Multi-objective evolutionary algorithms for optimal scheduling

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Summary

Multi-objective optimization is an effective technique for finding optimal solutions that balance several conflicting objectives. It has been applied in many fields of our world, because practical problems usually have more than one desired goal. For example, developing a new vehicle component might involve minimizing weight while maximizing strength; choosing a portfolio might involve maximizing the expected return while minimizing the risk. The multi-objective optimization problems solved in the thesis originated from the CIMPLO (Cross-Industry Predictive Maintenance Optimization Platform) project. In the CIMPLO project, given a vehicle fleet, each vehicle comprises a set of components, and each component can be maintained in a workshop among given workshops with varying processing times and costs. The goal is to find the best maintenance order, location and time for each component, i.e., to optimize the maintenance schedule of the vehicle fleet. The maintenance schedule of the vehicle fleet is optimized to bring business advantages to industries, such as, to reduce maintenance time, increase safety, and decrease repair expenses. This problem is strongly NP-hard since the flexible job shop scheduling problem (FJSP) has been proven to be a strongly NP-hard problem and the vehicle fleet maintenance scheduling optimization (VFMSO) problem can be seen as an extension of the FJSP: the VFMSO provides a non-specific operation sequence and involves the processing costs of the operation on machines besides the processing times as in the FJSP. Therefore, evolutionary algorithms (EAs) have been chosen to solve our real-world application problem because they have proven to be a particularly suitable metaheuristic method to solve multi-objective optimization problems.

First of all, a multi-objective evolutionary algorithm (MOEA) is developed for general multi-objective optimization problems and it plays an important role in solving our application problems. The proposed MOEA is called diversity indicator-based MOEA (DI-MOEA). The main features or advantages of DI-MOEA include: it uses

a hybrid selection scheme (the $\mu + \mu$ generational selection operator and $\mu + 1$ steady state selection operator) for combining the advantages of Pareto dominance-based approaches to ensure fast convergence to the Pareto front (PF) with indicator-based approaches to ensure convergence to a diverse set; it avoids the use of complex structure and parameters; it can achieve a uniformly distributed PF approximation; it requires no priori knowledge of the PF shape and location; the adopted diversity indicator in DI-MOEA (i.e., Euclidean distance based geometric mean gap indicator) is computationally efficient.

Secondly, to improve the performance of MOEAs, the edge-rotated cone order is proposed for the purpose of building an ordering which can guide the search towards the PF better than the Pareto dominance in MOEAs. The edge-rotated cone is designed by rotating the edges of the standard Pareto order cone towards the outside; therefore, an ordering among Pareto incomparable solutions is established because a solution can dominate an enlarged region in the objective space. The edge-rotated cone order is integrated in MOEAs by a hybrid approach which gives consideration to both convergence and diversity in the evolutionary search process.

To only focus the search on the preferred solutions, the target based MOEAs have been proposed and implemented as three algorithms: T-NSGA-II, T-SMS-EMOA and T-R2-EMOA. In these algorithms, different types of target (e.g., point or region), different shapes of target region (e.g., sphere or square), different positions of target (e.g., on the PF or not), one or multiple targets can be decided by the decision maker (DM) and involved as preference information to find preferred solutions without exploring the whole set of Pareto optimal solutions. Furthermore, to avoid the difficulty for specifying the preference information by the DM, an automatic preference based DI-MOEA (AP-DI-MOEA) is proposed to generate the preference region by identifying the knee point because the knee points are assumed to be the most interesting solutions, naturally preferred solutions and most likely the choice of the DMs. AP-DI-MOEA divides the computing budget into different parts to first find a rough entire PF and the knee region, then narrow down the preference region step by step to benefit its accuracy, and eventually obtain the preferred solutions.

After the proposal of the above algorithms, our goal is to solve the VFMSO problem. Since our problem is a special extension of the FJSP and the FJSP is very difficult to solve and not much research has been devoted to solving this problem in the past. An MOEA to solve the multi-objective FJSP is proposed first, in which multiple initialization approaches, various domain-specific genetic operators, and different local search strategies are designed and used; the Mixed-Integer Programming

Efficient Global Optimization (MIP-EGO) configurator is adopted to automatically find the optimal mutation probabilities. Based on the study on the FJSP, the MOEA to solve our real-world multi-objective VFMSO problems can then be developed. To this end, the problem has been formulated, a three-vector chromosome is proposed to represent a solution and corresponding genetic operators are designed. At the same time, the special designs for the VFMSO are proposed, such as the combination of components as one maintenance task, the definition of the execution window for each component based on its predicted remaining useful lifetime, the simulation of the penalty costs and the failures for handling uncertainties in the predictions.

Lastly, the static MOEAs and preference based MOEAs are applied to the VFMSO problems. Since continuously updating the schedule is required in the real-world scenario, the static algorithms are extended to many-objective dynamic MOEAs in which an extra objective, i.e., the schedule stability, is involved in to minimize the changes between the new schedule and the previous schedule, and the underlying idea is to reduce additional costs such as the cost of reallocation of tools and equipment, the cost of reordering of raw materials and etc.

In summary, this thesis provides advancements to the design of general purpose multi-objective and many-objective optimization algorithms for finding uniform approximations to the (preferred region of the) Pareto front, and successfully applied and customized the algorithms in the domain of flexible job shop scheduling and the more specific domain of dynamic prediction-based maintenance scheduling.