

Solving Travelling Salesman Problems using Genetic Algorithms

SEM6120 - Assignment 2

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1 Introduction

This report investigates the use of Genetic Algorithms to solve the Travelling Salesman Problem, introducing both topics as well as previous research and techniques.

Following this the design for the solution implemented will be detailed, focusing from high level system design to annotated code section to explain the choice behind the implementation.

This implementation is then used to produced the results in section 3 which give an insight into the affects of different crossover and mutation schemes on the performance of the genetic algorithm, specifically looking at

Finally the author will draw conclusions from these results and

1.1 Genetic Algorithms

Genetic algorithms are a biologically-inspired approach to heuristic search that mimic natural selection. Unlike many other evolutionary strategies and evolutionary programming, they are not designed to solve a specific problem, but are designed to solve the problem of optimisation which is made difficult by substantial complexity and uncertainty[1].

1.2 Travelling Salesman Problem

The Travelling Salesman Problem is a well-known NP-hard optimisation problem which asks the question: *“Given a number of cities and the distances between these cities, find the shortest touch which visits each city exactly once and returns to the first city.”*

Assuming each city is connected to every other city, this problem reaches a complexity of $O(n!)$ and is very resource intensive to brute force a problem with any decent number of nodes quickly become too larger problem to solve within a reasonable amount of time.

There are many heuristic algorithms which have been applied successfully to the Travelling Salesman Problem, including both Evolutionary and Genetic Algorithms.

Though the nature of Genetic Algorithms are suited to the optimisation of a Travelling Salesman Problem, normal methods of crossover and mutation cannot, generally, be applied directly to the problem. The representation of chromosomes has to be ordered (i.e. each city must appear once and only once) and additional methods of crossover and mutation have had to be designed for these ordered chromosomes.

2 Design

2.1 System Design

As with most coding problems with multiple options, a modular approach is necessary to keep code quality high. This is typically done by defining high-level interfaces for the changeable elements. In this case the obvious three interfaces are:

1. Selection Scheme
2. Crossover Scheme
3. Mutation Scheme

From these high-level classes, concrete sub-classes can be written to perform the actual logic. An example of this would be a specific class for Order-1 based crossover.

This leaves the problem of how to access these classes based on an input string; the easiest method for this is to use factories to access these classes, cutting down the number of specific imports required and centralising the logic for creating them.

2.1.1 Language Choice

Python was the choice of language, it is a dynamically typed language which provides several programming paradigms to work with, including procedural, object-orientated and functional paradigms.

It is a language the author is very familiar with and has the advantage of having many open source libraries to perform different scientific functions; some of these libraries have been used in the course of this project, including the popular `numpy` library for number processing and `matplotlib` to produce graphs.

The strange choice of `pygame` was made for the choice of displaying the GUI, but this games library gives simple yet powerful access to OpenGL and also manages platform dependencies.

2.1.2 UML Class Diagram

Figure 1 shows the initial UML Class diagram for this project. There are some elements which break from typical object-orientated design, noticeably the representation of nodes in a graph as a map of integers to a tuple of float, these parts are done so to re-use internal data structures of the Python programming language to speed up the implementation of many features.

This design is such that factories exist to create selection schemes, crossover schemes and mutators based on an input string to facilitate the switching of these elements via command line arguments.

This design was slowly improved through the project; the `CrossoverScheme` class implemented the `crossover` method, which then called a separate method, `do_crossover`, to generate `c1` based on `do_crossover(p1, p2)` and `c2` on `do_crossover(p2, p1)` to make the processing more uniform. Subclasses were still able to override the `crossover` method, but were encouraged to implement

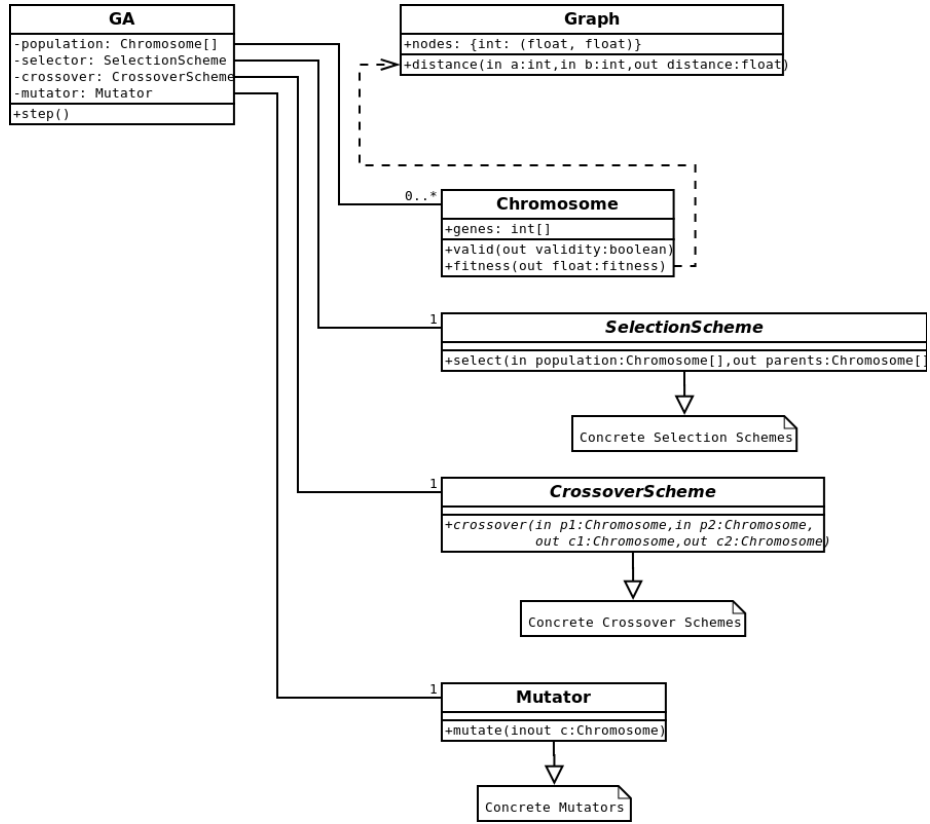


Figure 1: UML Class Diagram for the Genetic Algorithm

a `do_crossover` method unless the scheme required a different behaviour of child generation.

2.1.3 Representation of Graphs

The actual of representation of a graph is a map of the node identifier to the x and y co-ordinates of that node (as a tuple). This allows easy look up of nodes within the map to get the position of the node. This was chosen because of the representation of the problem in chromosomes - each gene represents a node in the graph.

With this representation, the fitness function would be the distance of the tour represented by these nodes:

$$d_{tour} = \sum_{i=0}^N \begin{cases} d(n_i, n_{i+1}) & \text{if } i + n < N \\ d(n_i, n_0) & \text{else} \end{cases} \quad (1)$$

Programatically, with the advantage of the functional and in-built elements of Python, this can be simplified to:

```
def d_tour():
    # Move the first element of the array to the end.
    shifted = nodes[1:] + nodes[:1]
```

```
return sum([distance(i, j) for (i, j) in zip(nodes, shifted)])
```

Listing 1: Distance of a tour

2.2 Use of Functional Programming Paradigms

As Python implements several different programming paradigms a lot of problems can be solved with a different approach than other languages can. Both genetic algorithms and the travelling salesman problem lend themselves towards a more functional approach with a lot of list processing. Using Python's list comprehensions and the in-built list functions shortened the amount of code required and makes the code a lot easier to understand for those who are used to this approach.

A very good example of this is the method for evaluating chromosomes in a population, returning a list sorted from the best to the worst:

```
def eval(population):
    return sorted(population,
                  key = lambda chromosome: chromosome.fitness())
```

Listing 2: Using function elements to improve succinctness and readability

2.3 Crossover Strategies

Three main types of crossover strategies were implemented for this research:

1. Cycle Crossover,
2. Order Crossover Operator,
3. M-Crossover Operator.

All three are designed to work with ordered chromosomes, meaning they can be applied directly to the Travelling Salesman Problem without any modification.

2.3.1 Cycle Crossover

Cycle crossover is one of the simplest order-based crossover operators. Unlike many other forms of order-based operators it makes no effort to preserve parts of the parent chromosomes.

To produce a child, c , from parents p_1 and p_2 a randomly selected point i is chosen. The gene at i in p_1 ($r = p_1(i)$) is removed and replaced with $p_1(i) = p_2(i)$. The position of the removed allele r is found in p_2 such that $i = \text{index}(r, p_2)$. This process is repeated until a cycle occurs (i.e. the removed allele r is the same as the initially removed allele).

Figure 2 shows this process step by step on two ordered chromosomes. Note that it is only by chance that parts of the tour are preserved.

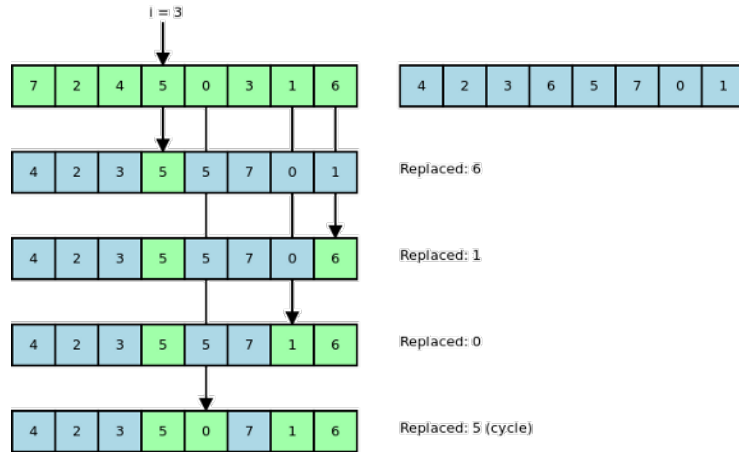


Figure 2: Cycle Crossover

2.3.2 Order Crossover Operator

The order crossover operator is another simple order-based crossover operator. Unlike cycle crossover, it preserves at least part of a tour from one of the parents.

To produce a child, c , from parents p_1, p_2 , a random segment from p_1 is appended to the remaining genes from p_2 , omitting any alleles that are also in the segment from p_1 .

Figure 3 shows this process step by step on two ordered chromosomes. Note that at least a part of the tour is always preserved and that it is often the case that a part of a tour from p_1 and p_2 is preserved in c .

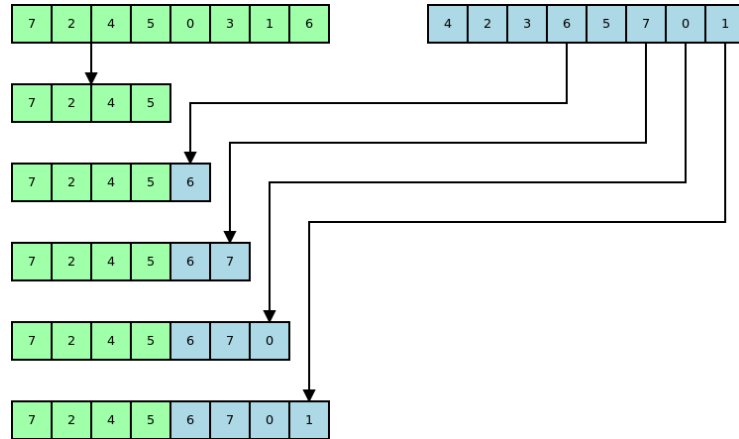


Figure 3: Order Crossover Operator

2.3.3 M-Crossover Operator

The m-crossover operator[2] produces multiple offspring (C) from parents p_1, p_2 then selects the best two from this process.

Like with the order crossover operator, this is based on segmenting the chromosomes. However, both chromosomes are split into several segments. Every segment of p_1 is inserted at any point in front, behind or between the segments of p_2 and vice versa. The new, elongated chromosome is then processed such that any allele in the added segment is removed from all other segments to produce the child at that point.

The fitness of these children is then evaluated and the best two are carried forward as the offspring of these parents.

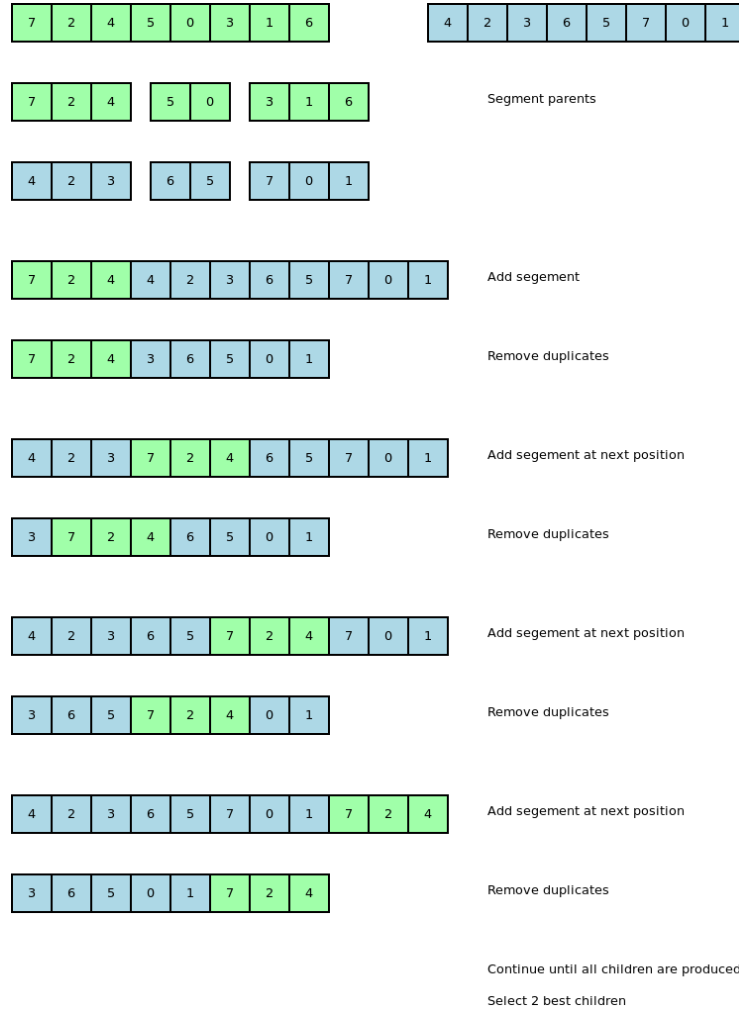


Figure 4: M-Crossover Operator

3 Results

3.1 Best and Mean Population Fitness against Number of Generations

3.2 Best and Mean Population Fitness against Runtime

3.3 Convergence

4 Conclusions

References

- [1] John H. Holland. *Adaptation in natural and artificial systems : an introductory analysis with applications to biology, control, and artificial intelligence*. MIT Press, April 1992.
- [2] D. N. Mudaliar and N. K. Modi. Unraveling travelling salesman problem by genetic algorithm using m-crossover operator. In *Signal Processing Image Processing & Pattern Recognition (ICSIPR), 2013 International Conference on*, pages 127–130. IEEE, February 2013.