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FACULTY OF ENGINEERING AND NATURAL SCIENCES
COMPUTER ENGINEERING DEPARTMENT**

**CMP3004
Formal Languages and Automata Theory
Spring 2021 Term Project Report**

Traveling Salesman Problem (TSP)

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1. INTRODUCTION

Travelling Salesman Problem (TSP) is an NP-complete problem which is one of the most intensively studied problems in the fields of computational mathematics. TSP is an algorithmic problem task to find the shortest possible route that visits every city exactly once and returns to the starting point.

2. PROJECT DEFINITION

In this project, we implemented three different heuristics to solve the TSP problem for the 4,663 cities in the Canada:

1. Nearest Neighbor Algorithm
2. Greedy Algorithm
3. Divide and Conquer Strategy

3. OBJECTIVES

Primary objectives of the project ordered by their importance:

1. Correctness of the implemented heuristic algorithm.
2. Best result for the shortest tour.
3. Running speed (efficiency) of the algorithm.
4. Readability of the code.

4. DESIRED OUTPUTS

The developed program will print following information on the console upon the execution:

- Name of the used heuristic.
- Tour path.
- Total tour length.
- Execution time.

5. HOW TO USE THE PROGRAM

We generated a **.jar** file for each heuristic algorithm (*nearest.jar*, *greedy.jar*, *divide.jar*), since executing the Main class from the terminal was a bit problematic. **Jar** files stored in **“out/artifacts/Workspace”** directory of the project.

Executing a jar file can be done by giving following command to terminal,

```
cd [PROJECT_FOLDER] &&
Java -jar out/artifacts/Workspace/greedy.jar
```

Path of the coordinates file (.tsp) hardcoded into the program,
“src/com/company/ca4663_only_coordinates.tsp”.

6. TOP-LEVEL DESIGN OF THE PROGRAM

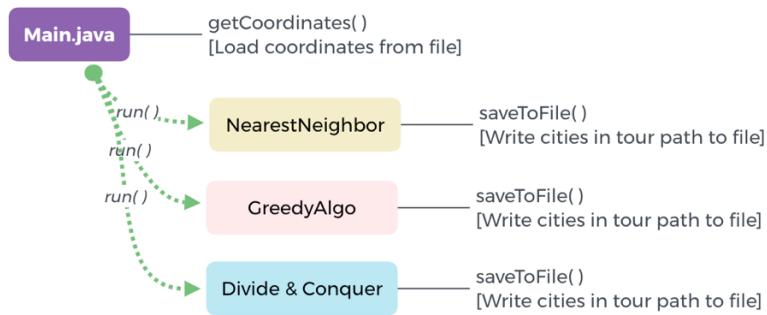


Figure 1. Top-level code design.

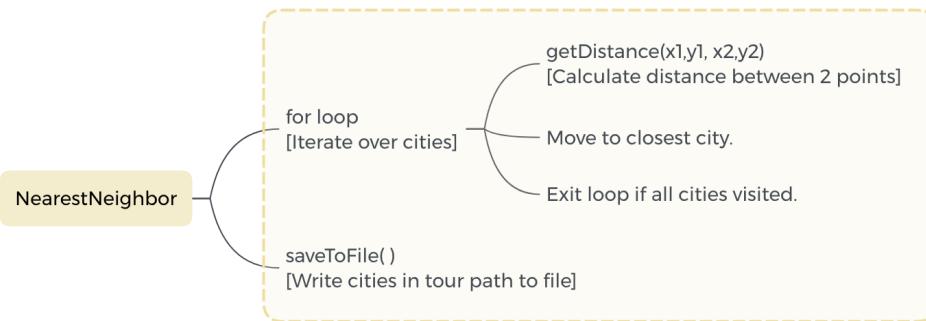


Figure 2. Design of the **Nearest Neighbor** algorithm.

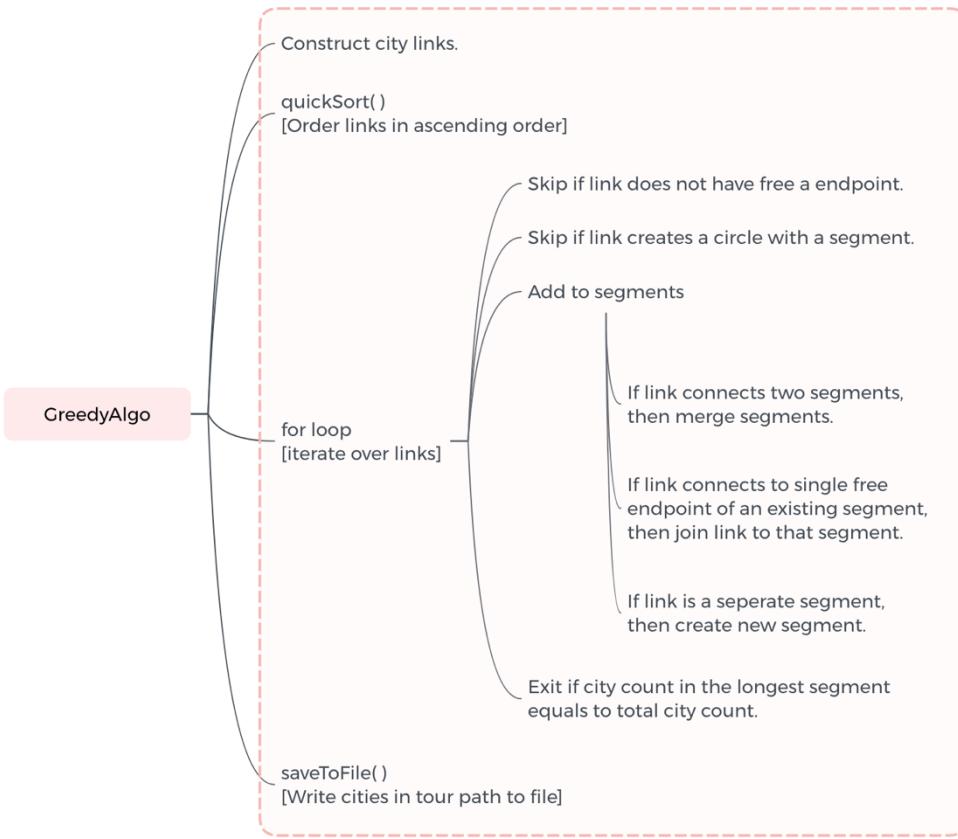


Figure 3. Design of the **Greedy** algorithm.

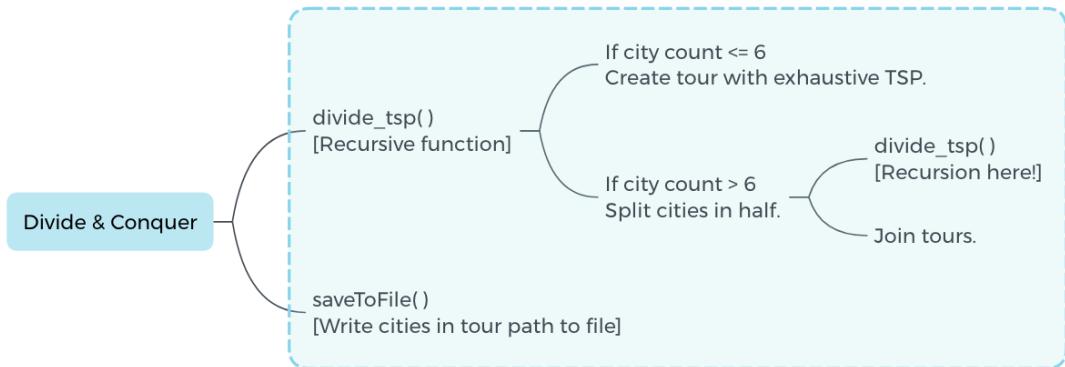


Figure 1. Design of the *Divide & Conquer* algorithm.

7. ALGORITHM PERFORMANCES COMPARED

Table 1. Performance results of heuristics sorted by shortest distance in ascending

HEURISTIC	SHORTEST TOUR	DIFFERENCE	TIME (ms)	STUDENT
Greedy Algorithm	1,542,862	+252,543	54,614	E. Burak Tokman
Repetitive Nearest N.	1,616,632	+326,313	504,803	Velid Nazari
Nearest Neighbor	1,680,435	+390,116	546	E. Burak Tokman
Divide & Conquer	1,710,413	+420,094	1,414,623	Batuhan Aydin

*Difference column shows the difference between the length of the **algorithm's** obtained shortest tour and length of the shortest **known** tour which is 1,290,319.

8. VISUALIZING THE HEURISTICS



Figure 2. Tour visualization of *Nearest Neighbor* Algorithm.

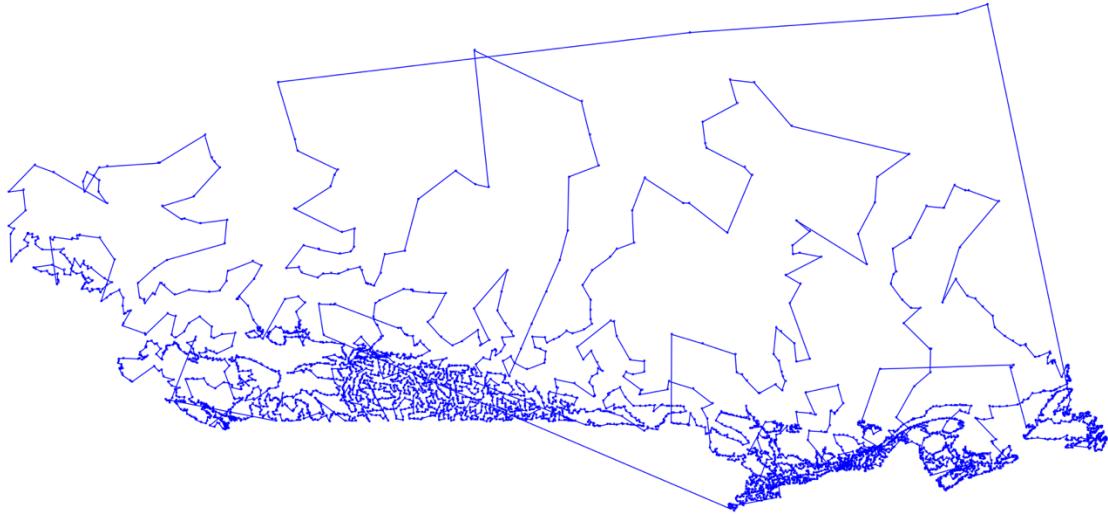


Figure 3. Tour visualization of the **Greedy** Algorithm.

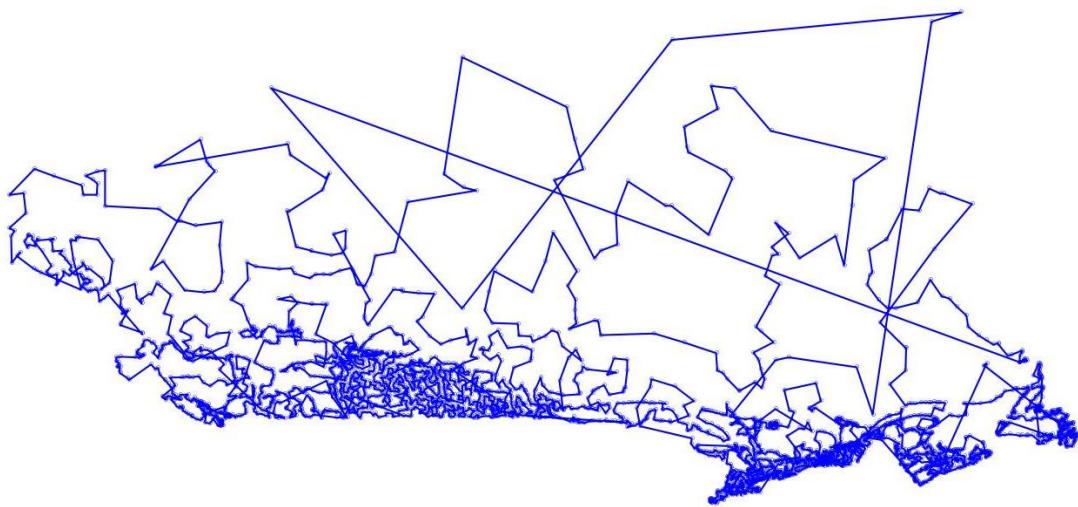


Figure 4. Tour visualization of the **Repetitive Nearest N**.



Figure 5. Tour visualization of the **Divide & Conquer Strategy**.

Visualization of the heuristics coded in Python. Each heuristic algorithm saves the coordinates of the cities in the tour path to a file in the “**src/com/company/**” directory with the respective algorithm name (*output_greedy.tsp*, *output_nearest.tsp*, *output_divide.tsp*).

For instance, the relative path of the output file of the **greedy** algorithm is “**src/com/company/output_greedy.tsp**”.

Greedy and Nearest Neighbor algorithms have different output file formats, values are separated with a tab. In the **Nearest Neighbor** algorithm and Divide & Conquer strategy’s output file. 1st column represents the ID of the city, 2nd and 3rd columns are X and Y coordinates.

Table 1. Example content of the Nearest Neighbor algorithm output.

ID	X	Y
1	41800.0	82650.0
2	41966.6667	82533.3333
6	42050.0	82583.3333
...		

In the **Greedy** algorithm output file, 1st column is the ID of the **first** city. 2nd and 3rd columns are the coordinates of the **first** city. 4th column is the ID of the **second** city, 5th and 6th columns are the coordinates of the **second** city.

Table 2. Example content of the Greedy algorithm output.

ID1	X1	Y1	ID2	X2	Y2
156	43716.6667	79250.0	160	43733.3333	79250.0
579	45266.6667	74233.3333	585	45283.3333	74233.3333
607	45333.3333	64766.6667	608	45333.3333	64783.3333
...					

9. SCREENSHOTS OF THE PROGRAM

```

Workspace -- bash
MacBook:Workspace hummingbird$ java -jar out/artifacts/Workspace_jar/nearest_neighbor_burak.jar
INPUT: src/com/company/ca4663_only_coordinates.tsp
LOADING COORDINATES...
CITY COUNT: 4663
NOTE: Coordinates will be printed without decimals to save space.

-----
STARTING: NearestNeighbor
Start city:1 x:41800 y:82650

----- TRAVEL BEGIN -----
MOVED to city:2 (41966, 82533) tourTotal=203
MOVED to city:6 (42050, 82583) tourTotal=300
MOVED to city:7 (42100, 82450) tourTotal=443
MOVED to city:14 (42250, 82433) tourTotal=593
MOVED to city:12 (42233, 82550) tourTotal=711
MOVED to city:16 (42300, 82716) tourTotal=891
MOVED to city:18 (42316, 82850) tourTotal=1025
MOVED to city:19 (42316, 82900) tourTotal=1075
MOVED to city:23 (42333, 82950) tourTotal=1128
MOVED to city:20 (42316, 82983) tourTotal=1165
MOVED to city:21 (42316, 83000) tourTotal=1182
MOVED to city:24 (42333, 83033) tourTotal=1219
MOVED to city:17 (42300, 83066) tourTotal=1266
MOVED to city:15 (42283, 83066) tourTotal=1283
MOVED to city:10 (42150, 82966) tourTotal=1450
MOVED to city:5 (42033, 82916) tourTotal=1576
MOVED to city:3 (41983, 82933) tourTotal=1629
MOVED to city:4 (42033, 82750) tourTotal=1819
MOVED to city:9 (42133, 82750) tourTotal=1919
MOVED to city:11 (42166, 82816) tourTotal=1994
MOVED to city:8 (42100, 83100) tourTotal=2285
MOVED to city:37 (42716, 82483) tourTotal=3157
MOVED to city:44 (42816, 82466) tourTotal=3258
MOVED to city:47 (42850, 82466) tourTotal=3292
MOVED to city:60 (42966, 82400) tourTotal=3426
MOVED to city:64 (43000, 82400) tourTotal=3459
MOVED to city:51 (42883, 82150) tourTotal=3735
MOVED to city:58 (42950, 82116) tourTotal=3810
WARNING: All cities visited. Returning to start.

----- TRAVEL END -----
TOUR COMPLETED!
CITIES: 4,663
LENGTH: 1,680,435
PATH:
TOUR: Path saved to output file.
COMPLETED: NearestNeighbor
DURATION: 573ms

Total execution time: 878ms
MacBook:Workspace hummingbird$ 

```

Figure 7. Console output screenshot of the **Nearest Neighbor** algorithm.

```

Workspace -- bash
greedy_burak.jar
INPUT: src/com/company/ca4663_only_coordinates.tsp
LOADING COORDINATES...
CITY COUNT: 4663
NOTE: Coordinates will be printed without decimals to save space.

-----
STARTING: Greedy
Constructing city links...
Ordering links with Quicksort by distance in ASCENDING...
LINK COUNT: 10869453

----- TRAVEL BEGIN -----
LINK ADDED: 156 <-> 160 dist: 16
LINK ADDED: 579 <-> 585 dist: 16
LINK ADDED: 607 <-> 608 dist: 16
LINK ADDED: 631 <-> 644 dist: 16
LINK ADDED: 633 <-> 646 dist: 16
LINK ADDED: 657 <-> 658 dist: 16
LINK ADDED: 671 <-> 680 dist: 16
LINK ADDED: 672 <-> 673 dist: 16
LINK ADDED: 692 <-> 693 dist: 16
LINK ADDED: 809 <-> 829 dist: 16
LINK ADDED: 822 <-> 838 dist: 16
LINK ADDED: 1052 <-> 1053 dist: 16
LINK ADDED: 1057 <-> 1058 dist: 16
LINK ADDED: 1100 <-> 1101 dist: 16
LINK ADDED: 1102 <-> 1118 dist: 16
LINK ADDED: 1241 <-> 1249 dist: 16
LINK ADDED: 1324 <-> 1334 dist: 16
LINK ADDED: 1790 <-> 1791 dist: 16
LINK ADDED: 1807 <-> 1808 dist: 16
LINK ADDED: 1844 <-> 1863 dist: 16
LINK ADDED: 1925 <-> 1937 dist: 16
LINK ADDED: 2331 <-> 2332 dist: 16
LINK ADDED: 3157 <-> 3161 dist: 16
LINK ADDED: 3575 <-> 3576 dist: 16
LINK ADDED: 694 <-> 695 dist: 16
LINK ADDED: 699 <-> 700 dist: 16
LINK ADDED: 724 <-> 734 dist: 16

LINK ADDED: 3967 <-> 4404 dist: 4718
LINK ADDED: 4650 <-> 4658 dist: 4819
LINK ADDED: 4555 <-> 4611 dist: 4848
LINK ADDED: 4532 <-> 4561 dist: 4848
LINK ADDED: 4607 <-> 4633 dist: 4973
LINK ADDED: 1892 <-> 3794 dist: 5005
LINK ADDED: 4588 <-> 4630 dist: 5033
LINK ADDED: 3090 <-> 4267 dist: 5271
LINK ADDED: 4347 <-> 4399 dist: 5463
LINK ADDED: 4526 <-> 4596 dist: 6692
LINK ADDED: 2074 <-> 4294 dist: 7083
LINK ADDED: 2123 <-> 3060 dist: 9050
LINK ADDED: 4656 <-> 4660 dist: 9557
LINK ADDED: 2006 <-> 3492 dist: 9591
LINK ADDED: 4646 <-> 4653 dist: 9697
LINK ADDED: 3764 <-> 3850 dist: 10771
LINK ADDED: 4620 <-> 4660 dist: 11061
LINK ADDED: 4661 <-> 4662 dist: 21519
LINK ADDED: 3040 <-> 4663 dist: 32455
LINK ADDED: 4658 <-> 4661 dist: 33388
CAUTION: Link creating cycle but every city visited!
LINK ADDED: 3 <-> 4288 dist: 35560
----- PATH -----
STOP: All cities travelled
----- TRAVEL END -----
TOUR COMPLETED!
LENGTH: 1,542,862
PATH:
TOUR: Path saved to output file.
COMPLETED: Greedy
DURATION: 59,496ms

Total execution time: 59,862ms
MacBook:Workspace hummingbird$ 

```

Figure 6. Console output screenshot of the **Greedy** algorithm.

```
=====
STARTING:      RepetitiveNearestNeighbor

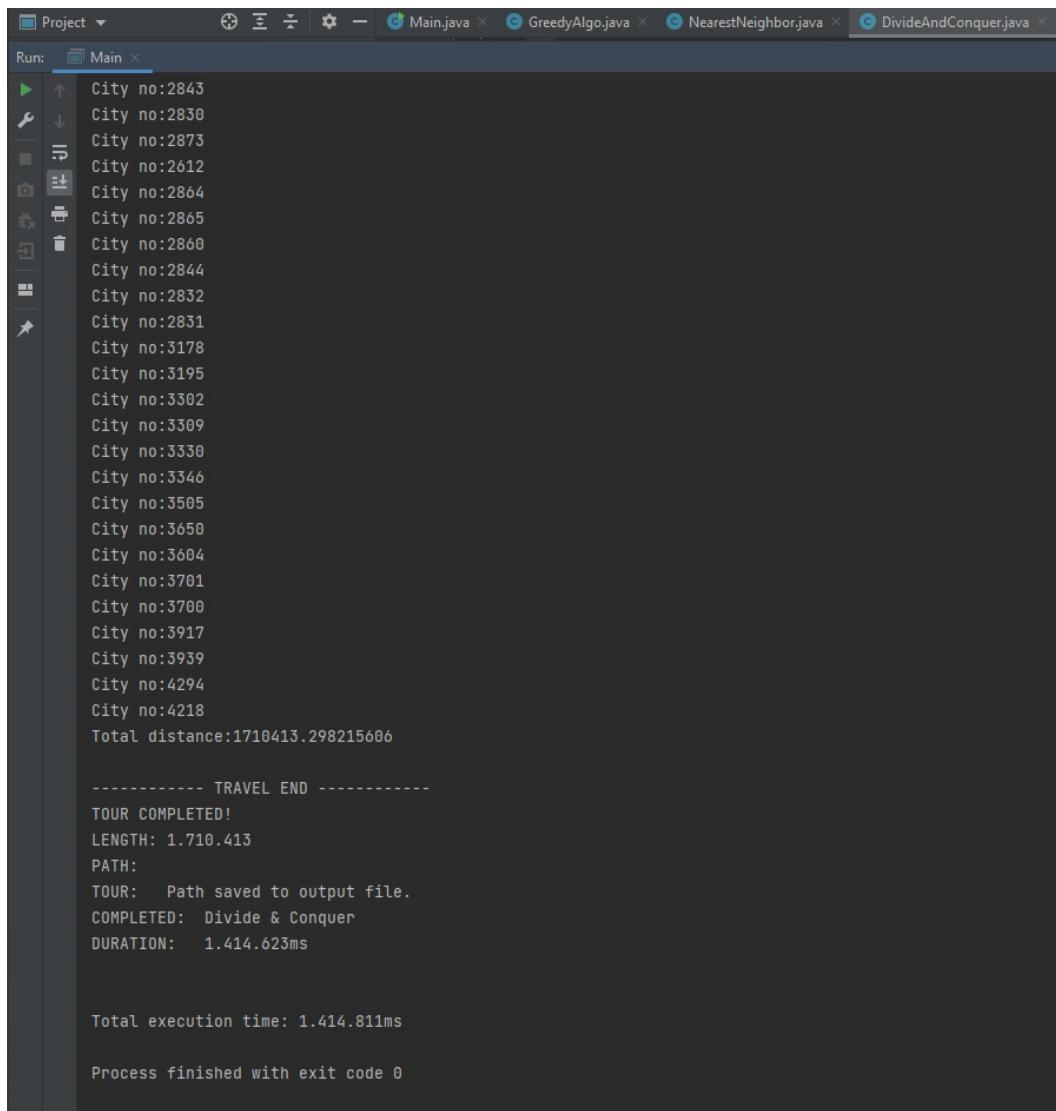
----- TRAVEL BEGIN -----

----- TRAVEL END -----

TOUR COMPLETED!
CITIES: 4,663
LENGTH: 1,616,632
PATH:
TOUR:  Path saved to output file.
COMPLETED:  RepetitiveNearestNeighbor
DURATION:  531,007ms

=====
```

Figure 6. Console output screenshot of the *Repetitive Nearest Neighbor* algorithm.



The screenshot shows a Java development environment with multiple tabs open at the top: Main.java, GreedyAlgo.java, NearestNeighbor.java, and DivideAndConquer.java. The main window displays the console output of the Divide & Conquer algorithm. The output lists city IDs from 2843 to 4218, followed by a total distance of 1710413.298215606. It then indicates the tour is completed with a length of 1.710.413 and a path saved to an output file. The execution time is listed as 1.414.811ms, and the process finished with exit code 0.

```
Project ▾ + - × | Main.java × | GreedyAlgo.java × | NearestNeighbor.java × | DivideAndConquer.java ×
Run: Main ×
City no:2843
City no:2830
City no:2873
City no:2612
City no:2864
City no:2865
City no:2860
City no:2844
City no:2832
City no:2831
City no:3178
City no:3195
City no:3302
City no:3309
City no:3330
City no:3346
City no:3505
City no:3650
City no:3604
City no:3701
City no:3700
City no:3917
City no:3939
City no:4294
City no:4218
Total distance:1710413.298215606

----- TRAVEL END -----
TOUR COMPLETED!
LENGTH: 1.710.413
PATH:
TOUR:  Path saved to output file.
COMPLETED:  Divide & Conquer
DURATION:  1.414.623ms

Total execution time: 1.414.811ms

Process finished with exit code 0
```

Figure 7. Console output screenshot of the *Divide & Conquer* algorithm.

10. CONCLUSION

In our implementations of the three heuristics to solve the TSP problem for cities in Canada, the best result (shortest tour length) we obtained is **1,542,862** with an execution time of **54,614ms** with the **Greedy Algorithm**.

**Complete list of the cities in the tour is shared in the appendix of the report to save on space.*

11. REFERENCES

- [1] P. Norvig, “*The Traveling Salesperson Problem*”,
<https://github.com/norvig/pytudes/blob/main/ipynb/TSP.ipynb>, April 2018.

APPENDIX

1. TOUR OF NEAREST NEIGHBOR

1, 2, 6, 7, 14, 12, 16, 18, 19, 23, 20, 21, 24, 17, 15, 10, 5, 3, 4, 9, 11, 8, 37, 44, 47, 60, 64, 51, 58, 73, 84, 83, 102, 99, 107, 98, 85, 75, 67, 56, 38, 31, 28, 26, 27, 29, 25, 22, 13, 30, 57, 43, 36, 34, 41, 35, 40, 33, 49, 62, 46, 45, 54, 39, 42, 55, 68, 95, 103, 100, 93, 90, 87, 79, 82, 71, 53, 48, 59, 65, 61, 50, 74, 81, 86, 89, 76, 70, 69, 80, 92, 52, 156, 160, 169, 170, 165, 161, 150, 151, 145, 142, 136, 133, 127, 123, 126, 134, 146, 154, 153, 158, 152, 157, 166, 171, 175, 186, 199, 212, 225, 237, 270, 275, 269, 287, 291, 325, 355, 389, 365, 366, 339, 345, 329, 315, 303, 292, 278, 276, 244, 217, 190, 187, 173, 188, 196, 168, 143, 144, 124, 113, 172, 185, 207, 236, 264, 302, 317, 364, 388, 403, 394, 350, 328, 349, 354, 324, 314, 268, 239, 206, 203, 227, 243, 251, 234, 240, 215, 224, 235, 216, 183, 193, 182, 184, 192, 195, 286, 301, 285, 313, 284, 267, 283, 323, 348, 338, 344, 322, 282, 281, 255, 233, 219, 214, 231, 246, 259, 321, 343, 387, 429, 458, 486, 514, 563, 596, 661, 740, 741, 826, 778, 840, 806, 705, 752, 767, 827, 731, 858, 904, 934, 993, 1035, 1112, 1156, 1164, 1264, 1364, 1399, 1437, 1479, 1491, 1502, 1519, 1545, 1585, 1637, 1659, 1664, 1665, 1597, 1606, 1615, 1638, 1628, 1607, 1705, 1800, 1828, 1847, 1888, 1908, 1909, 1972, 1993, 2000, 1960, 1952, 1938, 1879, 1880, 1881, 2038, 2065, 2119, 2100, 2021, 2013, 2143, 2234, 2324, 2454, 2466, 2538, 2630, 2812, 2305, 2283, 2306, 2314, 2335, 2376, 2401, 2445, 2455, 2482, 2497, 2498, 2527, 2547, 2598, 2446, 2144, 2022, 1944, 1902, 1792, 1753, 1731, 1616, 1509, 1472, 1442, 1481, 1520, 1576, 1639, 1685, 1670, 1694, 1742, 1760, 1747, 1803, 1821, 1882, 1793, 1732, 1706, 1695, 1889, 1939, 1994, 2197, 2499, 2599, 2548, 2557, 2828, 2807, 2842, 2829, 2843, 2830, 2873, 2864, 2865, 2860, 2844, 2831, 2832, 2520, 2377, 2284, 2136, 2155, 2090, 1988, 1974, 2005, 2010, 2016, 2017, 2047, 2011, 2018, 2023, 2024, 1953, 1954, 1995, 1955, 1975, 2033, 2056, 2066, 2001, 2082, 2172, 2006, 2121, 2126, 2127, 2173, 2145, 2235, 2285, 2307, 2325, 2389, 2521, 2573, 2642, 2747, 2753, 2788, 2661, 2680, 2668, 2688, 2696, 2681, 2662, 2623, 2669, 2614, 2540, 2484, 2447, 2337, 2251, 2175, 2110, 2236, 2237, 2238, 2348, 2427, 2347, 2439, 2531, 2705, 2750, 2778, 2808, 2898, 2990, 3033, 3075, 2899, 2833, 2779, 2670, 2697, 2706, 2514, 2448, 2364, 2252, 2200, 2349, 2356, 2457, 2471, 2379, 2365, 2440, 2239, 2201, 2158, 2263, 2456, 2643, 2789, 2834, 2891, 3024, 3068, 3153, 3154, 3180, 3186, 3174, 3187, 3203, 3214, 3237, 3181, 3204, 3205, 3197, 3206, 3250, 3232, 3207, 3284, 3322, 3347, 3401, 3425, 3456, 3511, 3577, 3626, 3669, 3687, 3668, 3661, 3659, 3629, 3597, 3591, 3552, 3462, 3468, 3418, 3406, 3331, 3311, 3145, 3115, 3005, 2875, 2735, 2721, 2617, 2503, 2472, 2353, 2352, 2458, 2561, 2589, 2616, 2738, 2720, 2699, 2671, 2625, 2550, 2449, 2450, 2351, 2286, 2315, 2274, 2350, 2402, 2380, 2485, 2607, 2615, 2698, 2729, 2762, 2707, 2644, 2624, 2663, 2845, 2878, 2900, 2959, 2971, 2919, 2795, 2773, 2689, 2575, 2574, 2708, 2774, 2846, 2920, 2926, 2991, 3061, 3050, 3080, 2984, 2892, 2780, 2645, 2700, 2664, 2835, 2893, 2755, 2781, 2907, 3034, 3042, 2908, 2944, 2960, 2961, 3057, 3105, 3069, 3188, 3220, 3323, 3381, 3439, 3458, 3480, 3562, 3627, 3676, 3677, 3688, 3699, 3651, 3616, 3585, 3559, 3498, 3499, 3473, 3448, 3402, 3348, 3312, 3266, 3238, 3155, 3132, 3070, 3051, 3006, 2921, 2927, 2909, 2939, 2972, 3117, 3124, 3262, 3263, 3388, 3380, 3495, 3565, 3617, 3639, 3678, 3707, 3712, 3823, 3814, 3809, 3834, 3759, 3716, 3690, 3679, 3652, 3622, 3583, 3520, 3514, 3469, 3430, 3417, 3440, 3531, 3530, 3588, 3653, 3717, 3735, 3765, 3766, 3801, 3777, 3817, 3837, 3874, 3898, 3918, 3838, 3785, 3784, 3795, 3802, 3871, 3882, 3905, 3852, 3803, 3772, 3767, 3786, 3804, 3796, 3824, 3808, 3753, 3718, 3642, 3682, 3737, 3743, 3663, 3625, 3587, 3560, 3534, 3539, 3540, 3488, 3407, 3413, 3403, 3345, 3290, 3275, 3209, 3216, 3208, 3182, 3240, 3288, 3289, 3372, 3420, 3451, 3484, 3515, 3563, 3606, 3522, 3500, 3431, 3428, 3460, 3395, 3371, 3349, 3298, 3305, 3248, 3200, 3135, 3101, 3072, 2986, 2948, 2855, 2797, 2765, 2886, 2979, 2922, 2820, 2764, 2763, 2648, 2541, 2524, 2525, 2367, 2366, 2339, 2396, 2515, 2633, 2618, 2683, 2682, 2609, 2690, 2790, 2861, 2901, 2885, 2902, 2854, 2903, 2928, 2847, 2809, 2929, 2997, 3015, 3071, 3052, 3133, 3172, 3199, 3164, 3222, 3296, 3304, 3319, 3370, 3419, 3437, 3470, 3483, 3475, 3459, 3449, 3445, 3441, 3412, 3393, 3297, 3247, 3239, 3313, 3344, 3394, 3450, 3476, 3545, 3569, 3647, 3648, 3680, 3702, 3681, 3624, 3592, 3596, 3634, 3589, 3578, 3512, 3553, 3637, 3658, 3708, 3736, 3747, 3696, 3654, 3662, 3695, 3636, 3612, 3660, 3691, 3657, 3623, 3586, 3532, 3481, 3474, 3482, 3533, 3544, 3392, 3343, 3303, 3253, 3221, 3189, 3118, 3084, 3156, 3215, 3285, 3324, 3359, 3416, 3427, 3382, 3267, 3111, 3134, 3100, 2985, 2931, 2940, 2992, 2930, 2775, 2487, 2403, 2224, 2223, 2308, 2137, 2161, 2360, 2451, 2459, 2562, 2673, 2722, 2796, 2736, 2672, 2757, 2608, 2506, 2395, 2338, 2186, 2148, 2214, 2215, 2390, 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1557, 1582, 1624, 1611, 1636, 1658, 1689, 1710, 1743, 1718, 1711, 1690, 1669, 1649, 1650, 1625, 1590, 1612, 1583, 1584, 1552, 1525, 1488, 1441, 1411, 1369, 1307, 1356, 1333, 1308, 1336, 1347, 1323, 1295, 1275, 1247, 1230, 1196, 1063, 1093, 1025, 1057, 1058, 1094, 983, 929, 895, 792, 710, 641, 755, 688, 721, 668, 577, 548, 520, 581, 629, 653, 711, 654, 793, 856, 722, 590, 589, 578, 582, 533, 466, 462, 467, 1105, 1077, 915, 907, 908, 972, 1026, 1013, 984, 951, 925, 817, 875, 898, 924, 950, 1012, 1040, 1064, 1103, 1138, 1154, 1176, 1214, 1240, 1260, 1279, 1309, 1343, 1378, 1367, 1386, 1405, 1424, 1433, 1434, 1427, 1416, 1417, 1398, 1387, 1388, 1370, 1368, 1357, 1348, 1362, 1363, 1358, 1337, 1344, 1338, 1334, 1324, 1296, 1315, 1350, 1339, 1349, 1359, 1371, 1372, 1380, 1381, 1406, 1390, 1373, 1316, 1297, 1268, 1261, 1225, 1178, 1130, 1104, 1177, 1379, 1389, 1420, 1391, 1421, 1471, 1455, 1527, 1627, 1675, 1684, 1682, 1691, 1465, 1407, 1302, 1159, 1109, 1079, 1145, 1015, 987, 973, 931, 918, 896, 884, 889, 867, 847, 834, 802, 794, 760, 759, 733, 734, 724, 712, 691, 670, 643, 630, 656, 692, 693, 725, 735, 744, 745, 746, 771, 784, 783, 795, 803, 819, 868, 857, 932, 988, 1016, 1017, 1018, 1065, 1020, 1019, 974, 953, 937, 916, 902, 901, 849, 1160, 1271, 944, 1032, 1033, 999, 899, 846, 833, 818, 732, 678, 655, 583, 513, 642, 549, 506, 555, 623, 669, 723, 832, 926, 952, 943, 967, 985, 1078, 1155, 1215, 1248, 1236, 1231, 1179, 1206, 1188, 1262, 1280, 1300, 1310, 1340, 1341, 1311, 1287, 1281, 1263, 1269, 1253, 1254, 1254, 1270, 1301, 1317, 1312, 1342, 1382, 1374, 1360, 1325, 1313, 1282, 1288, 1283, 1284, 1256, 1249, 1241, 1232, 1255, 1226, 1169, 1158, 1180, 1162, 1106, 1086, 1107, 1143, 1144, 1131, 1108, 1132, 1087, 1041, 1027, 1014, 1005, 986, 946, 930, 945, 909, 866, 900, 758, 690, 689, 757, 770, 782, 756, 679, 601, 591, 556, 521, 502, 542, 624, 569, 485, 507, 561, 543, 550, 522, 469, 468, 523, 524, 525, 592, 625, 585, 579, 562, 503, 534, 570, 584, 605, 659, 645, 632, 604, 603, 602, 609, 631, 644, 681, 696, 673, 672, 671, 680, 694, 695, 772, 761, 762, 773, 804, 820, 821, 848, 876, 835, 836, 786, 764, 774, 785, 763, 736, 682, 697, 726, 713, 727, 657, 658, 683, 737, 738, 714, 698, 699, 700, 715, 850, 837, 869, 838, 822, 823, 747, 775, 851, 824, 885, 910, 1006, 1059, 1095, 1146, 1181, 1197, 1182, 1189, 1207, 1242, 1257, 1318, 1335, 1383, 903, 1042, 1250, 1183, 1120, 1043, 975, 917, 852, 839, 749, 748, 739, 611, 612, 544, 571, 594, 613, 626, 634, 660, 646, 633, 685, 674, 703, 717, 684, 729, 728, 716, 776, 797, 796, 765, 702, 610, 701, 593, 526, 508, 509, 471, 444, 440, 437, 383, 384, 396, 472, 479, 447, 441, 392, 385, 409, 386, 342, 336, 353, 375, 393, 387, 429, 432, 458, 486, 514, 563, 596, 661, 740, 741, 826, 778, 840, 806, 564, 497, 487, 448, 424, 481, 441, 480, 496, 412, 348, 323, 313, 284, 267, 283, 214, 219, 233, 255, 282, 281, 322, 338, 344, 343, 321, 259, 246, 231, 202, 211, 213, 312, 335, 334,

337, 309, 299, 258, 266, 263, 254, 223, 242, 250, 253, 308, 280, 262, 257, 261, 298, 297, 307, 320, 395, 374, 361, 382, 402, 423, 431, 439, 451, 463, 478, 470, 586, 1544, 1783, 1765, 1745, 1744, 1982, 2597, 2621, 2546, 2465, 2640, 2916, 3414, 3244, 2425, 2519, 2572, 1983, 1838, 1839, 1846, 1834, 1866, 1893, 1900, 1950, 1984, 1999, 1887, 1920, 1971, 1928, 1878, 1877, 1820, 1811, 1819, 1784, 1739, 1738, 1746, 1766, 1757, 1752, 1777, 1951, 1712, 1692, 1566, 1508, 1532, 1528, 1490, 1478, 1462, 1458, 1430, 1345, 1327, 1326, 1289, 1044, 1034, 1139, 1163, 1161, 1021, 1133, 1111, 1110, 1066, 1080, 1050, 1007, 954, 919, 960, 933, 891, 825, 787, 719, 595, 635, 750, 627, 527, 557, 614, 686, 718, 751, 805, 870, 890, 777, 704, 798, 766, 636, 572, 530, 558, 637, 730, 285, 317, 302, 264, 236, 207, 185, 165, 156

3. TOUR OF DIVIDE & CONQUER ALGORITHM

Main	Run:	Main	Run:	Main	Run:	Main	Run:	Main	Run:	Main	Run:	Main
CITY PATH	▶	city no:2376	▶	City no:2469	▶	City no:2566	▶	City no:2883	▶	City no:2072	▶	City no:2061
City no:4078	↙	City no:2335	↙	City no:2374	↙	City no:2544	↙	City no:2293	↙	City no:2054	↙	City no:2261
City no:4086	⤒	City no:2314	⤒	City no:2413	⤒	City no:2463	⤒	City no:2294	⤒	City no:2261	⤒	City no:2211
City no:3923	⤓	City no:2306	⤓	City no:2442	⤓	City no:2479	⤓	City no:2496	⤓	City no:2211	⤓	City no:2233
City no:3967	⤔	City no:2305	⤔	City no:2422	⤔	City no:2517	⤔	City no:2556	⤔	City no:2182	⤔	City no:2087
City no:3908	⤖	City no:2572	⤖	City no:2512	⤖	City no:2437	⤖	City no:2611	⤖	City no:2008	⤖	City no:1924
City no:4221	⤗	City no:2519	⤗	City no:2594	⤗	City no:2493	⤗	City no:2658	⤗	City no:1817	⤗	City no:1870
City no:4369	⤘	City no:2465	⤘	City no:2571	⤘	City no:2387	⤘	City no:2858	⤘	City no:1859	⤘	City no:1871
City no:4157	⤙	City no:2313	⤙	City no:2537	⤙	City no:2411	⤙	City no:2859	⤙	City no:1907	⤙	City no:1991
City no:4154	⤚	City no:2323	⤚	City no:2481	⤚	City no:2464	⤚	City no:2811	⤚	City no:1980	⤚	City no:1992
City no:3693	⤛	City no:2375	⤛	City no:2545	⤛	City no:2518	⤛	City no:2806	⤛	City no:1949	⤛	City no:1937
City no:3764	⤜	City no:2526	⤜	City no:2776	⤜	City no:3040	⤜	City no:3397	⤜	City no:1855	⤜	City no:1859
City no:3414	⤝	City no:2596	⤝	City no:2678	⤝	City no:3108	⤝	City no:1957	⤝	City no:1832	⤝	City no:1881
City no:3510	⤞	City no:2725	⤞	City no:2719	⤞	City no:3162	⤞	City no:2037	⤞	City no:1806	⤞	City no:2009
City no:3608	⤟	City no:2805	⤟	City no:2810	⤟	City no:3150	⤟	City no:2069	⤟	City no:1796	⤟	City no:2106
City no:3715	⤠	City no:2852	⤠	City no:2704	⤠	City no:3091	⤠	City no:2040	⤠	City no:1773	⤠	City no:2062
City no:3646	⤡	City no:2851	⤡	City no:2677	⤡	City no:3049	⤡	City no:2019	⤡	City no:1786	⤡	City no:2042
City no:3694	⤢	City no:2872	⤢	City no:2657	⤢	City no:2989	⤢	City no:1969	⤢	City no:2181	⤢	City no:1998
City no:3513	⤣	City no:2857	⤣	City no:2638	⤣	City no:2964	⤣	City no:1949	⤣	City no:2154	⤣	City no:1783
City no:3226	⤤	City no:2850	⤤	City no:2480	⤤	City no:3121	⤤	City no:1855	⤤	City no:2099	⤤	City no:1838
City no:3219	⤥	City no:2863	⤥	City no:2421	⤥	City no:3152	⤥	City no:1832	⤥	City no:2073	⤥	City no:1839
City no:3436	⤦	City no:2841	⤦	City no:2420	⤦	City no:3142	⤦	City no:1814	⤦	City no:2154	⤦	City no:1846
City no:3301	⤧	City no:2819	⤧	City no:2412	⤧	City no:3143	⤧	City no:1806	⤧	City no:2061	⤧	City no:1834
City no:3244	⤨	City no:2804	⤨	City no:2345	⤨	City no:3082	⤨	City no:1796	⤨	City no:2054	⤨	City no:1866
City no:2916	⤩	City no:2803	⤩	City no:2322	⤩	City no:3056	⤩	City no:1773	⤩	City no:2261	⤩	City no:1900
City no:2640	⤪	City no:2818	⤪	City no:2328	⤪	City no:3041	⤪	City no:1786	⤪	City no:2211	⤪	City no:1893
City no:2546	⤫	City no:3031	⤫	City no:2292	⤫	City no:2882	⤫	City no:2233	⤫	City no:2182	⤫	City no:1887
City no:2621	⤬	City no:3066	⤬	City no:2304	⤬	City no:2827	⤬	City no:2233	⤬	City no:2182	⤬	City no:1784
City no:2597	⤭	City no:3083	⤭	City no:2291	⤭	City no:2734	⤭	City no:2182	⤭	City no:2087	⤭	City no:1819
City no:2425	⤮	City no:2802	⤮	City no:2327	⤮	City no:2393	⤮	City no:2087	⤮	City no:2008	⤮	City no:1811
City no:2324	⤯	City no:2965	⤯	City no:2334	⤯	City no:2414	⤯	City no:2008	⤯	City no:1924	⤯	City no:1811
City no:2454	⤰	City no:3010	⤰	City no:2290	⤰	City no:2394	⤰	City no:1924	⤰	City no:1924	⤰	City no:1820
City no:2466	⤱	City no:2890	⤱	City no:2373	⤱	City no:2423	⤱	City no:1924	⤱	City no:1924	⤱	City no:1820
City no:2538	⤲	City no:2840	⤲	City no:2344	⤲	City no:2424	⤲	City no:1924	⤲	City no:1924	⤲	City no:1820
City no:2630	⤳	City no:2686	⤳	City no:2392	⤳	City no:2495	⤳	City no:2211	⤳	City no:2211	⤳	City no:1893
City no:2812	⤴	City no:2629	⤴	City no:2386	⤴	City no:2444	⤴	City no:2233	⤴	City no:2233	⤴	City no:1887
City no:2445	⤵	City no:2595	⤵	City no:2303	⤵	City no:2567	⤵	City no:2182	⤵	City no:2182	⤵	City no:1784
City no:2455	⤶	City no:2639	⤶	City no:2536	⤶	City no:2679	⤶	City no:2087	⤶	City no:2087	⤶	City no:1819
City no:2401	⤷	City no:2585	⤷	City no:2478	⤷	City no:2958	⤷	City no:2008	⤷	City no:2008	⤷	City no:1811
City no:2376	⤸	City no:2443	⤸	City no:2566	⤸	City no:2883	⤸	City no:1924	⤸	City no:1924	⤸	City no:1820

Main	Run:	Main	Run:	Main	Run:	Main	Run:	Main	Run:	Main	Run:	Main
CITY PATH		City no:2378		City no:2469		City no:2566		City no:2883		City no:2072		City no:2061
City no:4078		City no:2335		City no:2374		City no:2544		City no:2293		City no:2054		City no:2054
City no:4086		City no:2314		City no:2413		City no:2463		City no:2294		City no:2261		City no:2261
City no:3923		City no:2306		City no:2442		City no:2479		City no:2496		City no:2211		City no:2211
City no:3967		City no:2305		City no:2422		City no:2517		City no:2556		City no:2233		City no:2233
City no:3908		City no:2572		City no:2512		City no:2437		City no:2611		City no:2182		City no:2182
City no:4221		City no:2519		City no:2594		City no:2493		City no:2658		City no:2087		City no:2087
City no:4369		City no:2465		City no:2571		City no:2387		City no:2858		City no:2008		City no:2008
City no:4157		City no:2313		City no:2537		City no:2411		City no:2859		City no:1924		City no:1924
City no:4154		City no:2323		City no:2481		City no:2464		City no:2811		City no:1817		City no:1817
City no:3693		City no:2375		City no:2545		City no:2518		City no:2806		City no:1870		City no:1870
City no:3764		City no:2526		City no:2776		City no:3040		City no:3397		City no:1859		City no:1859
City no:3414		City no:2596		City no:2678		City no:3108		City no:1957		City no:1871		City no:1871
City no:3510		City no:2725		City no:2719		City no:3162		City no:2037		City no:1907		City no:1907
City no:3608		City no:2805		City no:2810		City no:3150		City no:2069		City no:1991		City no:1991
City no:3715		City no:2852		City no:2704		City no:3091		City no:2040		City no:1980		City no:1980
City no:3646		City no:2851		City no:2677		City no:3049		City no:2019		City no:1992		City no:1992
City no:3694		City no:2872		City no:2657		City no:2989		City no:1969		City no:1937		City no:1937
City no:3513		City no:2857		City no:2638		City no:2964		City no:1949		City no:1959		City no:1959
City no:3226		City no:2850		City no:2480		City no:3121		City no:1855		City no:1981		City no:1981
City no:3219		City no:2863		City no:2421		City no:3152		City no:1832		City no:2009		City no:2009
City no:3436		City no:2841		City no:2420		City no:3142		City no:1814		City no:2073		City no:2073
City no:3301		City no:2819		City no:2412		City no:3143		City no:1806		City no:2106		City no:2106
City no:3244		City no:2804		City no:2345		City no:3082		City no:1796		City no:1773		City no:1773
City no:2916		City no:2803		City no:2322		City no:3056		City no:1786		City no:2099		City no:2099
City no:2640		City no:2818		City no:2328		City no:3041		City no:2181		City no:2081		City no:2081
City no:2546		City no:3031		City no:2292		City no:2882		City no:2154		City no:1838		City no:1838
City no:2621		City no:3066		City no:2304		City no:2827		City no:2134		City no:1839		City no:1839
City no:2597		City no:3083		City no:2291		City no:2734		City no:2072		City no:1846		City no:1846
City no:2425		City no:2802		City no:2327		City no:2393		City no:2072		City no:1861		City no:1861
City no:2324		City no:2965		City no:2334		City no:2414		City no:2054		City no:1887		City no:1887
City no:2454		City no:3010		City no:2290		City no:2394		City no:2261		City no:1900		City no:1900
City no:2466		City no:2890		City no:2373		City no:2423		City no:2211		City no:1893		City no:1893
City no:2538		City no:2840		City no:2344		City no:2424		City no:2233		City no:1887		City no:1887
City no:2630		City no:2686		City no:2392		City no:2495		City no:2182		City no:1784		City no:1784
City no:2812		City no:2629		City no:2386		City no:2444		City no:2087		City no:1819		City no:1819
City no:2445		City no:2595		City no:2303		City no:2567		City no:2008		City no:1811		City no:1811
City no:2455		City no:2639		City no:2536		City no:2679		City no:1924		City no:1820		City no:1820
City no:2401		City no:2585		City no:2478		City no:2958						
City no:2376		City no:2443		City no:2566		City no:2883						

Main	Run:	Main	Main	Main	Main	Main	Main	Main
City no:1820		City no:2064	City no:1997	City no:1319	City no:1207	City no:1510	City no:1143	
City no:1777		city no:2088	city no:1664	city no:1303	City no:1242	City no:1524	City no:1144	
City no:1826		city no:2108	City no:1659	City no:1265	City no:1335	City no:1515	City no:1131	
City no:1873		city no:2030	City no:1637	City no:1266	City no:1465	City no:1514	City no:1108	
City no:1778		City no:1901	City no:1585	City no:1237	City no:1302	City no:1501	City no:1087	
City no:1790		city no:1987	City no:1545	City no:1190	City no:1407	City no:1505	City no:1132	
City no:1791		city no:2020	City no:1519	City no:1234	City no:1271	City no:1487	City no:1145	
City no:1775		city no:2043	City no:1502	City no:1233	City no:1313	City no:1460	City no:1079	
City no:1776		city no:2003	City no:1491	City no:1216	City no:1288	City no:1093	City no:1109	
City no:1827		city no:1986	City no:1479	City no:1272	City no:1282	City no:1057	City no:1159	
City no:1800		city no:1929	City no:1399	City no:1290	City no:1283	City no:1058	City no:1016	
City no:1828		city no:1985	City no:1364	City no:1243	City no:1284	City no:1094	City no:988	
City no:1847		City no:1951	City no:1437	City no:1198	City no:1249	City no:1154	City no:932	
City no:1888		city no:1928	City no:1615	City no:1184	City no:1241	City no:1138	City no:902	
City no:1908		city no:1878	City no:1638	City no:1220	City no:1256	City no:1103	City no:901	
City no:1909		city no:1877	City no:1705	City no:1264	City no:1232	City no:1064	City no:876	
City no:1972		city no:1920	City no:1607	City no:1430	City no:1180	City no:1040	City no:848	
City no:2021		city no:1971	City no:1628	City no:1458	City no:1215	City no:1012	City no:835	
City no:2013		city no:1999	City no:1472	City no:1462	City no:1236	City no:1104	City no:836	
City no:1993		city no:1950	City no:1509	City no:1478	City no:1254	City no:1130	City no:821	
City no:2000		city no:1984	City no:1616	City no:1508	City no:1253	City no:1105	City no:820	
City no:1952		city no:1983	City no:1731	City no:1490	City no:1231	City no:1077	City no:804	
City no:1960		city no:1766	City no:1753	City no:1528	City no:1206	City no:1155	City no:784	
City no:1938		city no:1757	City no:1576	City no:1532	City no:1179	City no:1078	City no:771	
City no:1879		city no:1739	City no:1520	City no:1566	City no:1188	City no:1106	City no:772	
City no:1880		city no:1738	City no:1481	City no:1327	City no:1178	City no:1162	City no:773	
City no:1881		city no:1746	City no:1442	City no:1326	City no:1225	City no:1169	City no:763	
City no:1792		city no:1752	City no:1191	City no:1289	City no:1177	City no:1158	City no:785	
City no:1902		City no:1712	City no:1186	City no:1345	City no:1214	City no:1086	City no:786	
City no:2283		City no:1692	City no:1185	City no:1544	City no:1176	City no:952	City no:737	
City no:2196		City no:1767	City no:1199	City no:1250	City no:1275	City no:926	City no:764	
City no:2234		City no:1740	City no:1217	City no:1183	City no:1247	City no:943	City no:774	
City no:2143		City no:1713	City no:1227	City no:1257	City no:1230	City no:967	City no:736	
City no:2038		City no:1758	City no:1221	City no:1318	City no:1196	City no:985	City no:726	
City no:2065		City no:1759	City no:1273	City no:1383	City no:1229	City no:944	City no:727	
City no:2119		City no:1741	City no:1291	City no:1197	City no:1307	City no:999	City no:683	
City no:2100		City no:1728	City no:1320	City no:1181	City no:1369	City no:1033	City no:713	
City no:2077		City no:1665	City no:1365	City no:1182	City no:1411	City no:1032	City no:697	
City no:2044		City no:1606	City no:1375	City no:1189	City no:1488	City no:1107	City no:682	
City no:2064		City no:1597	City no:1319	City no:1207	City no:1516	City no:1143	City no:681	

City no:681	Main x	Main x	Main x	Main x	Main x	Main x	Main x	Main x	Main x	Main x	Main x
City no:673	City no:580	City no:870	City no:480	City no:65	City no:1	City no:162	City no:1500				
City no:672	City no:592	City no:805	City no:441	City no:48	City no:4	City no:131	City no:1494				
City no:671	City no:625	City no:750	City no:481	City no:53	City no:11	City no:108	City no:1172				
City no:680	City no:525	City no:686	City no:448	City no:59	City no:9	City no:105	City no:1173				
City no:693	City no:524	City no:718	City no:487	City no:90	City no:5	City no:104	City no:1210				
City no:692	City no:523	City no:751	City no:497	City no:93	City no:3	City no:94	City no:1193				
City no:735	City no:562	City no:719	City no:403	City no:10	City no:8	City no:97	City no:1205				
City no:725	City no:585	City no:635	City no:355	City no:10	City no:15	City no:115	City no:1211				
City no:694	City no:579	City no:595	City no:388	City no:95	City no:17	City no:107	City no:1259				
City no:695	City no:570	City no:636	City no:364	City no:68	City no:10	City no:98	City no:1409				
City no:656	City no:714	City no:787	City no:350	City no:55	City no:18	City no:99	City no:1354				
City no:630	City no:738	City no:825	City no:394	City no:42	City no:16	City no:75	City no:1286				
City no:569	City no:849	City no:891	City no:424	City no:39	City no:12	City no:85	City no:1306				
City no:485	City no:916	City no:960	City no:349	City no:45	City no:25	City no:63	City no:1330				
City no:507	City no:937	City no:919	City no:328	City no:54	City no:29	City no:66	City no:1469				
City no:561	City no:953	City no:954	City no:286	City no:62	City no:30	City no:78	City no:1541				
City no:550	City no:974	City no:1007	City no:251	City no:46	City no:23	City no:91	City no:1610				
City no:543	City no:1018	City no:1066	City no:234	City no:32	City no:24	City no:96	City no:1630				
City no:522	City no:1017	City no:1086	City no:240	City no:33	City no:21	City no:88	City no:1641				
City no:534	City no:1065	City no:1056	City no:301	City no:49	City no:20	City no:72	City no:1655				
City no:503	City no:1166	City no:1116	City no:317	City no:40	City no:19	City no:77	City no:1668				
City no:468	City no:1059	City no:1111	City no:302	City no:35	City no:37	City no:106	City no:1771				
City no:469	City no:1026	City no:1133	City no:325	City no:41	City no:44	City no:109	City no:1656				
City no:470	City no:1019	City no:1021	City no:291	City no:34	City no:47	City no:111	City no:1631				
City no:478	City no:1095	City no:1044	City no:236	City no:36	City no:64	City no:114	City no:1459				
City no:463	City no:1146	City no:1161	City no:264	City no:43	City no:60	City no:120	City no:1395				
City no:451	City no:1006	City no:1163	City no:235	City no:67	City no:51	City no:117	City no:1428				
City no:526	City no:885	City no:1139	City no:216	City no:56	City no:58	City no:118	City no:1436				
City no:508	City no:910	City no:1034	City no:224	City no:38	City no:73	City no:112	City no:1429				
City no:439	City no:776	City no:806	City no:215	City no:31	City no:57	City no:110	City no:1581				
City no:431	City no:797	City no:615	City no:193	City no:28	City no:84	City no:101	City no:1642				
City no:402	City no:903	City no:564	City no:92	City no:26	City no:83	City no:139	City no:1673				
City no:423	City no:1042	City no:778	City no:76	City no:27	City no:10	City no:137	City no:1734				
City no:509	City no:917	City no:840	City no:80	City no:22	City no:13	City no:147	City no:1750				
City no:610	City no:975	City no:826	City no:70	City no:13	City no:16	City no:155	City no:1763				
City no:702	City no:1126	City no:741	City no:69	City no:14	City no:13	City no:128	City no:1735				
City no:593	City no:1043	City no:661	City no:52	City no:7	City no:12	City no:143	City no:1697				
City no:701	City no:933	City no:596	City no:50	City no:2	City no:11	City no:168	City no:1688				
City no:586	City no:890	City no:496	City no:61	City no:6	City no:12	City no:144	City no:1726				
	City no:870	City no:480	City no:65	City no:1	City no:16	City no:124					

Main	Main	City no:2843
City no:2090	↑ City no:1973	City no:2830
City no:2155	↓ City no:2004	City no:2873
City no:2136	↔ City no:2031	City no:2612
City no:2284	⤵ City no:2014	City no:2864
City no:2377	⤴ City no:1994	City no:2865
City no:2046	⤷ City no:1939	City no:2860
City no:1910	⤸ City no:1889	City no:2844
City no:1940	⤹ City no:1706	City no:2832
City no:1945	⤻ City no:1695	City no:2831
City no:1794	⤼ City no:1803	City no:3178
City no:1848	⤽ City no:1821	City no:3195
City no:1840	⤾ City no:1882	City no:3302
City no:1812	⤿ City no:1793	City no:3309
City no:1930	⤿ City no:1732	City no:3330
City no:1921	⤿ City no:1492	City no:3346
City no:1961	⤿ City no:1400	City no:3505
City no:2015	⤿ City no:1238	City no:3650
City no:2055	⤿ City no:1148	City no:3604
City no:2388	⤿ City no:1136	City no:3701
City no:2346	⤿ City no:1122	City no:3700
City no:2198	⤿ City no:1135	City no:3917
City no:2075	⤿ City no:1147	City no:3939
City no:2089	⤿ City no:1165	City no:4294
City no:2120	⤿ City no:1235	City no:4218
City no:2074	⤿ City no:1258	Total distance:1710413.298215606
City no:2045	⤿ City no:1328	
City no:2032	⤿ City no:1351	----- TRAVEL END -----
City no:2029	⤿ City no:1685	TOUR COMPLETED!
City no:2483	⤿ City no:1639	LENGTH: 1.710.413
City no:2528	⤿ City no:1670	PATH:
City no:2539	⤿ City no:1694	TOUR: Path saved to output file.
City no:2557	⤿ City no:1747	COMPLETED: Divide & Conquer
City no:2548	⤿ City no:1760	DURATION: 1.414.623ms
City no:2599	⤿ City no:1742	
City no:2499	⤿ City no:1944	
City no:2197	⤿ City no:2022	Total execution time: 1.414.811ms
City no:1973	⤿ City no:2482	
City no:2004	⤿ City no:2497	Process finished with exit code 0
City no:2031	⤿ City no:2498	
City no:2014	⤿ City no:2527	