CIT CORK INSTITUTE OF TECHNOLOGY

INSTITIÚID TEICNEOLAÍOCHTA CHORCAÍ

Metaheuristic Optimization

Assignment 1

Due date:

Assignment should be submitted to Canvas by 23:59 on Sunday November 8th 2020.

As per CIT regulations, submitting within 7 days of the deadline will result in a 10% penalty, between 7 and 14 days late will result in a 20% penalty, and later than 14 days after the due date will result in a 100% penalty applied.

Part 1: NP-completeness

This problem concerns the proof of the NP-completeness of 3COL

1. Convert the formula F below into a 3SAT formula F', find a solution to F' and verify that this is a solution to F
   a. If the last digit of your student id is less than 3 use

      $$F = (z_1 \vee -z_2) \wedge (-z_1 \vee z_2 \vee z_3 \vee z_4 \vee z_5 \vee -z_6)$$

   b. If the last digit of your student id is either 3, 4 or 5 use

      $$F = (-w_3 \vee w_4) \wedge (w_1 \vee -w_2 \vee w_3 \vee -w_4 \vee -w_5 \vee w_6)$$

   c. If the last digit of your student id is either 6 or 7 use

      $$F = (-p_1 \vee -p_3) \wedge (p_1 \vee -p_2 \vee p_3 \vee -p_4 \vee p_5 \vee -p_6)$$

   d. If the last digit of your student id is greater than 7 use

      $$F = (q_1 \vee q_4) \wedge (-q_1 \vee q_2 \vee q_3 \vee -q_4 \vee -q_5 \vee q_6)$$

2. Convert the following subclauses in your F' to a 3Col graph

   The first and third clauses of F' if the first letter of your first name is in the range A-I

   The first and fourth clauses of F' if the first letter of your first name is in the range J-R

   The second and third clauses of F' if the first letter of your first name is in the range S-Z

Part 2: Genetic Algorithms

The Traveling Salesman Problem (TSP) is one which has commanded much attention in Artificial Intelligence because it is so easy to describe and so difficult to solve. The problem can simply be stated as: if a traveling salesman wishes to visit exactly once each of a list m cities (where the cost of traveling from city i to city j is c_{ij}) and then return to the home city, what is the least costly route the traveling salesman can take.

The importance of the TSP is that it is representative of a larger class of problems known as combinatorial optimization problems. The TSP problem belongs in the class of combinatorial optimization problems known as NP-hard. Today, no one has found a polynomial-time algorithm for the TSP.

A Simple Genetic Algorithm

A simple genetic algorithm can be defined in the following 9 steps:

Step 1: create an initial population of P chromosomes (generation 0)
Step 2: evaluate the fitness of each chromosome
Step 3: Select P parents from the current population via proportional selection (i.e., the selection probability is proportional to the fitness).
Step 4: choose at random a pair of parents for mating. Exchange bit strings with a crossover operation to create two offspring (e.g., one-point crossover)
Step 5: process each offspring by the mutation operation, and insert the resulting offspring in the new population
Step 6: repeat steps 4 and 5 until all parents are selected and mated (P offspring are created)
Step 7: replace the old population of chromosomes in the new population
Step 8: evaluate the fitness of each chromosome in the new population
Step 9: go back to step 3 if the number of generations is less than some upper bound. Otherwise, the final result is the best chromosome created during the search.

Selection Probability:

The parent chromosomes are selected for mating via **Binary Tournament Selection**.

Initial population

In addition to the crossover and mutation operators you will also evaluate the impact of the GAs with the following initial populations:

- Randomly generated population
- Nearest neighbor insertion: Choose first city randomly, each city thereafter choose city closest to the last city added to the route and append to the route

Crossover and mutation operators

Write a program that solves the TSP using Genetic Algorithms. Explain and implement the following crossover & mutation operators:

- Uniform order-based Crossover
- Order-1 Crossover
- Inversion Mutation
- Scramble Mutation

I/O Specification

In this assignment you will use the same I/O format as defined in the first lab (week 2).

Problem instances

In this project, you will use the following problem instances to evaluate the performance of your algorithms:

if the first letter of your surname is in the range A-I inst-0.tsp, inst-13.tsp, and inst-5.tsp
if the first letter of your surname is in the range J-R inst-4.tsp, inst-16.tsp, and inst-6.tsp
if the first letter of your surname is in the range S-Z inst-19.tsp, inst-20.tsp, and inst-7.tsp

Assignment of Marks:

The deliverable of this project will consists of a python code file(s) and a report. You must follow the correct scheme with last digit of id and first letter of first and last names, you must state what you used to avoid confusion. Marks will be lost if this is not done correctly, similarly the random seed must be set and must be your student id.

The following is the allocation of marks.

20%: Solution - Part 1.

Rubric (Solution and verification aspect only refers to SAT to 3SAT):

Reduction is logically well designed, documented and explained. Solution is correct (7.5 -10 Marks)	Reduction is logically well designed. Solution is correct (5-7.5 Marks)	Reduction has slight logic errors that do no significantly affect the results. Solution has slight errors (3-5 Marks)	Reduction has significant logic errors. Solution has errors (1-2 Marks)	Reduction is completely incorrect. Solution completely incorrect. (0 Marks)

Part 2:

- Implementation of Genetic algorithms with the above mentioned crossover and mutation operations: 35 marks

	The Operator is logically well designed without inappropriate design choices (e.g., unnecessary loops)	The Operator always works properly and meets the specification of the operator	The operator works properly in limited cases	The operator is incorrectly implemented
Uniform Order-based Crossover	(5-7 Marks)	(3-4 Marks)	(1-2 Marks)	(0 Marks)
Order-1 Crossover	(5-7 Marks)	(3-4 Marks)	(1-2 Marks)	(0 Marks)
Inversion Mutation	(5-7 Marks)	(3-4 Marks)	(1-2 Marks)	(0 Marks)
Scramble Mutation	(5-7 Marks)	(3-4 Marks)	(1-2 Marks)	(0 Marks)
Binary Tournament Selection	(5-7 Marks)	(3-4 Marks)	(1-2 Marks)	(0 Marks)

- 10%: A basic evaluation: the basic evaluation should describe the following two basic configurations:

Configuration	**Initial Solution**	**Crossover**	**Mutation**	**Selection**
1	Random	Order-1 Crossover	Inversion Mutation	Binary Tournament Selection
2	Random	Uniform Crossover	Scramble Mutation	Binary Tournament Selection

Population size = 100
Mutation rate = 0.05

Rubric:

Excellent presentation, depth and insight analysis of the empirical results (8-10 Marks)	Good presentation of the results (e.g., describing the results with well structured tables) (7-5 Marks)	Incomplete and/or unclear presentation of the results (3-5 Marks)	The results are inconsistent with the logic of the configuration/operators (0-2 Marks)

- 20%: Evaluation of your GA, i.e., initial population, crossover & mutation operators. You are expected to evaluate the following combination of operations:

Configuration	**Initial Solution**	**Crossover**	**Mutation**	**Selection**
3	Random	Order-1 Crossover	Scramble Mutation	Binary Tournament Selection
4	Random	Uniform Crossover	Inversion Mutation	Binary Tournament Selection
5	Heuristic	Order-1 Crossover	Scramble Mutation	Binary Tournament Selection
6	Heuristic	Uniform Crossover	Inversion Mutation	Binary Tournament Selection

Additionally, you are expected to investigate the impact of varying the population size, and explore different mutation rates.

Rubric:

Evaluation configurations [3-6]	Excellent presentation, depth and insight analysis of the empirical results. (8-10 Marks)	Good presentation of the results (e.g., describing the results with well structured tables) (7-5 Marks)	Lack of clear and logical presentation of the results. Missing or incomplete results (3-5 Marks)	The results are inconsistent with the logic of the configuration/ operators (0-2 Marks)
Additional Experiments	Excellent design, presentation, analysis, and conclusions of the additional experiments [8-10 Marks]	A reasonable attempt to design and presentation of the additional experiments (7-5 Marks)	Poor design and description of the additional experiments (3-5 Marks)	The results are inconsistent with the logic of operators (0-2 Marks)

- 15%: Your report should contain a description of the algorithms and an evaluation of your results. And it should describe the experimental design, what experiments are and what they are intended to show. Use tables and figures where appropriate.

You should assess the overall performance of your optimization algorithms for solving the travelling salesman problem. Typically, to evaluate the performance of your algorithm for a single configuration you would run your algorithm multiple times (at least 5 times in this project with at least 500 iterations per execution) and record the best fitness for all runs. You can then report the mean and median fitness across all runs. You should consider runtime as well as fitness when assessing performance.

Submission:

This assignment is due on Sunday November 8th 2020. You must submit the following files (in a single zip file):

- All source code.
- A Readme file, which briefly describes all submitted files. In the Readme file, you should also provide information about compiling environment, compiling steps, execution instructions, etc.
- A Sample file, which describes the tests you have run on your program. Also describes any cases for which your program is known not to work correctly.

You must **submit the pdf separately via the Turnitin assignment** submission:

- Report document (pdf) - including your solutions for Part 1 & Part 2.

Academic Integrity:

This is an **individual** assignment. The work you submit must be your own. In no way, shape or form should you submit work as if it were your own when some or all of it is not.

Collusion: Given how much freedom there is in the assignment, everybody's work will be different. It will be obvious if there is collusion. All parties to collusion will be penalized.

Deliberate plagiarism: You must not plagiarise the programs, results, writings or other efforts of another student or any other third-party. Plagiarism will meet with severe penalties, which can include exclusion from the University.

Inadvertent plagiarism: In reporting your exploration of the research literature be careful to avoid inadvertent plagiarism (e.g where paraphrases of the source material are too close to the original).

Falsification and fabrication: The experimental results reported must come from the experiments that you have run. Do not falsify or fabricate results.

Your report will be checked for signs of collusion, plagiarism, falsification and fabrication. You may be called to discuss your submission and implementation with me and this will inform the grading, any penalties and any disciplinary actions.