XXIV ONPCE: Oficina Nacional de Problemas de Corte e Empacotamento, Planejamento e Programação da Produção e Correlatos

An Evolutionary Algorithm applied to the Multi-Objective Flexible Job-Shop Scheduling Problem

Luis Henrique Pauleti Mendes, Fábio Luiz Usberti[1]
Institute of Computing - State University of Campinas
Mário César San Felice[2]
Department of Computing - Federal University of São Carlos

Multi-objective optimization problems (MOPs) are an important field of operations research. Such problems arise in many real-world situations where multiple conflicting points of view must be taken into account. A MOP can be stated as $\min_{x\in\mathcal{X}} \mathbf{f}(x) = (f_1(x), \ldots, f_m(x))^T$, where $\mathcal{X} \subseteq \mathbb{R}^n$ is an n-dimensional decision space, $\mathbf{f} : \mathcal{X} \to \mathbb{R}^m$ consists of m real-valued objective functions, where each one needs to be minimized. It is often the case that improvement in one objective leads to the deterioration of another. Thus, it is generally not possible to find a single solution that optimizes all objectives. Instead, we seek the best trade-off solutions, referred to as Pareto-optimal solutions, which are of particular interest to decision makers.

Over the past decades, population-based methods such as Evolutionary Algorithms (EAs) have become increasingly popular for solving MOPs. These methods, known as Multi-Objective Evolutionary Algorithms (MOEAs), offer the advantage of finding a set of Pareto-optimal solutions due to their inherent parallel structure and populational search strategy. Our work focuses on a new MOEA that combines features from the Multi-Parent Biased Random-key Genetic Algorithm with Implicit Path-Relinking (BRKGA-MP-IPR) [1] and from the Elitist Non-Dominated Sorting Genetic Algorithm (NSGA-II) [5]. We employ the techniques of fast non-dominated sorting and crowding distance from NSGA-II to determine the order for selecting the elite set. While the standard BRKGA has been previously hybridized with NSGA-II to address some specific MOPs [4], as far as we know, our approach, called Non-dominated Sorting Biased Random-Key Genetic Algorithm (NS-BRKGA), is the first general framework extended from the BRKGA-MP-IPR which can be easily applied to solve any MOP. In fact, it has already been successfully applied to the Multi-Objective Multi-Dimensional Knapsack Problem (MOMDKP) [6]. Moreover, new features were developed in our methodology to improve the population diversity and the resulting non-dominated frontier. These features include polynomial mutation and selection bias towards solutions with high diversity in the genotype space.

In this work, we apply the NS-BRKGA algorithm to the Multi-Objective Flexible Job-Shop Scheduling Problem (MOFJSSP) [3]. The MOFJSSP is a task of scheduling jobs on machines, where each job consists of a sequence of ordered operations that can be executed on various machines with different processing times. Given a set of jobs and machines, the goal of the MOFJSSP is to find a feasible schedule that minimizes multiple objectives, such as the makespan (the maximal completion time of the jobs), the total completion time, the maximal machine workload, and the total workload of the machines. To this end, we consider an instance

---

[1] luis.mendes@ic.unicamp.br, fusberti@ic.unicamp.br

[2] felice@ufscar.br

of the MOFJSSP defined by a set $J = \{j_1, \ldots, j_n\}$ of n jobs and a set $M = \{m_1, \ldots, m_m\}$ of m machines. For each job $j \in J$, we have a sequence $O_j = (o_{j,1}, \ldots, o_{j,n_j})$ of n_j ordered operations, where each operation $o_{j,i} \in O_j$ can be executed on any machine from the set $M_{j,i} \subseteq M$, with a processing time of $p_{i,j,k} \in \mathbb{N}$. The NS-BRKGA algorithm is used to find a suitable machine and sequence of operations for each job that correspond to an optimal trade-off among the objectives.

We have conducted computational experiments using a set of 10 benchmark instances from [3] to evaluate the performance of the NS-BRKGA algorithm. Our algorithm was compared against 5 other MOEAs, all of which are available in the PAGMO 2.18 library[3]. Each algorithm was run 25 times independently for each instance, on a computer with an Intel Xeon CPU E5-2420 of 1.90GHz and 32GB of RAM, with a time limit of 1h, totaling 1250h of computational time. We used the hypervolume ratio I_{HVR}, modified inverted generational distance I_{IGD^+}, and epsilon indicator I_ϵ as quality indicators to compare the performance of the algorithms [2]. The results of our experiments, as summarized in Table 1, indicate that the NS-BRKGA algorithm is competitive with other MOEAs from the literature.

Metric	**NSGA-II**	**NSPSO**	**MOEA/D-DE**	**MHACO**	**IHS**	**NS-BRKGA**
$\mathbf{I_{HVR}}$	0.9920 ± 0.0060	0.9700 ± 0.0300	0.9400 ± 0.0200	0.9400 ± 0.0300	0.9500 ± 0.0200	0.9890 ± 0.0080
$\mathbf{I_{IGD^+}}$	0.0004 ± 0.0005	0.0100 ± 0.0100	0.0300 ± 0.0300	0.0300 ± 0.0300	0.0400 ± 0.0300	0.0010 ± 0.0010
$\mathbf{I_\epsilon}$	1.0000 ± 0.0005	0.9900 ± 0.0200	0.9600 ± 0.0400	0.9600 ± 0.0500	0.9900 ± 0.0300	1.0000 ± 0.0000

Tabela 1: Results obtained by each algorithm.

Referências

[1] Carlos E. Andrade, Rodrigo F. Toso, José F. Gonçalves, and Mauricio G.C. Resende. The Multi-Parent Biased Random-Key Genetic Algorithm with Implicit Path-Relinking and its real-world applications. *European Journal of Operational Research*, 289(1):17–30, 2021.

[2] Charles Audet, Jean Bigeon, Dominique Cartier, Sébastien Le Digabel, and Ludovic Salomon. Performance indicators in multiobjective optimization. *European Journal of Operational Research*, 292(2):397–422, 2021.

[3] Paolo Brandimarte. Routing and scheduling in a flexible job shop by tabu search. *Annals of Operations research*, 41(3):157–183, 1993.

[4] Jonatas BC Chagas, Julian Blank, Markus Wagner, Marcone JF Souza, and Kalyanmoy Deb. A non-dominated sorting based customized random-key genetic algorithm for the bi-objective traveling thief problem. *Journal of Heuristics*, 27(3):267–301, 2021.

[5] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan. A fast and elitist multiobjective genetic algorithm: NSGA-II. *IEEE Transactions on Evolutionary Computation*, 6(2):182–197, April 2002.

[6] Luis Henrique Pauleti Mendes, Fábio Luiz Usberti, and Mário César San Felice. An Evolutionary Algorithm applied to the Multi-Objective Multi-Dimensional Knapsack Problem. In *LIV Simpósio Brasileiro de Pesquisa Operacional*, Juiz de Fora - MG, 2022.

---

[3] `https://esa.github.io/pagmo2/`