# A general framework for evolutionary multiobjective optimization via manifold learning

Li, Ke Kwong, Sam

Under certain mild condition, the Pareto-optimal set (PS) of a continuous multiobjective optimization problem, with m objectives, is a piece-wise continuous (m - 1)-dimensional manifold. This regularity property is important, yet has been unfortunately ignored in many evolutionary multiobjective optimization (EMO) studies. The first work that explicitly takes advantages of this regularity property in EMO is the regularity model-based multiobjective estimation of distribution algorithm (RM-MEDA). However, its performance largely depends on its model parameter, which is problem dependent. Manifold learning, also known as nonlinear dimensionality reduction, is able to discover the geometric property of a low-dimensional manifold embedded in the high-dimensional ambient space. This paper presents a general framework that applies advanced manifold learning techniques in EMO. At each generation, we first use a principal curve algorithm to obtain an approximation of the PS manifold. Then, the Laplacian eigenmaps algorithm is employed to find the low-dimensional representation of this PS approximation. Afterwards, we identify the neighborhood relationship in this low-dimensional representation, which is also applicable for the original high-dimensional data. Based on the neighborhood relationship, we can interpolate new candidate solutions that obey the geometric property of the PS manifold. Empirical results validate the effectiveness of our proposal.(C) 2014 Elsevier B.V. All rights reserved.

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# An estimation of distribution algorithm for hybrid flow shop scheduling under stochastic processing times

Wang, K. Choi, S. H. Qin, H.

The estimation of distribution algorithm (EDA) has recently emerged as a promising alternative to traditional evolutionary algorithms for solving combinatorial optimisation problems. This paper presents a novel two-phase simulation-based EDA (TPSB-EDA) for minimising the makespan of a hybrid flow shop under stochastic processing times. To address the stochastic scheduling problem efficiently, the proposed TPSB-EDA incorporates a two-phase simulation model to estimate the performance of candidate solutions. In this model, an optimal back propagation network is firstly applied to identify a set of roughly good solutions, and then the selected solutions are further evaluated by a discrete-event simulation algorithm. Moreover, an annealing selection mechanism (ASM) is adopted to preserve the population diversity of EDA. Different from the selection operators of common EDAs, the ASM uses Boltzmann probability in the annealing algorithm to select part of population to establish the probabilistic model. Computation results indicate that the TPSB-EDA provides good solutions in the aspects of solution quality and computational efficiency.

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# Parameter Optimization Algorithms for Evolving Rule Models Applied to Freshwater Ecosystems

Cao, Hongqing Recknagel, Friedrich Orr, Philip T.

Predictive rule models for early warning of cyanobacterial blooms in freshwater ecosystems were developed using a hybrid evolutionary algorithm (HEA). The HEA has been designed to evolve IF-THEN-ELSE model structures using genetic programming and to optimize the stochastical constants contained in the model using population-based algorithms. This paper intensively investigates the performances of the following six alternative population-based algorithms for parameter optimization (PO) of rule models within this hybrid methodology: 1) hill climbing (HC); 2) simulated annealing (SA); 3) genetic algorithm (GA); 4) differential evolution (DE); 5) covariance matrix adaptation evolution strategy (CMA-ES); and 6) estimation of distribution algorithm (EDA). The comparative study was carried out by predictive modeling of chlorophyll-a concentrations and the potentially toxic cyanobacterium Cylindrospermopsis raciborskii cell concentrations based on water quality time-series data in Lake Wivenhoe, Queensland, Australia, from 1998 to 2009. The experimental results demonstrate that with these PO methods, the rule models discovered by the HEA proved to be both predictive and explanatory whose IF condition indicates threshold values for some crucial water quality parameters. When comparing different PO algorithms, HC always performed best followed by DE, GA, and EDA, while CMA-ES performed worst and the performance of SA varied with different data sets.

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# Generalized decomposition and cross entropy methods for many-objective optimization

Giagkiozis, I. Purshbuse, R. C. Fleming, P. J.

Decomposition-based algorithms for multi-objective optimization problems have increased in popularity in the past decade. Although convergence to the Pareto optimal front (PF) for such algorithms can often be superior to that of Pareto-based alternatives, the problem of effectively distributing Pareto optimal solutions in a high-dimensional space has not been solved. In this work, we introduce a novel concept which we call generalized decomposition. Generalized decomposition provides a framework with which the decision maker (DM) can guide the underlying search algorithm toward specific regions of interest, or the entire Pareto front, with the desired distribution of Pareto optimal solutions. The method simplifies many-objective problems by unifying the three performance objectives of an a posteriori multi-objective optimizer - convergence to the PF, evenly distributed Pareto optimal solutions and coverage of the entire front - to only one, that of convergence. A framework, established on generalized decomposition, and an estimation of distribution algorithm (EDA) based on low-order statistics, namely the cross-entropy method, is created to illustrate the benefits of the proposed concept for many-objective problems. The algorithm - MACE-gD - is shown to be highly competitive with the existing best-in-class decomposition-based algorithm (MOEA/D) and a more elaborate EDA method (RM-MEDA). (C) 2014 Elsevier Inc. All rights reserved.

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# Improved estimation of distribution algorithm for the problem of single-machine scheduling with deteriorating jobs and different due dates

Wu, Hua-Pin Huang, Min

This paper investigates single-machine scheduling problem, which is an NP-hard problem, with deteriorating jobs and different due dates tominimize total tardiness. First, two special polynomially solvable cases of the problem and a mixed-integer programming (MIP) model are proposed. Since the large-scale problem needs a long time when the MIP is solved using the CPLEX, the improved estimation of distribution algorithm (EDA) is proposed to solve the problem with a large size. EDA depends on the probabilistic model, which denotes the distribution of decision variables in the feasible region space. Meanwhile, EDA owns efficient search capability and convergence. To obtain an improved initial population, an efficient initialization scheme based on the feature of two special cases and a heuristic algorithm are adopted in the process of constructing the initial population. The probabilistic model is composited based on elite solutions from each generation. Simultaneously, mutation is embedded tomaintain the diversity of the population. Compared with the results, numerical experiments show that the proposed algorithm can obtain good near-optimal solutions within a short period.

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# The cooperative estimation of distribution algorithm: a novel approach for semiconductor final test scheduling problems

Hao, Xin-Chang Wu, Jei-Zheng Chien, Chen-Fu Gen, Mitsuo

A large number of studies have been conducted in the area of semiconductor final test scheduling (SFTS) problems. As a specific example of the simultaneous multiple resources scheduling problem, intelligent manufacturing planning and scheduling based on meta-heuristic methods, such as the genetic algorithm (GA), simulated annealing, and particle swarm optimization, have become common tools for finding satisfactory solutions within reasonable computational times in real settings. However, only a few studies have analyzed the effects of interdependent relations during group decision-making activities. Moreover, for complex and large problems, local constraints and objectives from each managerial entity and their contributions toward global objectives cannot be effectively represented in a single model. This paper proposes a novel cooperative estimation of distribution algorithm (CEDA) to overcome these challenges. The CEDA extends a co-evolutionary framework incorporating a divide-and-conquer strategy. Numerous experiments have been conducted, and the results confirmed that CEDA outperforms hybrid GAs for several SFTS problems.

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# Multiobjective Estimation of Distribution Algorithm Based on Joint Modeling of Objectives and Variables

Karshenas, Hossein Santana, Roberto Bielza, Concha Larranaga, Pedro

This paper proposes a new multiobjective estimation of distribution algorithm (EDA) based on joint probabilistic modeling of objectives and variables. This EDA uses the multidimensional Bayesian network as its probabilistic model. In this way, it can capture the dependencies between objectives, variables and objectives, as well as the dependencies learned between variables in other Bayesian network-based EDAs. This model leads to a problem decomposition that helps the proposed algorithm find better tradeoff solutions to the multiobjective problem. In addition to Pareto set approximation, the algorithm is also able to estimate the structure of the multiobjective problem. To apply the algorithm to many-objective problems, the algorithm includes four different ranking methods proposed in the literature for this purpose. The algorithm is first applied to the set of walking fish group problems, and its optimization performance is compared with a standard multiobjective evolutionary algorithm and another competitive multiobjective EDA. The experimental results show that on several of these problems, and for different objective space dimensions, the proposed algorithm performs significantly better and on some others achieves comparable results when compared with the other two algorithms. The algorithm is then tested on the set of CEC09 problems, where the results show that multiobjective optimization based on joint model estimation is able to obtain considerably better fronts for some of the problems compared with the search based on conventional genetic operators in the state-of-the-art multiobjective evolutionary algorithms.

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# Design and Optimization of Heat-Integrated Distillation Column Schemes through a New Robust Methodology Coupled with a Boltzmann-Based Estimation of Distribution Algorithm

Gutierrez-Guerra, Roberto Cortez-Gonzalez, Jazmin Murrieta-Duenas, Rodolfo Gabriel Segovia-Hernandez, Juan Hernandez, Salvador Hernandez-Aguirre, Arturo

The technology of the heat-integrated distillation column (HIDiC) has shown to be a potential energy-saving alternative for separating close-boiling mixtures. However, the economic aspects are a critical factor to extensive use of this distillation sequence in real applications. In this research, a novel stochastic optimization algorithm called Boltzmann univariate marginal distribution algorithm (BUMDA) with constraints handling has been implemented to optimize HIDiC sequences. Three binary mixtures were examined: butanol-isobutanol, n-heptane-cyclohexane, and benzene-toluene. The evaluation was performed by applying a new robust methodology using the interface Matlab-Excel-Aspen Plus. The model Radfrac was used in the simulations in Aspen Plus. The minimization of the total annual cost was established as the fitness function of the problem. Results showed the great robustness presented by the BUMDA algorithm for solving successfully this kind of complex optimization problem. Thus, the HIDiC design to separate the alcohol mixture showed energy savings of 84% and a cost that was lower (2%) than that of the conventional column. In addition, the hydrocarbon mixtures reached energy savings of 62.5% (n-heptane-cyclohexane) and 52.5% (benzene-toluene). Nevertheless, the total annual cost (TAC) of the HIDiC is larger than the TAC of the conventional column (32% and 35%, respectively).

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# Simulation optimization for a flexible jobshop scheduling problem using an estimation of distribution algorithm

Perez-Rodriguez, Ricardo Joens, S. Hernandez-Aguirre, Arturo Alberto-Ochoa, Carlos

The flexible jobshop scheduling problem permits the operation of each job to be processed by more than one machine. The idea is to assign the processing sequence of operations on the machines and the assignment of operations on machines such that the system objectives can be optimized. The assignment mentioned is a difficult task to implement on real manufacturing environments because there are many assumptions to satisfy, especially when the amount of work is not constant or sufficient to keep the manufacturing process busy for a long time, causing intermittent idle times. An estimation of distribution algorithm-based approach coupled with a simulation model is developed to solve the problem and implement the solution. Using the proposed approach, the shop performance can be noticeably improved when different machines are assigned to different schedules.

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# Improved RM-MEDA with local learning

Li, Yangyang Xu, Xia Li, Peidao Jiao, Licheng

In this paper, local learning is proposed to improve the speed and the accuracy of convergence performance of regularity model-based multiobjective estimation of distribution algorithm (RM-MEDA), a typical multi-objective optimization algorithm via estimation of distribution. RM-MEDA employs a model-based method to generate new solutions, however, this method is easy to generate poor solutions when the population has no obvious regularity. To overcome this drawback, our proposed method add a new solution generation strategy, local learning, to the original RM-MEDA. Local learning produces solutions by sampling some solutions from the neighborhood of elitist solutions in the parent population. As it is easy to search some promising solutions in the neighborhood of an elitist solution, local learning can get some useful solutions which help the population attain a fast and accurate convergence. The experimental results on a set of test instances with variable linkages show that the implement of local learning can accelerate convergence speed and add a more accurate convergence to the Pareto optimal.

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# copulaedas: An R Package for Estimation of Distribution Algorithms Based on Copulas

Gonzalez-Fernandez, Yasser Soto, Marta

The use of copula-based models in EDAs (estimation of distribution algorithms) is currently an active area of research. In this context, the copulaedas package for R provides a platform where EDAs based on copulas can be implemented and studied. The package offers complete implementations of various EDAs based on copulas and vines, a group of well-known optimization problems, and utility functions to study the performance of the algorithms. Newly developed EDAs can be easily integrated into the package by extending an S4 class with generic functions for their main components. This paper presents copulaedas by providing an overview of EDAs based on copulas, a description of the implementation of the package, and an illustration of its use through examples. The examples include running the EDAs defined in the package, implementing new algorithms, and performing an empirical study to compare the behavior of different algorithms on benchmark functions and a real-world problem.

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# A block based estimation of distribution algorithm using bivariate model for scheduling problems

Chang, Pei-Chann Chen, Meng-Hui

Recently, estimation of distribution algorithms (EDAs) have gradually attracted a lot of attention and have emerged as a prominent alternative to traditional evolutionary algorithms. In this paper, a block-based EDA using bivariate model is developed to solve combinatorial problems. Instead of generating a set of chromosomes, our approach generates a set of promising blocks using bivariate model and these blocks are reserved in an archive for future use. These blocks will be updated every other k generation. Then, two rules, i.e., AC1 and AC2, are developed to generate a new chromosome by combining the set of selected blocks and rest of genes. This block based approach is very efficient and effective when compared with the traditional EDAs. According to the experimental results, the block based EDA outperforms EDA, GA, ACO and other evolutionary approaches in solving benchmark permutation problems. The block based approach is a new concept and has a very promising result for other applications.

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# An exploratory research of elitist probability schema and its applications in evolutionary algorithms

Zhang, Hong-Guang Liu, Yuan-An Tang, Bi-Hua Liu, Kai-Ming

An important problem in the study of evolutionary algorithms is how to continuously predict promising solutions while simultaneously escaping from local optima. In this paper, we propose an elitist probability schema (EPS) for the first time, to the best of our knowledge. Our schema is an index of binary strings that expresses the similarity of an elitist population at every string position. EPS expresses the accumulative effect of fitness selection with respect to the coding similarity of the population. For each generation, EPS can quantify the coding similarity of the population objectively and quickly. One of our key innovations is that EPS can continuously predict promising solutions while simultaneously escaping from local optima in most cases. To demonstrate the abilities of the EPS, we designed an elitist probability schema genetic algorithm and an elitist probability schema compact genetic algorithm. These algorithms are estimations of distribution algorithms (EDAs). We provided a fair comparison with the persistent elitist compact genetic algorithm (PeCGA), quantum-inspired evolutionary algorithm (QEA), and particle swarm optimization (PSO) for the 0-1 knapsack problem. The proposed algorithms converged quicker than PeCGA, QEA, and PSO, especially for the large knapsack problem. Furthermore, the computation time of the proposed algorithms was less than some EDAs that are based on building explicit probability models, and was approximately the same as QEA and PSO. This is acceptable for evolutionary algorithms, and satisfactory for EDAs. The proposed algorithms are successful with respect to convergence performance and computation time, which implies that EPS is satisfactory.

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# A new real-coded Bayesian optimization algorithm based on a team of learning automata for continuous optimization

Moradabadi, Behnaz Beigy, Hamid

Estimation of distribution algorithms have evolved as a technique for estimating population distribution in evolutionary algorithms. They estimate the distribution of the candidate solutions and then sample the next generation from the estimated distribution. Bayesian optimization algorithm is an estimation of distribution algorithm, which uses a Bayesian network to estimate the distribution of candidate solutions and then generates the next generation by sampling from the constructed network. The experimental results show that the Bayesian optimization algorithms are capable of identifying correct linkage between the variables of optimization problems. Since the problem of finding the optimal Bayesian network belongs to the class of NP-hard problems, typically Bayesian optimization algorithms use greedy algorithms to build the Bayesian network. This paper proposes a new real-coded Bayesian optimization algorithm for solving continuous optimization problems that uses a team of learning automata to build the Bayesian network. This team of learning automata tries to learn the optimal Bayesian network structure during the execution of the algorithm. The use of learning automaton leads to an algorithm with lower computation time for building the Bayesian network. The experimental results reported here show the preference of the proposed algorithm on both uni-modal and multi-modal optimization problems.

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# Distributed Estimation of Distribution Algorithms for continuous optimization: How does the exchanged information influence their behavior?

Muelas, Santiago Mendiburu, Alexander LaTorre, Antonio Pena, Jose-Maria

One of the most promising areas in which probabilistic graphical models have shown an incipient activity is the field of heuristic optimization and, in particular, in Estimation of Distribution Algorithms. Due to their inherent parallelism, different research lines have been studied trying to improve Estimation of Distribution Algorithms from the point of view of execution time and/or accuracy. Among these proposals, we focus on the so-called distributed or island-based models. This approach defines several islands (algorithms instances) running independently and exchanging information with a given frequency. The information sent by the islands can be either a set of individuals or a probabilistic model. This paper presents a comparative study for a distributed univariate Estimation of Distribution Algorithm and a multivariate version, paying special attention to the comparison of two alternative methods for exchanging information, over a wide set of parameters and problems - the standard benchmark developed for the IEEE Workshop on Evolutionary Algorithms and other Metaheuristics for Continuous Optimization Problems of the ISDA 2009 Conference. Several analyses from different points of view have been conducted to analyze both the influence of the parameters and the relationships between them including a characterization of the configurations according to their behavior on the proposed benchmark. (c) 2014 Published by Elsevier Inc.

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# Quality Analysis of Discretization Methods for Estimation of Distribution Algorithms

Chen, Chao-Hong Chen, Ying-ping

Estimation of distribution algorithms (EDAs). since they were introduced, have been successfully used to solve discrete optimization problems and hence proven to be an effective methodology for discrete optimization. To enhance the applicability of EDAs, researchers started to integrate EDAs with discretization methods such that the EDAs designed for discrete variables can be made capable of solving continuous optimization problems. In order to further our understandings of the collaboration between EDAs and discretization methods, in this paper, we propose a quality measure of discretization methods for EDAs. We then utilize the proposed quality measure to analyze three discretization methods: fixed-width histogram (FWH). fixed-height histogram (FHH), and greedy random split (GRS). Analytical measurements are obtained for FHH and FWH, and sampling measurements are conducted for FHH. FWH, and GRS. Furthermore, we integrate Bayesian optimization algorithm (BOA), a representative EDA, with the three discretization methods to conduct experiments and to observe the performance difference. A good agreement is reached between the discretization quality measurements and the numerical optimization results. The empirical results show that the proposed quality measure can be considered as an indicator of the suitability for a discretization method to work with EDAs.

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# An improved NSGA-II algorithm for multi-objective lot-streaming flow shop scheduling problem

Han, Yu-Yan Gong, Dun-wei Sun, Xiao-Yan Pan, Quan-Ke

Crossover and mutation operators in NSGA-II are random and aimless, and encounter difficulties in generating offspring with high quality. Aiming to overcoming these drawbacks, we proposed an improved NSGA-II algorithm (INSGA-II) and applied it to solve the lot-streaming flow shop scheduling problem with four criteria. We first presented four variants of NEH heuristic to generate the initial population, and then incorporated the estimation of distribution algorithm and a mutation operator based on insertion and swap into NSGA-II to replace traditional crossover and mutation operators. Last but not least, we performed a simple and efficient restarting strategy on the population when the diversity of the population is smaller than a given threshold. We conducted a serial of experiments, and the experimental results demonstrate that the proposed algorithm outperforms the comparative algorithms.

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# ASYNCHRONOUS PARALLEL ALGORITHMS FOR STRATEGIC HYBRID SEARCHING BASED ON A MIXTURE GAUSSIAN MODEL

Said, Said Mohamed Nakamura, Morikazu

Technically exploring a solution space in an effective way helps not only to find good quality solutions, but also to reduce computation time. This paper proposes an optimization technique that utilizes hybridization, strategic search, parallelization, and asynchronous cooperation. A master-slave topology has been formulated in which the master strategically sorts out portions of the search space in four phases with the help of a clustering algorithm and assumes the role of an estimation of distribution algorithm to model the solution distribution within the space using a Gaussian mixture model without variable dependency. The new algorithm models a solution distribution by considering not only the mean vector of clustered solutions obtained from previous searches, as per the continuous univariate marginal distribution algorithm, but also by including information about the quality of solutions. With sorted probability distributions assigned by the master, slaves use genetic algorithms to extensively explore the solution space. The effect of our proposal has been experimentally analyzed in continuous domains, and the resultant algorithm shows significant improvements both in finding relatively good solutions and in reducing computation time.

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# Evolutionary Synthesis of Cube Root Computational Circuit Using Graph Hybrid Estimation of Distribution Algorithm

Slezak, Josef Petrzela, Jiri

The paper is focused on evolutionary synthesis of analog circuit realization of cube root function using proposed Graph Hybrid Estimation of Distribution Algorithm. The problem of cube root function circuit realization was adopted to demonstrate synthesis capability of the proposed method. Individuals of the population of the proposed method which represent promising topologies are encoded using graphs and hypergraphs. Hybridization with local search algorithm was used. The proposed method employs univariate probabilistic model.

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# A Distance-Based Ranking Model Estimation of Distribution Algorithm for the Flowshop Scheduling Problem

Ceberio, Josu Irurozki, Ekhine Mendiburu, Alexander Lozano, Jose A.

The aim of this paper is two-fold. First, we introduce a novel general estimation of distribution algorithm to deal with permutation-based optimization problems. The algorithm is based on the use of a probabilistic model for permutations called the generalized Mallows model. In order to prove the potential of the proposed algorithm, our second aim is to solve the permutation flowshop scheduling problem. A hybrid approach consisting of the new estimation of distribution algorithm and a variable neighborhood search is proposed. Conducted experiments demonstrate that the proposed algorithm is able to outperform the state-of-the-art approaches. Moreover, from the 220 benchmark instances tested, the proposed hybrid approach obtains new best known results in 152 cases. An in-depth study of the results suggests that the successful performance of the introduced approach is due to the ability of the generalized Mallows estimation of distribution algorithm to discover promising regions in the search space.

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# Solving system-level synthesis problem by a multi-objective estimation of distribution algorithm

Wang, Ling Fang, Chen Suganthan, Ponnuthurai Nagaratnam Liu, Min

In this paper, the system-level synthesis problem (SLSP) is modeled as a multi-objective mode-identity resource-constrained project scheduling problem with makespan and resource investment criteria (MOMIRCPSP-MS-RI). Then, a hybrid Pareto-archived estimation of distribution algorithm (HPAEDA) is presented to solve the MOMIRCPSP-MS-RI. To be specific, the individual of the population is encoded as the activity-mode-priority-resource list (AMPRL), and a hybrid probability model is used to predict the most promising search area, and a Pareto archive is used to preserve the non-dominated solutions that have been explored, and another archive is used to preserve the solutions for updating the probability model. Moreover, specific sampling mechanism and updating mechanism for the probability model are both provided to track the most promising search area via the EDA-based evolutionary search. Finally, the modeling methodology and the HPAEDA are tested by an example of a video codec based on the H.261 image compression standard. Simulation results and comparisons demonstrate the effectiveness of the modeling methodology and the proposed algorithm. (C) 2013 Elsevier Ltd. All rights reserved.

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# Repairing normal EDAs with selective repopulation

Ivvan Valdez P, S. Hernandez, Arturo Botello, Salvador

The standard Estimation of Distribution Algorithm (EDA), usually, suffers from premature convergence due to an inherent inability to maintain an adequate variance and to preserve diverse candidate solutions. Normal multivariate EDAs have especially shown a lack of exploration even for convex objective functions. This article introduces several techniques which can be used to enhance the standard Normal multivariate EDA performance. The most important ones are based on (1) pre-selecting the candidate solutions to be evaluated, (2) replacing only a fraction of the population and (3) computing weighted estimators of the mean and covariance matrix. The resulting Normal EDA is competitive with similar approaches, as it is evidenced by statistical comparisons. (C) 2013 Elsevier Inc. All rights reserved.

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# A Novel Graph-Based Estimation of the Distribution Algorithm and Its Extension Using Reinforcement Learning

Li, Xianneng Mabu, Shingo Hirasawa, Kotaro

In recent years, numerous studies have drawn the success of estimation of distribution algorithms (EDAs) to avoid the frequent breakage of building blocks of the conventional stochastic genetic operators-based evolutionary algorithms (EAs). In this paper, a novel graph-based EDA called probabilistic model building genetic network programming (PMBGNP) is proposed. Using the distinguished graph (network) structure of a graph-based EA called genetic network programming (GNP), PMBGNP ensures higher expression ability than the conventional EDAs to solve some specific problems. Furthermore, an extended algorithm called reinforced PMBGNP is proposed to combine PMBGNP and reinforcement learning to enhance the performance in terms of fitness values, search speed, and reliability. The proposed algorithms are applied to solve the problems of controlling the agents' behavior. Two problems are selected to demonstrate the effectiveness of the proposed algorithms, including the benchmark one, i.e., the Tileworld system, and a real mobile robot control.

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# Estimation of distribution algorithm for a class of nonlinear bilevel programming problems

Wan, Zhongping Mao, Lijun Wang, Guangmin

In this paper, a novel evolutionary algorithm called estimation of distribution algorithm (EDA) is proposed for solving a special class of nonlinear bilevel programming problems (BLPPs) in which the lower level problem is a convex programming problem for each given upper level decision. This special type of BLPP is transformed into a equivalent single-level constrained optimization problem using the Karush-Kuhn-er conditions of the lower level problem. Then, we propose an EDA based on the statistical information of the superior candidate solutions to solve the transformed problem. We stress that the new population of individuals is sampled from the probabilistic distribution of those superior solutions. Thus, one of the main advantages of EDA over most other meta-heuristics is its ability to adapt the operators to the structure of the problem, although adaptation in EDA is usually limited by the initial choice of the probabilistic model. In addition, two specific rules are established in the initialization procedure to make use of the hierarchical structure of BLPPs and to handle the constraints. Moreover, without requiring the differentiability of the objective function, or the convexity of the search space of the equivalent problem, the proposed algorithm can address nonlinear BLPPs with non-differentiable or non-convex upper level objective function and upper level constraint functions. Finally, the proposed algorithm has been applied to 16 benchmark problem; in five of these problems, all of the upper level variables and lower level variables are 10-dimensional. The numerical results compared with those of other methods reveal the feasibility and effectiveness of the proposed algorithm. (C) 2013 Elsevier Inc. All rights reserved.

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# An Estimation-of-Distribution Algorithm Approach to Redundancy Allocation Problem for a High-Security System

Melo, Haydee Watada, Junzo

Reliability is an issue that has recently captivated the attention of researchers. Its goal is to develop new techniques to design more reliable systems, which can operate without failing during operation. A result of this growth in technology is an increase in the complexity and susceptibility of more complex systems. The principal objective of redundancy allocation is to maximize the availability of a system while reducing the cost, volume or weight. This paper proposes an Estimation-of-Distribution Algorithm (EDA) approach as a new meta-heuristic method to solve a redundancy allocation problem (RAP) for a high security control system.

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# A Cloud Computing Resource Scheduling Scheme Based on Estimation of Distribution Algorithm

Chen, Niansheng Fang, Xiaoping Wang, Xin

Resource scheduling is one of the key problems of cloud computing, no wonder, the scheduling policy and algorithm affect the performance of the cloud system directly. In order to improve the utilization of cloud computing resources and keep load balancing, a cloud computing resource scheduling algorithm based on estimation of distribution algorithm is proposed. In this algorithm, the idea of population based incremental learning(PBIL) algorithm is fully used. In this paper, cloud computing resource scheduling algorithm model is established firstly, and then objective solution is made by using the PBIL algorithm. Finally, the simulation analysis of algorithm performance is conducted. The simulation results show that the PBIL algorithm can take shorter time to complete task and achieve resource load balancing, especially, for the resource scheduling with large-scale task, the advantages are more apparent.

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# Estimation of Distribution Algorithm using Variety of Information

Yu, Juan He, Yuyao

Former information of probability model and inferior individuals were discarded in the research of estimation of distribution algorithm usually, but they may contain useful information. In this paper, the former probability information is introduced to avoid premature convergence caused by continuously select superior individuals of current population tobuilt probability model, and the individual sampling from superior probability model is filtered by inferior probability model to avoid generating inferior individuals. The algorithm is simulated through the widely used knapsack examples, the results verify the validity of the proposed method, and give suggestion for the choice of parameter through simulation and analysis.

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# Research of Batch Scheduling with Arrival Time Based on Estimation of Distribution Algorithm

Li, Dong Zhou, Xiaofeng Peng, Feifei Liu, Chang

Estimation of distribution has been used to solve the batch scheduling problem with job release problem, which minimizing the makespan as the objective function. According to the characteristic of the batch scheduling problem with job release time and the estimation of distribution algorithm, this paper builds the probabilistic model based on the characteristic of batching process and designs the mechanism of personal sampling and probability update, then proposes a new estimation of distribution algorithm to solve the batch scheduling problem with job release time. The mechanism of population generation and probability updating has been improved in the standard compact genetic algorithm (a kind of EDA) which accelerate the convergence rate of algorithm. Moreover, the influence of parameter setting is investigated based on design of experiment and suitable parameter values are suggested. Simulation results based on some instances and comparisons with some exiting algorithms demonstrate the effectiveness and robustness of the proposed algorithm.

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# A Guided Hopfield Evolutionary Algorithm with Local Search for Maximum Clique Problem

Yang, Gang Li, Xirong Xu, Jieping Jin, Qin Sun, Hui

In this paper, a novel hybrid evolutionary algorithm combining a Hopfield net and a local search strategy is proposed to solve maximum clique problem. The algorithm makes full use of powerful searching capability of Hopfield net and probabilistic statistic feature of estimation of distribution algorithm to produce wider search in global solution domain. In particular, a possible extension way correlated with local search optimization is introduced to affect the mutation probability thus to produce guided evolution. Experiments on the popular DIMACS benchmark demonstrate that the hybrid evolutionary algorithm produces comparable and better results than other compared algorithms, including EA/G which is a state-of-the-art algorithm in the field of evolutionary computation.

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# Integration of Evolutionary Computing and Reinforcement Learning for Robotic Imitation Learning

Tan, Huan Balajee, Kannan Lynn, DeRose

This paper proposes an evolutionary reinforcement learning method by combining Estimation of Distribution Algorithm and Reinforcement Learning. The Reinforcement Learning method in our method is based on Policy Improvement with Path Integrals (PI2). Estimation of Distribution Algorithm is incorporated into this reinforcement learning method to improve the generation of roll outs with certain noises. This method can accelerate the converging of the learning results and improve the overall system performance. Additionally, this method provides a potential solution to integrate the exploratory evolutionary algorithms and the greedy policy learning method. The proposed method is applied in a robotic imitation learning experiment in this paper and the experimental results demonstrate the effectiveness and robustness of our proposed algorithm.

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# Team of Bayesian Optimization Algorithms to Solve Task Assignment Problems in Heterogeneous Computing Systems

Li, Jie Zhang, JunQi Kang, Qi Jiang, ChangJun

A Bayesian optimization algorithm (BOA) belongs to estimation of distribution algorithms (EDAs). It is characterized by combining a Bayesian network and evolutionary algorithms to solve nearly decomposable optimization problems. BOA is less popularly applied to solve high dimensionality complex optimization problems. A key reason is that the cost of training all dimensions by BOA becomes expensive with the increase of problem dimensionality. Since data are relatively sparse in a high dimensional space, even though BOA can train all dimensions simultaneously, the interdependent relations between different dimensions are difficult to learn. Its search ability is thus significantly reduced. In this paper, we propose a team of Bayesian optimization algorithms (TBOA) to search and learn dimensionality. TBOA consists of multiple BOAs, in which each BOA corresponds to a dimension of the solution domain and it is responsible for the search of this dimension's value region. The proposed TBOA is used to solve the real problem of task assignment in heterogeneous computing systems. Extensive experiments demonstrate that the computational cost of the overall training in TBOA is decreased very significantly while keeping high solution accuracy.

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# An Analysis of the Local Optima Storage Capacity of Hopfield Network Based Fitness Function Models

Swingler, Kevin Smith, Leslie

A Hopfield Neural Network (HNN) with a new weight update rule can be treated as a second order Estimation of Distribution Algorithm (EDA) or Fitness Function Model (FFM) for solving optimisation problems. The HNN models promising solutions and has a capacity for storing a certain number of local optima as low energy attractors. Solutions are generated by sampling the patterns stored in the attractors. The number of attractors a network can store (its capacity) has an impact on solution diversity and, consequently solution quality. This paper introduces two new HNN learning rules and presents the Hopfield EDA (HEDA), which learns weight values from samples of the fitness function. It investigates the attractor storage capacity of the HEDA and shows it to be equal to that known in the literature for a standard HNN. The relationship between HEDA capacity and linkage order is also investigated.

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# USV Course Controller Optimization Based on Elitism Estimation of Distribution Algorithm

Xu, Qingyang

PID controller is used in most of the course-keeping closed-loop control of Unmanned Surface Vehicle (USV). However, the parameters of PID are difficult to tuning. In this paper, we adopt an elitism estimation of distribution algorithm (EEDA) to optimize the PID, which makes use of the probabilistic model to estimate the optimal solution distribution. It has a better global searching ability. A linear Nomoto model is adopted to simulate the USV, and the PID controller is used to control the course of the USV. The simulation results exhibit the validity of the EEDA.

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# MAX-SAT Problem using Evolutionary Algorithms

Ali, H. M. Mitchell, David Lee, Daniel C.

MAX-SAT is a classic NP-hard optimization problem. Many real problems can be easily represented in, or reduced to MAX-SAT, and thus it has many applications. Finding optimum solutions of NP-hard optimization problems using limited computational resources seems infeasible in general. In particular, all known exact algorithms for MAX-SAT require worst-case exponential time, so evolutionary algorithms can be useful for finding good quality solutions in moderate time. We present the results of an experimental comparison of the performance of a number of recently proposed evolutionary algorithms for MAX-SAT. The algorithms include the Artificial Bee Colony (ABC) algorithm, Quantum Inspired Evolutionary Algorithm (QEA), Immune Quantum Evolutionary Algorithm (IQEA), Estimation of Distribution Algorithm (EDA), and randomized Monte Carlo (MC). Our experiments demonstrate that the ABC algorithm has better performance than the others. For problems with Boolean domain, such as MAX-SAT, the ABC algorithm requires specification of a suitable similarity measure. We experimentally evaluate the performance of the ABC algorithm with five different similarity measures to indicate the better choice for MAX-SAT problems.

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# An Improved Ant Colony Algorithm based on Distribution Estimation

Bei, Fang

In last two decades, Ant colony algorithm got extensive application in combinatorial optimization, function optimization and other fields. Ant colony algorithm is easy to fall into local optimum. A novel estimation of distribution algorithm by fusion improvement on ant colony algorithm and PBIL estimation of distribution algorithm is proposed. The algorithm introduce probability distribution model of PBIL algorithm to guide route choice, which greatly improves the faults that positive feedback mechanism of pheromone. Although the hybrid ant colony algorithm has achieved good results, this is just the preliminary attempt of distributed estimation algorithm combined with ant colony algorithm. Probability distribution model of other distribution estimation algorithm can also be used to guide the choice of ant colony optimal path.

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# An Implicitly Parallel EDA Based on Restricted Boltzmann Machines

Probst, Melte Rothlauf, Franz Grahl, Joern

We present a parallel version of RBM-EDA. RBM-EDA is an Estimation of Distribution Algorithm (FDA) that models dependencies between decision variables using a Restricted Boltzmann Machine (RBM). In contrast to other EDAs, RBM-EDA mainly uses matrix-matrix ultiplications for model estimation and sampling. Hence, for implementation, standard libraries for linear algebra can be used. This allows an easy parallelization and leads to a high utilization of parallel architectures. The probabilistic model of the parallel version and the version on a single core are identical. We explore the speedups gained from running RBM-EDA on a Graphics Processing Unit. For problems of bounded difficulty like deceptive traps, parallel RBM-EDA is faster by several orders of magnitude (up to 750 times) in comparison to a single-threaded implementation on a CPU. As the speedup grows linearly with problem size, parallel RBM-EDA may be particularly useful for large problems.

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# A Novel Population-based Multi-Objective CMA-ES and the Impact of Different Constraint Handling Techniques

Rodrigues, Silvio Bauer, Pavol Bosman, Peter A. N.

The Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES) is a well-known, state-of-the-art optimization algorithm for single-objective real-valued problems, especially in black-box settings. Although several extensions of CMAES to multi-objective (MO) optimization exist, no extension incorporates a key component of the most robust and general CMA-ES variant: the association of a population with each Gaussian distribution that drives optimization. To achieve this, we use a recently introduced framework for extending population-based algorithms from single- to multi-objective optimization. We compare, using six well-known benchmark problems, the performance of the newly constructed MO-CMA- ES with existing variants and with the estimation of distribution algorithm (EDA) known as iMAMaLGaM, that is also an instance of the framework, extending the single- objective EDA iAMaLGaM to MO. Results underline the advantages of being able to use populations. Because many real-world problems have constraints, we also study the use of four constraint-handling techniques. We find that CMA-ES is typically less robust to these techniques than iAMaLGaM. Moreover, whereas we could verify that a penalty method that was previously used in literature leads to fast convergence, we also find that it has a high risk of finding only nearly, but not entirely, feasible solutions. We therefore propose that other constraint-handling techniques should be preferred in general.

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# Estimation of Distribution Algorithm using Factor Graph and Markov Blanket Canonical Factorization

Helmi, B. Hoda Rahmani, Adel T.

Finding a good model and efficiently estimating the distribution is still an open challenge in estimation of distribution algorithms (EDAs). Factorization encoded by models in most of the EDAs are constrained. However for optimization of many real-world problems, finding the model capable of representing complex interactions without much computational complexity overhead is the key challenge. On the other hand factor graph which is the most natural graphical model for representing additively decomposable functions is rarely employed in EDAs. In this paper we introduce Factor Graph based EDA (FGEDA) which learns factor graph as the model and estimate the probability distribution represented by the learned factor graph using Markov blanket canonical factorization. The class of factorization that is employed for approximation of distribution in FGEDA is expanded relative to famous EDAs. We have used matrix factorization for learning the factor graph of the problem based on the pairwise mutual information between pair of variables. Gibbs sampling and BB- wise crossover are used to generate new samples. Empirical evaluation as well as theoretical analysis of the approach show the efficiency and power of FGEDA in the optimization of functions with complex interactions. It is showed experimentally that FGEDA outperform other well- known EDAs.

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# Inferring and Exploiting Problem Structure with Schema Grammar

Cox, Chris R. Watson, Richard A.

In this work we introduce a model-building algorithm that is able to infer problem structure using generative grammar induction. We define a class of grammar that can represent the structure of a problem space as a hierarchy of multivariate patterns (schemata), and a compression algorithm that can infer an instance of the grammar from a collection of sample individuals. Unlike conventional sequential grammars the rules of the grammar define unordered set-membership productions and are therefore insensitive to gene ordering or physical linkage. We show that when grammars are inferred from populations of fit individuals on shuffled nearest-neighbour NK-landscape problems, there is a correlation between the compressibility of a population and the degree of inherent problem structure. We also demonstrate how the information captured by the grammatical model from a population can aid evolutionary search. By using the lexicon of schemata inferred into a grammar to facilitate variation, we show that a population is able to incrementally learn and then exploit its own structure to find fitter regions of the search space, and ultimately locate the global optimum.

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# A New EDA by a Gradient-Driven Density

Segovia Dominguez, Ignacio Hernandez Aguirre, Arturo Ivvan Valdez, S.

This paper introduces the Gradient-driven Density Function (del D-d) approach, and its application to Estimation of Distribution Algorithms (EDAs). In order to compute the del D-d, we also introduce the Expected Gradient Estimate (EGE), which is an estimation of the gradient, based on information from other individuals. Whilst EGE delivers an estimation of the gradient vector at the position of any individual, the del D-d delivers a statistical model (e.g. the normal distribution) that allows the sampling of new individuals around the direction of the estimated gradient. Hence, in the proposed EDA, the gradient information is inherited to the new population. The computation of the EGE vector does not need additional function evaluations. It is worth noting that this paper focuses in black-box optimization. The proposed EDA is tested with a benchmark of 10 problems. The statistical tests show a competitive performance of the proposal.

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# Using Estimation of Distribution Algorithm to Coordinate Decentralized Learning Automata for Meta-task Scheduling

Li, Jie Zhang, Junqi

Learning automaton (LA) is a reinforcement learning model that aims to determine the optimal action out of a set of actions. It is characterized by updating a selection probability vector through a sequence of repetitive feedback cycles interacting with an environment. Decentralized learning automata (DLAs) consists of many learning automata (LAs) that learn at the same time. Each LA independently selects an action based on its own selection probability vector. In order to provide an appropriate central coordination mechanism in DLAs, this paper proposes a novel decentralized coordination learning automaton (DCLA) using a new selection probability vector which is combined with the probability vectors derived from both LA and estimation of distribution algorithm (EDA). LA contributes to the own learning experience of each LA while EDA estimates the distribution of the whole swarm's promising individuals. Thus, decentralized LAs can be coordinated by EDA using the swarm's comprehensive knowledge. The proposed automaton is applied to solve the real problem of meta-task scheduling in heterogeneous computing system. Extensive experiments demonstrate a superiority of DCLA over other counterpart algorithms. The results show that the proposed DCLA provides an effective and efficient way to coordinate LAs for solving complicated problems.

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# Creating Stock Trading Rules Using Graph-Based Estimation of Distribution Algorithm

Li, Xianneng He, Wen Hirasawa, Kotaro

Though there are numerous approaches developed currently, exploring the practical applications of estimation of distribution algorithm (EDA) has been reported to be one of the most important challenges in this field. This paper is dedicated to extend EDA to solve one of the most active research problems - stock trading, which has been rarely revealed in the EDA literature. A recent proposed graph-based EDA called reinforced probabilistic model building genetic network programming (RPMBGNP) is investigated to create stock trading rules. With its distinguished directed graph-based individual structure and the reinforcement learning-based probabilistic modeling, we demonstrate the effectiveness of RPMBGNP for the stock trading task through real-market stock data, where much higher profits are obtained than traditional non-EDA models.

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# HMOEDA\_LLE: a hybrid multi-objective estimation of distribution algorithm combining locally linear embedding

Zhang, Yuzhen Dai, Guangming Peng, Lei Wang, Maocai

Based on the regularity that: the Pareto set of a continuous m-objectives problem is a piecewise continuous (m-1)-dimensional manifold, a novel hybrid multi-objective optimization algorithm is proposed in this paper. In the early evolutionary stage, traditional crossover and mutation operations are used to produce offspring, in addition, the locally linear embedding (LLE) with small neighbor parameter approach is introduced to learn the local geometry of the manifold. When certain regularity in population's distribution is detected, new offspring are sampled from the probability models created by the statistical distribution information. An entropy-based criterion is imported to determine the switching time of the two different phases of evolutionary search. The proposed hybrid multi-objective estimation of distribution algorithm combining locally linear embedding (HMOEDA\_LLE) adopts several widely used test problems to conduct the comparison experiments with two state-of-the-art multi-objective evolutionary algorithms NSGA-II and RM-MEDA. The simulated results show the effectiveness of the entropy-based criterion and the proposed algorithm has better optimization performance.

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# Overtime Capacity Expansion in Order Acceptance with Node Based Estimation of Distribution Algorithms

Wattanapornprom, Watcharee Li, Tieke Wattanapornprom, Warin Chongstitvatana, Prabhas

Order acceptance with overtime capacity expansion requires trading off between over and under capacity utilization in order to gain more profits. This research proposes an overtime capacity utilization order acceptance model and proposes adaptations of node based estimation of distribution algorithm to solve the order acceptance decisions in multi-process environments. The results show that node based coincidence algorithm is a potential algorithm which can maximize both profit and can maximize the capacity utilization at the same time.

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# A Probability Model based Evolutionary Algorithm with Priori and Posteriori Knowledge for Multiobjective Knapsack Problems

Li, Yang Zhou, Aimin Zhang, Guixu

Most evolutionary algorithms utilize the posteriori knowledge learned from the running process to guide the search. It is arguable that the priori knowledge about the problems to tackle can also play an important role in problem solving. To demonstrate the importance of both priori and posteriori knowledge, in this paper, we proposes a decomposition based estimation of distribution algorithm with priori and posteriori knowledge (MEDA/D-PP) to tackle multiobjective knapsack problems (MOKPs). In MEDA/D-PP, an MOKP is decomposed into a number of single objective subproblems and those subproblems are optimized simultaneously. A probability model, which incorporates both priori and posteriori knowledge, is built for each subproblem to sample new trail solutions. The proposed method is applied to a variety of test instances and the experimental results show that the proposed algorithm is promising. It is demonstrated that priori knowledge can improve the search ability of the algorithm and posteriori knowledge is helpful to guide the search.

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# Dynamic Optimization of Chemical Engineering Problems Using Affinity Propagation Based Estimation of Distribution Algorithm

Luo, Na Feng, Wei Wang, Xiaoqiang Qian, Feng

Dynamic optimization has attracted much attention for its wide applications in engineering problems. However, it is still a challenge for high nonlinear, multi-dimensional and multimodal problems. Estimation of Distribution Algorithm was proposed in which probabilistic models extracted relevant features of the complex search space and then generated new individuals during optimization. In order to decrease the dependences among control variables in dynamic optimization, affinity propagation was applied to cluster the individuals in evolutionary iterations. In each cluster, the probabilistic density function of Gaussian mixture model refined the promising spaces with high quality solutions and avoided the random combination of different control variables. To evaluate the performance of the new approach, three dynamic optimization problems of chemical process are used as cases comparing with three state-of-the-art global optimization methods. The results showed that the new approach could achieve the best solution in most cases with less computational effort and higher efficiency.

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# Multi-objective Optimal Temperature Control for Organic Rankine Cycle Systems

Zhang, Jianhua Ren, Mifeng Xiong, Jing Lin, Mingming

The Organic Rankine Cycle (ORC) has attracted a lot of interests for its ability to recover low-grade heat and the possibility to be implemented in decentralized low-capacity power plants. In this paper, a new optimal temperature control method is proposed for ORC systems with non-Gaussian disturbances which influence the quality of exhaust gas. The objective here is to control the speed of the pump so that the superheated vapor temperature follows a target one. It means that the error between those two temperatures is minimized both in magnitude and randomness, which are characterized by mean value and entropy, respectively. Therefore, the proposed control strategy is regarded as a multi-objective optimization problem. To solve this problem, a Multi-Objective Estimation of Distribution Algorithm (MOEDA) is adopted to obtain all the possible optimal control inputs. Simulation results show the effectiveness of the proposed technique.

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# A Modified RBM-Based Estimation of Distribution Algorithm for Steelmaking-Continuous Casting Scheduling

Jiang, Shenglong Liu, Min Hao, Jinghua

In order to solve steelmaking-continuous casting scheduling problem which is considered as a critical module of planning and scheduling in modern iron and steel enterprise, this paper propose a data-based evolutionary algorithm. Firstly, a mixed integer programming model considering practical constraints and multi-objectives is provided. Secondly, we develop a modified estimation of distribution algorithm based on restricted Boltzmann machine, which incorporates a backward list scheduling method, a solution representation with job permutation within each batch, and a local search method used to enhance the performance of this algorithm. To verify the proposed approach, a number of instances from real-world industrial data are generated. The final numerical results show that the proposed data-based algorithm is efficient and effective to solve practical steelmaking-continuous casting scheduling problems.

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# An Online Method for the Real-time Aircraft Arrival Sequencing and Scheduling Problem

Ji, Xiaopeng Fang, Jing Yan, Ran

Aircraft arrival sequencing and scheduling (ASS) is a hot topic in air traffic control, which has been proven to be an NP-hard problem. So far, many efforts have been made by modeling this problem in a static case, in which the information of all the landing aircrafts is known in advance. However, the air traffic environment in the airport is dynamic. As new aircrafts are arriving at the airport continually, the corresponding adjustment should be considered for the scheduling. From this point of view, an online method which is based on estimation of distribution algorithm (EDA) is introduced in this paper. At any moment in the sequencing operation, the method only focuses on those aircrafts which have already arrived at the airport but have not been assigned to land. Experiments show that the proposed method is effective and efficient to achieve a better result in solving the real-time ASS.

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# Hybrid Self-organizing Migrating Algorithm Based on Estimation of Distribution

Lin Zhi-yi Wang Li-juan

A new hybrid self-organizing migrating algorithm based on estimation of distribution (HSOMA) is proposed to resolve the defect of premature convergence in the self-organizing migrating algorithm (SOMA) and improve the search ability of SOMA. In order to make full use of the statistical information on population and increase the diversity of migration behavior, HSOMA introduces the thought of estimation of distribution algorithm (FDA) into SOMA and reproduces the genes of new individuals by both SOMA and FDA. The proportion of the use of two algorithms is decided by a control parameter. In this way, HSOMA can increase the population diversity and improve the convergence speed. HSOMA is tested on several complex benchmark functions taken from literature and its efficiency is compared with SOMA, the continuous domain Population-Based Incremental Learning algorithm(PBILc) and hybrid migrating behavior based self-organizing migrating algorithm(HBSOMA). On the basis of comparison it is concluded that HSOMA shows better global search ability and convergence accuracy.

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# Multivariate Gaussian Copula in Estimation of Distribution Algorithm with Model Migration

Hyrs, Martin Schwarz, Josef

The paper presents a new concept of an islandbased model of Estimation of Distribution Algorithms (EDAs) with a bidirectional topology in the field of numerical optimization in continuous domain. The traditional migration of individuals is replaced by the probability model migration. Instead of a classical joint probability distribution model, the multivariate Gaussian copula is used which must be specified by correlation coefficients and parameters of a univariate marginal distributions. The idea of the proposed Gaussian Copula EDA algorithm with model migration (GC-mEDA) is to modify the parameters of a resident model respective to each island by the immigrant model of the neighbour island. The performance of the proposed algorithm is tested over a group of five well-known benchmarks.

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# Chaos Elitism Estimation of Distribution Algorithm

Xu, Qingyang

Estimation of distribution algorithm (EDA) is a kind of EAs, which is based on the technique of probabilistic model and sampling. This paper presents a chaos elitism EDA to improve the performance of traditional EDA to solve high dimensional optimization problems. The famous elitism strategy is introduced to maintain a good convergent performance. The chaos perturbation strategy is used to improve the local search ability. Some simulation experiments conducted to verify the performance of CEEDA. The results of CEEDA are promising, and it is comparable with other EDA.

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# An EDA-based Community Detection in Complex Networks

Parsa, Mohsen Ghassemi Mozayani, Nasser Esmaeili, Ahmad

Communities are basic units of complex networks and understanding of their structure help us to understand the structure of a network. Communities are groups of nodes that have many links inside and few links outside them. Community detection in a network can be modeled as an optimization problem. We can use some measures such as Modularity and Community Score for evaluating the quality of a partition of nodes. In this paper, we present a new algorithm for detecting communities in networks based on an Estimation of Distribution Algorithm (EDA) with the assumption that the problem variables are independent. EDAs are those evolutionary algorithms that build and sample the probabilistic models of selected solutions instead of using crossover and mutation operators. In this paper, we assess our algorithm by synthetic and real data sets and compare it with other community detection algorithms.

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# A hybrid competent multi-swarm approach for many-objective problems

Castro, Olacir R., Jr. Pozo, Aurora

Many-objective optimization problems (MaOPs) are a class of multi-objective problems that presents more than three functions to be optimized. As most Pareto based algorithms scale poorly according to the number of objectives, researchers are working on alternatives to overcome these limitations. An algorithm that has shown good results in solving MaOPs is the Iterated Multi-swarm (I-Multi) which presents a clever multi-swarm strategy to spread the solutions across different areas of the objective space while keeping a good convergence. As the I-Multi is a very recent algorithm, alternative approaches are yet to be explored. Here we investigate the use of an Estimation of Distribution Algorithm (EDA) in the multi-swarm stage of I-Multi. EDAs create a model based on the best solutions found and sample new solutions based in this model. An EDA that presents good performance is the rBOA which is a real-valued version of the Bayesian optimization algorithm. This work presents an algorithm called C-Multi consisting of a hybrid between the I-Multi and the rBOA with the aim to join the diversity strength of I-Multi and the convergence characteristic of rBOA. An experimental study is conducted using the seven well-known DTLZ test functions with 3, 5, 10, 15 and 20 objectives to evaluate the performance of the algorithms as the number of objectives scales up. The results point that the new algorithm presents superior convergence and diversity on hard problems.

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# Application of Estimation of Distribution Algorithm in HW/SW Partition

Yu, Juan He, Yuyao Li, Xiaoqiang

Hardware/software (HW/SW) partitioning problem is NP hard problem. An improved algorithm based on estimation of distribution algorithms is proposed to solve HW/SW partitioning problem. Estimation of distribution algorithm is good in globe search but poor in local search and may suffer from" premature convergence" beacause of diversity loss. The improved algorithm strengthens the local searching ability by cloning and searching the elite solutions and improves the diversity loss by correcting the probability model. Numerical simulation is carried out and compared with existing algorithm, the results show the effectiveness of the improved estimation of distribution algorithm in solving HW/SW partitioning problem.

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# Solving TSP Problems with Hybrid Estimation of Distribution Algorithms

Zhang, Xiaoxia Ma, Yunyong

In this paper, a hybrid Estimation of Distribution Algorithms is proposed to solve traveling salesman problem, and a greedy algorithm is used to improve the quality of the initial population. It sets up a Bayes probabilistic model of the TSP. The roulette method is adopted to generate the new population. In order to prevent falling into local optimum, the mutation and limit were proposed to enhance the exploitation ability. At the same time, three new neighborhood search strategies and the second element optimization method are presented to enhance the ability of the local search. The simulation results and comparisons based on benchmarks validate the efficiency of the proposed algorithm.

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# An Effective Estimation of Distribution Algorithm for Multi-track Train Scheduling Problem

Wang, Shengyao Wang, Ling

In this paper, an effective estimation of distribution algorithm (EDA) is presented for solving the multi-track train scheduling problem (MTTSP). The individual of the EDA is represented as the permutation of train priority. With a proper track assignment rule, the individual is decoded into feasible schedule. In addition, the EDA builds a probability model for describing the distribution of the solution space. In every generation, it samples the promising region for generating new individuals and updates the probability model with the superior population. Moreover, the influence of parameter setting is investigated based on design-of-experiment method and a set of suitable parameter values is suggested. Simulation results based on some instances and comparisons with the existing algorithm demonstrate the effectiveness and efficiency of the EDA.

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# A Bayesian Statistical Inference-Based Estimation of Distribution Algorithm for the Re-entrant Job-Shop Scheduling Problem with Sequence-Dependent Setup Times

Chen, Shao-Feng Qian, Bin Liu, Bo Hu, Rong Zhang, Chang-Sheng

In this paper, a bayesian statistical inference-based estimation of distribution algorithm (BEDA) is proposed for the re-entrant job-shop scheduling problem with sequence-dependent setup times (RJSSPST) to minimize the maximum completion time (i.e., makespan), which is a typical NP hard combinatorial problem with strong engineering background. Bayesian statistical inference (BSI) is utilized to extract sub-sequence information from high quality individuals of the current population and determine the parameters of BEDA's probabilistic model (BEDA\_PM). In the proposed BEDA, BEDA\_PM is used to generate new population and guide the search to find promising sequences or regions in the solution space. Simulation experiments and comparisons demonstrate the effectiveness of the proposed BEDA.

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# An Enhanced Estimation of Distribution Algorithm for No-Wait Job Shop Scheduling Problem with Makespan Criterion

Chen, Shao-Feng Qian, Bin Hu, Rong Li, Zuo-Cheng

In this paper, an enhanced estimation of distribution algorithm (EEDA) is proposed for the no-wait job shop scheduling problem (NWJSSP) with the makespan criterion, which has been proved to be strongly NP-hard. The NWJSSP can be decomposed into the sequencing and the timetabling problems. The proposed EEDA and a shift timetabling method are used to address the sequencing problem and the timetabling problem, respectively. In EEDA, the EDA-based search is applied to guiding the search to some promising sequences or regions, and an Interchange-based local search is presented to perform the search from these promising regions. Moreover, each individual or sequence of EEDA is decoded by applying a shift timetabling method to solving the corresponding timetabling problem. The experimental results show that the combination of the EEDA and the shift timetabling method can accelerate the convergence speed and is helpful in achieving more competitive results.

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# Master-Slave Asynchronous Evolutionary Hybrid Algorithm and its Application in VANETs Routing Optimization

Said, Said Mohamed Nakamura, Morikazu

Hybrid algorithms incorporated with parallel processing techniques are very powerful tools for efficiently solving very complex optimization problems. We present asynchronous parallel computer architecture adaptation based on hybridization of Genetic Algorithms (GAs) and Estimation of Distribution Algorithms (EDAs). In this master-slave formulation, slaves perform evolutionary computation independently using GAs, while master supervises and controls the searching process. Master's role is to probabilistically study the characteristics of solution space and directs the slaves on good searching spots. This study reports some few findings on the ability of our hybrid algorithm to solve some instances of BQP problem as well as AODV routing optimization in VANETs. For both problems our hybrid algorithm has obtained best results in terms of quality of solutions as well as computational speed.

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# A Modified Screening Estimation of Distribution Algorithm for Large-Scale Continuous Optimization

Mishra, Krishna Manjari Gallagher, Marcus

Continuous Estimation of Distribution Algorithms (EDAs) commonly use a Gaussian distribution to control the search process. For high-dimensional optimization problems, several practical issues arise when estimating a large covariance matrix from the selected population. Recent work in continuous EDAs has aimed to address these issues. The Screening Estimation of Distribution Algorithm (sEDA) is one such algorithm which, uniquely, utilizes the objective function values obtained during the search. A sensitivity analysis technique is then used to reduce the rank of the covariance matrix, according to the estimated sensitivity of the fitness function to individual variables in the search space.

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# Evolution Strategies with an RBM-Based Meta-Model

Makukhin, Kirill

Evolution strategies have been demonstrated to offer a state-of-theart performance on different optimisation problems. The efficiency of the algorithm largely depends on its ability to build an adequate meta-model of the function being optimised. This paper proposes a novel algorithm RBM-ES that utilises a computationally efficient restricted Boltzmann machine for maintaining the meta-model. We demonstrate that our algorithm is able to adapt its model to complex multidimensional landscapes. Furthermore, we compare the proposed algorithm to state-of the art algorithms such as CMA-ES on different tasks and demonstrate that the RBM-ES can achieve good performance.

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# Multiobjective Memetic Estimation of Distribution Algorithm Based on an Incremental Tournament Local Searcher

Yang, Kaifeng Mu, Li Yang, Dongdong Zou, Feng Wang, Lei Jiang, Qiaoyong

A novel hybrid multiobjective algorithm is presented in this paper, which combines a new multiobjective estimation of distribution algorithm, an efficient local searcher and epsilon-dominance. Besides, two multiobjective problems with variable linkages strictly based on manifold distribution are proposed. The Pareto set to the continuous multiobjective optimization problems, in the decision space, is a piecewise low-dimensional continuous manifold. The regularity by the manifold features just build probability distribution model by globally statistical information from the population, yet, the efficiency of promising individuals is not well exploited, which is not beneficial to search and optimization process. Hereby, an incremental tournament local searcher is designed to exploit local information efficiently and accelerate convergence to the true Pareto-optimal front. Besides, since epsilon-dominance is a strategy that can make multiobjective algorithm gain well distributed solutions and has low computational complexity, epsilon-dominance and the incremental tournament local searcher are combined here. The novel memetic multiobjective estimation of distribution algorithm, MMEDA, was proposed accordingly. The algorithm is validated by experiment on twenty-two test problems with and without variable linkages of diverse complexities. Compared with three state-of-the-art multiobjective optimization algorithms, our algorithm achieves comparable results in terms of convergence and diversity metrics.

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# Mathematical Modeling and EDA-based Network Planning for Broadband Power Line Communication Access Systems

Oberoi, J. S. Lee, D. C.

In this paper, we present a mathematical model of power line communication access systems and a technique for an efficient network deployment. We focus on the problem of designing an infrastructure network model which fits the power line communication needs and installing an apt number of base stations and repeaters at adequate locations suited to serve all the subscribers to the required level at a low cost to the utility company. The computational complexity of determining an optimal deployment by using exhaustive search grows exponentially with the number of base stations, repeaters and the users. We propose a heuristic method combined with an Estimation-of-Distribution Algorithm (EDA) for this assignment problem. EDA is a probabilistic evolutionary algorithm which updates its population at each iteration on the basis of the probability densities obtained from the population of superior candidates evaluated and chosen at the previous iteration.

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# Multivariate Cauchy EDA Optimisation

Sanyang, Momodou L. Kaban, Ata

We consider Black-Box continuous optimization by Estimation of Distribution Algorithms (EDA). In continuous EDA, the multivariate Gaussian distribution is widely used as a search operator, and it has the well-known advantage of modelling the correlation structure of the search variables, which univariate EDA lacks. However, the Gaussian distribution as a search operator is prone to premature convergence when the population is far from the optimum. Recent work suggests that replacing the univariate Gaussian with a univariate Cauchy distribution in EDA holds promise in alleviating this problem because it is able to make larger jumps in the search space due to the Cauchy distribution's heavy tails. In this paper, we propose the use of a multivariate Cauchy distribution to blend together the advantages of multivariate modelling with the ability of escaping early convergence to efficiently explore the search space. Experiments on 16 benchmark functions demonstrate the superiority of multivariate Cauchy EDA against univariate Cauchy EDA, and its advantages against multivariate Gaussian EDA when the population lies far from the optimum.

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# Nonconvex Functions Optimization Using an Estimation of Distribution Algorithm Based on a Multivariate Extension of the Clayton Copula

de Mello, Harold D., Jr. Abs da Cruz, Andre V. Vellasco, Marley M. B. R.

This paper presents a copula-based estimation of a distribution algorithm with parameter updating for numeric optimization problems. This model implements an estimation of a distribution algorithm using a multivariate extension of Clayton's bivariate copula (MEC-EDA) to estimate the conditional probability for generating a population of individuals. Moreover, the model uses traditional mutation and elitism operators jointly with a heuristic for a population restarting in the evolutionary process. We show that these approaches improve the overall performance of the optimization compared to other copula-based EDAs.

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# An Estimation of Distribution Algorithm for energy-aware Steelmaking Continuous Casting Scheduling

Wang, Guirong Li, Qiqiang Yuan, Maorong

This paper addresses the Steelmaking Continuous Casting production scheduling problem(SCC) with power consumption as the main objective. An encoding and decoding scheme is proposed and an effective Estimation of Distribution Algorithm (EDA) is presented to solve it. Simulation experiments indicate that EDA can solve the SCC problem efficiently and has fast speed of convergency.

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# An Estimation of Distribution Algorithm (EDA) Variant with QGA for Flowshop Scheduling Problem

Latif, Muhammad Shahid Hong Zhou Ali, Amir

In this research article, a hybrid approach is presented which based on well-known meta-heuristics algorithms. This study based on integration of Quantum Genetic Algorithm (QGA) and Estimation of Distribution Algorithm, EDA, (for simplicity we use Q-EDA) for flowshop scheduling, a well-known NP hard Problem, while focusing on the total flow time minimization criterion. A relatively new method has been adopted for the encoding of jobs sequence in flowshop known as angel rotations instead of random keys, so QGA become more efficient. Further, EDA has been integrated to update the population of QGA by making a probability model. This probabilistic model is built and used to generate new candidate solutions which comprised on best individuals, obtained after several repetitions of proposed (Q-EDA) approach. As both heuristics based on probabilistic characteristics, so exhibits excellent learning capability and have minimum chances of being trapped in local optima. The results obtained during this study are presented and compared with contemporary approaches in literature. The current hybrid Q-EDA has implemented on different benchmark problems. The experiments has showed better convergence and results. It is concluded that hybrid Q-EDA algorithm can generally produce better results while implemented for Flowshop Scheduling Problem (FSSP).

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# A Fast Elitism Gaussian Estimation of Distribution Algorithm and Application for PID Optimization

Xu, Qingyang Zhang, Chengjin Zhang, Li

Estimation of distribution algorithm (EDA) is an intelligent optimization algorithm based on the probability statistics theory. A fast elitism Gaussian estimation of distribution algorithm (FEGEDA) is proposed in this paper. The Gaussian probability model is used to model the solution distribution. The parameters of Gaussian come from the statistical information of the best individuals by fast learning rule. A fast learning rule is used to enhance the efficiency of the algorithm, and an elitism strategy is used to maintain the convergent performance. The performances of the algorithm are examined based upon several benchmarks. In the simulations, a one-dimensional benchmark is used to visualize the optimization process and probability model learning process during the evolution, and several two-dimensional and higher dimensional benchmarks are used to testify the performance of FEGEDA. The experimental results indicate the capability of FEGEDA, especially in the higher dimensional problems, and the FEGEDA exhibits a better performance than some other algorithms and EDAs. Finally, FEGEDA is used in PID controller optimization of PMSM and compared with the classical-PID and GA.

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