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A multi-agent based optimization method applied to the quadratic assignment problem

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ABSTRACT

Inspired by the idea of interacting intelligent agents of a multi-agent system, we introduce a multi-agent based optimization method applied to the quadratic assignment problem (MAOM-QAP). MAOM-QAP is composed of several agents (decision-maker agent, local search agents, crossover agents and perturbation agent) which are designed for the purpose of intensified and diversified search activities. With the help of a reinforcement learning mechanism, MAOM-QAP dynamically decides the most suitable agent to activate according to the state of search process. Under the coordination of the decision-maker agent, the other agents fulfill dedicated search tasks. The performance of the proposed approach is assessed on the set of well-known QAP benchmark instances, and compared with the most advanced QAP methods of the literature. The ideas proposed in this work are rather general and could be adapted to other optimization tasks. This work opens the way for designing new distributed intelligent systems for tackling other complex search problems.

1. Introduction

The quadratic assignment problem (QAP) is one of the most popular combinatorial optimization problems with a number of practical applications like planning, backboard wiring in electronics, analysis of chemical reactions for organic compounds, design of typewriter keyboards balancing turbine runners (Burkard, Mirchandani, & Francis, 1991; Duman & Or, 2007). The QAP is known to be computationally difficult since it belongs to the class of NP-hard problems (Sahni & Gonzalez, 1976).

QAP was initially introduced to formulate the location of a set of indivisible economical activities. Given a flow f_{ij} from facility i to facility j for all i, j in $\{1, 2, \ldots n\}$ and a distance d_{ab} between locations a and b for all a, b in $\{1, 2, \ldots n\}$, the QAP is to assign the set of n facilities to the set of n locations while minimizing the sum of the products of the flow and distance matrices. Let Π be the set of the permutation functions $\pi : \{1, 2, \ldots n\} \rightarrow \{1, 2, \ldots n\}$. The QAP is mathematically formulated as follows:

$$Minimize_{\pi \in \Pi} F(\pi) = \sum_{i=1}^{n} \sum_{j=1}^{n} f_{ij} d_{\pi_i \pi_j} \quad (1)$$

The computational challenge of the QAP has motivated many solution approaches including exact methods like (Erdogan & Tansel, 2007; Hahn, Grant, & Hall, 1998) and numerous heuristic methods. Among the most representative heuristic methods, we can mention the popular robust tabu search algorithm (Ro-TS) (Taillard, 1991), the memetic algorithm (Merz & Freisleben, 2000), the improved hybrid genetic algorithm (IHGA) (Misevicius, 2004), the iterated tabu search algorithm (ITS) (Misevicius, Lenkevicius, & Rubliauskas, 2006), the population-based iterated local search (PILS) (Stützle, 2006), the hybrid genetic algorithm MRT (Drezner, 2008), the cooperative parallel tabu search algorithm (CPTS) (James, Rego, & Glover, 2009), the breakout local search (BLS) (Benlic & Hao, 2013) and the memetic search algorithm (BMA) (Benlic & Hao, 2015). These methods generally perform well on a number of benchmark instances. Yet, no single method clearly dominates all other methods.

In this work, we investigate a new solution approach for the QAP based on the principles of multi-agent systems (MAS). Our work is motivated by appealing features of a MAS which could be advantageously used to elaborate intelligent computing systems (Baykasoğlu & Kaplanoğlu, 2015; Couellan, Jan, Jorquera, & Georgé, 2015; Gonçalves, Guimarães, & Souza, 2014; Guo, Goncalves, & Hsu, 2013; Martin, Ouelhadj, Smetb, Beullens, & Özcan, 2013; Satunin & Babkin, 2014; Wang & Wang, 2015; Zheng & Wang, 2015). Compared with the existing studies on the QAP, this work has the following main contributions:

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- The proposed algorithm is the first distributed method for the QAP that adopts multi-agent systems as a source of inspiration for optimization.
- The proposed algorithm integrates a set of collaborative agents (local search agents, crossover agents, perturbation agent) which are managed dynamically by a distributed model to ensure a suitable balance of intensification and diversification of the given search space.
- Decision making is based on reinforcement learning which is used to adjust the probability of applying dedicated actions to trigger specific agents under specific conditions.
- We show the viability of the proposed approach by presenting computational results on the set of 135 well-known QAP benchmark instances.
- The proposed approach is general and could be adapted to design distributed intelligent systems for other complex search problems.

The rest of the paper is organized as follows. Section 2 is dedicated to literature review. Section 3 describes the proposed distributed algorithm. Section 4 shows computational results and comparisons with representative QAP algorithms of the literature. An analysis of the proposed algorithm is also provided. In the last section, we provide concluding comments and research perspectives.

2. Literature review

In this section, we first present a brief summary of some of the most representative heuristic algorithms for the QAP. These algorithms will be used as reference methods for our computational study. Note that none of these QAP approaches can be considered as the most effective method for all QAP benchmark instances, due to the differences in structures of the QAP benchmark instances. We also provide a literature review of some recent applications of multi-agent systems for solving search problems.

The robust tabu search (Ro-TS) algorithm proposed by Taillard (1991) is an early and influential heuristic. Ro-TS employs the swap move which exchanges two elements of a solution (a permutation). The tabu list forbids the reverse exchange of a swap move during the next h iterations. The tabu tenure h varies randomly within a given interval. The most important new feature introduced in Ro-TS is that a complete swap neighborhood is explored in $O(n^2)$ instead of $O(n^3)$ as in previous algorithms. We use this technique in our algorithm.

The improved hybrid genetic algorithm (IHGA) is presented by Misevicius (2004). IHGA integrates a robust local improvement procedure and a new optimized crossover. The optimized crossover uses M runs of an uniform crossover to produce a child that has the best fitness value. The offspring is then improved with a tabu search procedure and a solution reconstruction procedure. The reconstruction is achieved by performing a number of random swaps. IHGA uses also a shift mutation, which simply shifts all the items of the solution in a wrap-around fashion by a predefined number of positions. Later Misevicius et al. proposed an iterated tabu search (ITS) (Misevicius et al., 2006) which iterates between a traditional tabu search and a perturbation phase in order to escape an attained local optimum.

The particular population-based iterated local search (PILS) proposed by Stützle (2006) is an extension of iterated local search (ILS). The algorithm applies the don't look bit strategy, inspired by local search algorithms for the TSP. When a local optimum is attained, ILS executes a perturbation move that exchanges k randomly chosen items. In PILS, the population contains p solutions and in each iteration q new solutions are generated. The new population of p solutions is created from the p former solutions and the q new solutions.

The cooperative parallel tabu search algorithm (CPTS) introduced by James et al. (2009) applies in parallel several tabu search (TS) runs on multiple processors. The TS procedure is the same as Ro-TS (Taillard, 1991), but uses different stopping conditions and tabu tenures for each processor. The cooperation and information exchanges between the TS processes are realized with the help of a global reference set.

The Breakout Local Search (BLS) described by Benlic and Hao (2013) is based on a local search phase and a dedicated perturbation phase. The local search phase aims to reach new local optima while the perturbation phase is used to discover new promising regions. The perturbation mechanism of BLS dynamically determines the number of perturbation moves and adaptively chooses between two types of moves of different intensities depending on the current search state. Perturbations are either guided by using a tabu list or simply based on random moves. BLS is later integrated into the memetic search framework in Benlic and Hao (2015). BMA combines BLS as local optimizer, a crossover operator, a pool updating strategy, and an adaptive mutation mechanism. BMA outperforms its local search component (BLS).

In this work, we introduce a new multi-agent optimization method for the QAP (MAOM-QAP) inspired by multi-agent systems. The proposed method is motivated by specific features offered by MAS like distributed computing, agent cooperation and dynamic decision making. Indeed, multi-agent systems have been successfully applied to solve many challenging and divers problems encountered in various settings. The review below, which is by no means exhaustive, aims to describe some recent MAS-related studies to illustrate the interest of MAS for building expert and intelligent systems for problem solving.

In Gonçalves et al. (2014), the authors presented an evolutionary multi-agent system to solve the join ordering optimization problem of queries in relational database management systems in a non-distributed environment. For this, they defined a working environment composed by a set of collaborative agents, where each agent is designed to find the best solution, i.e. the best join order for the relations in a query. Interesting results are reported with the proposed approach.

Satunin and Babkin (2014) tackled a challenging design problem raised in flexible public transportation systems, i.e., the design of demand responsive transport systems (DRT) which aims to provide a share transportation services with flexible routes and focus on optimizing economic and environmental values. The proposed approach uses a distributed multi-agent system to model DRT where various autonomous agents represent interests of systems stakeholders. The authors reported very interesting results with the proposed approach.

Baykasoğlu and Kaplanoğlu (2015) developed a multi-agent based approach for a load/truck planning problem in transportation logistics. The proposed approach is characterized by its cooperative structure which is motivated by real-world third party logistics company operations and uses negotiation mechanisms among the agents to handle the dynamic events. The solutions obtained by using the proposed approach demonstrate the usefulness of the approach in providing high-quality solutions while generating real-time schedules.

Couellan et al. (2015) are interested in solving challenging optimization problems raised in training problems of Support Vector Machines (SVM). They observe that multi-agents systems are able to break down a complex optimization problem into elementary oracle tasks which are solved by performing a collaborative solution process. Based on this observation, they proposed a multi-agent system to solve the basic SVM training problem and provide several perspectives for binary classification, hyperparameters selection, multiclass learning as well as unsupervised learning.

Zheng and Wang (2015) proposed a multi-agent optimization algorithm for solving the resource-constrained project scheduling problem. The proposed algorithm uses multiple agents working in a grouped environment where each agent represents a feasible solution. The evolution of agents is achieved by using four main