Traveling Salesman Problem solution

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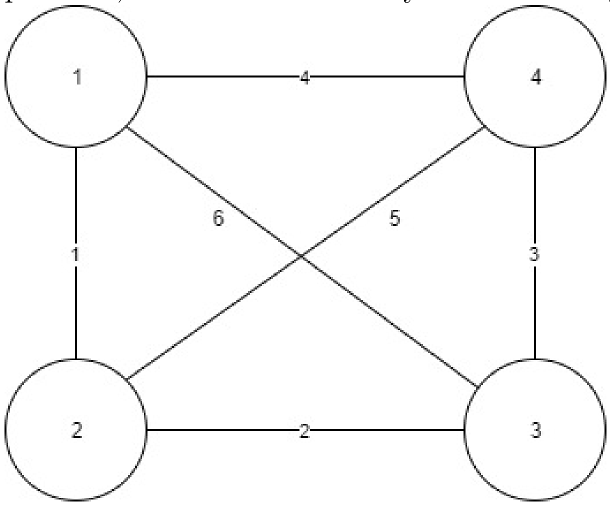
Abstract

This paper discuss how to solve the Traveling Salesman Problem. I tried naive/BF solution at first. After research some other algorithm, I impoved my solution and use genetic algorithm.

Traveling Salesman Problem solution

Introduction

Travelling salesman problem: Given a set of cities and distance between every pair of cities, the problem is to find the shortest possible route that visits every city exactly once and returns to the starting point. This problem is a famous NP hard problem, which means there is no polynomial time know the solution for the problem. However, when the number of city is very small, we can easily figure out the answer. For example, consider the given graph. There are 4 cities, which is 1,2,3,4. We can quickly figure out that the shortest route would be 1+2+3+4=10. However, if we search deep for how we get this out. The answer is that, we generate all the possible route, which is 1*2*3=6 possible ways. What's more when we are doing this we set 1 as the starting and ending point automatically. Theoretically, the idea is right. Calculate all the possible route and find out the minimum. Although the idea is simple, in real world, there would be much more cities involved. As the number of city goes up, the possible routes would increase like crazy. It will take too much time to calculate it, even we use computer programming. In this case, researchers find some other way to solve this problem, even the answer may not be exactly the right one, it is still very close.



Naive/BF implementation

There are a lot of solutions for the traveling salesman problem. Naïve/BF is the simplest one. The idea about naïve solution is easy to understand. Consider all the possible routes and compare with other and find the lowest cost. The algorithm of naïve/BF implementation is:

1. Consider a city as the starting and ending point.
2. Generate all (n-1) permutations of cities, which means generate all the possible routes.
3. Calculate cost of every permutation and keep track of min cost route.
4. Return the minimum cost route.

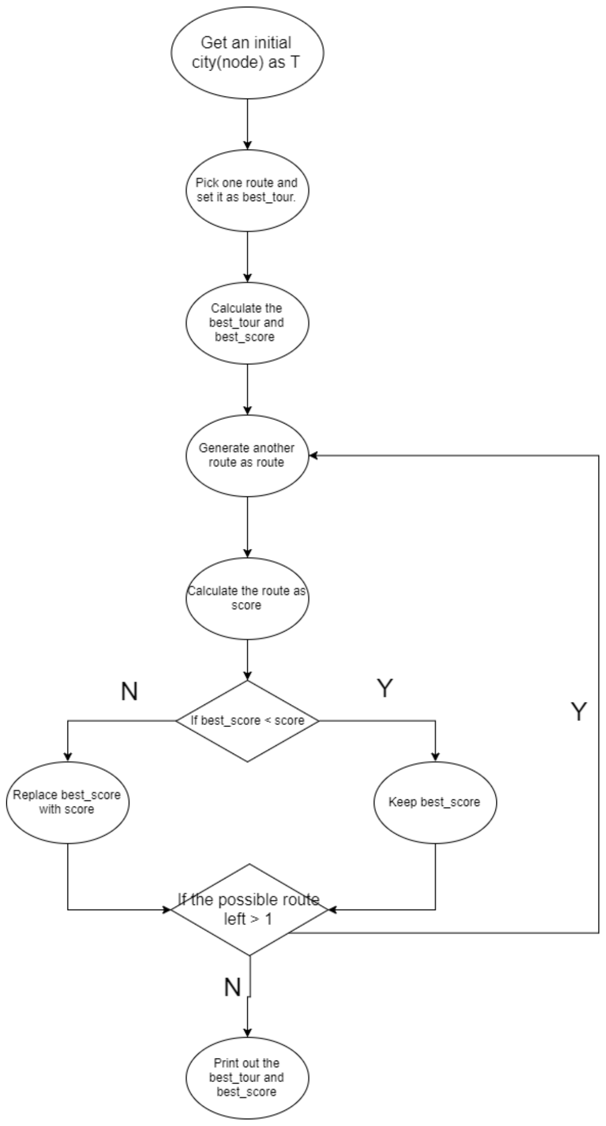
The code below is the pseudocode and flowchart for the BF implementation.

```
void brute_force_solver(const Tsp_map& cities) {
Tour tour(cities.get_default_tour());


double best_score = cities.score(tour);
Tour best_tour(tour);
cout << tour << " score = " << best_score << endl;
while (next_permutation(tour.begin() + 1, tour.end())) {
double s = cities.score(tour);
if (s < best_score) {
best_score = s;
best_tour = tour;
}


cout << tour << " score = " << s << endl;
} // while


cout << "best tour: " << best_tour
<< "\nscore = " << best_score << endl;
```


Get an initial city(node) as T
Pick one route and set it as best_tour.
Calculate the best_tour and best_score
Generate another route as route
Calculate the route as score
If best_score < score
N
Y
Y
Replace best_score with score
Keep best_score
If the possible route left > 1
N
Print out the best_tour and best_score

Based on the flowchart and pseudocode, we can generate those advantages about the naïve/BF implementation:

1. Naïve/BF implementation will find the most correct route if we have enough time to run this program. (The idea about most correct route I will declare it later in the paper)

2. Simple algorithm, and easy coding.

However, we can generate some disadvantages as well.

1. It is not efficient.

2. It takes too much time to run the program, no one in the real world would ever take so much time to calculate this. Not good for real problem.

Literature Review

Genetic Algorithm

Since the naive solution is not good enough, researchers need to create some new algorithm to solve the problem. one of those algorithms is called genetic algorithm. It is a meta-heuristic inspired by the nature world, which is the process of natural selection. Implement this genetic algorithm into TSP, it will performance much more better than the naive solution. The idea about genetic algorithm is different than the naive solution. First, we also need to consider a city as starting and ending point, and then generate one route from starting point to ending point. Second, it is the part that different from naive solution. As the algorithm named, we will do the a magic part, which is called crossover and mutation. With this step, we will crossover and mutate our parameter in the TSP problem which will lead to some new routes. Third, find the lowest cost route, and repeat the second step. In order to understand more, we can think the genetic algorithm in this way, you find a route, and then you change some way in the middle of your previous routes. In this case, you will get some different cost of the routes. However, it must have one route is the closest to the correct answer. Thus, we repeat this steps over and over again untill the lowest cost route stop changing. The following is the genetic algorithm from Mohd. Haque and Khalid Magld.

> Step 1: Construct a tree or minimum spanning tree from the graph based on the group size. Root node is the starting point of the salesman.
> Step 2: Construct the tours from each leaf node and from starting node in tree in the following way.
> Step 3: Applying the GA to this tree. I. Select any chromosome form the tree II. Here we have two kind of crossover one is inside the chromosome and other in between two chromosomes. a) One point - part of the first parent is copied and the rest is taken in the same order as in the second parent b) Two point - two parts of the first parent are copied and the rest between is taken in the same order as in the second parent c) None - no crossover, offspring is

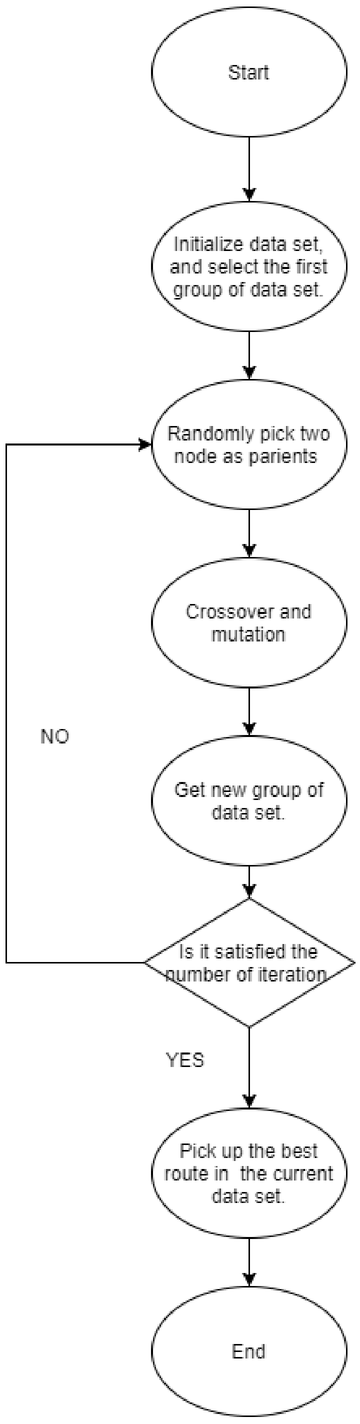
exact copy of parents III. Mutation can be done to the chromosome in the following ways. a) Normal random - a few cities are chosen and exchanged b) Random, only improving - a few cities are randomly chosen and exchanged only if they improve solution (increase fitness) c) Systematic, only improving - cities are systematically chosen and exchanged only if they improve solution (increase fitness) d) None - no mutation
Step 4: Add the entire route from the entire computed tree (from step 3) with the route using EAX; consider two best route from the tree as A and B. If result of EAX is better than our A and B than take the result of EAX Otherwise take best route from A and B.
Step 5: Compute the fitness score from the route formed from step 5 using fitness function if new route has better fitness score than previous then replace the route.
Step 6: Repeat step 3 to step 5 until better fitness score is obtained or all computed tree (from Step 3) have been added to the route.
Step 7: return the best result.(Mohd. JuneDul Haque and Khalid. W Magld, 2012)

Ant Colony Optimization

Ant Colony Optimization is another interesting algorithm to solve the TSP. I think ACO has some similar features with genetic algorithm. For example, the first sample data is very important. In this case, sometime we need to restart the whole process to check if we are on the right way.(Sarita Rai and Rajkumar Sharma, 2015)

My Solution and Experiments

After research others algorithm to solve the TSP. I improved my previous naive solution to genetic algorithm which is much better and more efficient. The following is


Start
Initialize data set, and select the first group of data set.
Randomly pick two node as parients
Crossover and mutation
Get new group of data set.
Is it satisfied the number of iteration
NO
YES
Pick up the best route in the current data set.
End

the flowchart.

Compare my genetic algorithm with naive solution, genetic algorithm is much more faster and efficient. The reason is obvious, in the naive solution, the program will list all the possible routes which means it will goes to every possible nodes and then get the best route. However, in genetic algorithm, we use sample data set instead of whole data set which means the program didn't need to go through every route to find the best routes. Even though, in the genetic algorithm, the iteration time still would affect the time. In the test I made, when the iteration time is 500, the time is 2.074s, and when the iteration times is 1500, the running time increase to around 6s. However, with more iteration time, the best route is smaller, which means more iteration time will make the result much more close to the correct answer.

Conclusions and Future Work

Based on the experiments, we can easily find out that genetic algorithm is much faster and more efficient than naive solution. However, I didn't do the Ant Colony Optimization part. Thus, in the future, we can still do competition between genetic algorithm and ACO. Besides, in the genetic algorithm, we can also do more experiment about the the relation between iteration times and total data sets. Even though more iteration times can lead our answer much close to correct one, I feel there should be a relation between those two variables.

References

Mohd. JuneDul Haque and Khalid. W. Magld. (2012) Improving the Solu- tion of Traveling Salesman Problem Using Genetic, Memetic Algorithm and Edge assembly Crossover

Ayman Srour, Zulaiha Ali Othman, and Abdul Razak Hamdan. (2014) A Water Flow-Like Algorithm for the Travelling Salesman Problem

Sabah Sadiq. (2012) The Traveling Salesman Problem: Optimizing Delivery Routes Using Genetic Algorithms

Sarita Rai and Rajkumar Sharma. (2015) Solution to Travelling Salesman Problem by Nature Inspired Algorithm

Eric Kuang. (2012) A 2-opt-based Heuristic for the Hierarchical Traveling Salesman Problem

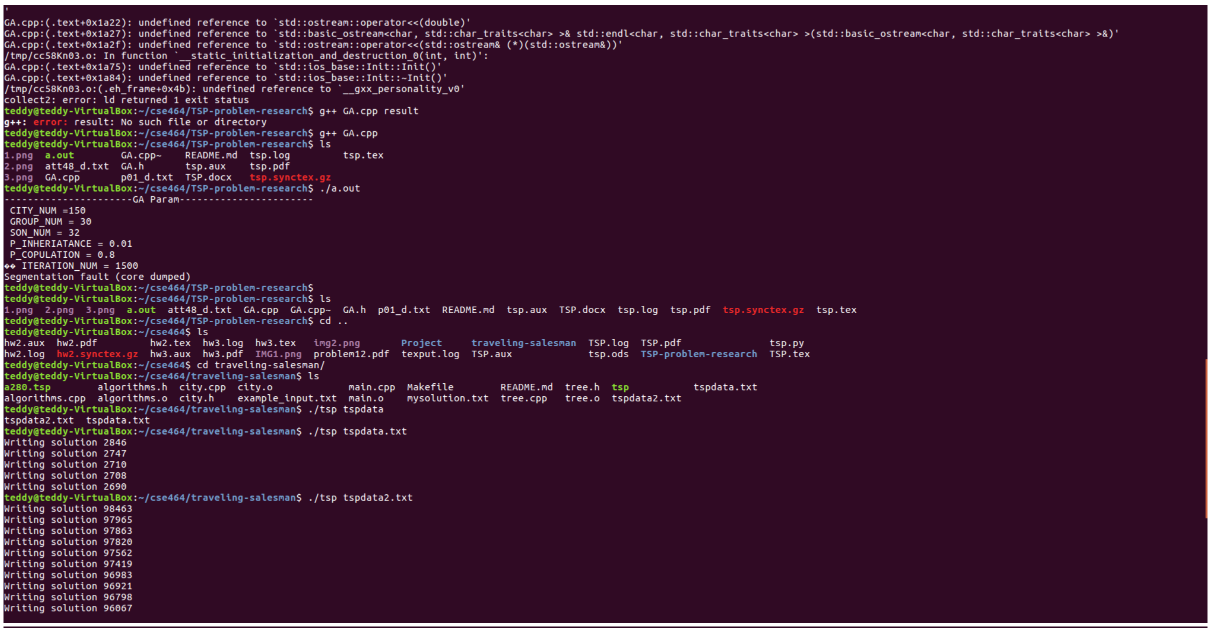
Houchaoqun. (2017) TSP genetic algorithm, ”$http : //blog.csdn.net/houchaoqun_{x}mu/article/details/54584264$”

Appendix

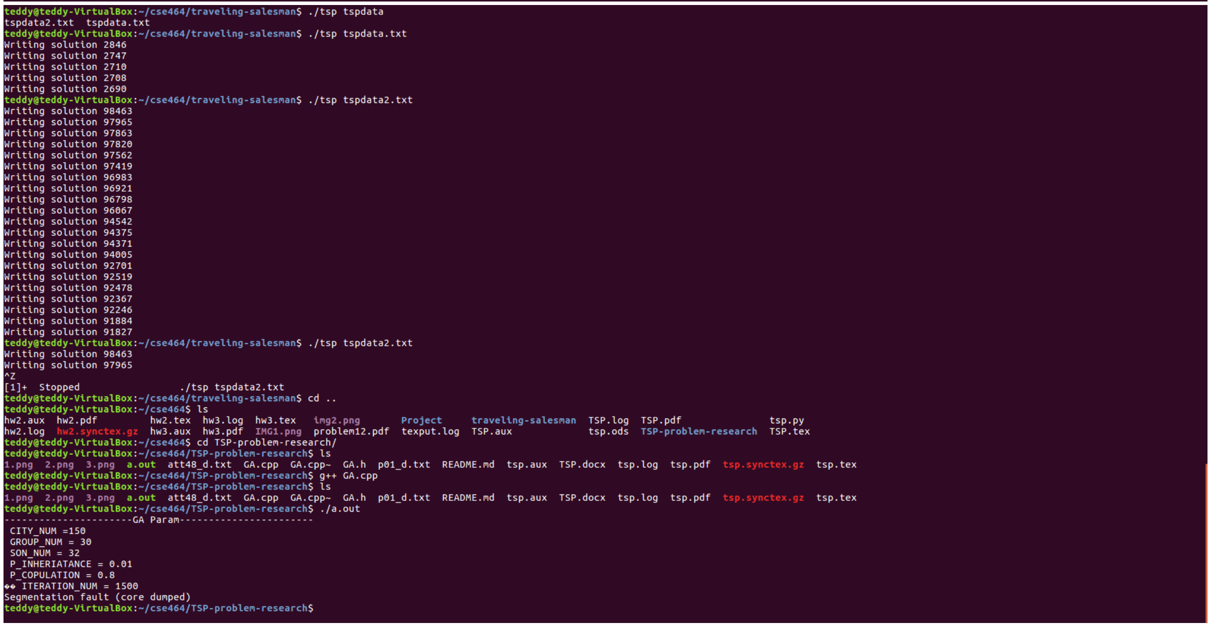
peer review

I did all the research and paper work by myself.

screenshot



```
'
GA.cpp:(.text+0x1a22): undefined reference to `std::ostream::operator<<(double)'
GA.cpp:(.text+0x1a27): undefined reference to `std::basic_ostream<char, std::char_traits<char> >& std::endl<char, std::char_traits<char> >(std::basic_ostream<char, std::char_traits<char> >&)'
GA.cpp:(.text+0x1a2f): undefined reference to `std::ostream::operator<<(std::ostream& (*)(std::ostream&))'
/tmp/cc58Kn03.o: In function `__static_initialization_and_destruction_0(int, int)':
GA.cpp:(.text+0x1a75): undefined reference to `std::ios_base::Init::Init()'
GA.cpp:(.text+0x1a84): undefined reference to `std::ios_base::Init::~Init()'
/tmp/cc58Kn03.o:(.eh_frame+0x4b): undefined reference to `__gxx_personality_v0'
collect2: error: ld returned 1 exit status
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$ g++ GA.cpp result
g++: error: result: No such file or directory
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$ g++ GA.cpp
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$ ls
1.png  a.out        GA.cpp~    README.md  tsp.log         tsp.tex
2.png  att48_d.txt  GA.h       tsp.aux    tsp.pdf
3.png  GA.cpp       p01_d.txt  TSP.docx   tsp.synctex.gz
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$ ./a.out
----------------------GA Param----------------------
 CITY_NUM =150
 GROUP_NUM = 30
 SON_NUM = 32
 P_INHERIATANCE = 0.01
 P_COPULATION = 0.8
�� ITERATION_NUM = 1500
Segmentation fault (core dumped)
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$ ls
1.png  2.png  3.png  a.out  att48_d.txt  GA.cpp  GA.cpp~  GA.h  p01_d.txt  README.md  tsp.aux  TSP.docx  tsp.log  tsp.pdf  tsp.synctex.gz  tsp.tex
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$ cd ..
teddy@teddy-VirtualBox:~/cse464$ ls
hw2.aux  hw2.pdf         hw2.tex  hw3.log  hw3.tex   img2.png       Project     traveling-salesman  TSP.log  TSP.pdf              tsp.py
hw2.log  hw2.synctex.gz  hw3.aux  hw3.pdf  IMG1.png  problem12.pdf  texput.log  TSP.aux             tsp.ods  TSP-problem-research  TSP.tex
teddy@teddy-VirtualBox:~/cse464$ cd traveling-salesman/
teddy@teddy-VirtualBox:~/cse464/traveling-salesman$ ls
a280.tsp        algorithms.h  city.cpp  city.o             main.cpp  Makefile        README.md  tree.h  tsp           tspdata.txt
algorithms.cpp  algorithms.o  city.h    example_input.txt  main.o    mysolution.txt  tree.cpp   tree.o  tspdata2.txt
teddy@teddy-VirtualBox:~/cse464/traveling-salesman$ ./tsp tspdata
tspdata2.txt  tspdata.txt
teddy@teddy-VirtualBox:~/cse464/traveling-salesman$ ./tsp tspdata.txt
Writing solution 2846
Writing solution 2747
Writing solution 2710
Writing solution 2708
Writing solution 2690
teddy@teddy-VirtualBox:~/cse464/traveling-salesman$ ./tsp tspdata2.txt
Writing solution 98463
Writing solution 97965
Writing solution 97863
Writing solution 97820
Writing solution 97562
Writing solution 97419
Writing solution 96983
Writing solution 96921
Writing solution 96798
Writing solution 96067
```



```
teddy@teddy-VirtualBox:~/cse464/traveling-salesman$ ./tsp tspdata
tspdata2.txt  tspdata.txt
teddy@teddy-VirtualBox:~/cse464/traveling-salesman$ ./tsp tspdata.txt
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Writing solution 2690
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Writing solution 98463
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Writing solution 96921
Writing solution 96798
Writing solution 96067
Writing solution 94542
Writing solution 94375
Writing solution 94371
Writing solution 94005
Writing solution 92701
Writing solution 92519
Writing solution 92478
Writing solution 92367
Writing solution 92246
Writing solution 91884
Writing solution 91827
teddy@teddy-VirtualBox:~/cse464/traveling-salesman$ ./tsp tspdata2.txt
Writing solution 98463
Writing solution 97965
^Z
[1]+  Stopped                 ./tsp tspdata2.txt
teddy@teddy-VirtualBox:~/cse464/traveling-salesman$ cd ..
teddy@teddy-VirtualBox:~/cse464$ ls
hw2.aux  hw2.pdf         hw2.tex  hw3.log  hw3.tex   img2.png       Project     traveling-salesman  TSP.log  TSP.pdf              tsp.py
hw2.log  hw2.synctex.gz  hw3.aux  hw3.pdf  IMG1.png  problem12.pdf  texput.log  TSP.aux             tsp.ods  TSP-problem-research  TSP.tex
teddy@teddy-VirtualBox:~/cse464$ cd TSP-problem-research/
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$ ls
1.png  2.png  3.png  a.out  att48_d.txt  GA.cpp  GA.cpp~  GA.h  p01_d.txt  README.md  tsp.aux  TSP.docx  tsp.log  tsp.pdf  tsp.synctex.gz  tsp.tex
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$ g++ GA.cpp
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$ ls
1.png  2.png  3.png  a.out  att48_d.txt  GA.cpp  GA.cpp~  GA.h  p01_d.txt  README.md  tsp.aux  TSP.docx  tsp.log  tsp.pdf  tsp.synctex.gz  tsp.tex
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$ ./a.out
----------------------GA Param----------------------
 CITY_NUM =150
 GROUP_NUM = 30
 SON_NUM = 32
 P_INHERIATANCE = 0.01
 P_COPULATION = 0.8
�� ITERATION_NUM = 1500
Segmentation fault (core dumped)
teddy@teddy-VirtualBox:~/cse464/TSP-problem-research$
```

code

```cpp
#include <iostream>

#include <fstream>
```

```
#include <iomanip>

#include <stdlib.h>

#include <ctime>

#include <algorithm>

#include "GA.h"

using namespace std;

int IndexCross_i;

int IndexCross_j;

int main(){


time_t T_begin = clock();

Graph G;

CreateGraph(G);

srand ( unsigned ( time(0) ) );

InitialGroup(G);

TSP_Evolution(G);

time_t T_end = clock();

double RunningTime = double(T_end - T_begin) / CLOCKS_PER_SEC;

cout<<endl<<" RunningTime = " << RunningTime << " "<<endl;

system("pause");


return 0;


}




void CreateGraph(Graph &G){


ifstream read_in;


read_in.open("/home/teddy/cse464/TSP-problem-research/att48_d.txt");
```

```
if (!read_in.is_open())

{

cout<<"read fail."<<endl;

return;

}



read_in >> G.vex_num;

// read_in >> G.arc_num;

G.arc_num = 0;

for (int i = 0;i < G.vex_num; i++)

{

read_in >> G.vexs[i];
}
G.vexs[G.vex_num] = '\0';
for (int i = 0; i < G.vex_num;i++)
{
for (int j = 0; j < G.vex_num; j++)
{
read_in >> G.arcs[i][j];
```

```
if (G.arcs[i][j] > 0)
{
G.arc_num++;
}
}
}
for (int i = 0; i < G.vex_num; i++)
{
cout << G.vexs[i] << " ";
}
}
void InitialGroup(Graph G){
cout<<"----------------------GA Param-----------------------"<<endl;
cout<<" CITY_NUM ="<< CITY_NUM <<endl;
cout<<" GROUP_NUM = "<< GROUP_NUM <<endl;
cout<<" SON_NUM = "<< SON_NUM <<endl;
cout<<" P_INHERIATANCE = "<< P_INHERIATANCE <<endl;
cout<<" P_COPULATION = "<< P_COPULATION <<endl;
cout<<" ITERATION_NUM = "<< ITERATION_NUM <<endl;
double total_length = 0.0;
for(int i = 0;i < GROUP_NUM; i++){

for (int j = 0;j < G.vex_num; j++)
{
TSP_Groups[i].path[j] = G.vexs[j];
}
random_shuffle(TSP_Groups[i].path + 1, TSP_Groups[i].path + G.vex_num);
if (Check_path(G, TSP_Groups[i]))
{
TSP_Groups[i].length_path = CalculateLength(G, TSP_Groups[i]);
total_length += TSP_Groups[i].length_path;
```

```
}else{
cout<<"error"<<endl;
TSP_Groups[i].length_path = MAX_INT;
TSP_Groups[i].P_Reproduction = 0;
}
}
Calc_Probablity(G, total_length);
TSP_Evaluate(G);
}




void Calc_Probablity(Graph G, double total_length){

double TempTotal_P = 0.0;


for (int i = 0; i < GROUP_NUM ;i++)

{

TSP_Groups[i].P_Reproduction = (1.0 / TSP_Groups[i].length_path ) *
    total_length;

TempTotal_P += TSP_Groups[i].P_Reproduction;

}


for (int i = 0;i < GROUP_NUM; i++)
```

```
{

TSP_Groups[i].P_Reproduction = TSP_Groups[i].P_Reproduction / TempTotal_P;

}

}



void TSP_Evolution(Graph G){

/* */

int iter = 0;

while(iter < ITERATION_NUM){



int Father_index = Evo_Select(G);

int Mother_index = Evo_Select(G);



while (Mother_index == Father_index)

{



Mother_index = Evo_Select(G);

}
```

```
TSP_solution Father = TSP_Groups[Father_index];

TSP_solution Mother = TSP_Groups[Mother_index];


int M = GROUP_NUM - GROUP_NUM/2;

Length_SonSoliton = 0;

while(M){
double Is_COPULATION = ((rand()%100 + 0.0) / 100);
if (Is_COPULATION > P_COPULATION)
{
// cout<<"Is_COPULATION = "<<Is_COPULATION<<endl;
}else{
Evo_Cross(G, Father, Mother);
M--;
}
}
double total_length = 0.0;
for (int IndexVariation = 0;IndexVariation < Length_SonSoliton;
    IndexVariation++)
{
double RateVariation = (rand()%100) / 100;
if (RateVariation < P_INHERIATANCE)

{
```

```
Evo_Variation(G, IndexVariation);


}


if (!Check_path(G, Son_solution[IndexVariation]))


{
cout<<"error"<<endl;
}
Son_solution[IndexVariation].length_path = CalculateLength(G,
    Son_solution[IndexVariation]);
total_length += Son_solution[IndexVariation].length_path;
}
Calc_Probablity(G, total_length);


Evo_UpdateGroup(G);
iter++;
}
}
int Evo_Select(Graph G){
double selection_P = ((rand()%100 + 0.0) / 100);
// cout<<"selection_P = "<<selection_P<<endl;
double distribution_P = 0.0;
for (int i = 0; i < GROUP_NUM; i++)
{
distribution_P += TSP_Groups[i].P_Reproduction;
if (selection_P < distribution_P)
{
return i;
}
}
```

```
cout<<"Error(Evo_select)"<<endl;
return 0;
}
void Evo_Cross(Graph G, TSP_solution TSP_Father, TSP_solution TSP_Mother){
IndexCross_i = rand() % (CITY_NUM - 1) + 1; //
IndexCross_j = rand() % (CITY_NUM - 1) + 1; //
if (IndexCross_i > IndexCross_j)
{
int temp = IndexCross_i;
IndexCross_i = IndexCross_j;
IndexCross_j = temp;
}
if (IndexCross_j == CITY_NUM || IndexCross_i == 0)
{
cout<<"[error... ]"<<endl;
}
int Father_Cross[CITY_NUM];
int Mother_Cross[CITY_NUM];
int Length_Cross = 0;
for (int i = IndexCross_i;i <= IndexCross_j; i++)
{
Father_Cross[Length_Cross] = TSP_Father.path[i];
Mother_Cross[Length_Cross] = TSP_Mother.path[i];
Length_Cross++;
}
int *Conflict_Father;
int *Conflict_Mother;
int Length_Conflict = 0;
Conflict_Father = Get_Conflict(Father_Cross, Mother_Cross, Length_Cross,
    Length_Conflict);
```

```
Conflict_Mother = Get_Conflict(Mother_Cross, Father_Cross, Length_Cross,
    Length_Conflict);
int city_temp;
for (int i = IndexCross_i; i <= IndexCross_j; i++)
{
city_temp = TSP_Father.path[i];
TSP_Father.path[i] = TSP_Mother.path[i];
TSP_Mother.path[i] = city_temp;
}
TSP_solution Descendant_ONE = Handle_Conflict(G, TSP_Father, Conflict_Father,
    Conflict_Mother, Length_Conflict);
TSP_solution Descendant_TWO = Handle_Conflict(G, TSP_Mother, Conflict_Mother,
    Conflict_Father, Length_Conflict);
Son_solution[Length_SonSoliton++] = Descendant_ONE;
Son_solution[Length_SonSoliton++] = Descendant_TWO;
}
TSP_solution Handle_Conflict(Graph G, TSP_solution ConflictSolution, int
    *Detection_Conflict, int *Model_Conflict, int Length_Conflict){
for (int i = 0; i <= Length_Conflict; i++)
{
bool flag_FindCity = false;
int index = 0;
// [0, IndexCross_i)
for (index = 0; index < IndexCross_i; index++)
{
if (Model_Conflict[i] == ConflictSolution.path[index])
{
flag_FindCity = true;
break;
}
}
if (!flag_FindCity)
{
// [IndexCross_i + 1, G.vex_num)
for (index = IndexCross_j + 1; index < G.vex_num; index++)
{
if (Model_Conflict[i] == ConflictSolution.path[index])
{
break;
}
}
}
// 9 8 [1 4 0 3 2] 3 2 0 --> ConflictSolution
// 8 7 [4 5 6 7 1] 9 6 5
// [0 3 2] --> Detection_Conflict
// [4 5 6] --> Model_Conflict
// cout<<"index = "<<index<<endl;
ConflictSolution.path[index] = Detection_Conflict[i];
}

if (!Check_path(G, ConflictSolution))
{
cout<<"error"<<endl;
}
// cout<<" length_path = "<<ConflictSolution.length_path<<" P_Reproduction =
    "<<ConflictSolution.P_Reproduction<<endl;
return ConflictSolution;
}
int *Get_Conflict(int Detection_Cross[], int Model_Cross[], int Length_Cross,
    int &Length_Conflict){
int *Conflict = new int[CITY_NUM];
Length_Conflict = 0;
```

```
for (int i = 0; i < Length_Cross; i++)
{
bool flag_Conflict = true;
for (int j = 0; j < Length_Cross; j++)
{
if (Detection_Cross[i] == Model_Cross[j])
{
j = Length_Cross;
flag_Conflict = false;
}
}
if (flag_Conflict)
{
Conflict[Length_Conflict] = Detection_Cross[i];
Length_Conflict++;
}
}
return Conflict;
}
void Evo_Variation(Graph G, int Index_Variation){
int City_i = (rand() % (CITY_NUM - 1)) + 1;
int City_j = (rand() % (CITY_NUM - 1)) + 1; //
while(City_i == City_j){
City_j = (rand() % (CITY_NUM - 1)) + 1;
}
int temp_City = Son_solution[Index_Variation].path[City_i];
Son_solution[Index_Variation].path[City_i] =
    Son_solution[Index_Variation].path[City_j];
Son_solution[Index_Variation].path[City_j] = temp_City;
}
void Evo_UpdateGroup(Graph G){
```

```
TSP_solution tempSolution;
for (int i = 0; i < Length_SonSoliton; i++)
{
for (int j = Length_SonSoliton - 1; j > i; j--)
{
if ( Son_solution[i].length_path > Son_solution[j].length_path )
{
tempSolution = Son_solution[i];
Son_solution[i] = Son_solution[j];
Son_solution[j] = tempSolution;
}
}
}
for (int i = 0; i < Length_SonSoliton; i++)
{
for (int j = 0; j < GROUP_NUM; j++)
{
if ( Son_solution[i].length_path < TSP_Groups[j].length_path )
{
TSP_Groups[j] = Son_solution[i];
break;
}
}
}
TSP_Evaluate(G);
}
double CalculateLength(Graph G, TSP_solution newSolution){
double _length = 0;
for (int i = 0; i < G.vex_num - 1; i++)
{
int _startCity = newSolution.path[i] - 1;
int _endCity = newSolution.path[i+1] - 1;
if (G.arcs[_startCity][_endCity] == -1)
{
return MAX_INT;
}
else{
_length += G.arcs[_startCity][_endCity];
}
}
if (G.arcs[newSolution.path[G.vex_num - 1]][newSolution.path[0] - 1] == -1)
{
return MAX_INT;
}
else{
_length += G.arcs[newSolution.path[G.vex_num - 1] - 1][newSolution.path[0] -
    1];
// cout<<"_length = "<<_length<<endl;
return _length;
}
}
bool Check_path(Graph G, TSP_solution CurrentSolution){
for (int i = 0; i < G.vex_num;i++)
{
for (int j = i + 1; j < G.vex_num; j++)
{
if (CurrentSolution.path[i] == CurrentSolution.path[j])
{
return false;
}
}
}
```

```
return true;
}
void TSP_Evaluate(Graph G){
TSP_solution bsetSolution;
bsetSolution = TSP_Groups[0];
for (int i = 1; i < GROUP_NUM; i++)
{
if (bsetSolution.length_path > TSP_Groups[i].length_path)
{
bsetSolution = TSP_Groups[i];
}
}
cout<<" bsetSolution = ";
for (int i = 0;i < G.vex_num;i++)
{
cout<<bsetSolution.path[i]<<" -> ";
}
cout<<bsetSolution.path[0]<<" length = "<<bsetSolution.length_path<<endl;
}
```