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Travelling Salesman Problem

Biologically Inspired Computing

Navn: Torstein gombos
Username: Tagombos

Innhold

Introduction

The travelling salesman problem is an optimization problem about finding the shortest route between cities around the world. I will in this report implement various optimization methods and test performance on time and result. The questions in the assignment are answered in each chapter.

Tools

I program the methods using python 3.6. The data used comes from “European_citites.CSV”.

Code

This is an explanation on how to run the script and how the script is written. For documentation about the various modules, methods and functions, see the documentation files in the same folder. An explanation on how to run the script exists also in the readme file.

How to run

The code is divided into three scripts:

Everything is run from the main script TSP.py. This reads the data from the CSV file and runs the different methods and algorithms according to the arguments given from the user. It then returns the results and prints and plots in a manner that can answer the questions in the assignment.

The user can input the following arguments in the command line terminal when running the script:

What algorithm to use:

1. *– m ex* *Exhaustive search*
2. *– m hc* *Hill climber*
3. *– m ga* *Genetic Algorithm*
4. *– m hybrid* *Hybrid Algorithm*

Route length:

– r <number of cities> *max 24, if exhaustive search, 11 cities is max.*

Learning model:

1. *– l lamarckian* *Uses the Lamarckian learning model*
2. *– l baldwinian* *Uses the baldwinian learning model.*

If no arguments are given, TSP.py will run an exhaustive search for the 10 first cities and return the shortest route, its distance and execution time.

Code Structure

Code is divided into three scripts

1. *TSP.py*
   Everything is run from here
2. *Routes.py*
   Everything regarding setting up routes or calculating distances is done from here
3. *Simple_search_algorithms.py*
   All the algorithms used for the assignment is implemented here

Exhaustive search

What is the shortest route and what is the distance?

Implementing exhaustive search for 10 cities yielded following route:

The shortest route using exhaustive search:
Barcelona Belgrade Istanbul Bucharest Budapest Berlin Copenhagen Hamburg Brussels Dublin Barcelona
The total distance is 7486.31km

Code execution: 3.715876340866089s

How long did it take the program to find it?

The code used about 3.7s when finding optimal route for 10 cities

How long would you expect it take with all 24 cities?

Since it does not matter what the starting point is as long as the sequence of cities is the same. One can therefore do $(n-1)!$ permutations

Number of cities	Distance(km)	Time(s)	Permutations
6	5018.81	0.00203	120
7	5487.89	0.00697	720
8	6667.49	0.04188	5040
9	6678.55	0.36299	40320
10	7486.31	3.54444	362880
11	8339.36	39.1216	3628800

$Time(s) = \frac{3.54s}{363880} * (24-1)! \ = 7.96975211 \times 10^9 \text{ years}$ (converted answer from seconds to years)

Hill Climbing

How well does hill climber perform on the same first 10 cities?

Implementing hill climbing for the first 10 cities yielded:

The shortest route:
Hamburg -> Copenhagen -> Berlin -> Budapest -> Bucharest -> Istanbul -> Belgrade -> Barcelona -> Dublin -> Brussels -> Hamburg ->
The total distance is 7486.31km

Code execution: 0.013934135437011719s

$$\frac{3.5s}{0.013s} = 269\%\ faster\ than\ exhaustive\ search$$

However, it does not always reach global minimum,.

Performing 20 hill climbs on random sequence of 10 cities:

The shortest route was 7486.31km:
Istanbul -> Belgrade -> Barcelona -> Dublin -> Brussels -> Hamburg -> Copenhagen -> Berlin -> Budapest -> Bucharest -> Istanbul ->

The longest route was 9410.61km:
Belgrade -> Brussels -> Dublin -> Barcelona -> Istanbul -> Bucharest -> Copenhagen -> Hamburg -> Berlin -> Budapest -> Belgrade ->

The mean was: 7998.818500000001
The standard deviation was: 549.2403150215758

Code execution: 0.31919145584106445s

Performing 20 hill climbs on random sequence of 24 cities:

The shortest route was 13483.66km:
Barcelona -> Madrid -> Dublin -> London -> Brussels -> Paris -> Milan -> Munich -> Prague -> Vienna -> Budapest -> Belgrade -> Sofia -> Istanbul -> Bucharest -> Warsaw -> Berlin -> Hamburg -> Copenhagen -> Stockholm -> Saint Petersburg -> Moscow -> Kiev -> Rome -> Barcelona ->

The longest route was 17955.05km:
Saint Petersburg -> Barcelona -> Madrid -> Paris -> Brussels -> Copenhagen -> Stockholm -> Moscow -> Kiev -> Hamburg -> Dublin -> London -> Berlin -> Prague -> Munich -> Milan -> Rome -> Vienna -> Belgrade -> Sofia -> Istanbul -> Bucharest -> Budapest -> Warsaw -> Saint Petersburg ->

The mean was: 15190.461
The standard deviation was: 1045.0609307640743

Code execution: 1.2655680179595947s

Genetic Algorithm

The genetic algorithm I have written follows simple GA structure:

Initialize Population	An *x* amount of random generated routes
Evaluate Population (Fitness)	Total distance for each route
Select Parents	Based on a fitness proportionate selection Uses windowing to scale probabilities
Create Offspring	Uses partially mapped crossover between selected parents
Mutate Offspring	Random swap on a small selection of offsprings to keep some diversity
Replace population	Normally replaces entire population with offspring unless hybrid mode is selected.

Performing genetic algorithm with three different population sizes:

Conclude which is better in terms of tour length and number of generations of evolution:

Tour length: All 24 cities, Best of: 20 runs,

Population	Evaluations	Best fitness(km)	Worst fitness(km)	Mean(km)	Standard deviation(km)
200	80 000	12511	17410	14869	1031
400	160 000	13049	16117	14778	873
500	200 000	12960	16001	14307	815

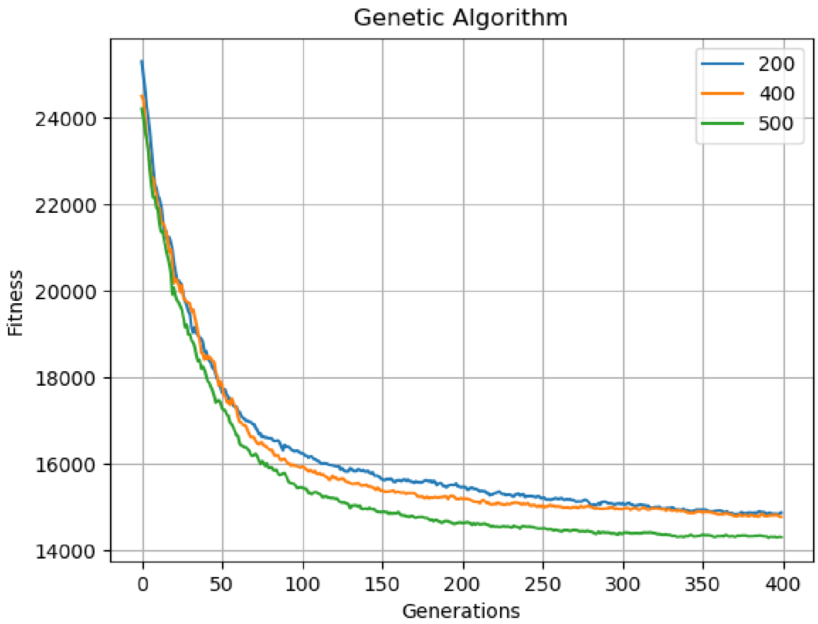


Figure 1 Shows average fitness from 20 runs. Legend is population size.

Even though the smallest population had the over all best individual, the largest population of 300 more individuals performs a lot better on an average of 20 runs.

How well does genetic algorithm perform compared to exhaustive search on time

Comparisons are performed with one run of GA for both 10 cities and 24 cities to check time. The number of evaluated cities for each population should be:

For 10 cities, 300 generations were used: $500 * 100 = 50\ 000\ tours$

Route length: 10 cities
Generations: 100

Population size:	Evaluations	Time(s)	Best distance(km)
200	20 000	0.38	7870
500	50 000	1.17	7486
800	80 000	2.26	7846

We see that genetic algorithm outperforms exhaustive search in time, even though the algorithm uses more evaluations than necessary. The two graphs below show that for 10 cities, it quickly converges to the global maximum for 10 cities. Time spent is also quite less than for exhaustive search, which uses 3.7s for 10 cities

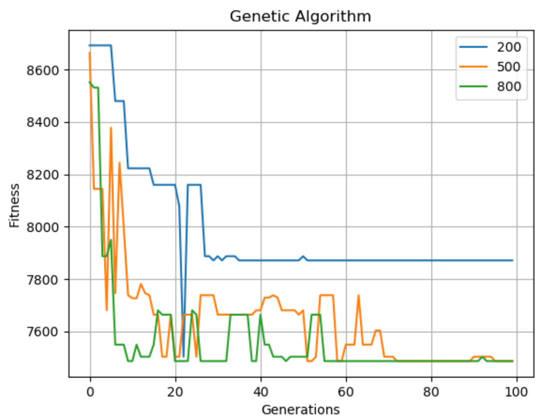


Figure 2. Single run

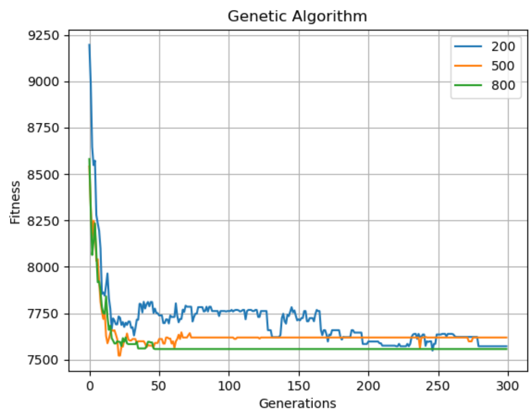


Figure 3. Average of 5 runs

Route length: 24 cities
Generations: 200

Population size:	Evaluations	Time(s)	Best distance(km)
200	50 000	3.06	15204
700	70 000	6.08	15204
1200	240 000	9.97	13797

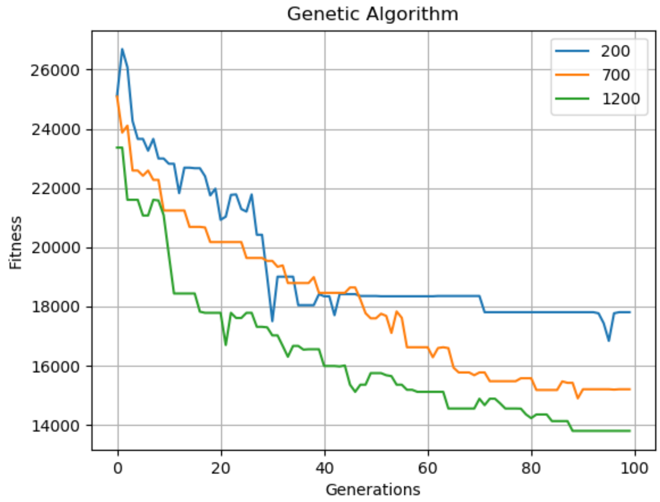


Figure 4 Result from one, timed run

From one run it manages to get decent result, though it is a stochastic method, and results varies. The best result achieved under 14000km in under 10 seconds, which compares to exhaustive is of course a lot less time.

Figure 5 routes are 24 cities long

Hybrid algorithm

This method involves doing a local search on each individual to optimize the population before going to the next generation. For this method, Hill Climber is used as local search. After hill climber is executed, one can use either Lamarckian or Baldwinian learning methods. Lamarckian will keep both fitness and optimized offsprings over to the next generation and usually converges fast towards local or global minimum. Baldwinian will do a local search, but only keep the fitness for the next generation and select offspring as normal.

An assumption has been made that the hill climber method will only change an individual if the individual was improved when a permutation operation is done. I have therefore not written code that checks if the overall fitness was improved after a local search, since hill climber is written so that it should be impossible for it to worsen.

Results of baldwinian

Baldwiniand:
Route length: 24
Generations: 70
Local searches: max 20 for each individual

Population	Evaluations	Best fitness(km)	Worst fitness(km)	Mean(km)	Standard deviation(km)
20	1000	17121	22125	20004	1454
30	1500	16821	20110	18545	905
50	2500	16306	20050	18024	1082

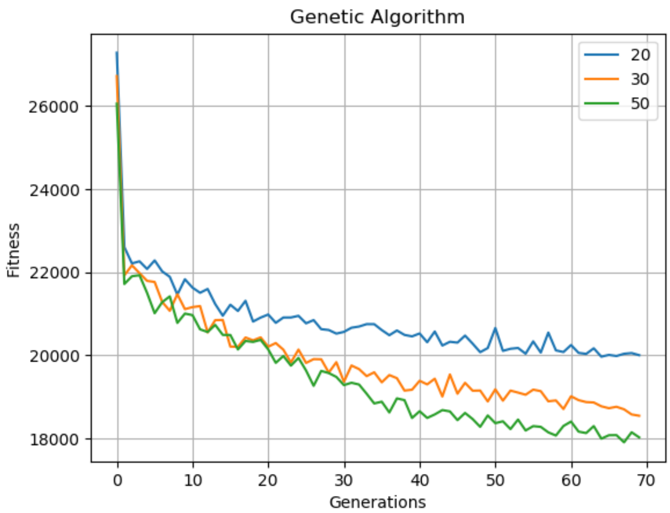
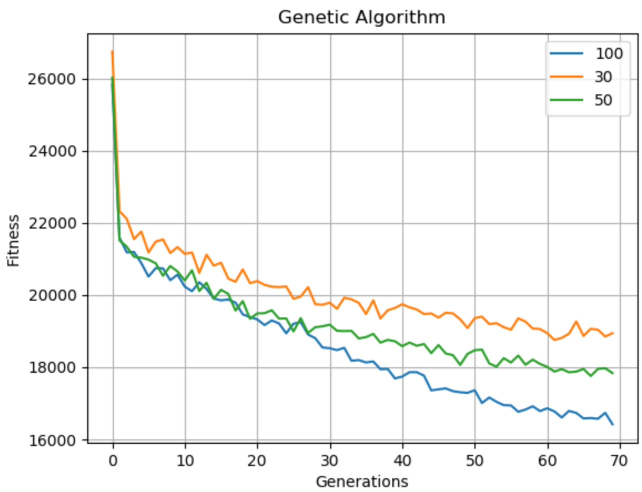


Figure 6 Average of 20 runs - Baldwinian

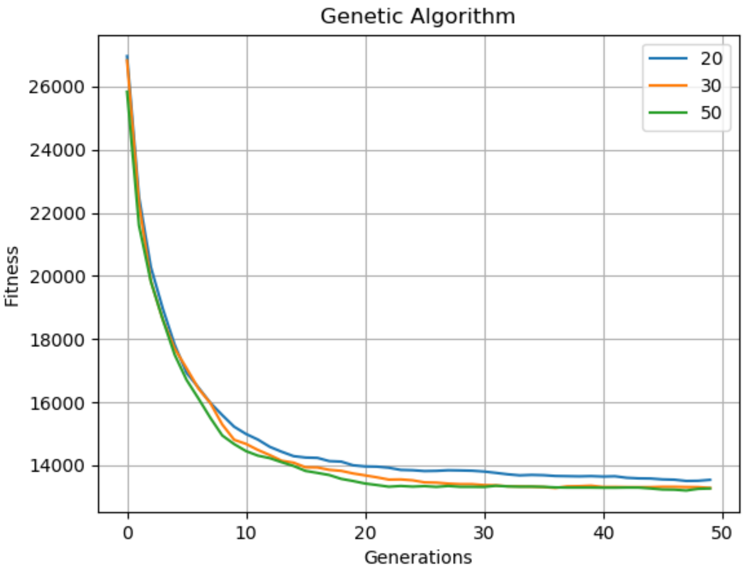
Baldwinian was performed with a lot less evaluations, since it spends a lot of time doing local searches. It does not seem to perform very well with as few evaluations. Figure 1 clearly shows that pure GA has converged further at the point of 70 generations. Though the population of Baldwinian is quite a lot smaller than when using pure GA. When tested with a population of 100, it shows more improvement.



Results of Lamarckian

Lamarckian:
Route length: 24
Generations: 50
Local searches: max 20 per individual

Population	Evaluations	Best fitness(km)	Worst fitness(km)	Mean(km)	Standard deviation(km)
20	1000	12737	14259	13537	442
30	1500	12396	14315	13281	563
50	2500	12287	14221	13264	534



With only a few evaluations compared to GA. Lamarckian outperforms all pervious stochastic methods by a lot. Even the smallest number of evaluations, which was 1000, beats pure GA, whose largest number of evaluations was over 200 000 and it was still beat. Execution time was an issue though. It took over 800 seconds to do all the evaluations.