Towards a Distributed Implementation of Chemical Reaction Optimization for the Multi-factory Permutation Flowshop Scheduling Problem

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Abstract

The Distributed Permutation Flowshop Scheduling Problem (DPFSP) is one of the most computationally complex problems. It has gained a wide attention not only in theoretical studies but also in manufacturing industry. In recent years, a lot of work has been done and many heuristics and metaheuristics have been proposed to tackle the DPFSP. Unfortunately, all the existing algorithms are centralized despite the fact that the distributed approaches are known to be more practical for the complex scheduling problems. Thus, we argue that distributed artificial intelligence techniques, namely Multi-Agent Systems (MAS), offer an appropriate tool to tackle problems of a distributed nature when they are properly designed and implemented. Thanks to their flexibility, adaptively and extensibility; MAS represents a promising variant to achieve a better performance. In this study, by combining the population-based evolutionary searching abilities of Chemical Reaction Optimization (CRO) metaheuristic with the capabilities of MAS in modeling hard combinatorial problems, we suggest an agent-based evolutionary algorithm called CROMAS to effectively solve the DPFSP. We tested our algorithm on well-known benchmark instances and compared its performance with respect to other recent methods. Experiments reveal that CROMAS is very effective and able to provide competitive results.

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1. Introduction

Scheduling problems are ubiquitous in various areas of manufacturing industry engineering and science. They play a significant role in enhancing the productivity, improving the utilization of resources, reducing cost and raising customer satisfaction. The Permutation Flowshop Scheduling Problem (PFSP), which is an NP-complete problem, represents one of typical scheduling problems. It can be briefly described as follows: there are \( n \) jobs to be processed on a set of \( m \) machines disposed in series. Each job must enter the machines in the same order. The goal is to find...
a job permutation that satisfies one or multiple objectives. Due to its so many applications in practice, considerable efforts from researchers and engineers have been devoted to solve this problem. Hence, since the seminal paper of Johnson\(^1\) on the two-machine PFSP, the development of more effective and efficient scheduling methods have never reached an end. However, the classical PFSP is based on the assumption that products are manufactured in a single firm. Nevertheless, with the mode of today’s economical environment, single-factory production scheduling problems, are no longer useful as in the past. With the increased globalization of production systems and the extremely stiff worldwide competition, conventional single factory firms are being found to be insufficiently flexible, less responsive to emergencies, and unable to deal with changing dynamic market demands. In fact, by putting in place a well established distributed manufacturing and scheduling strategies, enterprises can maintain a competitive position in the fast changing market requirements. Furthermore, several studies have proven that distributed manufacturing allows companies to be closer to customers and, by doing so, they reinforce production flexibility, comply with local laws and adapt on demand-driven approaches. Therefore, enterprises start to shift from traditional centralized environment to multi-site production shops in order to comply with this industrial trend and profit of globalization. Under the distributed environment, Naderi and Ruiz\(^2\) extended the regular PFSP to the Distributed Permutation Flowshop Scheduling Problem (DPFSP) where more than one factory is available to process jobs. The problem is clearly more difficult and complex than the classical PFSP. It mainly focuses on solving two related issues simultaneously:

1. Assigning the various jobs to factories,
2. Determining the production schedule at each factory.

The complexity and the wide range of applications of the DPFSP have challenged us to integrate and combine different problem-solving paradigms to the attempt of improving algorithms’ ability. Proceeding from that, agent-based evolutionary computation seems to be an attractive way ready to exploit to achieve satisfactory results. In this paper, we suggest an alliance between Multi-Agent System (MAS) technology and Chemical Reaction Optimization (CRO) metaheuristic. The proposed model is called CROMAS and the studied objective is the minimization of the maximum completion time or makespan. On the first hand, agent-based software, is a rapidly developing area of research. This methodology originally came from the field of artificial intelligence where it’s considered as a credible alternative to conventional approaches. A multi-agent system could be defined as an organized set of entities called agents, with the goal of decomposing the resolution of a complex task into a set of easier local problems. They offer the advantages of cooperation and interactions between independent and intelligent entities which work towards a common objective; best system’s performance. In recent years, many attentions have been paid to model MAS, and hence, they have been successfully applied to solve a variety of difficult optimization problems such as the regular PFSP\(^3\) and the flexible Job Shop problem\(^4\) to name just a few. On the other hand, over the past decade the interest in evolutionary algorithms has been a hot topic. CRO, as a newly established one, has proven superior performance when compared with other powerful metaheuristics such as Genetic Algorithm, Simulated Annealing and Tabu Search. After an in depth study of the CRO algorithm, several attractive properties have been highlighted. Its high flexibility which allows the design of different operators to manipulate solutions, its good trade-off between intensification and diversification and its fairly stable convergence rate serve as a potent motivation to employ it as a solution for the DPFSP.

The outline for the rest of the paper is as follows: the next section provides an overview of the Distributed Permutation Flowshop Scheduling Problem and the Chemical Reaction Optimization. In Section 3, the proposed evolutionary based Multi-Agent System is presented in detail. The computational results are given in Section 4. Section 5 summarizes our contributions and proposes some avenues for future researches.

2. Technical backgrounds

2.1. Problem description and state-of-the-art

The DPFSP is a generalization of the regular PFSP. It can be formally described as follows:\(^2\): a set \(J = \{1, 2, ..., n\}\) have to be processed on a set \(G = \{F\}\) that are located in different places. Each factory contains the same set \(M\) of \(m\) machines \(m = \{1, 2, ..., m\}\). Each job \(j, j \in J\), consists of a sequence of \(m\) operations \(O_{j1}, O_{j2}, ..., O_{jm}\). Each operation is associated with a processing time \(p_{jk}\) which is
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