Chapter 10
Recombination Operators in Permutation-Based Evolutionary Algorithms for the Travelling Salesman Problem

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ABSTRACT

The Travelling Salesman Problem (TSP) is one of the most widely studied optimization problems due to its many applications in domains such as logistics, planning, routing, and scheduling. Approximation algorithms to address this NP-hard problem include genetic algorithms, ant colony systems, and simulated annealing. This chapter concentrates on the evolutionary approaches to TSP based on permutation encoded individuals. A comparative analysis of several recombination operators is presented based on computational experiments for TSP instances and a generalized version of TSP. Numerical results emphasize a good performance of two proposed crossover schemes: best-worst recombination and best order recombination which take into account information from the global best and/or worst individuals besides the genetic material from parents.

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1. INTRODUCTION

The Travelling Salesman Problem (TSP) is a well-known NP-hard problem intensively studied in operations research and computer science and commonly engaged as a standard test bed for combinatorial optimization methods. Given a number of cities and the cost of travelling (or the distance) between any two cities, TSP aims to find a minimum length closed tour that visits each city exactly once. The study of TSP is of significant importance to several application domains in planning, scheduling and logistics. TSP applications include drilling of printed circuit boards, x-ray crystallography, computer wiring, vehicle routing, order-picking problem in warehouses and scheduling problems (Matai, 2010).

Because TSP is NP-hard and exact solutions cannot be found in polynomial time by any algorithm, there is a high interest in developing good approximation methods for solving TSP able to determine a near-optimal (or optimal) solution using reasonable resources. Heuristic approaches to TSP include genetic algorithms (Larranaga, 1999), ant colony systems (Dorigo, 1997) and simulated annealing (Laarhoven, 1987).

This chapter focuses on the traditional evolutionary approach to TSP by which potential solutions are represented as permutation of cities (path representation) and the quality of an individual is assessed based on the corresponding tour cost. An important search operator in genetic algorithms is the recombination of two individuals which should be able to produce new potentially more efficient tours. Main existing recombination operators specific to permutation-based encoding are described. Two previously introduced operators (Gog, 2006a, 2006b, 2007) - called adaptive goal guided crossover (AGGX) and best-worst crossover (BWX) - are presented. Furthermore, we introduce the best order crossover (BOX) operator. AGGX, BWX and BOX rely on different schemes for the recombination of genetic material from parents, global best individual, global worst individual and/or the parent’s line best ancestor individual. The comparative performance of all these recombination operators inside a standard genetic algorithm is analyzed for both TSP and a generalized version of TSP. The study is based on extensive numerical experiments for various instances from the TSP library (Reinelt, 1991).

The structure of this chapter is as follows: TSP is described and formalized; genetic algorithms are briefly reviewed with a focus on a simple evolutionary approach to TSP in terms of solution representation and fitness function; existing crossover operators for permutation-based encoding are reviewed; the proposed recombination operators are described in detail; numerical experiments are given for TSP and a generalized version of TSP and comparative results are discussed.

2. THE TRAVELLING SALESMAN PROBLEM

Given a list of cities and a starting point, a travelling salesman has to visit every city exactly once and then return to the starting city. A set of \( k \) points in a plane is given, corresponding to the location of \( k \) cities. The objective is to find the shortest route for the travelling salesman. The number of possible tours for \( k \) cities is \((k-1)!/2\) which represents a very large search space.

The Travelling Salesman Problem (TSP) can be formalized as follows. A set of \( k \) cities

\[
C = \{c_1, c_2, \ldots, c_k\}
\]

is given. For each pair

\[
(c_i, c_j), \ i \neq j,
\]

Let