

Multi-parent extension of partially mapped crossover for combinatorial optimization problems

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ABSTRACT

This paper proposes the multi-parent partially mapped crossover (MPPMX), which generalizes the partially mapped crossover (PMX) to a multi-parent crossover. The mapping list and legalization of PMX are modified to deal with the issues that arise from the increase of parents in PMX. Experimental results on five traveling salesman problems show that MPPMX significantly improves PMX by up to 13.95% in mean tour length. These preferable results not only demonstrate the advantage of the proposed MPPMX over PMX, but also confirm the merit of using more than two parents in crossover.

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1. Introduction

Genetic algorithms (GAs) (Holland, 1975) have effectively solved a variety of combinatorial and numerical optimization problems. The operators in GAs include the selection, crossover, mutation, and survivor. Crossover is the most salient GA operator. It produces offspring by recombining parental genetic material. Traditionally, the number of parents used in crossover is two. This idea is reasonable because, to the best of our knowledge, no organisms on Earth apply multi-parent reproduction. In computer simulations, nevertheless, it is not necessary to limit the number of parents for crossover to two. This idea, to use more than two parents in crossover, is then implemented as multi-parent crossover. The GAs that use multi-parent crossover are named multi-parent genetic algorithms (Ting, 2005).

Beyond two parents in binary-coded GAs, Eiben et al. proposed scanning crossover (Eiben, Raué, & Ruttkay, 1994) and diagonal crossover (Eiben & van Kemenade, 1997; Eiben, van Kemenade, & Kok, 1995) as the generalization of uniform crossover and one-point crossover, respectively. Their experimental results on several test functions show that, in terms of success rate, both scanning crossover and diagonal crossover outperform their two-parent versions, namely uniform crossover and one-point crossover. Mühlenbein, Schomisch, and Born (1991) and Voigt and Mühlenbein (1995) introduced the concept of global recombination into GAs as gene pool recombination. Instead of two parents, gene pool recombination samples the genes for crossover from the gene pool,

which consists of several pre-selected parents. Studies indicate that gene pool recombination and its variants are easier to analyze and can converge faster than two-parent recombination. Tsutsui and Jain (1998) proposed multi-cut crossover and seed crossover, wherein multi-cut crossover generalizes the classic two-point crossover and achieves empirically better performance compared to diagonal crossover.

For real-coded GAs, Tsutsui and Ghosh (1998) presented a series of multi-parent crossovers: center of mass crossover, multi-parent feature-wise crossover, and seed crossover. They showed that these multi-parent crossovers can lead to better performance, though this performance is problem-dependent. Another multi-parent crossover, simplex crossover (Tsutsui, Yamamura, & Higuchi, 1999), generates offspring using the simplex sampled from multiple parents. Experimental results show that this method performs well with three or four parents on multimodal and epistatic problems. Kita, Ono, and Kobayashi (1999) introduced multiple parents into unimodal normal distribution crossover to enhance the diversity of the offspring. This multi-parent extension of unimodal normal distribution crossover exhibits an improvement in search ability on highly epistatic problems. Gong and Ruan (2004) proposed the fitness-weighted crossover. It gives the fitter parents a bigger influencing factor, which is used to determine the contribution of parents to their offspring.

The above literature demonstrates the superiority of multi-parent crossover over two-parent crossover. The effectiveness of these multi-parent crossover operators is validated mostly on numerical optimization problems (Eiben, 2002; Ting, 2005; Tsutsui & Jain, 1998). As for combinatorial optimization problems, there exists only the adjacency based crossover (Eiben et al., 1994). Nevertheless, experimental results point out that using more than two parents in adjacency based crossover has no tangible benefit. Effective

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multi-parent crossover for combinatorial optimization problems is still lacking.

This paper proposes the *multi-parent partially mapped crossover* (MPPMX) for combinatorial optimization problems. Specifically, MPPMX generalizes the partially mapped crossover (PMX) (Goldberg & Lingle, 1985), which is widely used for combinatorial optimization problems, e.g., Drechsler, Becker, and Göckel (1997), Skliarova and Ferrari (2002) and Tseng, Wang, and Shih (2007). The traveling salesman problem (TSP) is an important representative of combinatorial optimization problems. Many practical problems, such as scheduling (Ho & Ji, 2009; Pan & Huang, 2009), manufacturing control system (Skliarova & Ferrari, 2002), and bioinformatics (Ezziane, 2006), can be transformed into the TSP. In this paper, the evaluation of the proposed MPPMX will focus on the performance on the TSP.

The remainder of this paper is organized as follows. Section 2 gives a brief review of GAs for combinatorial optimization problems. In Section 3, we describe in detail the proposed MPPMX. Section 4 presents a performance evaluation. Finally, conclusions are drawn in Section 5.

2. Genetic algorithms for combinatorial optimization problems

The basic idea of GAs is to enhance candidate solutions by simulating the mechanisms of natural evolution, such as selection, crossover, and mutation. The operation of crossover is subject to chromosome representation, which can be binary, integer, real, or order.

Order (or permutation) is the most common representation of chromosomes with combinatorial optimization problems that GAs have to tackle. In a 9-city TSP, for example, a visiting schedule 5–9–7–4–1–2–8–3–6 can be simply represented as a chromosome in the form of order (5,9,7,4,1,2,8,3,6). GAs that use order representation for chromosomes are called order-based GAs.

Even though order representation facilitates GAs to handle combinatorial optimization problems, it also causes an intrinsic constraint in the operation of chromosomes, because no duplicate numbers are allowed in a chromosome. Therefore, the crossover for binary-coded GAs, such as one-point, two-point, and uniform crossovers, cannot be directly applied to order-based GAs. Fig. 1 illustrates the failure of two-point crossover for the TSP. The

two-point crossover yields duplicate genes 1, 2, 5 in Offspring 1 and 4, 6, 7 in Offspring 2. Thus, both offspring are illegal, i.e. infeasible for being a visiting schedule.

To address the issue of the legality of an order, several crossover operators for order-based GAs are proposed. Partially mapped crossover (PMX) (Goldberg & Lingle, 1985) is one of the most popular and effective crossovers for order-based GAs to deal with combinatorial optimization problems, especially the TSP. In view of the operation, PMX can be regarded as a modification of two-point crossover but additionally uses a mapping relationship to legalize offspring that have duplicate numbers. The algorithm of PMX is given below.

Algorithm 1. Partially mapped crossover (PMX)

1. **Substring selection:** Cut each parent into two substrings, and then select one substring for each parent at random.
 2. **Substring exchange:** Exchange the two selected substrings to produce proto-offspring.
 3. **Mapping list determination:** Determine the mapping relationship based on the selected substrings.
 4. **Offspring legalization:** Legalize proto-offspring with the mapping relationship.
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Fig. 2 illustrates how PMX legalizes the offspring in Fig. 1. Assume that the selected substrings in Step 1 are [4 3 7 6] for Parent 1 and [1 2 5 3] for Parent 2. These two substrings are then exchanged to produce proto-offspring in Step 2. Note that the proto-offspring are possibly illegal. Steps 3 and 4 in PMX then fix the illegal offspring. In Step 3, the mapping relationship is established according to the selected substrings, e.g., '1' to '4', '2' to '3' until '6', and '5' to '7' in Fig. 2. To legalize the proto-offspring, the fourth step of PMX replaces the duplicates genes with the corresponding genes in the mapping relationship.

Mutation is another important operator in GAs. This operator changes a small amount of genes to activate the population diversity. Several mutation operators have been proposed for order-based GAs. This study adopts the well-known swap mutation (Syswerda, 1991), which swaps genes at two randomly chosen loci.

3. Multi-parent partially mapped crossover

In light of the considerable success of PMX in combinatorial optimization problems, this paper proposes the multi-parent partially mapped crossover (MPPMX) to extend PMX into a multi-parent crossover for better performance. Satisfying the legality of offspring is key to the design of the crossover for order-based representation. The increase of parents, however, complicates the determination of the mapping relationship and the legalization

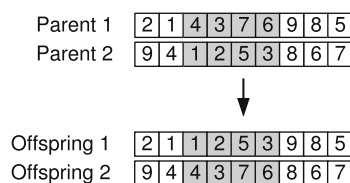


Fig. 1. Failure of two-point crossover in order-based GAs.

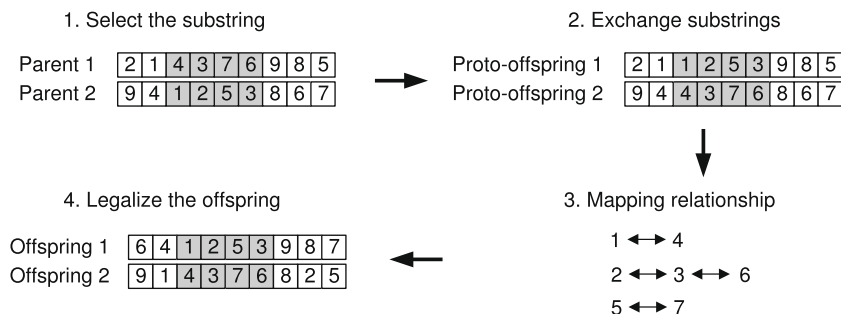


Fig. 2. Example of PMX.

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