Ekhine Ceberio, Josu

Since their introduction, Estimation of Distribution Algorithms (EDAs) have proved to be very competitive algorithms to solve many optimization problems. However, despite recent developments, in the case of permutation-based combinatorial optimization problems, there are still many aspects that deserve further research. One of them is the influence of the codification employed to represent the solutions on the overall performance of the algorithm. When considering classical EDAs, optimizing permutation problems is challenging, and specific mechanisms are needed to hold the restrictions associated with the permutation nature of solutions.

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# Multi-objective Optimization of Unit Restoration During Network Reconstruction Based on DE-EDA

Wang, Tao Zhu, Hainan Wang, Zhonggang Wang, Yijie Sun, Na Dong, Yunhui

The restoration of unit is the basis of the whole power system restoration. The start-up sequence of units has an influence on both the target network reconstruction whose goal nodes are units which are selected to supply with cranking power and the total power generation capability over a restoration period during network reconstruction. This paper provides a multi-objective optimization model of unit restoration of which optimization goals are to minimize the restoration cost of the target network and to maximize the total power generation capability. The weight of lines is dynamically set to extent the search space for avoiding the loss of the optimal solution when the target network is reconstructed. The model is solved by differential evolution and estimation of distribution algorithm (DE-EDA). Simulation results on IEEE 30-bus system show that the proposed optimization model and algorithm are able to find the solutions which have better convergence and are better spread; the effectiveness of the proposed optimization model and algorithm is further validated by the simulation result on Shandong west power grid of China.

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# A Gaussian Process Assisted Offline Estimation of Multivariate Gaussian Distribution Algorithm

Ma, Xin-Xin Chen, Wei-Neng Yang, Qiang

Surrogated assisted evolutionary algorithms are commonly used to solve real-world expensive optimization problems. However, in some situations, no online data is available during the evolution process. In this situation, we have to build surrogate models based on offline historical data, which is known as offline data-driven optimization. Since no new data can be used to improve the surrogate models, offline data-driven optimization remains a challenging problem. In this paper, we propose a Gaussian process assisted offline estimation of multivariate Gaussian distribution algorithm to address the offline data-driven optimization problem. Instead of using surrogate models to predict the fitness values of individuals, we utilize a surrogate model to predict the rankings of individuals based on the frequently used lower confidence bound. In this way, the robustness of the proposed algorithm could be enhanced. Experiments are conducted on five commonly used benchmark problems. The experimental results demonstrate that the proposed offline surrogate model and the multivariate Gaussian estimation of distribution algorithm are able to achieve competitive performance.

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# Comparative Mixing for DSMGA-II

Komarnicki, Marcin M. Przewozniczek, Michal W. Durda, Tomasz M.

Dependency Structure Matrix Genetic Algorithm-II (DSMGA-II) is a recently proposed optimization method that builds the linkage model on the base of the Dependency Structure Matrix (DSM). This model is used during the Optimal Mixing (OM) operators, such as the Restricted Mixing (RM) and the Back Mixing (BM). DSMGA-II was shown to solve theoretical and real-world optimization problems effectively. In this paper, we show that the effectiveness of DSMGA-II and its improved version, namely Two-edge Dependency Structure Matrix Genetic Algorithm-II (DSMGA-IIe), is relatively low for NK-landscape problems. Thus, we propose the Comparative Mixing (CM) operator that extends the RM operator. The CM operator modifies the linkage information obtained from the DSM-based linkage model by comparing the receiver individual with a randomly selected member of the population. Such modification enables DSMGA-II to solve NK-landscape problems effectively and does not limit DSMGA-II performance on most problems for which it was already shown effective.

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# On measuring and improving the quality of linkage learning in modern evolutionary algorithms applied to solve partially additively separable problems

Przewozniczek, Michal W. Frej, Bartosz Komarnicki, Marcin M.

Linkage learning is frequently employed in modern evolutionary algorithms. High linkage quality may be the key to an evolutionary method's effectiveness. Similarly, the faulty linkage may be the reason for its poor performance. Many state-of-the-art evolutionary methods use a Dependency Structure Matrix (DSM) to obtain linkage. In this paper, we propose a quality measure for DSM. Based on this measure, we analyze the behavior of modern evolutionary methods. We show the dependency between the linkage and the effectiveness of the considered methods. Finally, we propose a framework that improves the quality of the linkage.

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# <i>k</i> Satisfiability Programming by using Estimation of Distribution Algorithm in Hopfield Neural Network

Rasli, Norul Fazira Ahmad Kasihmuddin, Mohd Shareduwan Mohd Mansor, Mohd Asyraf Basir, Md Faisal Md Sathasivam, Saratha

Hopfield Neural Network (HNN) is a sort of neural network that is strongly dependent to energy minimization of solution. Although HNN managed to solve various optimization problem, the output of HNN suffered from a lack of interpretability and variation. This has severely limited the practical usability of HNN in doing logic programming. Inspired by random neuron perturbation, Estimation of Distribution Algorithm (EDA) has been proposed to explore various optimal neuron state. EDAs employs a probabilistic model to sample the neuron state in order to move toward the various optimal location of global minimum energy. In this paper, a new Mutation Hopfield Neural Network (MHNN) will be proposed to do k Satisfiability programming. Based on the experimental result, the proposed MHNN has outperformed conventional HNN in various performance metric.

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# BIVARIATE DEPENDENCY FOR THE VEHICLE ROUTING PROBLEM WITH TIME WINDOWS

Ricardo, Perez-Rodriguez Arturo, Hernandez-Aguirre

The main purpose of the vehicle routing problem (VRP) is to deliver a set of customers with known demands on minimum travel routes starting and terminating at the same depot. The vehicle routing problem with time windows (VRPTW) requires the delivery made in a specific time window for every customer and returning to the depot before a due time. Contrary to current research, an estimation of distribution algorithm-based approach is proposed and developed to solve the problem and implement the solution. The approach mentioned makes use of a probability model based on the Pearson's correlation coefficient to describe the distribution of the solution space. Different and diverse instances served as input and test parameters in order to show that the estimation of any relationship and/or interaction between vertices on the sequence of the VRPTW solution can be improved. A better position for each vertex on the sequence can be estimated through a probability model using the Pearson's correlation coefficient.

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# Multi-speed Gearbox Synthesis Using Global Search and Non-convex Optimization

Piacentini, Chiara Cheong, Hyunmin Ebrahimi, Mehran Butscher, Adrian

We consider the synthesis problem of a multi-speed gearbox, a mechanical system that receives an input speed and transmits it to an outlet through a series of connected gears, decreasing or increasing the speed according to predetermined transmission ratios. Here we formulate this as a bi-level optimization problem, where the inner problem involves non-convex optimization over continuous parameters of the components, and the outer task explores different configurations of the system. The outer problem is decomposed into sub-tasks and optimized by a variety of global search methods, namely simulated annealing, best-first search and estimation of distribution algorithm. Our experiments show that a three-stage decomposition coupled with a best-first search performs well on small-size problems, and it outmatches other techniques on larger problems when coupled with an estimation of distribution algorithm.

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# A comparative study on evolutionary algorithms for the 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) proposed recently is a novel permutation optimisation problem. In ARP-MPDT, a number of task points are located at different places and their states change over time. The agent must go to the task points in turn to execute the tasks, and the execution time of each task depends on the task state. The optimisation objective is to minimise the time for the agent to complete all the tasks. In this paper, five evolutionary algorithms are redesigned and tried to solve this problem, including a permutation genetic algorithm (GA), a variant of the particle swarm optimisation (PSO) and three variants of the estimation of distribution algorithm (EDA). In particular, a dual-model EDA (DM-EDA) employing two probability models was proposed. Finally, comparative tests confirm that the DM-EDA has a stronger adaptability than the other algorithms though GA performs better for the large-scale instances.

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# A Hybrid Estimation-of-Distribution Algorithm for Scheduling Flexible Job Shop With Limited Buffers Based on Petri Nets

Gao, Zhenxin Feng, Yanxiang Xing, Keyi

This article focuses on the production scheduling problem in the flexible job shop (FJS) environment with limited buffers. Limited manufacturing resources and buffers may lead to blockage and deadlock phenomenon. In order to establish production scheduling with minimum makespan, the timed Petri net (PN) model of a production process is established. Based on this PN model, a novel Hybrid Estimation-of-Distribution Algorithm (HEDA) is proposed for solving the considered scheduling problem. A candidate solution for the problem is coded as an individual that consists of a route sequence for processing jobs and a permutation with repetition of jobs. A deadlock prevention policy is used to check the feasibility of individuals, such that it can be decoded into a feasible sequence of transitions, i.e., a feasible schedule. By using an effective voting procedure of elite individuals, two probability models in HEDA corresponding to different subsections of individuals are constructed. Based on the probability models, offspring individuals are then produced. As an improvement strategy, simulated-annealing-based local search is designed and incorporated into HEDA to enhance the entire algorithm's search ability. The proposed hybrid HEDA is tested on FJS examples. The results show its feasibility and effectiveness.

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# Enhancing Gaussian Estimation of Distribution Algorithm by Exploiting Evolution Direction With Archive

Liang, Yongsheng Ren, Zhigang Yao, Xianghua Feng, Zuren Chen, An Guo, Wenhua

As a typical model-based evolutionary algorithm, estimation of distribution algorithm (EDA) possesses unique characteristics and has been widely applied in global optimization. However, the commonly used Gaussian EDA (GEDA) usually suffers from premature convergence, which severely limits its search efficiency. This paper first systematically analyzes the reasons for the deficiency of traditional GEDA, then tries to enhance its performance by exploiting the evolution direction, and finally develops a new GEDA variant named EDA(2). Instead of only utilizing some good solutions produced in the current generation to estimate the Gaussian model, EDA(2) preserves a certain number of high-quality solutions generated in the previous generations into an archive and employs these historical solutions to assist estimating the covariance matrix of Gaussian model. By this means, the evolution direction information hidden in the archive is naturally integrated into the estimated model, which in turn can guide EDA(2) toward more promising solution regions. Moreover, the new estimation method significantly reduces the population size of EDA(2) since it needs fewer individuals in the current population for model estimation. As a result, a fast convergence can be achieved. To verify the efficiency of EDA(2), we tested it on a variety of benchmark functions and compared it with several state-of-the-art EAs. The experimental results demonstrate that EDA(2) is efficient and competitive.

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Biomedical Classification Problems Automatically Solved by Computational Intelligence Methods

Carlos Padierna, Luis Villasenor-Mora, Carlos Lopez Juarez, Silvia Alejandra

Biomedical classification problems are of great interest to both medical practitioners and computer scientists. Due to the harmful consequences of a wrong decision in this ambit, computational methods must be carefully designed to provide a reliable tool for helping physicians to obtain accurate predictions on unseen cases. Computational Intelligence (CI) provides robust models to perform optimization, classification and regression tasks. These models have been previously designed, mainly based on the expertise of computer scientists, to solve a vast number of biomedical problems. As the number of both CI algorithms and biomedical problems continues to grow, selecting the right method to solve a given problem becomes more challenging. To deal with this complexity, a systematic methodology for selecting a suitable model for a given classification problem is required. In this work, we review the more promising classification and optimization algorithms and reformulate them into a synergic framework to automatically design and optimize pattern classifiers. Our proposal, including state-of-the-art evolutionary algorithms and support vector machines, is tested on a variety of biomedical problems. Experimental results on benchmark datasets allow us to conclude that the automatically designed classifiers reach higher or equal performance than those designed by computer specialists.

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# Information Fusion in Offspring Generation: A Case Study in Gene Expression Programming

Liu, Tonglin Zhang, Hengzhe Zhang, Hu Zhou, Aimin

Gene expression programming (GEP), which is a variant of genetic programming (GP) with a fixed-length linear model, has been applied in many domains. Typically, GEP uses genetic operators to generate offspring. In recent years, the estimation of distribution algorithm (EDA) has also been proven to be efficient for offspring generation. Genetic operators such as crossover and mutation generate offspring from an implicit model by using the individual information. By contrast, EDA operators generate offspring from an explicit model by using the population distribution information. Since both the individual and population distribution information are useful in offspring generation, it is natural to hybrid EDA and genetic operators to improve the search efficiency. To this end, we propose a hybrid offspring generation strategy for GEP by using a univariate categorical distribution based EDA operator and its original genetic operators. To evaluate the performance of the new hybrid algorithm, we apply the algorithm to ten regression tasks using various parameters and strategies. The experimental results demonstrate that the new algorithm is a promising approach for solving regression problems efficiently. The GEP with hybrid operators outperforms the original GEP that uses genetic operators on eight out of ten benchmark datasets.

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# Dynamic Bandwidth Scheduling of Software Defined Networked Collaborative Control System

Yan, Xiang Sun, Yanfei Mei, Bizhou

From the perspective of collaborative design of control and scheduling, a software-defined networked collaborative control system (SD-NCCS) is established. On this basis, the system performance of SD-NCCS is analyzed and the average sensitivities of reference are used in utility function to evaluate the effects of network-induced delays. Moreover, the network pricing mechanism and game theory are introduced and a dynamic bandwidth resource allocation model of the overall control system for optimal performance is obtained. Thus, the problem of the network resource allocation of the SD-NCCS has been converted to be the problem of solving the Nash equilibrium point under the non-cooperative game model. Furthermore, the Nash equilibrium solution under this frame is obtained using the estimation distributed algorithm (EDA). Finally, a simple example is included to illustrate the performance of our scheme.

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# Berth scheduling at marine container terminals A universal island-based metaheuristic approach

Kavoosi, Masoud Dulebenets, Maxim A. Abioye, Olumide Pasha, Junayed Theophilus, Oluwatosin Wang, Hui Kampmann, Raphael Mikijeljevic, Marko

Purpose - Marine transportation has been faced with an increasing demand for containerized cargo during the past decade. Marine container terminals (MCTs), as the facilities for connecting seaborne and inland transportation, are expected to handle the increasing amount of containers, delivered by vessels. Berth scheduling plays an important role for the total throughput of MCTs as well as the overall effectiveness of the MCT operations. This study aims to propose a novel island-based metaheuristic algorithm to solve the berth scheduling problem and minimize the total cost of serving the arriving vessels at the MCT.

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# An Estimation of Distribution Algorithm With Multi-Leader Search

Wang, Xiaofei Han, Tong Zhao, Hui

The estimation of distribution algorithm (EDA) is a well-known stochastic search method but is easily affected by the ill-shaped distribution of solutions and can thus become trapped in stagnation. In this paper, we propose a novel modified EDA with a multi-leader search (MLS) mechanism, namely, the MLS-EDA. To strengthen the exploration performance, an enhanced distribution model that considers the information of population and distribution is utilized to generate new candidates. Moreover, when the algorithm stagnates, the MLS mechanism will be activated to perform a local search and shrink the search scope. The performance of the MLS-EDA in addressing complex optimization problems is verified using the CEC 2014 and CEC 2017 testbeds with 30D, 50D and 100D tests. Several modern algorithms, including the top-performing methods in the CEC 2014 and CEC 2017 competitions, are considered as competitors. The competitive performance of our proposed MLS-EDA is discussed based on the comparison results.

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# Estimation of distribution-based multiobjective design space exploration for energy and throughput-optimized MPSoCs

Murad, Maryam Hussain, Ishfaq Ahmad, Ayaz Qadri, Muhammad Yasir Qadri, Nadia N.

Modern multicore architectures comprise a large set of components and parameters that require being matched to achieve the best balance between power consumption and throughput performance for a particular application domain. The exploration of design space for finding the best power-throughput trade-off is a combinatorial optimization problem with a large number of combinations, and. in general, its solution is prohibitively difficult to be explored exhaustively. However, fortunately, evolutionary algorithms (EAs) have the potential to efficiently solve this problem with reasonable computational complexity. In this paper, we consider a multiobjective design space exploration (DSE) problem with two conflicting objectives. The first objective corresponds to power consumption minimization while the second objective relates to throughput maximization. We approach this problem by employing the estimation of distribution algorithm (EDA), which belongs to the family of EAs. The proposed EDA-based DSE (EDA-DSE) scheme efficiently selects the design parameters (i.e. cache size, number of cores, and operating frequency) with an efficient power-throughput ratio. The proposed scheme is verified using cycle-accurate simulations over a set of benchmarks and the simulation results show a significant reduction in energy-delay product for all benchmark applications when compared to the default baseline configuration and genetic algorithm.

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# A probability distribution function for investigating node infection and removal times

Tafazzoli, Tala Sadeghiyan, Babak

Considering the important issue of computer infections by worms spread via networks, the theme of source identification has been a prominent research field that aims at investigating infection propagation including acquiring knowledge about the infection and the node removal times when a worm infection happens. This information helps in identifying the patient zero in the worm attack and may be used by computer forensic investigators and network administrators to spot the culprits and to identify related network vulnerabilities. In this paper, we tackle this problem by developing new probabilistic models based on Bayesian networks. We learn a probability distribution to calculate, at every time step, the probability that each node is infected by a scanning worm, using historical data and features extracted from the network and application layers. With the mentioned probability distribution, the node infection status can be inferred using feature values at each time step. We propose a four-step method to investigate the time of infection and removal of each node probabilistically. First, features are extracted and derived from network traffic data. There are no suitable training and test datasets publicly available for our tests; therefore, we developed the training and test datasets using simulations of the Code Red II worm. Second, a prior model is built using training data. Third, the probabilistic model is built by the estimation of distribution algorithm. Fourth, the infection probability of nodes is inferred given the probability distribution and feature values at each time step. It has already been shown that the number of infectious nodes can be probabilistically approximated backward in time through the stochastic Back-to-Origin Markov model. We combine our first model with the prior stochastic Back-to-Origin Markov model to develop our second model. To evaluate our first and second models, we conducted experiments that show that these models can pinpoint the source node and the infection time of nodes with acceptable accuracy. It should be noted that our method could be employed with other propagating worm types including ransomware worms.

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