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A new approach for multi-criteria scheduling

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ABSTRACT

In this paper we propose a new approach, recommended for solving certain class of multi-criteria scheduling problems, with the use of cloud exploration of the solution space supported by fine-grained parallel computing. The approach allow us to approximate Pareto front more accurately than other known algorithms in competitive time. To show and check advantageous properties of the proposed approach, the new solution algorithm, called VESA, was implemented for the case of bi-criteria flow shop scheduling problem and tested against a number of high-quality benchmarks known in the literature. Vector processing technologies are used to enhance the efficiency of solution search and acceptance rates for the extended simulated annealing metaheuristic. Results are compared using, among others, the independent Hyper-Volume Indicator (I_H) measure. Computer test of VESA confirms excellent approximation of the Pareto front.

1. Introduction

Technological advancement is inseparably connected with higher customer expectations and the necessity of performance increase. Companies, in order to maintain their position in highly competitive market, are compelled to use more advanced systems for production planning. Optimization of production scheduling remains a difficult task that relies on complex computational models, especially when the optimization concerns multiple criteria (objectives).

Approaches used to solve optimization tasks generated in problems of control, planning, designing and management have completely changed during recent years. Cases with unimodal, convex, differentiable scalar goal functions disappeared from research labs, because a lot of satisfactory efficient methods were already developed. Thus, all that remains are the hard cases: multimodal, multi-criteria, non-differentiable, NP-hard, discrete problems, often with huge dimensionality. These practical tasks, generated by industry and market, have caused serious troubles in seeking global optimum. Great effort has been done by scientists in recent years in order to reinforce power of solution methods and to fulfill expectations of practitioners. The results obtained from algorithms development are still moderate at best, proving the remaining needs for further research in this area. In this paper we focus on the multiple-criteria cases, thanks to increasing power of computational capabilities of modern computer systems.

2. State of the art

Solving multi-criteria discrete optimization problems requires a method of comparing different solutions in terms of a vector of goal functions. Excellent taxonomy of possible approaches depending on user preferences, forms and time moments of their expressing, one can find in (Parveen & Ullah, 2011). The concept of Pareto efficiency is the one among most commonly used, since leaves the user final decision about the choice of solution without unknown or unexpressed a priori user preferences. Because of the strong NP-hardness of almost all practical scheduling problems, exact approaches (chiefly B&B schemes, examined mainly for two-machine cases), although theoretically excellent, in fact remain useless for practitioners, Tyagi, Varshney, and Chandramouli (2013). Hence, sufficiently good approximations of Pareto front are still welcome. The majority of approaches used to this aim are focused on quite sophisticated evolutionary algorithms and local search method, with few of them designed for independent multiple threads parallel computing in mind. Quite rarely appeared simulated annealing algorithms applied to the considered case, despite their evident simplicity of implementation; we perceive this fact as a lack of advanced ideas suitable for parallel SA. Coming back to the scheduling area, the commonly considered is the bi-criteria flow-shop scheduling problem, having a moderately complicated model and relatively well developed sequencing

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algorithms with rich set of benchmarks. Thus, provided below a short survey of algorithms and techniques is oriented on the flow shop problem (also leading in our research) and a few dominant approximate approaches.

A representative among evolutionary algorithms working in single-processor environment is *Multi-Objective Genetic Algorithm* (MOGA), Murata, Ishibuchi, and Tanaka (1996), designed for multi-criteria flow shop and implemented in bi-criteria case. A set of non-dominated solutions is created on the base of successive populations, by the process of solution management. To spread the search through the solution space, the weighted sum of individual criteria was used with random weights assigned at each iteration. Additionally, a method of sustaining elite solutions is included, adding a few Pareto solutions from the elite set to the next generation of population. An improved version of MOGA, called CMOGA proposed next, Murata, Ishibuchi, and Gen (2001), introduced new weight distribution between optimization criteria. The special cell structure allows on better weight selection, which in turn, caused the algorithm to find a better approximation of the Pareto front.

Another variant of genetic algorithm, equipped with initialization procedure inserting four good solutions into initial random population, was proposed by Pasupathy, Rajendran, and Suresh (2006). Their algorithm uses an external population in order to keep already found non-dominated solutions. Its evolution strategy is similar to the one used in NSGA-II algorithm (Deb, Pratap, Agarwal, & Meyarivan, 2002), but improving quality of Pareto frontier is based on two different local search procedures, applied to external population after performing the main part of the algorithm.

Application of simulated annealing has a lot of references, see survey (Hooda & Dhingra, 2011), however among enumerated there papers we do not find neither our approach nor significant progress in multi-criteria view. A simple single-trajectory simulated annealing algorithm was used for solving multicriteria problem transformed to single-criteria case by using weighted sum of two criteria, see Charavarthy and Rajendran (1999). To reinforce algorithm quality, a supporting local search method were introduced. The initial solution is constructed from one of the following methods: (a) *Earliest Due Date* (EDD), (b) *Least Static Slack* (LSS) and (c) NEH heuristic (Nawaz, Enscore, & Ham, 1983). The neighborhood generation is performed by the method of swapping two adjacent jobs.

Inspired by *Pareto Archived Evolution Strategy* (PAES) algorithm, Suresh and Mohanasundaram proposed *Pareto Archived Simulated Annealing* (PASA) algorithm (Suresh & Mohanasundaram, 2004), which is based on a new perturbation method. A scheme called *Segment Random Insertion* (SRI) is used to generate neighborhood of selected solution. To maintain good non-dominated solutions, an external archive is used. Starting solution is generated at random, while new solutions are selected using calibrated weighted sum of criteria.

A multiobjective parallel genetic algorithm was proposed in paper (Rashidi, Jahandar, & Zandieh, 2010). Evaluation was Pareto-based and used procedure called *Redirect*, which helped the algorithm to overcome the local optima. Test results showed that the proposed algorithm obtains solutions of good quality. Another algorithm, a *Genetic Local Search Algorithm* (GLSA), was proposed in (Ishibuchi & Murata, 1998). It applied local search procedure to maximize fitness value for each individual generated by genetic operators.

3. Philosophy of the new approach

Metaheuristics designed for conventional scheduling problems usually generate final solutions by the means of transforming the current solution (or set of solutions) into another over the course of subsequent iterations. The goal is to find the optimal solution (single-criteria case) or a Pareto front (multi-criteria case) or their approximation. Thus various metaheuristics employ various iteration-to-iteration transformation and produce different step-by-step trajectories of solutions. In Fig. 1, we can compare the search policies employed by existing approaches, namely SA (a) and GA (b). The first algorithm (Fig. 1a) considers single solution per iteration and chooses the next solution by employing a neighborhood search method (NS). Similar approach is shared by tabu search (TS). Ultimately, only single solutions are processed, which affects the quality of Pareto front approximation, even if external Pareto archive is used.

The GA (Fig. 1b) operates on sets of solutions (called populations or clouds), by the use of several genetic operators (GA) including mutation, crossover and selection, aiming to obtain a sufficient number of almost uniformly distributed non-dominated solutions. Such population-based metaheuristics (GA, ACO, PSO) considered by many authors as the most preferable for the generation of Pareto front, because the Pareto front itself (or its approximation) usually consists of many solutions (a population). However, the final results strongly depends on the transformation used to generate new populations and although great effort has been done in this field, GA and similar approaches for multi-criteria scheduling are still in the developing phase.

While the population-based approaches are often more popular, we observed that the SA algorithm performs well in the single- and even some multi-criteria cases. From there, we devised the possibility of a non-trivial extension of classic SA approach (Fig. 1a), by including the notion of solution sets (clouds), with the aim to improve the search process and allow more non-dominated solutions to be included into our archive. The proper formulation of such approach includes discussion and research on several basic topics, namely: (1) how to define the "cloud" of solution, (2) which solution should be accepted from current "cloud" to generate the next iteration cloud, (3) how to avoid local optima on the trajectory of the search and (4) what strategies should be employed in order to better approximate the Pareto front. Starting from the well-known single-trajectory simulated annealing (SA) approach we design desired algorithm in the way similar to parallel simulated annealing (pSA), having in mind the simplicity of implementation of both mentioned cases. Going over applications of SA to multi-criteria problems with Pareto fronts, we do not find in the literature neither

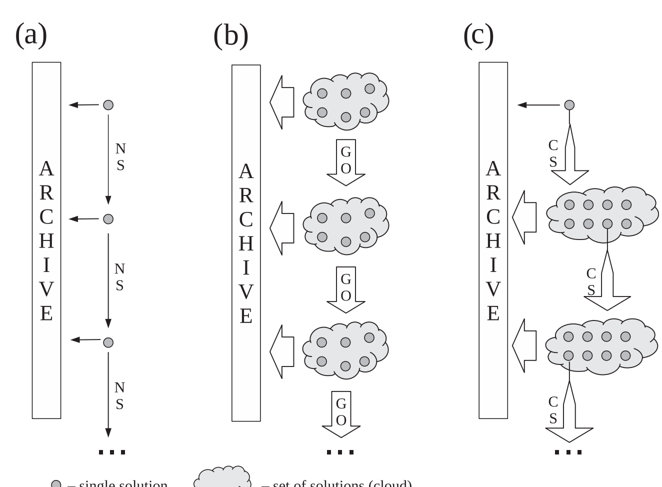

Fig. 1. Trajectory and Pareto archive update policy for different algorithms: (a) single trajectory (SA), (b) trajectory of clouds (GA), and (c) proposed approach (VESA). NS – neighborhood search, GO – genetic operators, CS – cloud search.