



Artificial Intelligence: Week 04 Assignment Analysis (2022-2)

Course / Class:	Artificial Intelligence Class 01
Professor:	Dae-Won Kim
Submission Date:	2022. 10. 03
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Name:	주영석

Objective: Learning and Improving the principle of Greedy, Hill-Climbing, and Simulated Annealing Algorithm for TSP Problems

(4.1) Execute and analyze Greedy, HC, and SA sample code.

[Level 1: Beginning] Write each execution result (Path Plot, Execution Time, Solution Path, Minimum Cost) for the provided input data.

1. Greedy Algorithm

1) Data 1



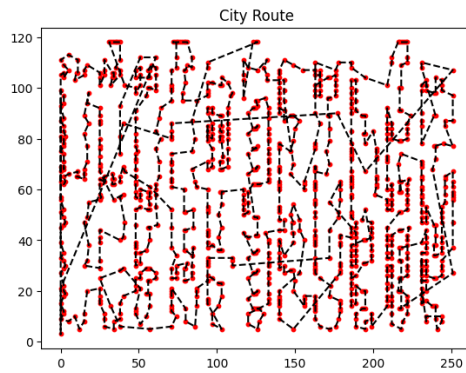
a) Path Plot:

b) Execution Time: 0.14426302909851074

c) Solution Path: [0, 5, 13, 14, 15, 16, 24, 17, 12, 4, 11, 6, 7, 1, 2, 8, 9, 3, 10, 23, 41, 40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 18, 19, 20, 21, 22, 42, 43, 60, 59, 58, 57, 56, 55, 50, 51, 49, 48, 47, 46, 54, 53, 45, 44, 52, 73, 67, 63, 74, 76, 77, 80, 81, 86, 87, 91, 93, 98, 101, 100, 99, 104, 105, 106, 112, 107, 108, 114, 118, 115, 119, 116, 121, 128, 127, 126, 125, 124, 123, 120, 117, 113, 122, 129, 111, 97, 92, 88, 68, 64, 61, 65, 69, 70, 66, 62, 75, 78, 82, 83, 84, 85, 79, 71, 72, 89, 90, 94, 95, 96, 103, 102, 110, 109, 130, 0]

d) Cost: 687.7892183230354

2) Data 2



a) Path Plot:

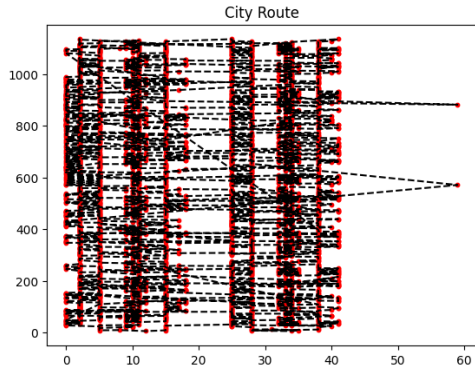
b) Execution Time: 0.19902491569519043

c) Solution Path: [0, 22, 21, 54, 23, 1, 55, 63, 62, 60, 59, 67, 68, 78, 91, 90, 89, 118, 119, 121, 131, 137, 136, 130, 127, 148, 149, 144, 151, 152, 147, 146, 145, 138, 132, 128, 126, 170, 173, 204, 206, 207, 208, 175, 174, 226, 236, 237, 227, 250, 253, 252, 251, 263, 235, 225, 224, 203, 202, 201, 200, 199, 205, 198, 197, 196, 195, 194, 193, 192, 191, 190, 216, 217, 218, 234, 248, 247, 233, 246, 245, 232, 215, 189, 188, 187, 186, 185, 184, 183, 182, 213, 214, 223, 242, 243, 231, 264, 257, 258, 259, 260, 265, 266, 261, 268, 262, 267, 269, 297, 298, 270, 271, 272, 302, 303, 304, 300, 299, 309, 310, 311, 312, 316, 325, 334, 337, 336, 333, 324, 315, 323, 314, 313, 356, 386, 387, 388, 357, 389, 408, 419, 420, 436, 450, 446, 445, 444, 443, 442, 441, 440, 439, 438, 437, 428, 412, 413, 429, 435, 430, 414, 415, 431, 432, 416, 417, 433, 434, 418, 401, 402, 385, 384, 400, 399, 398, 397, 381, 382, 383, 380, 396, 395, 393, 378, 379, 342, 349, 355, 377, 376, 375, 374, 373, 372, 371, 370, 369, 392, 405, 410, 423, 406, 424, 407, 426, 427, 411, 460, 459, 458, 457, 456, 455, 468, 469, 470, 481, 491, 503, 518, 525, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 530, 523, 508, 522, 507, 495, 485, 475, 484, 494, 506, 521, 474, 483, 493, 505, 520, 473, 482, 492, 504, 519, 471, 490, 502, 516, 515, 501, 467, 454, 480, 489, 500, 514, 466, 479, 488, 499, 513, 465, 478, 487, 498, 512, 464, 477, 486, 497, 511, 524, 528, 526, 517, 472, 463, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 529, 580, 606, 607, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 615, 630, 633, 637, 631, 620, 616, 608, 609, 597, 596, 598, 599, 600, 561, 562, 563, 564, 565, 602, 621, 638, 649, 648, 690, 691, 689, 688, 696, 695, 686, 687, 647, 699, 702, 716, 715, 714, 721, 720, 712, 701, 700, 711, 710, 709, 698, 708, 697, 678, 679, 680, 677, 676, 675, 674, 673, 672, 671, 670, 669, 668, 667, 666, 665, 664, 663, 662, 661, 660, 659, 658, 657, 692, 713, 703, 730, 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d) Cost: 4683.17962574481

3) Data 3



a) Path Plot:

b) Execution Time: 0.727625846862793

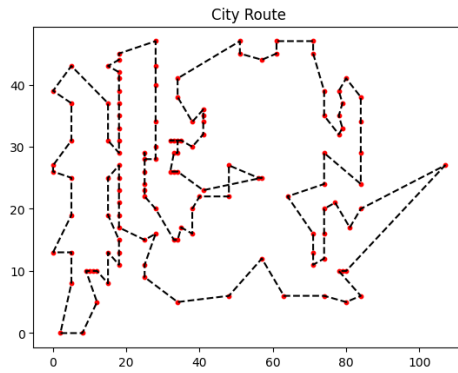
c) Solution Path: [0, 209, 208, 582, 581, 580, 579, 578, 577, 206, 207, 204, 576, 575, 574, 573, 572, 571, 198, 199, 200, 202, 203, 864, 978, 1216, 1479, 1215, 977, 976, 1214, 863, 975, 1213, 1212, 974, 861, 1478, 1537, 1805, 1804, 1536, 1477, 1211, 973, 860, 972, 1210, 1209, 971, 859, 858, 970, 1207, 1206, 969, 857, 1205, 1204, 968, 967, 1203, 1532, 1533, 1534, 1535, 566, 567, 191, 192, 193, 194, 195, 569, 568, 190, 189, 188, 187, 186, 184, 183, 182, 181, 180, 563, 562, 561, 560, 178, 179, 852, 851, 559, 558, 557, 176, 175, 174, 173, 172, 171, 554, 553, 847, 848, 849, 850, 1475, 1527, 1774, 1887, 1886, 1773, 1772, 1885, 1884, 1771, 1525, 1472, 1197, 963, 1196, 1471, 1470, 1195, 962, 961, 1194, 1469, 1524, 1768, 1881, 1880, 1767, 1523, 1468, 1193, 960, 1191, 1466, 1465, 1190, 959, 958, 1189, 1464, 1766, 1765, 1764, 1461, 1187, 1188, 1462, 1463, 957, 838, 837, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 547, 166, 165, 164, 163, 839, 840, 841, 842, 548, 167, 168, 549, 550, 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d) Cost: 12695.859851064295

2. Hill-Climbing Algorithm

1) Data 1



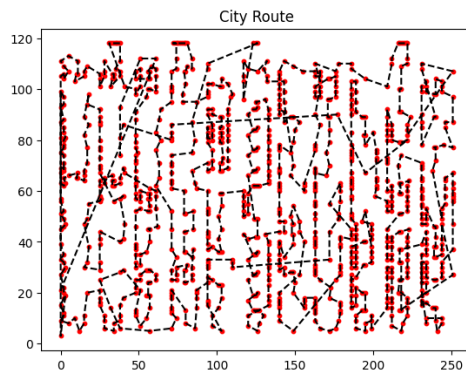
a) Path Plot:

b) Execution Time: 0.5087740421295166

c) Solution Path: [0, 6, 7, 1, 2, 8, 9, 3, 10, 22, 21, 34, 35, 36, 37, 38, 39, 40, 41, 23, 42, 43, 60, 59, 58, 57, 56, 55, 50, 51, 49, 48, 47, 46, 54, 63, 67, 74, 76, 77, 80, 86, 87, 91, 93, 81, 68, 64, 61, 65, 69, 70, 66, 62, 75, 78, 82, 83, 84, 85, 79, 71, 72, 90, 89, 94, 95, 96, 103, 102, 110, 109, 114, 118, 115, 119, 116, 121, 128, 127, 126, 125, 108, 107, 98, 101, 100, 99, 104, 105, 106, 112, 123, 124, 130, 120, 117, 113, 129, 122, 111, 97, 92, 88, 73, 52, 44, 53, 45, 28, 29, 30, 31, 32, 33, 20, 19, 27, 26, 25, 18, 24, 16, 15, 14, 13, 17, 12, 4, 11, 5, 0]

d) Cost: 615.1070309552543

2) Data 2



a) Path Plot:

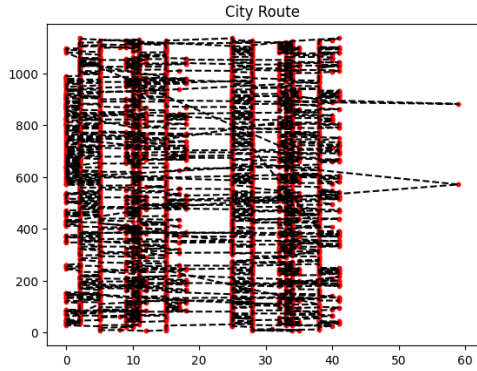
b) Execution Time: 2.6052777767181396

c) Solution Path: [0, 22, 21, 54, 23, 1, 55, 63, 62, 60, 59, 67, 68, 78, 91, 90, 89, 118, 119, 121, 131, 137, 136, 130, 127, 148, 149, 144, 151, 152, 147, 146, 145, 138, 132, 128, 126, 170, 173, 204, 206, 207, 208, 175, 174, 226, 236, 237, 227, 250, 253, 252, 251, 263, 235, 225, 224, 203, 202, 201, 200, 199, 205, 198, 197, 196, 195, 194, 193, 192, 191, 190, 216, 217, 218, 234, 248, 247, 233, 246, 245, 232, 215, 189, 188, 187, 186, 185, 184, 183, 182, 213, 214, 223, 242, 243, 231, 264, 257, 258, 259, 249, 172, 168, 159, 158, 141, 133, 134, 142, 135, 124, 123, 105, 104, 103, 117, 102, 86, 81, 71, 85, 80, 70, 97, 98, 99, 100, 101, 155, 166, 171, 156, 167, 140, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 84, 88, 77, 87, 76, 83, 82, 74, 73, 72, 64, 61, 65, 56, 36, 52, 35, 12, 13, 14, 38, 37, 39, 40, 15, 41, 42, 43, 53, 44, 45, 17, 46, 19, 47, 48, 20, 16, 11, 10, 34, 9, 33, 51, 32, 8, 7, 31, 6, 30, 50, 29, 4, 28, 27, 3, 254, 209, 163, 160, 161, 169, 293, 294, 295, 296, 722, 822, 960, 933, 917, 899, 900, 901, 902, 876, 875, 874,

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d) Cost: 4667.781238594947

3) Data 3



a) Path Plot:

b) Execution Time: 8.707124948501587

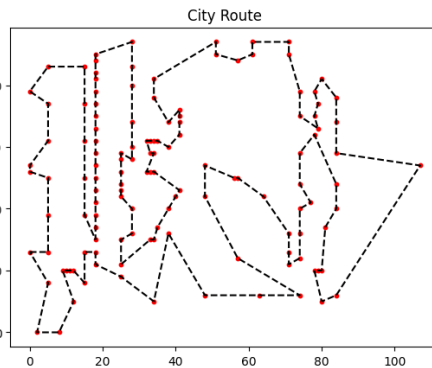
c) Solution Path: [0, 209, 208, 582, 581, 580, 579, 578, 577, 206, 207, 204, 576, 575, 574, 573, 572, 571, 198, 199, 200, 202, 203, 864, 978, 1216, 1479, 1215, 977, 976, 1214, 863, 975, 1213, 1212, 974, 861, 1478, 1537, 1805, 1804, 1536, 1477, 1211, 973, 860, 972, 1210, 1209, 971, 859, 858, 970, 1207, 1206, 969, 857, 1205, 1204, 968, 967, 1203, 1532, 1533, 1534, 1535, 566, 567, 191, 192, 193, 194, 595, 569, 568, 190, 189, 188, 187, 186, 184, 183, 182, 181, 180, 563, 562, 561, 560, 178, 179, 852, 851, 559, 558, 557, 176, 175, 174, 173, 172, 171, 554, 553, 847, 848, 849, 850, 1475, 1527, 1774, 1887, 1886, 1773, 1772, 1885, 1884, 1771, 1525, 1472, 1197, 963, 1196, 1471, 1470, 1195, 962, 961, 1194, 1469, 1524, 1768, 1881, 1880, 1767, 1523, 1468, 1193, 960, 1191, 1466, 1465, 1190, 959, 958, 1189, 1464, 1766, 1765, 1764, 1641, 1187, 1188, 1462, 1463, 957, 838, 837, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 547, 166, 165, 164, 163, 839, 840, 841, 842, 548, 167, 168, 549, 550, 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2180, 2179, 2178, 2493, 2177, 2494, 2495, 3137, 3444, 3443, 3248, 2866, 3135, 3440, 3442, 3134, 2654, 2865, 2864, 3133, 3132, 2863, 2653, 2862, 3131, 3626, 3438, 3439, 2860, 3129, 3128, 2652, 3127, 3436, 3625, 3624, 3622, 3623, 3433, 3434, 3435, 3247, 2651, 2859, 3126, 3124, 3123, 2857, 2649, 2854, 3245, 3120, 3121, 2855, 2650, 2856, 3122, 3246, 3432, 3431, 3621, 3620, 3521, 3429, 3428, 2851, 3117, 3119, 2853, 0]

d) Cost: 12679.451928328106

3. Simulated Annealing Algorithm

1) Data 1



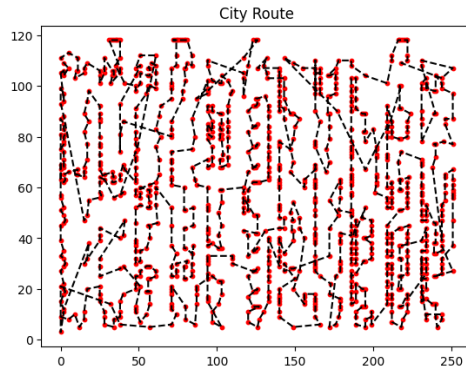
a) Path Plot:

b) Execution Time: 3.6528360843658447

c) Solution Path: [0, 5, 6, 7, 1, 2, 8, 9, 3, 10, 23, 22, 21, 20, 19, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 60, 59, 58, 57, 56, 55, 51, 50, 49, 48, 47, 46, 54, 53, 45, 44, 63, 67, 74, 77, 80, 81, 68, 64, 61, 69, 65, 62, 66, 70, 75, 78, 82, 83, 84, 85, 79, 71, 72, 90, 89, 94, 95, 96, 103, 102, 110, 109, 118, 115, 119, 116, 121, 128, 127, 126, 130, 129, 122, 113, 117, 120, 123, 124, 125, 114, 108, 107, 112, 106, 105, 104, 99, 100, 101, 98, 93, 91, 87, 86, 92, 111, 97, 88, 76, 73, 52, 25, 26, 18, 24, 16, 15, 14, 13, 17, 12, 4, 11, 0]

d) Cost: 624.0496529643049

2) Data 2



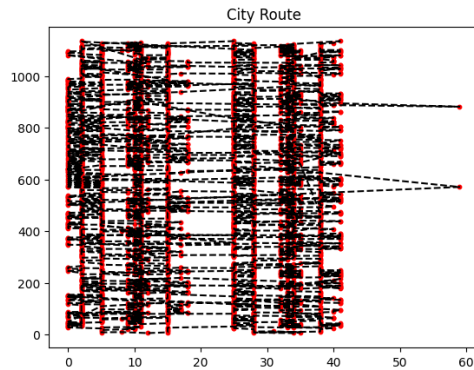
a) Path Plot:

b) Execution Time: 23.9480037689209

c) Solution Path: [0, 22, 21, 54, 23, 1, 55, 63, 62, 60, 59, 67, 68, 78, 91, 90, 89, 118, 119, 121, 131, 137, 136, 130, 127, 148, 149, 126, 128, 132, 138, 145, 146, 147, 152, 151, 144, 170, 173, 204, 206, 207, 226, 236, 237, 227, 250, 253, 252, 251, 263, 235, 225, 224, 203, 202, 201, 200, 199, 205, 254, 209, 175, 208, 174, 163, 160, 161, 169, 293, 294, 295, 296, 313, 314, 323, 315, 324, 333, 336, 337, 334, 325, 316, 312, 311, 310, 309, 299, 300, 304, 303, 302, 272, 271, 270, 298, 297, 269, 267, 262, 268, 261, 266, 265, 260, 249, 191, 190, 216, 217, 218, 234, 248, 247, 233, 246, 245, 232, 215, 189, 188, 187, 186, 185, 184, 183, 182, 213, 214, 223, 242, 243, 231, 264, 257, 258, 259, 284, 283, 282, 308, 281, 280, 305, 306, 307, 335, 328, 318, 317, 327, 338, 339, 340, 345, 341, 329, 319, 320, 330, 346, 347, 331, 321, 322, 286, 287, 288, 289, 290, 291, 292, 343, 350, 344, 357, 388, 356, 386, 387, 453, 510, 496, 476, 462, 461, 451, 452, 359, 358, 389, 408, 419, 420, 436, 450, 446, 445, 444, 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776, 775, 774, 773, 772, 771, 770, 769, 768, 767, 766, 765, 764, 763, 725, 739, 740, 741, 742, 707, 724, 705, 704, 623, 617, 612, 603, 604, 632, 572, 571, 570, 569, 568, 567, 566, 595, 627, 693, 684, 651, 652, 653, 654, 655, 656, 642, 641, 640, 639, 622, 643, 635, 636, 628, 613, 626, 619, 618, 625, 624, 605, 579, 578, 577, 576, 575, 574, 573, 545, 544, 543, 542, 541, 540, 539, 538, 537, 536, 535, 534, 528, 526, 517, 472, 463, 524, 511, 497, 486, 477, 464, 487, 498, 512, 478, 465, 513, 499, 488, 479, 447, 448, 449, 368, 367, 366, 365, 362, 361, 360, 425, 394, 390, 403, 421, 422, 409, 404, 391, 364, 363, 354, 353, 352, 351, 348, 332, 326, 279, 277, 276, 275, 274, 273, 301, 285, 244, 157, 129, 3, 5, 24, 18, 57, 58, 66, 75, 69, 79, 95, 94, 93, 92, 120, 125, 122, 139, 143, 162, 150, 153, 164, 179, 180, 181, 211, 212, 222, 230, 241, 256, 255, 240, 229, 228, 221, 239, 238, 220, 219, 176, 177, 178, 210, 165, 154, 96, 97, 98, 171, 166, 155, 101, 100, 99, 70, 80, 85, 25, 2, 26, 49, 27, 28, 4, 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d) Cost: 4521.315274768777

3) Data 3



a) Path Plot:

b) Execution Time: 79.60868906974792

c) Solution Path: [0, 209, 208, 582, 581, 580, 579, 578, 577, 206, 207, 204, 576, 575, 574, 573, 572, 571, 198, 199, 200, 202, 203, 864, 978, 1216, 1479, 1215, 977, 976, 1214, 863, 975, 1213, 1212, 974, 861, 1478, 1537, 1805, 1804, 1536, 1477, 1211, 973, 860, 972, 1210, 1209, 971, 859, 858, 970, 1207, 1206, 969, 857, 1205, 1204, 968, 967, 1203, 1532, 1533, 1534, 1535, 566, 567, 191, 192, 193, 194, 195, 569, 568, 190, 189, 188, 187, 186, 184, 183, 182, 181, 180, 563, 562, 561, 560, 179, 178, 852, 851, 559, 558, 557, 176, 175, 174, 173, 172, 171, 554, 553, 847, 848, 849, 850, 1475, 1527, 1774, 1887, 1886, 1773, 1772, 1885, 1884, 1771, 1525, 1472, 1197, 963, 1196, 1471, 1470, 1195, 962, 961, 1194, 1469, 1524, 1768, 1881, 1880, 1767, 1523, 1468, 1193, 960, 1191, 1466, 1465, 1190, 959, 958, 1189, 1464, 1766, 1765, 1764, 1461, 1187, 1188, 1462, 1463, 957, 838, 837, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 547, 166, 165, 164, 163, 839, 840, 841, 842, 548, 167, 168, 549, 550, 551, 552, 170, 169, 845, 846, 843, 1769, 1883, 1882, 2255, 2549, 2550, 2256, 2257, 2258, 2259, 2260, 2262, 2263, 2264, 2553, 2554, 2555, 2557, 2558, 2559, 2560, 2269, 2270, 1889, 1888, 2268, 2267, 2266, 2265, 2252, 2551, 2677, 2913, 3190, 3192, 2915, 2916, 3193, 3194, 2917, 2918, 3195, 3196, 2919, 2678, 3197, 2920, 2679, 3261, 3262, 3500, 3533, 3534, 3263, 2922, 2681, 2563, 2562, 2680, 2921, 3198, 2271, 2272, 1890, 1779, 1531, 1530, 1529, 1528, 1777, 1776, 1476, 1200, 965, 1201, 1202, 966, 564, 565, 570, 196, 1775, 1526, 1474, 1199, 964, 1198, 1473, 2548, 2547, 2546, 2254, 2253, 2544, 2543, 2674, 2911, 2675, 3185, 3485, 3484, 3483, 3260, 3184, 2909, 2908, 3183, 3182, 3259, 2907, 2672, 2670, 2905, 3180, 3257, 3179, 2904, 2903, 3178, 3256, 3177, 2902, 2669, 2535, 2534, 2533, 2244, 2245, 2246, 2247, 2248, 2537, 2536, 2538, 2250, 2251, 2252, 2541, 2540, 2539, 2542, 2673, 2910, 3482, 3481, 3480, 3644, 3643, 3642, 3641, 3479, 3478, 3477, 3640, 3639, 3476, 3475, 3474, 3638, 3637, 3473, 3472, 3636, 3635, 3471, 3254, 3173, 2898, 2667, 2897, 3172, 3171, 2896, 2666, 2895, 3170, 3169, 3253, 2894, 2665, 2893, 3168, 3468, 3531, 3530, 3467, 3466, 3165, 3465, 3464, 3463, 3462, 3461, 3632, 3631, 3460, 3158, 2661, 2662, 2884, 3252, 3159, 3160, 2885, 2886, 3161, 3162, 2887, 2888, 3163, 3164, 2663, 2889, 2890, 3166, 2891, 2892, 2664, 3167, 2524, 2525, 2229, 2228, 2227, 2226, 2225, 2224, 2223, 2222, 2220, 2519, 2518, 2517, 2219, 2218, 2217, 2216, 2215, 2214, 2516, 2515, 2513, 2213, 2512, 2211, 2210, 2874, 3146, 3147, 2875, 3451, 3452, 3522, 3523, 3524, 3453, 3525, 3526, 3527, 3454, 3150, 2878, 2879, 2660, 3151, 3152, 2880, 2881, 3153, 3457, 3456, 3528, 3155, 3156, 2883, 3157, 3459, 1798, 1737, 1736, 1876, 1874, 1735, 1873, 1872, 1734, 1733, 1732, 1871, 1870, 1731, 1730, 1515, 1729, 1728, 1869, 1868, 1727, 1726, 1724, 1425, 1153, 1154, 1426, 1428, 1156, 1157, 942, 1429, 1514, 1430, 943, 797, 485, 486, 487, 796, 484, 483, 481, 110, 111, 112, 113, 114, 115, 117, 488, 798, 800, 489, 118, 119, 120, 121, 122, 123, 124, 493, 495, 803, 802, 801, 492, 491, 944, 1159, 1432, 1516, 1431, 1158, 1160, 1433, 1434, 1161, 1163, 1436, 1518, 946, 947, 1164, 1437, 1438, 1165, 948, 1519, 1439, 1166, 806, 807, 500, 501, 127, 499, 498, 497, 496, 126, 805, 804, 1520, 1738, 1739, 1740, 1440, 951, 1168, 950, 1167, 949, 808, 809, 810, 130, 131, 132, 133, 134, 135, 504, 137, 506, 507, 138, 139, 140, 141, 142, 143, 144, 145, 511, 512, 514, 515, 146, 516, 517, 518, 519, 520, 521, 522, 149, 148, 147, 150, 151, 152, 153, 525, 826, 827, 828, 829, 830, 831, 528, 158, 159, 160, 157, 156, 155, 154, 526, 825, 824, 523, 823, 822, 956, 1180, 1453, 1452, 1179, 955, 954, 1451, 1450, 1178, 1176, 1448, 1447, 1175, 1174, 1446, 1445, 1173, 1172, 953, 1444, 1443, 1171, 1169, 1441, 1521, 952, 812, 813, 814, 816, 509, 508, 510, 817, 818, 819, 820, 1749, 1748, 1747, 1746, 1745, 1743, 1742, 1879, 1878, 2520, 2521, 2522, 2523, 2230, 2231, 2233, 2234, 2235, 2526, 2527, 2528, 2236, 2238, 2239, 2240, 2241, 2530, 2529, 2531, 2532, 2242,

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529, 534, 546, 555, 556, 177, 185, 197, 201, 205, 210, 214, 219, 227, 5, 6, 232, 231, 230, 599, 600, 602, 603, 233, 604, 605, 7, 8, 9, 234, 238, 12, 13, 14, 240, 239, 612, 613, 614, 615, 616, 241, 618, 1005, 1251, 1581, 1582, 1485, 1252, 1006, 875, 619, 242, 243, 244, 246, 245, 621, 620, 1819, 1818, 1817, 1816, 1579, 1484, 1250, 1004, 874, 1249, 1248, 1003, 1002, 1247, 1246, 1001, 1000, 1245, 1244, 999, 998, 1243, 1242, 1241, 997, 1571, 1572, 1573, 1574, 1575, 1576, 1577, 1578, 1950, 1949, 1948, 1947, 1946, 2318, 2317, 2963, 3299, 3207, 2962, 2714, 2579, 1945, 2316, 3282, 2937, 2694, 11, 237, 236, 235, 10, 610, 611, 609, 608, 607, 606, 1239, 1240, 1273, 886, 887, 1025, 889, 1026, 888, 1274, 1602, 1601, 1600, 643, 644, 275, 276, 277, 645, 646, 647, 1490, 1276, 1275, 1027, 1603, 1604, 1285, 1612, 1613, 1614, 1491, 1291, 1615, 662, 663, 304, 302, 2021, 1623, 1624, 1832, 1833, 1306, 1052, 898, 1053, 1307, 1308, 1054, 1055, 1309, 899, 1056, 1310, 1312, 1057, 900, 854, 901, 1058, 1313, 1314, 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[Level 2: Approaching] After executing each algorithm, briefly write what you understood and what you thought.

The greedy algorithm sample code starts from the city with index 0 which is initialized in the variable *FIRST_IDX*. First, the algorithm function checks the distance from the current city to other cities by using the *euclidean_distances* function. Then it iteratively chooses the next city, which has the shortest distance from the current city while not included in the path. The next city is added to the path array *best_path*. After visiting all cities, the function adds the starting city into the last of the path array and calculates the overall cost, which is the total distance of the path, by the summation of the result array of the *path_cost* function.

The hill-climbing algorithm sample code initializes the solution with the greedy algorithm identical to the greedy algorithm sample code. After constructing a single solution, the *hill-climbing* function performs 'hill-climbing' with the 2-opt transformation function. In the *hill_climbing* function, the *two_opt* function is called *MAX_EVALUATION* times, which is the termination condition, and in the *two_opt* function, random choice of 2 cities in the path is performed *SUB_ITERATIONS* times. When a single random choice of 2 cities is made, a new path with flipped cities is made, and the evaluated cost is compared between the current path and the new path. After this 2-opt operation is performed *SUB_ITERATIONS* times, the new best path is returned to the *hill_climbing* function.

The simulated annealing algorithm sample code also initializes the solution with the greedy algorithm. After constructing a single solution, the *sa* function performs simulated annealing with 2-opt transformation by calling the *two_opt_swap* function. The initial part of the *two_opt_swap* function is identical to the 2-opt function of the hill-climbing algorithm sample code: randomly select and swap two cities and update the best path if the cost is smaller than the current path. After iterating the previous steps *SUB_ITERATIONS* times, the function then performs a 2-opt transformation using the global temperature parameter, which is initialized as 100. While the temperature is larger than *TEMP_LIMIT*, which is the termination condition, the newly generated path by random 2-opt swap transformation with a higher cost than the current path has a probability to be accepted. The acceptance probability is calculated as $1/\exp(\text{new_path_cost} - \text{current_path_cost})/\text{temperature}$. The temperature value decreases exponentially through iteration, $\text{temperature} = \text{COOLING_RATIO} * \text{temperature}$, where the *COOLING_RATIO* is initialized with a value of 0.5.

The greedy algorithm makes a single solution path, which is constructed by selecting the nearest neighbor city from the current city. This algorithm is very simple and fast, which takes much less time than HC, SA algorithms, and probably any other traditional exhaustive search algorithms. Thus, the greedy algorithm is used to initialize the hill-climbing and simulated annealing algorithm. The hill-climbing algorithm and simulated annealing algorithm show slightly better result costs than the greedy algorithm. But results showed that the simulated annealing algorithm doesn't always return a better solution than the hill-climbing algorithm by allowing a worse transformation of the solution. And the increase in the execution time was largest in the simulated annealing algorithm and smallest in the greedy algorithm.

(4.2) Execute and analyze Greedy, HC, and SA algorithm which you proposed.

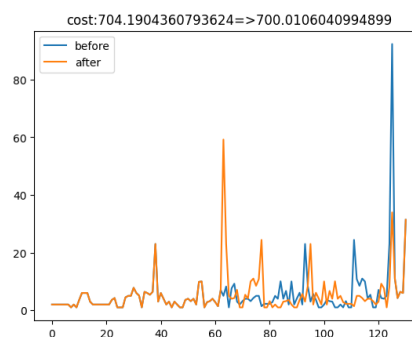
[Level 3: Proficient] Write your idea that can improve each sample algorithm, and briefly explain the reason with example.

First, the greedy algorithm has a problem: the algorithm doesn't know whether the single greedy selection leads to the global optimal path. While selecting the next city, the selected minimum distance is low in the early part, but the distance becomes much larger in the later part. To improve this, we can add a simple look-ahead technique to the greedy algorithm. We have an array of distances to other cities from the current city, and from this array, we can set some candidates to the next city which has the shortest distance. From these candidates, we can construct some limited length of look-ahead paths with a greedy algorithm and calculate its cost.

For instance, let's assume that an algorithm selects 2 candidates (city *a* and *b*) as the next city and calculates greedy paths (look-ahead) with length 3 for each candidate. When two candidate cities have the following look-ahead path with distances (*a*) 5-2-2, (*b*) 3-9-9, the greedy algorithm would have selected city *b* because the distance to city *b* is the smallest. But when calculating lookahead cost, city *a* has a cost value of 9 and city *b* 21. Then, the improved algorithm would select city *a* although the distance from the current city is not the minimum. In this way, the greedy algorithm can be improved.

Second, the sample code for the hill-climbing algorithm selects two cities randomly at the 2-opt transformation. The idea to improve this hill-climbing algorithm is to select the city with the largest distance value to transform. In the 2-opt function, from the largest distance city, make the 2-opt transformation for all cities in the path. After comparing all available transformations between the largest distance city and other cities, if the cost has decreased, return the new path and cost value. If the cost hasn't decreased, next, select the city with the second largest distance, and so on. We can repeat this 2-opt function for termination condition, timeout, or maximum iteration count. Also, when the 2-opt function returns the same path which has been given as an input path, then the hill-climbing algorithm can terminate. In this way, the largest distance in the solution path can be replaced with higher priority.

The below screenshot is the cost array of the path before(blue) and after(orange) the first 2-opt transformation of *data1.txt* of the improved hill-climbing algorithm. The blue line has a very high value at the last part of the path. After the first 2-opt transformation, the peak cost value has disappeared.



Lastly, the sample code of the simulated annealing algorithm simply repeats basic hill-climbing local search and fixed temperature and cooling simulated annealing with random 2-opt transformation. To improve this, we can make a modification to the temperature. First, initialize the temperature to the common constant value. Then for the basic hill-climbing local search loop, make a 2-opt transformation between the longest distance in the path and all other cities, which is the same as the improved hill-climbing algorithm. After performing the 2-opt transformation and evaluation for all cities, if the total cost has been reduced, then execute the simulated annealing with the temperature. But when the total cost has not been reduced, increase the temperature with the heating ratio, and make a 2-opt transformation between the second longest distance in the path and all other cities, and so on. This modification in the simple hill-climbing loop will make the temperature increase. When the longest distances in the path cannot be reduced, there will be more chance for a bad move to be allowed in the simulated annealing step. This may have an effect that some

bad moves allowed in the simulated annealing step can make the longest distance reduced in the next execution of the function.

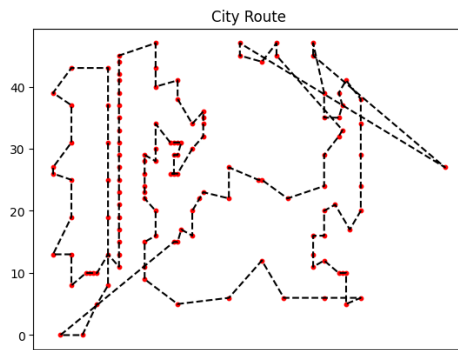
Next, for the simulated annealing step, we can divide the cooling ratio into 2 steps. When the temperature is lower than a threshold, which has a lower probability for a bad move to be allowed like the simple hill-climbing algorithm, apply a lower cooling ratio to decrease the temperature slowly. This means increased time for searching the local search space with a lower probability for the bad moves to be allowed, after the previously executed 2-opt transformation hill-climbing with the longest distances steps and high temperature simulated annealing phases.

Additionally, for all three algorithms, the first city index is chosen randomly, to prevent starting from the corner.

[Level 4: Exemplary] Write each execution result (Path Plot, Execution Time, Solution Path, Minimum Cost) for the provided input data.

1. Greedy Algorithm

1) Data 1



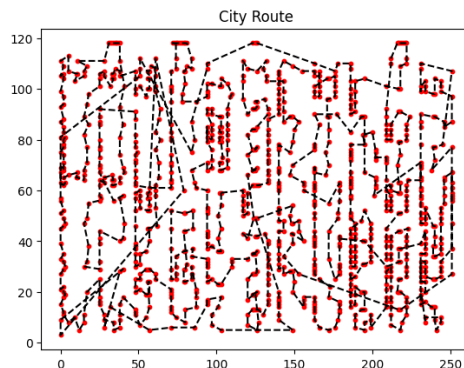
a) Path Plot:

b) Execution Time: 0.10836100578308105

c) Solution Path: [102, 103, 110, 109, 115, 119, 116, 121, 128, 127, 126, 125, 124, 123, 112, 106, 105, 101, 100, 99, 104, 113, 117, 120, 122, 129, 111, 97, 92, 88, 73, 52, 44, 45, 53, 54, 46, 47, 48, 49, 50, 51, 55, 56, 57, 62, 66, 70, 75, 69, 65, 64, 61, 68, 78, 82, 83, 84, 85, 79, 71, 72, 58, 59, 60, 43, 42, 41, 40, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 18, 16, 15, 14, 13, 11, 5, 0, 6, 7, 1, 2, 8, 9, 3, 10, 23, 22, 21, 20, 19, 24, 17, 12, 4, 63, 67, 74, 76, 77, 80, 81, 86, 87, 91, 93, 98, 107, 108, 114, 118, 95, 96, 94, 89, 90, 130, 102]

d) Cost: 656.9430935731139

2) Data 2



a) Path Plot:

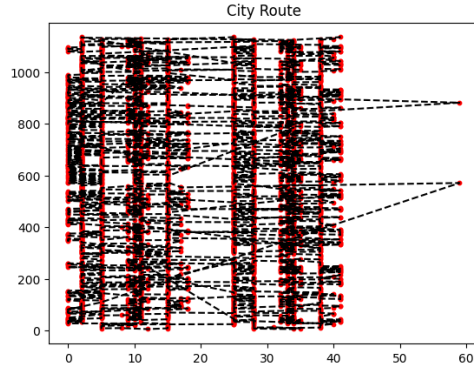
b) Execution Time: 0.3907790184020996

c) Solution Path: [248, 234, 233, 247, 246, 245, 232, 215, 216, 217, 218, 191, 190, 189, 188, 187, 186, 185, 184, 183, 182, 213, 214, 223, 242, 243, 231, 264, 257, 258, 259, 260, 265, 266, 261, 268, 262, 267, 269, 263, 251, 252, 253, 250, 237, 227, 226, 236, 235, 225, 224, 206, 173, 204, 174, 175, 148, 149, 144, 137, 131, 130, 136, 127, 118, 119, 91, 90, 89, 88, 84, 77, 87, 76, 83, 82, 74, 73, 72, 64, 61, 65, 56, 36, 52, 35, 12, 13, 14, 38, 37, 39, 40, 15, 41, 42, 43, 53, 44, 45, 17, 46, 19, 47, 48, 20, 21, 22, 0, 23, 1, 55, 54, 60, 62, 59, 67, 68, 78, 63, 121, 126, 128, 132, 138, 145, 146, 147, 152, 151, 170, 163, 169, 161, 160, 168, 172, 159, 158, 141, 133, 134, 142, 135, 124, 123, 105, 104, 103, 117, 102, 86, 81, 71, 85, 80, 70, 97, 98, 99, 100, 101, 155, 166, 171, 156, 167, 140, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 203, 202, 201, 200, 199, 205, 198, 197, 196, 195, 194, 193, 192, 249, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 270, 271, 272, 302, 303, 304, 300, 299, 309, 310, 311, 312, 316, 325, 334, 337, 336, 333, 324, 315, 323, 314, 313, 356, 386, 387, 388, 357, 389, 408, 419, 420, 436, 450, 446, 445, 444, 443, 442, 441, 440, 439, 438, 437, 428, 412, 413, 429, 435, 430, 414, 415, 431, 432, 416, 417, 433, 434, 418, 401, 402, 385, 384, 400, 399, 398, 397, 381, 382, 383, 380, 396, 395, 393, 378, 379, 342, 349, 355, 377, 376, 375, 374, 373, 372, 371, 370, 369, 392, 405, 410, 423, 406, 424, 407, 426, 427, 411, 460, 459, 458, 457, 456, 455, 468, 469, 470, 481, 491, 503, 518, 525, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 596, 597, 598, 599, 600, 561, 562, 563, 564, 565, 602, 621, 638, 649, 648, 690, 691, 689, 688, 696, 695, 686, 687, 647, 699, 702, 716, 715, 714, 721, 720, 712, 701, 700, 711, 710, 709, 698, 708, 697, 678, 679, 680, 677, 676, 675, 674, 673, 672, 671, 670, 669, 668, 667, 666, 665, 664, 663, 662, 661, 660, 659, 658, 657, 692, 713, 703, 730, 729, 728, 727, 726, 719, 706, 693, 684, 651, 652, 653, 654, 655, 656, 642, 641, 640, 639, 622, 632, 623, 617, 612, 603, 604, 573, 574, 575, 576, 577, 578, 579, 580, 606, 607, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 615, 630, 633, 637, 631, 620, 616, 608, 609, 610, 611, 601, 531, 532, 527, 533, 509, 462, 453, 452, 451, 461, 475, 485, 495, 507, 522, 523, 508, 530, 560, 559, 521, 506, 494, 484, 474, 483, 493, 505, 520, 473, 482, 492, 504, 519, 471, 490, 467, 454, 501, 515, 529, 545, 544, 543, 542,

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d) Cost: 4658.261504837338

3) Data 3



a) Path Plot:

b) Execution Time: 9.956009864807129

c) Solution Path: [1273, 1601, 1600, 1025, 887, 889, 1026, 890, 1274, 1602, 1990, 1991, 1992, 1989, 1988, 1986, 1985, 1984, 1983, 1982, 2347, 2348, 2349, 2350, 2591, 2742, 2995, 2994, 2741, 2590, 2740, 2993, 2992, 2739, 2738, 2991, 2990, 2737, 2736, 2989, 2988, 2735, 2734, 2987, 3214, 2589, 2733, 2986, 2985, 2732, 2588, 3213, 2984, 2731, 2587, 2586, 2730, 2983, 3212, 2982, 2729, 2728, 2585, 2981, 3211, 2980, 2727, 2726, 2979, 3315, 3316, 3563, 3564, 3317, 3318, 3565, 3566, 3319, 3567, 3568, 3320, 3321, 3569, 3570, 3322, 3323, 3324, 3325, 3326, 3327, 3328, 2997, 2592, 3215, 3329, 3331, 3332, 3333, 3334, 2999, 2595, 2746, 2594, 2744, 2593, 2353, 2354, 2355, 1994, 1995, 1996, 1997, 1998, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2014, 2368, 2367, 2366, 2365, 2363, 2362, 2361, 2360, 2359, 2358, 2357, 2596, 2749, 3002, 3001, 2748, 2747, 3000, 3336, 3337, 3338, 3005, 2752, 2597, 2751, 3004, 3006, 2753, 2754, 3007, 3008, 2755, 2598, 2599, 2756, 2609, 3010, 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d) Cost: 12664.63196243489

2. Hill-Climbing Algorithm

1) Data 1



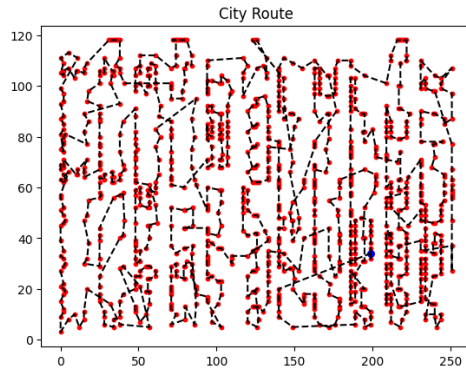
a) Path Plot:

b) Execution Time: 2.021566152572632

c) Solution Path: [123, 124, 125, 126, 108, 107, 112, 106, 105, 101, 100, 99, 104, 113, 117, 120, 129, 122, 111, 97, 92, 88, 73, 52, 44, 45, 28, 29, 30, 19, 27, 26, 25, 24, 17, 12, 4, 11, 13, 14, 15, 16, 18, 5, 0, 6, 7, 1, 2, 8, 9, 3, 10, 23, 22, 21, 20, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 60, 59, 58, 72, 71, 79, 85, 84, 83, 82, 78, 68, 64, 61, 65, 69, 75, 70, 66, 62, 57, 56, 55, 51, 50, 49, 48, 47, 46, 54, 53, 63, 67, 74, 76, 77, 80, 81, 86, 87, 91, 93, 98, 89, 90, 94, 95, 96, 103, 102, 110, 109, 114, 118, 115, 119, 116, 121, 128, 127, 130, 123]

d) Cost: 589.5235378560776

2) Data 2



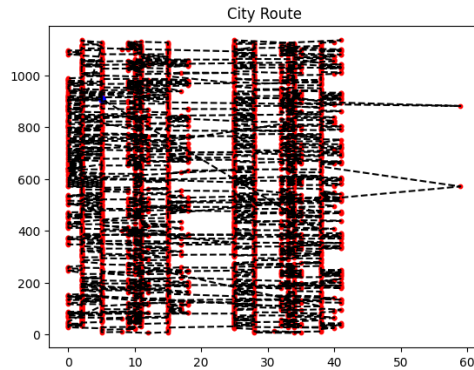
a) Path Plot:

b) Execution Time: 58.390592098236084

c) Solution Path: [829, 828, 830, 831, 832, 833, 834, 835, 807, 799, 798, 797, 796, 795, 794, 793, 792, 791, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 743, 744, 785, 804, 803, 802, 808, 814, 826, 825, 813, 823, 838, 847, 846, 845, 844, 905, 932, 931, 916, 915, 930, 958, 959, 965, 994, 993, 992, 991, 990, 989, 988, 987, 986, 985, 984, 1018, 1017, 1016, 1015, 1014, 1013, 1012, 1011, 1010, 1034, 1025, 1026, 1035, 1036, 1054, 1053, 1052, 1051, 1050, 1049, 1048, 1047, 1033, 1024, 1019, 1000, 1044, 1059, 1043, 1041, 1032, 1023, 1021, 1003, 1004, 1005, 1006, 1007, 1008, 1009, 978, 977, 976, 975, 974, 973, 972, 971, 970, 922, 908, 883, 884, 885, 886, 856, 855, 854, 853, 852, 849, 850, 851, 882, 881, 880, 877, 898, 928, 936, 939, 943, 944, 945, 923, 904, 909, 910, 924, 946, 947, 948, 949, 950, 951, 952, 953, 927, 913, 914, 929, 954, 955, 956, 957, 865, 864, 863, 862, 889, 890, 891, 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d) Cost: 4292.22047590145

3) Data 3



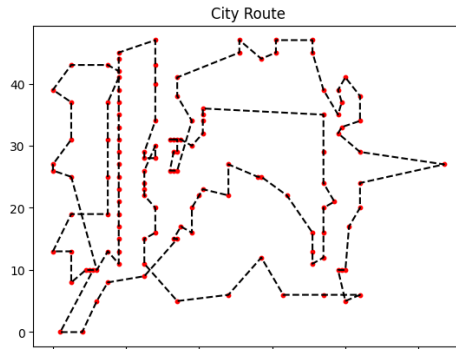
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b) Execution Time: 58.94817566871643

c) Solution Path: [825, 824, 523, 151, 152, 153, 525, 826, 827, 828, 829, 830, 831, 528, 158, 159, 160, 157, 156, 155, 154, 526, 1183, 1456, 1756, 1757, 1758, 1759, 1522, 1457, 1184, 1760, 1761, 1762, 1763, 1459, 1186, 1460, 1458, 1185, 833, 834, 835, 836, 532, 533, 162, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 547, 166, 165, 164, 163, 838, 837, 1188, 1462, 1461, 1187, 1764, 1765, 1463, 957, 958, 1189, 1464, 1465, 1190, 959, 1191, 1466, 1468, 1193, 960, 1523, 1767, 1880, 1881, 1882, 1883, 1769, 1768, 1524, 1469, 1194, 961, 962, 1195, 1470, 1471, 1196, 1197, 963, 1472, 1525, 1771, 1884, 1885, 1772, 1773, 1526, 1474, 1199, 964, 1198, 1473, 1527, 1774, 1887, 1886, 1775, 1475, 850, 849, 848, 847, 553, 554, 171, 172, 173, 174, 175, 176, 557, 558, 559, 851, 852, 560, 561, 562, 563, 180, 181, 182, 183, 184, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 569, 568, 567, 566, 858, 970, 1207, 1206, 969, 857, 1205, 1204, 968, 967, 1203, 1532, 1533, 1534, 1535, 1209, 971, 859, 972, 1210, 1211, 1477, 973, 860, 861, 974, 1212, 1478, 1537, 1805, 1804, 1536, 1806, 1807, 1538, 1539, 1540, 1214, 976, 863, 977, 1215, 1216, 978, 864, 1479, 1541, 1808, 1809, 1810, 1811, 1543, 1545, 1546, 1547, 1220, 1481, 1221, 1548, 1223, 1224, 983, 984, 1225, 1226, 1227, 985, 1228, 986, 866, 853, 987, 1229, 1230, 988, 989, 867, 1231, 1232, 868, 990, 1233, 869, 991, 870, 992, 871, 1235, 1565, 1564, 1563, 1562, 1561, 1560, 1559, 1558, 1557, 1556, 1555, 1554, 1552, 1551, 1550, 1549, 583, 584, 585, 586, 588, 589, 590, 591, 592, 213, 4, 3, 2, 1, 212, 211, 0, 209, 208, 582, 581, 580, 579, 578, 577, 206, 207, 204, 576, 575, 574, 573, 572, 571, 198, 199, 200, 202, 203, 865, 979, 1217, 1480, 1542, 1218, 980, 981, 1219, 1910, 1909, 1908, 1907, 1906, 1905, 1904, 1903, 2286, 2287, 2285, 2284, 2283, 2282, 2280, 2279, 2278, 1899, 1900, 1902, 2567, 2690, 2931, 3201, 2930, 2689, 2688, 2929, 2928, 3200, 2687, 2566, 2565, 2686, 2927, 3199, 2926, 2685, 2684, 2925, 2923, 2682, 2681, 2563, 2922, 2921, 3198, 2680, 2562, 2271, 2272, 1891, 1892, 1894, 1895, 1896, 1897, 2276, 2275, 2274, 2273, 2277, 1898, 3268, 3536, 3535, 3267, 3266, 3265, 3264, 3263, 3534, 3533, 3500, 3262, 3261, 2920, 2679, 3197, 3196, 2919, 2678, 2918, 3195, 3194, 2917, 2916, 3193, 3192, 2915, 2913, 3190, 2677, 2676, 3189, 3491, 3490, 3489, 3488, 3487, 3186, 3187, 3188, 2912, 2549, 2550, 2256, 2257, 2258, 2259, 2260, 2262, 2263, 2264, 2553, 2554, 2555, 2557, 2558, 2559, 2560, 2269, 2270, 1889, 1888, 2268, 2267, 2266, 2265, 2552, 2551, 3493, 3494, 3495, 3496, 3498, 3499, 3492, 2548, 2547, 2546, 2254, 2253, 2544, 2543, 2674, 2911, 2675, 3185, 3485, 3484, 3483, 3260, 3184, 2909, 2908, 3183, 3182, 3259, 2907, 2672, 2670, 2905, 3180, 3257, 3179, 2904, 2903, 3178, 3256, 3177, 2902, 2669, 2535, 2534, 2533, 2244, 2245, 2246, 2247, 2248, 2537, 2536, 2538, 2250, 2251, 2252, 2541, 2540, 2539, 2542, 2673, 2910, 3482, 3481, 3480, 3644, 3643, 3642, 3641, 3479, 3478, 3477, 3640, 3639, 3476, 3475, 3474, 3638, 3637, 3473, 3472, 3636, 3635, 3471, 3254, 3173, 2898, 2667, 2897, 3172, 3171, 2896, 2666, 2895, 3170, 3169, 3253, 2894, 2665, 2893, 3168, 3468, 3531, 3530, 3467, 3466, 3165, 2890, 2889, 2663, 3164, 3163, 2888, 2887, 3162, 3161, 2886, 2885, 3160, 3159, 3252, 2884, 2662, 2661, 3158, 3460, 3631, 3632, 3461, 3462, 3463, 3464, 3465, 3166, 2891, 2892, 2664, 3167, 2524, 2525, 2229, 2228, 2227, 2226, 2225, 2224, 2223, 2222, 2220, 2519, 2518, 2517, 2212, 2217, 2216, 2215, 2214, 2516, 2515, 2513, 2213, 2512, 2211, 2210, 2209, 2511, 2510, 2509, 2207, 2208, 2206, 2205, 2507, 2204, 2203, 2202, 2201, 2200, 2198, 2197, 2196, 2195, 2194, 2505, 2504, 2502, 2501, 2191, 2192, 2193, 2190, 2189, 2187, 2186, 2185, 2497, 2498, 2499, 2500, 2658, 2872, 3144, 3251, 3142, 2870, 2869, 3141, 3140, 2868, 2657, 2656, 2867, 3139, 3249,

3. Simulated Annealing Algorithm

1) Data 1



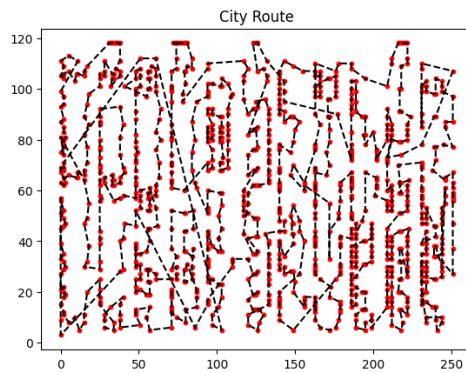
a) Path Plot:

b) Execution Time: 1.504441738128662

c) Solution Path: [7, 1, 2, 8, 9, 3, 10, 23, 41, 40, 22, 21, 20, 19, 6, 0, 5, 11, 13, 14, 15, 4, 12, 17, 24, 52, 67, 63, 74, 76, 77, 80, 81, 86, 87, 91, 93, 98, 101, 100, 99, 104, 105, 106, 112, 107, 108, 109, 85, 84, 83, 82, 78, 75, 62, 66, 70, 69, 65, 61, 64, 68, 79, 71, 72, 89, 90, 94, 95, 96, 103, 102, 110, 115, 119, 116, 121, 128, 127, 118, 114, 126, 130, 125, 124, 123, 120, 117, 113, 122, 129, 111, 97, 92, 88, 73, 44, 45, 53, 54, 46, 47, 48, 49, 56, 55, 50, 51, 57, 58, 59, 60, 43, 42, 39, 38, 37, 36, 35, 34, 33, 32, 31, 30, 29, 28, 27, 26, 25, 18, 16, 7]

d) Cost: 656.838964184765

2) Data 2



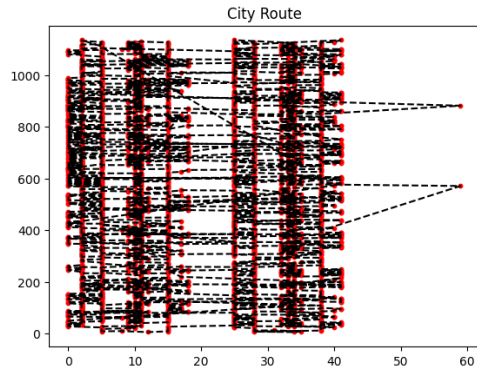
a) Path Plot:

b) Execution Time: 58.14745497703552

c) Solution Path: [39, 38, 37, 14, 13, 36, 52, 35, 12, 56, 61, 64, 65, 73, 74, 82, 83, 76, 87, 77, 84, 88, 89, 90, 91, 118, 119, 121, 131, 137, 136, 130, 127, 148, 149, 144, 151, 152, 147, 146, 145, 138, 132, 128, 126, 78, 68, 67, 62, 60, 59, 54, 22, 21, 0, 23, 1, 55, 63, 20, 48, 47, 19, 46, 17, 45, 44, 53, 43, 42, 41, 15, 40, 16, 72, 86, 81, 71, 85, 80, 70, 97, 98, 99, 100, 101, 102, 117, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 163, 169, 161, 160, 168, 172, 159, 158, 141, 133, 134, 142, 135, 124, 123, 140, 156, 167, 190, 191, 192, 193, 194, 195, 196, 197, 198, 205, 199, 200, 201, 202, 203, 204, 173, 206, 207, 208, 175, 174, 170, 224, 225, 235, 236, 226, 227, 237, 250, 253, 252, 251, 263, 269, 267, 262, 268, 261, 266, 265, 260, 259, 258, 248, 234, 233, 247, 246, 245, 232, 215, 216, 217, 218, 249, 257, 264, 243, 231, 242, 223, 214, 184, 185, 186, 187, 183, 182, 213, 212, 211, 181, 180, 179, 210, 221, 228, 239, 240, 229, 230, 241, 222, 256, 255, 280, 305, 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d) Cost: 4502.059269496778

3) Data 3



a) Path Plot:

b) Execution Time: 58.71691608428955

c) Solution Path: [2845, 3111, 3112, 2846, 2847, 3113, 3114, 2848, 2646, 3243, 3425, 3424, 3423, 3422, 3242, 3110, 3420, 3419, 3614, 3613, 3418, 3417, 3612, 3611, 3520, 3416, 3415, 3103, 2839, 2840, 3104, 3105, 3240, 2841, 2643, 2842, 3106, 3107, 2843, 2644, 3241, 3109, 2645, 2466, 2142, 2143, 2144, 2145, 2467, 2469, 2470, 2471, 2472, 2149, 2148, 2147, 2146, 1852, 1851, 1699, 1700, 1506, 1396, 1127, 927, 1126, 1395, 1394, 1505, 1125, 926, 1393, 925, 1392, 1697, 1850, 1849, 1504, 1391, 1124, 923, 922, 1123, 1390, 1389, 1122, 921, 920, 1121, 1387, 1386, 1120, 919, 1119, 1385, 1384, 1118, 1117, 1383, 1382, 1116, 1115, 1381, 1380, 1114, 1113, 1379, 1689, 1691, 1692, 1693, 1694, 1695, 1696, 756, 755, 754, 753, 752, 751, 749, 415, 416, 82, 83, 417, 418, 84, 419, 420, 422, 86, 423, 424, 425, 426, 427, 87, 428, 429, 430, 431, 88, 433, 434, 435, 436, 90, 437, 762, 763, 764, 439, 440, 91, 442, 443, 444, 93, 766, 765, 928, 1128, 1397, 1701, 1854, 1853, 1855, 1856, 1703, 1507, 1398, 1129, 929, 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d) Cost: 12272.582693516399