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A hybrid evolutionary algorithm for the resource constrained project scheduling problem

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Abstract: The resource constrained project scheduling problem (RCPSP) is an NP-hard optimization problem. RCPSP is one of the most important and challenging problem in the project management field. In the past few years, many researches have been proposed for solving the resource constrained project scheduling problem. The objective of this problem is to schedule the activities under the limited amount of the resources so that the project makespan is minimized. This paper proposes a new algorithm for solving RCPSP that combines the concepts of the biological immune system, the simulated annealing algorithm (SA), the tabu search algorithm (TS) and the genetic algorithm (GA) together. The performance of the proposed algorithm is evaluated and compared to the current state of the art metaheuristic algorithms. In this study, the benchmark data sets used in testing the performance of the proposed algorithm are obtained from Project Scheduling Problem Library (PSPLIB). The performance is measured in terms of the average percentage deviation from the critical path lower bound. The experimental results show that the proposed algorithm outperforms the state of the art metaheuristic algorithms on all standard benchmark data sets.

Keywords: Resource constrained project scheduling problem, Metaheuristic, Evolutionary algorithm

1 INTRODUCTION

The resource constrained project scheduling problem (RCPSP) is an NP-hard optimization problem. RCPSP is one of the most important and challenging problem in the project management field. The methods for solving the RCPSP have ranged from exact methods, to heuristic methods, to metaheuristic methods. In recent years, due to the need for solving large realistic project instances, the trend of the research has shifted toward the metaheuristic approaches. The objective of the RCPSP is to schedule the activities under the limited amount of the resources so that the project makespan is minimized [1]. Some metaheuristic methods for solving the RCPSP are reviewed in the following paragraph.

Debels et al [2] proposed a new metaheuristic which combines the scatter search with the electromagnetism optimization heuristic. Tseng and Chen [3] presented a hybrid metaheuristic, named ANGEL, for solving the RCPSP. ANGEL combines ant colony optimization, genetic algorithm and the local search strategy together. A new heuristic algorithm based on filter and fan method has been proposed in [4]. A hybrid metaheuristic algorithm based on the scatter search approach was developed by Ranjbar and Kianfar [5] to solve the RCPSP. Chen et al [6] proposed a hybrid algorithm, called ACOSS, for solving the RCPSP in real-time. The ACOSS algorithm combines a local search strategy, ant colony optimization, and a scatter search in an iterative process.

In this paper, a new hybrid evolutionary algorithm for the RCPSP is proposed. This proposed algorithm combines the concepts of the biological immune system, the simulated annealing algorithm (SA), the tabu search algorithm (TS) and the genetic algorithm (GA) together.

The rest of this paper is organized as follows: Section 2 is the problem definition of the RCPSP. Section 3 presents the proposed algorithm. A brief description of the test sets and the experimental results are given in Section 4. Finally, Section 5 is the conclusion.

2 PROBLEM DEFINITION

The resource constrained project scheduling problem (RCPSP) involves the scheduling of the project activities subject to precedence relations as well as the resource constraints in order to minimize the project duration.

The RCPSP can be stated as follows: A project consists of a set of N activities. Each activity j ($j \in N$) has duration of d_j and requires r_{jk} units of the resource type k. The resource type k has a limited capacity of R_k at any point in time. This means that the sum of the resource requirements for the resource k in any time period cannot exceed R_k. While the activity j is processed, the activity j requires r_{jk} units of the resource type k during every time instant of its non-preemptive duration d_j. In addition, the precedence relation between activities must also be taken into account, not just the resource restrictions.

Fig. 1 is an example of a project which consists of 6 activities (N = 6). Activities 0 and 5 are the dummy activities which represent the start and the end of the project respectively. Activities 1, 2, 3, and 4 are the real activities which require 3, 7, 6, and 2 units of the resource type k.

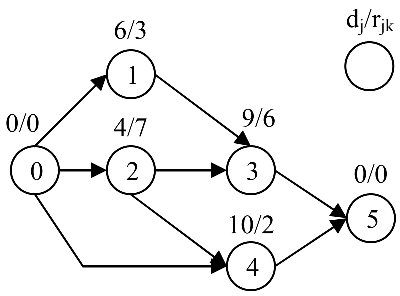

Fig. 1. An example of a project

3 PROPOSED ALGORITHM

The proposed algorithm is based on the concepts of the biological immune system, the simulated annealing algorithm (SA), the tabu search algorithm (TS) and the genetic algorithm (GA). The detailed procedure of the proposed algorithm (Fig. 2) is described as follows:

First, the initial population is generated by using the schedule generation scheme (SGS). The SGS consists of N stages, where N is the number of activities in the project. In each stage, one activity is selected and scheduled at its earliest possible time within the precedence and resource constraints. The SGS process stops when all activities are scheduled.

Second, the negative selection mechanism, to be discussed in Subsection 3.1, is employed to filter out the worst 10 percent of the whole population while the best 90 percent of the population are kept for the crossover process. The crossover operator used in this paper is the permutation encoding crossover (Fig. 3).

Third, the filtered-out chromosomes are forwarded to the TS-SA search algorithm, to be discussed in Subsection 3.2. After performing the TS-SA search, the new chromosomes obtained from the TS-SA search are combined with the new offspring obtained from the crossover operation.

Fourth, the mutation operation is performed on the combined population. The insertion mutation operator proposed by Fogel [7] is employed in this research.

Finally, the stopping criteria are checked. If any of the stopping criteria are met, the algorithm will be terminated. If not, the new population is selected from all solutions available in the current generation, both parents and their offspring; then go back to step 2.

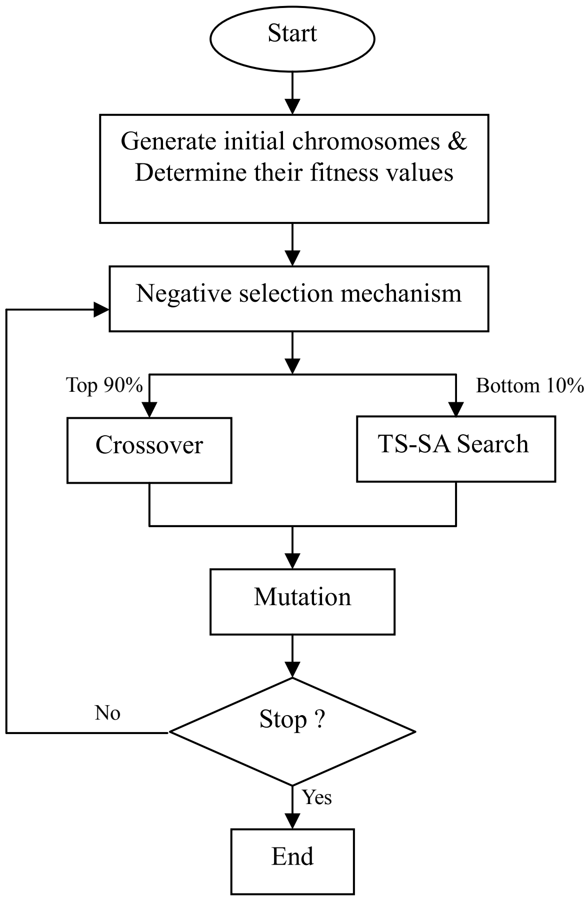

Fig. 2. Proposed algorithm

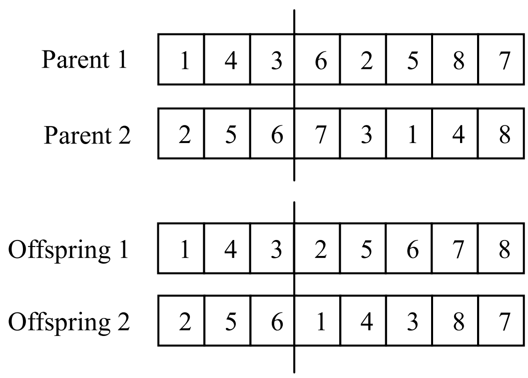

Fig. 3. Example of the permutation encoding crossover

3.1 Negative Selection Mechanism

Negative selection mechanism is inspired by the self/non-self discrimination behavior of the biological immune system. The purpose of the biological immune system is to recognize all cells within the body and categorizes those cells as either self (body cells) or non-self (antigens). When the antigens are found, the T-cells will bind themselves to the antigens and inject poisonous chemicals into them causing their destruction [8]. However, the immune system sometimes becomes dysfunctional by mistaking a body cell for a similar antigen. As a result, the body initiates the destructive operation against its own cells. In order to prevent the above undesirable phenomenon from happening, the negative selection mechanism is employed to remove the T-cells that bind too strongly to the body cells.

This paper employs the negative selection mechanism to remove the worst 10 percent of the whole population.

3.2 TS-SA Search Algorithm

The TS-SA search algorithm is a hybrid between the tabu search algorithm and the simulated annealing algorithm. For each filtered-out chromosome, M neighbor chromosomes are created by randomly mutating two genes in the chromosome. Next, the fittest neighbor is selected according to the tabu restrictions and aspiration criteria. If the best neighbor chromosome is fitter than the current chromosome, the current chromosome is replaced by the best neighbor chromosome. Otherwise, the simulated annealing concept is employed to determine whether the best neighbor chromosome should be accepted for further processing. If the criterion in (1) is met, the best neighbor chromosome will be used for further processing.

$$P(accept) > \varepsilon \qquad (1)$$

$$P(accept) = Exp\,[-(E_n - E_c)/T] \qquad (2)$$

where E_n is the fitness value of the best neighbor chromosome. E_c is the fitness value of the current chromosome. T is the temperature of the simulated annealing process. In this paper, the initial temperature is set at 90 degree; then the temperature gradually drops until it hits the pre-specified limit, which is 70 degree in this paper.

This TS-SA search is repeated until (1) the temperature of the simulated annealing process falls below a predefined value or (2) the best neighbor chromosome is fitter than the current chromosome.

4 EXPERIMENTAL RESULTS

The performance of the proposed algorithm is evaluated and compared to the current state of the art metaheuristic algorithms. In this study, the benchmark data sets used in testing the performance of the proposed algorithm are obtained from Project Scheduling Problem Library (PSPLIB) [9]. The whole set of projects with 60, 90, and 120 activities (data sets J60, J90, and J120) are considered. The test sets J60 and J90 contain 480 instances with 4 renewable resource types, while the J120 contains 600 instances.

The performance of the proposed model in solving the above mentioned test sets is shown in Table 1. The row labeled with "Sum" contains the sum of the makespans of all problem instances in each test set. The row labeled with "Avg. Dev. CPM (%)" displays the average percentage deviation from the critical path lower bound. The row labeled with "Avg. Dev. LB (%)" reports the average percentage deviation from the currently best known solution. The row labeled with "LB Found" displays the number of problem instances in which the proposed algorithm reports a makespan equal to the currently best known solution.

Table 2 illustrates the comparative results of the proposed algorithm and four of the current state of the art metaheuristic algorithms. In Table 2, the performance is compared in terms of the average percentage deviation from critical path lower bound. The experimental results show that the proposed algorithm outperforms the state of the art metaheuristic algorithms on all benchmark data sets.

Table 1. Experimental Results

	Data Set		
	J60	J90	J120
Sum	38397	45605	74179
Avg. Dev. CPM (%)	10.55%	9.57%	30.54%
Avg. Dev. LB (%)	0.99%	1.34%	4.42%
LB Found	410/480	390/480	291/600

Table 2. Comparative Results

	Average Percentage Deviation from Critical Path Lower Bound		
	J60	J90	J120
Proposed Algorithm	10.55%	9.57%	30.54%
Debels and Vanhoucke (2007) [10]	10.68%	10.35%	30.82%
Ranjbar (2008) [4]	10.56%	10.11%	31.42%
Ranjbar and Kianfar (2009) [5]	10.64%	10.04%	31.49%
Agarwal el al. (2011) [11]	11.29%	11.29%	34.15%

5 CONCLUSION

In this paper, a new metaheuristic algorithm for solving the resource constrained project scheduling problem is proposed. This proposed algorithm is based on the concepts of the biological immune system, the simulated annealing algorithm (SA), the tabu search algorithm (TS) and the genetic algorithm (GA). The experimental results show that the proposed model is capable of providing optimal or near-optimum solutions for all test sets.

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