A Quantum Inspired Evolutionary Framework for Multi-objective Optimization

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Abstract. This paper provides a new proposal that aims to solve multi-objective optimization problems (MOP_s) using quantum evolutionary paradigm. Three main features characterize the proposed framework. In one hand, it exploits the states superposition quantum concept to derive a probabilistic representation encoding the vector of the decision variables for a given MOP. The advantage of this representation is its ability to encode the entire population of potential solutions within a single chromosome instead of considering only a gene pool of individuals as proposed in classical evolutionary algorithms. In the other hand, specific quantum operators are defined in order to reward good solutions while maintaining diversity. Finally, an evolutionary dynamics is applied on these quantum based elements to allow stochastic guided exploration of the search space. Experimental results show not only the viability of the method but also its ability to achieve good approximation of the Pareto Front when applied on the multi-objective knapsack problem.

1 Introduction

Most of the real world problems either in scientific or engineering fields involve simultaneous optimization of several and often competing objectives that are subject to a set of constraints. These problems are known as multi-objective, multi-criteria or vector optimization problems [1]. Unlike single-objective optimization problems that may have a unique optimal solution, multi-objective optimization problems (MOP_s) have a set of alternative solutions known as Pareto optimal solutions. These solutions are optimal in the sense that no other solutions in the space are superior to them when all objectives are considered. Generally, the optimal solution obtained by individual optimization of the objectives is not a feasible solution to a MOP. Generally, a great number of non optimal solutions are obtained when solving a MOP. They don't optimize all objectives of the problem but they are compromise solutions. To identify best compromises, one makes use of relation of order between these solutions. This relation is called Dominance relation. Several dominance relations have been proposed in the literature [2]. The most commonly used is the Pareto Dominance. The set of the solutions that dominate all the others but don't dominate each other is called Pareto Optimal Set. Its image in the objective space is known as Pareto Front. For formal definition of these basic Pareto concepts, one can refer to [2,10]. Hence, obtaining a set of non dominated solutions and selecting a solution from this set are

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the main tasks of a multi-objective optimization process. Therefore, a decision making process is required.

Several methods have been proposed in the literature to handle MOP_s. A comprehensive state of the art can be found in [2,19]. Some of these methods rely on linear objective function aggregation. They are applied many times in order to find a different solution in each run. Others make use of Pareto dominance. They are known as Pareto-based methods. They allow finding multiple Pareto-optimal solutions in one single run. During the last years, stochastic optimization heuristics have been employed in order to move towards the true Pareto front over time. Among these heuristics, evolutionary algorithms have been widely investigated for two main reasons. In one hand, they allow defining population-based methods. This fact enables finding several members of the Pareto optimal set in a single run of the algorithm instead of having to perform a series of separate runs. In the other hand, evolutionary algorithms have abilities to cope with discontinuous and concave Pareto front. Several variants of evolutionary algorithms for multi-objective optimization have been adopted. They are characterized by two main and common features. The first one concerns the use of the Pareto dominance relation to rank individuals within a population. Non dominated individuals are given the highest rank. The second feature deals with the balance between the exploitation and exploration capabilities of the search process. For this purpose, some form of elitism is used to reward globally non dominated solutions intensifying in this manner the search in their neighbourhood. In the other side, diversity is maintained using appropriate mechanisms. The way these two issues are addressed distinguishes one approach from the other. Generally, designing appropriate fitness functions to capture the characteristics of a MOP and defining the adequate decision making process are among the main issues addressed by an evolutionary algorithm for multi-objective optimization. The first work on using evolutionary algorithms to solve MOP_s goes back to the mid-eighties [3]. Since the mid-nineties, an active and intensive research effort has been conducted in quest to develop powerful and efficient multi-objective evolutionary algorithms ($MOEA_s$) for which several reviews have been proposed. NPGA [4], NSGA-II [5,6], SPEA [7,8] and Micro-genetic algorithm proposed in [9] are notable examples of $MOEA_s$. An other approach concerns the use of artificial immune systems to solve MOP_s. In [10], the clonal selection principle has been tailored to MOP_s leading to a viable alternative.

Independently to multi-objective optimization research field, quantum computing principles have been recently successfully incorporated to evolutionary algorithms resulting in efficient hybrid algorithms [11,12]. Quantum computing is a new proposed paradigm which relies on ideas borrowed from quantum mechanics field. Compared to a purely evolutionary algorithm, a quantum-inspired evolutionary algorithm suggests a new philosophy to encode individuals using states superposition and to define the overall dynamics using in addition to genetic operators quantum gates or operators. Within this issue, we propose in this paper tackling the problem of multi-objective optimization by exploiting such ideas. This issue has not been investigated yet. We show how to suit some quantum concepts to the multi-objective knapsack problem.