Evolutionary Computation
Greedy Heuristics Report

Authors and Source Code

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- **Source Code Repository:** https://github.com/MZmuda-Trzebiatowski/Evolutionary-Computiation

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Problem Description

The problem involves a set of nodes, each defined by three columns of integers:

1. **X-coordinate**
2. **Y-coordinate**
3. **Node Cost**

The goal is to select exactly 50% of the nodes (rounding up if the total number of nodes is odd) and form a Hamiltonian cycle (a closed path) through the selected set. The objective is to minimize the total sum of the path length plus the total cost of the selected nodes.

- Distance Calculation: Distances are calculated as Euclidean distances, mathematically rounded to integer values.
- Optimization Constraint: A distance matrix must be calculated immediately after reading an instance. The optimization methods should only access this distance matrix, not the original node coordinates.

Implemented Algorithms (pseudocode)

N - # of nodes

K - # of nodes to be selected

1. **Random algorithm**

   A simple non-deterministic baseline.

   1. Initialize a list of all node indices (0 to N-1).
   2. Randomly shuffle this list.
   3. Select the first K elements from the shuffled list to form the tour.

2. **Nearest Neighbour end-only**

```
Initialize n ← size(d).

Initialize an empty list path and a boolean array used of size n ← false.

Add start_node to path and set used[start_node] ← true.

While |path| < k do
    a. Set best_node ← -1 and best_value ← ∞.
    b. Let current ← last element of path.
    c. For each node cand from 0 to n - 1 do
        If used[cand] = false then
            Compute val ← d[current][cand] + nodes[cand].cost.
            If val < best_value then
                best_value ← val
                best_node ← cand
    d. If best_node = -1, then break.
    e. Add best_node to path and set used[best_node] ← true.

Return path.
```

3. **Nearest Neighbour all-positions**

```
Initialize an empty list path and a boolean array used of size n ← false.

Add start_node to path and set used[start_node] ← true.

While |path| < k do
    a. Set next_node ← -1, best_position ← -1, and best_value ← ∞.
    b. For each unused node cand do
        Compute val ← d[cand][path[0]] + nodes[cand].cost.
        If val < best_value then
            best_value ← val
            next_node ← cand
    c. For each index i in path do
        Let after ← path[i] and before ← path[(i + 1) mod |path|].
        For each unused node cand do
            Compute val ← d[after][cand] + nodes[cand].cost +
d[cand][before] - d[after][before].
            If val < best_value then
                best_value ← val
                next_node ← cand
                best_position ← i
    d. Insert next_node into path after position best_position.
    e. Set used[next_node] ← true.

Return path.
```

4. **Greedy Cycle**

```
Initialize n ← size(d).

Initialize an empty list cycle and a boolean array used of size n ← false.

Add start_node to cycle and set used[start_node] ← true.

Select the second node:
    a. Set best_second ← -1 and best_value ← ∞.
    b. For each unused node cand do
        Compute val ← d[start_node][cand] + nodes[cand].cost.
        If val < best_value then
            best_value ← val
            best_second ← cand
    c. Add best_second to cycle and set used[best_second] ← true.

While |cycle| < k do
    a. Set next_node ← -1, best_position ← 0, and best_value ← ∞.
    b. Let c_size ← |cycle|.
    c. For each index i in cycle do
        Let after ← cycle[i] and before ← cycle[(i + 1) mod c_size].
        Set local_best ← ∞, local_node ← -1.
        For each unused node cand do
            Compute val ← d[after][cand] + nodes[cand].cost +
d[cand][before].
            If c_size > 2, then val ← val - d[after][before].
            If val < local_best then
                local_best ← val
                local_node ← cand
        If local_best < best_value then
            best_value ← local_best
            next_node ← local_node
            best_position ← i
    d. Insert next_node into cycle after position best_position.
    e. Set used[next_node] ← true.

Return cycle.
```

5. Nearest Neighbour all-positions with weighted 2-regret

```
Initialize n ← size(d).

Initialize an empty list path and a boolean array used of size n ← false.

Add start_node to path and set used[start_node] ← true.

While |path| < k do
    a. Initialize an empty list ranking.
    b. For each unused node i do
        i. Set best_first_val ← d[i][path[0]] + nodes[i].cost, best_first_pos ← 0.
        ii. Set best_second_val ← ∞, best_second_pos ← 0.
        iii. Let c_size ← |path|.
        iv. For each position pos from 1 to c_size - 1 do
            Compute
            val ← d[path[pos - 1]][i] + d[path[pos]][i] - d[path[pos - 1]][path[pos]] + nodes[i].cost.
            If val < best_first_val then
                Set best_second_val ← best_first_val, best_second_pos ← best_first_pos,
                best_first_val ← val, best_first_pos ← pos.
            Else if val < best_second_val then
                Set best_second_val ← val, best_second_pos ← pos.
        v. Compute end_val ← d[path[c_size - 1]][i] + nodes[i].cost.
        vi. If end_val < best_first_val then
            Set best_second_val ← best_first_val, best_second_pos ← best_first_pos,
            best_first_val ← end_val, best_first_pos ← c_size.
          Else if end_val < best_second_val then
            Set best_second_val ← end_val, best_second_pos ← c_size.
        vii. Add entry {i, best_first_pos, best_first_val, best_second_pos, best_second_val} to ranking.
    c. Set best_score ← -∞, best_node ← 0, best_pos ← 0.
    d. For each entry in ranking do
        Compute score ← w1 × (entry.second_val - entry.first_val) - w2 × entry.first_val.
        If score > best_score then
            best_score ← score, best_node ← entry.node, best_pos ← entry.first_pos.
    e. Insert best_node into path at position best_pos.
    f. Set used[best_node] ← true.

Return path.
```

6. Greedy Cycle with weighted 2-regret

```
Initialize n ← size(d).

Initialize an empty list cycle and a boolean array used of size n ← false.

Add start_node to cycle and set used[start_node] ← true.

Select the second node:
    a. Set best_second ← -1 and best_value ← ∞.
    b. For each unused node cand do
        Compute val ← d[start_node][cand] + nodes[cand].cost.
        If val < best_value then
            best_value ← val
            best_second ← cand.
    c. Add best_second to cycle and set used[best_second] ← true.

While |cycle| < k do
    a. Initialize an empty list ranking.
    b. For each unused node i do
        i. Set best_first_val ← ∞, best_second_val ← ∞.
        ii. Set best_first_pos ← 0, best_second_pos ← 0.
        iii. Let c_size ← |cycle|.
        iv. For each position pos from 1 to c_size do
            Compute
            val ← d[cycle[pos - 1]][i] + d[cycle[pos mod c_size]][i] + nodes[i].cost.
            If c_size > 2, then
                val ← val - d[cycle[pos - 1]][cycle[pos mod c_size]].
            If val < best_first_val then
                Set best_second_val ← best_first_val, best_second_pos ← best_first_pos,
                best_first_val ← val, best_first_pos ← pos.
            Else if val < best_second_val then
                Set best_second_val ← val, best_second_pos ← pos.
        v. Add entry {i, best_first_pos, best_first_val, best_second_pos, best_second_val} to ranking.
    c. Set best_score ← -∞, best_node ← 0, best_pos ← 0.
    d. For each entry in ranking do
        Compute
        score ← w1 × (entry.second_val - entry.first_val) - w2 × entry.first_val.
        If score > best_score then
            best_score ← score, best_node ← entry.node, best_pos ← entry.first_pos.
    e. Insert best_node into cycle at position best_pos.
    f. Set used[best_node] ← true.

Return cycle.
```

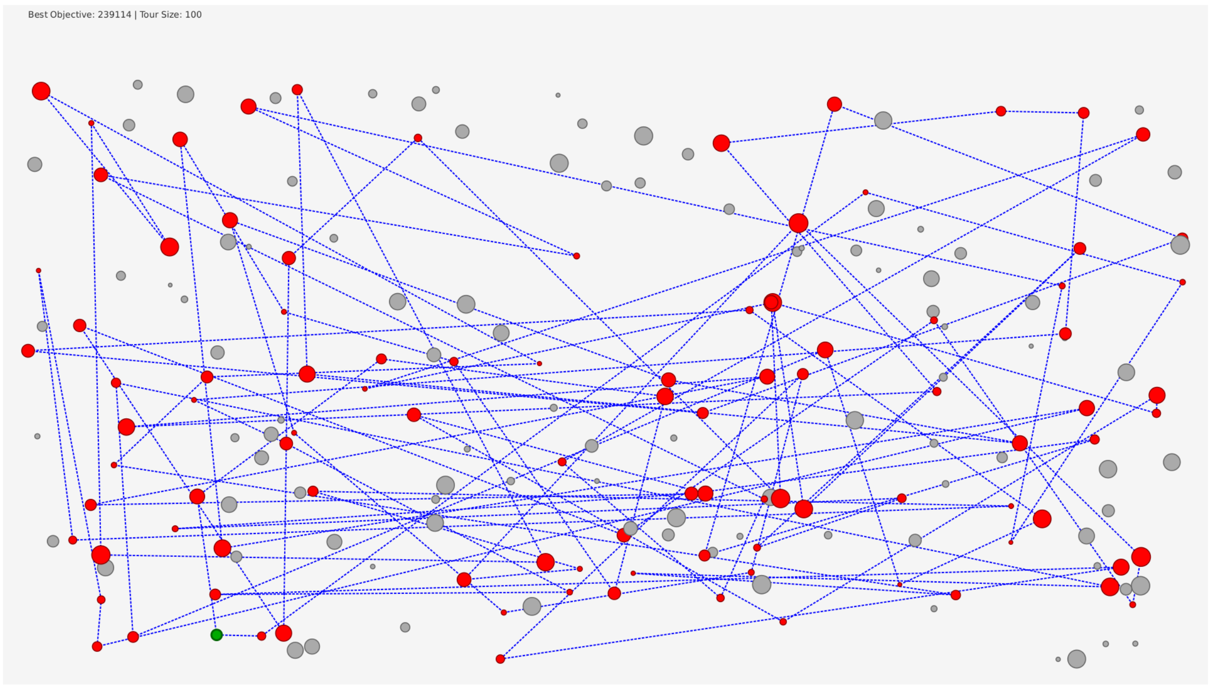
Results and Analysis

Algorithm	Instance A			Instance B		
	Min	Max	Avg	Min	Max	Avg
Random	239114	291474	264152	185581	238526	212540
NN end-only	83182	89433	85108.5	52319	59030	54390.4
NN all-pos	71695	75953	73302.4	44242	57283	48498.9
Greedy Cycle	71488	74410	72617.6	48765	57324	51339.5
NN all-pos 2-regret	108151	124921	117138	69933	80278	74444.5
Greedy Cycle 2-regret	105692	126951	115579	67809	78406	72740
NN all-pos 2-regret weighted (0.5, 0.5)	70010	75452	72401.2	44891	55247	47664.5
Greedy Cycle 2-regret weighted (0.5, 0.5)	71108	73395	72129.7	47144	55700	50897.1

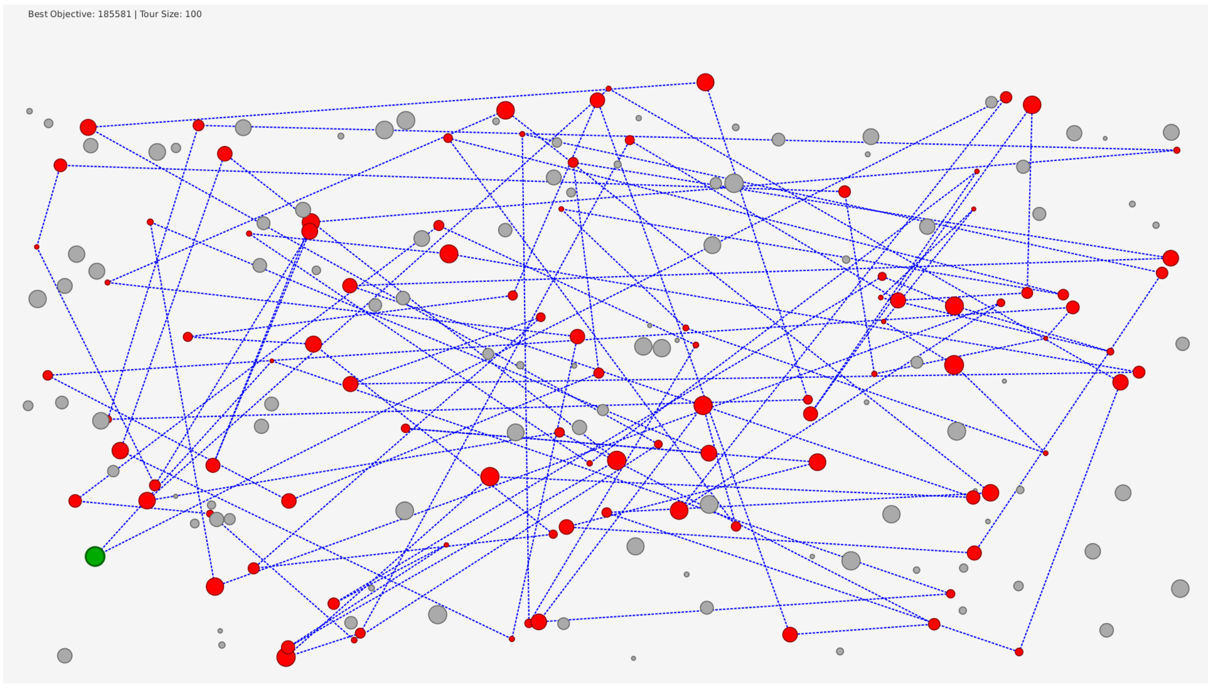
Visual Comparisons (Visual Comparision)

Size of the dot corresponds to it’s cost (the bigger it is the bigger the cost), and the green dot is the starting node.

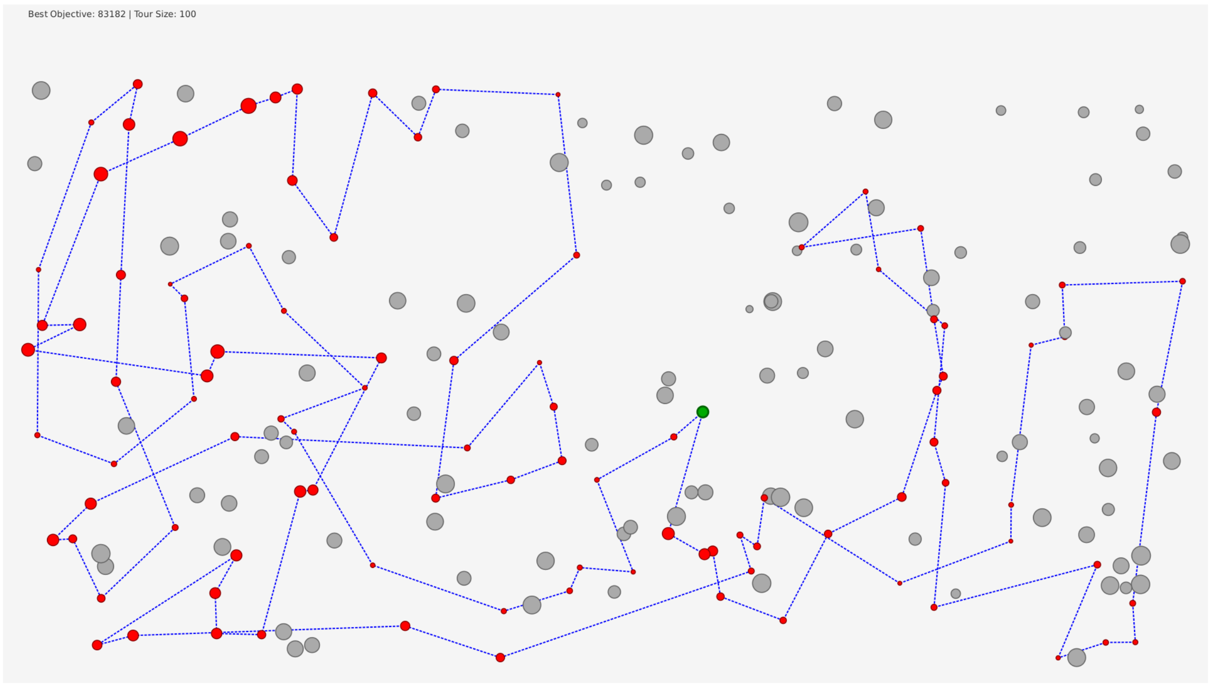
- Random algorithm
    - Instance A:



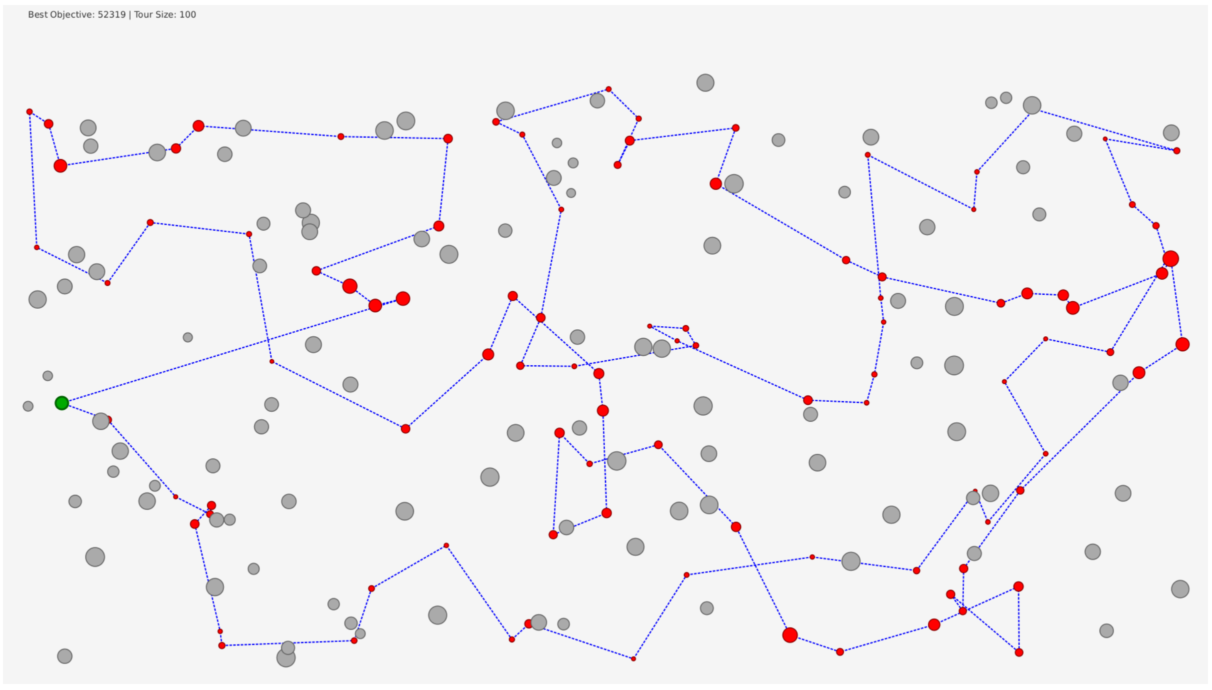
    - Instance B:



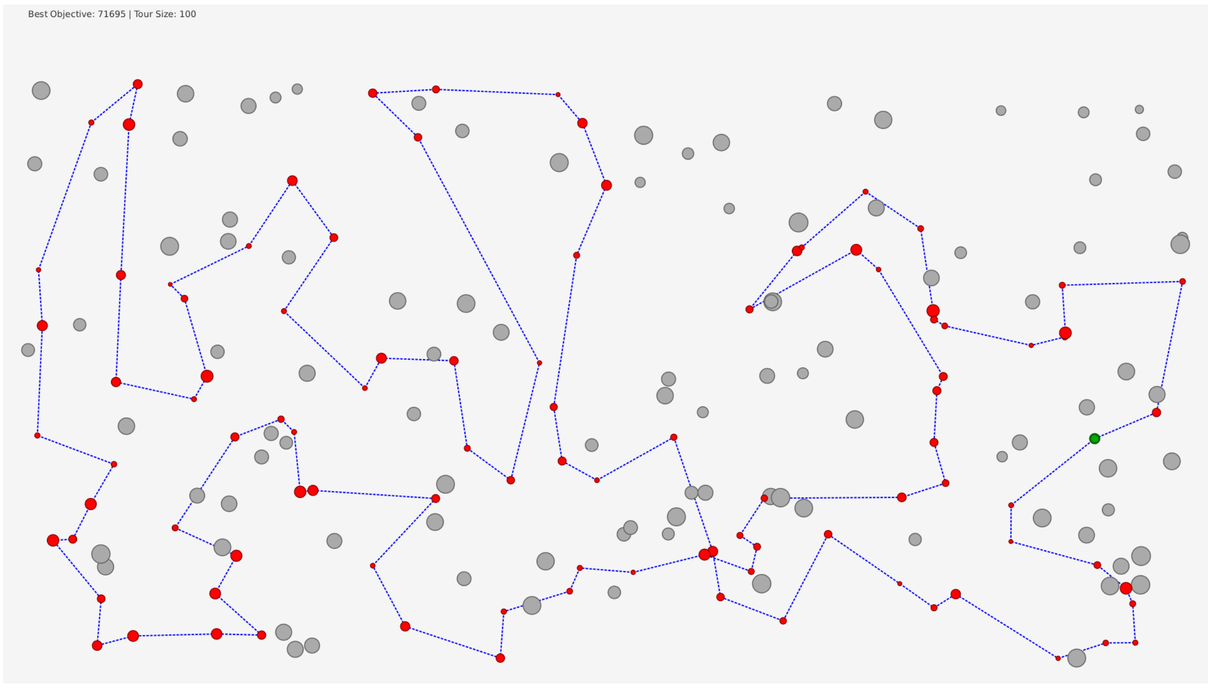
- Nearest Neighbour end-only
    - Instance A:



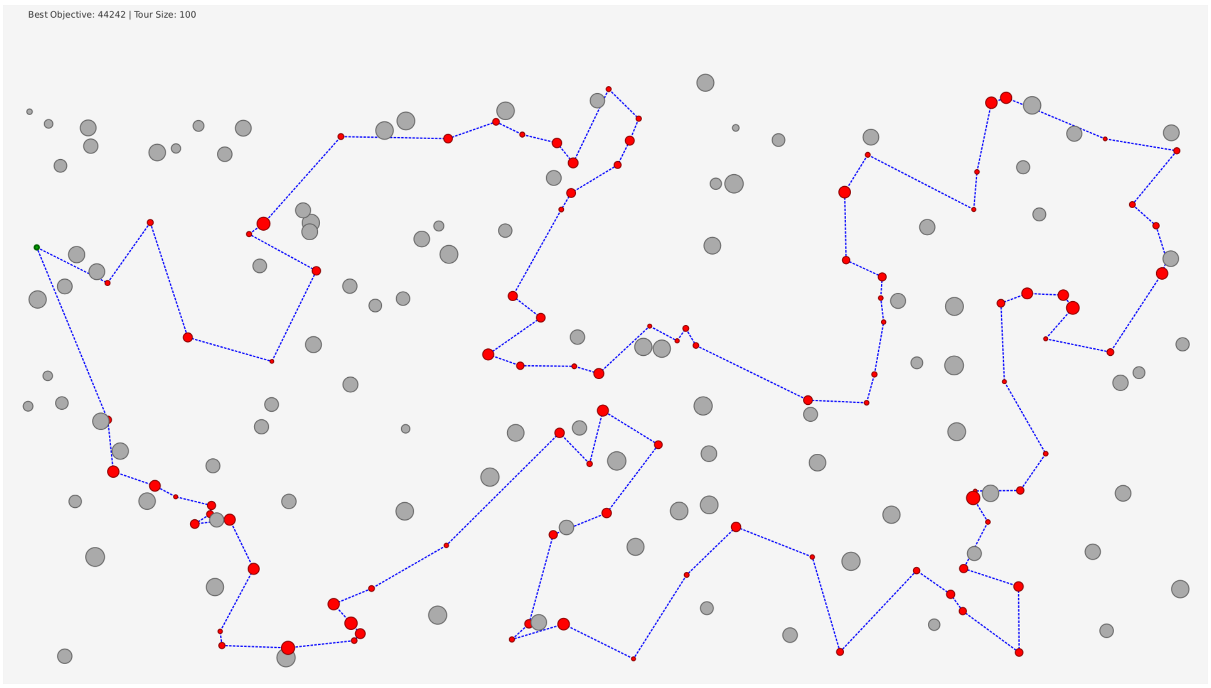
    - Instance B:



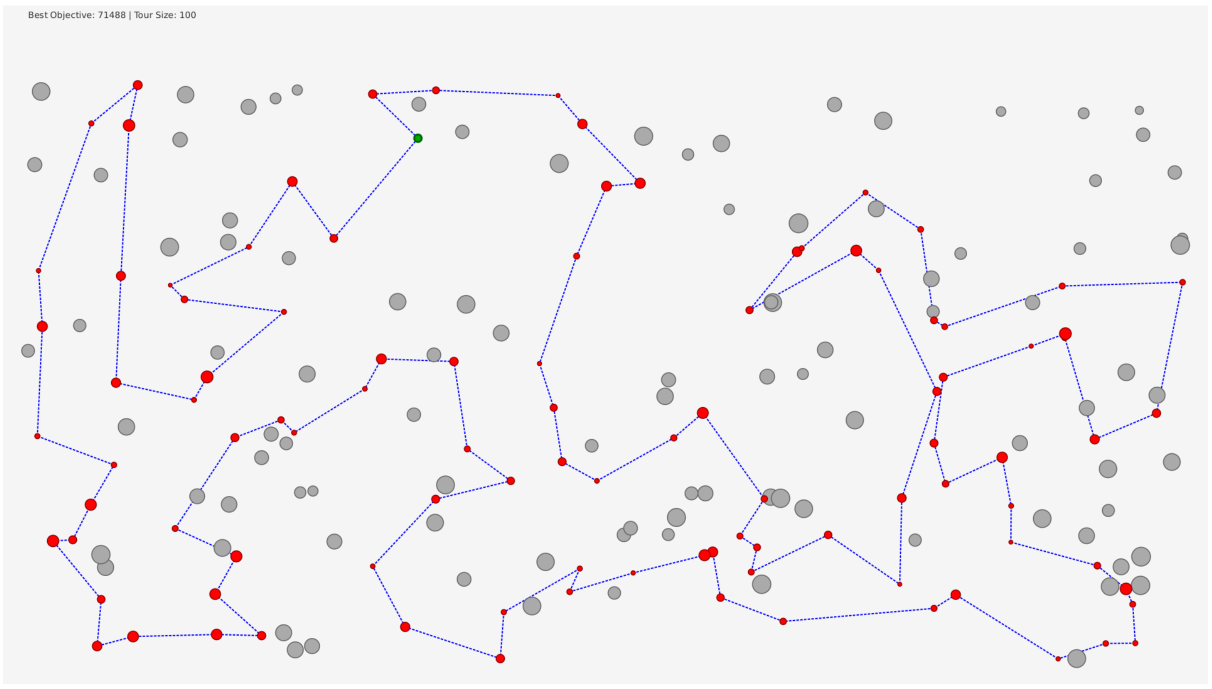
- Nearest Neighbour all-positions
    - Instance A:



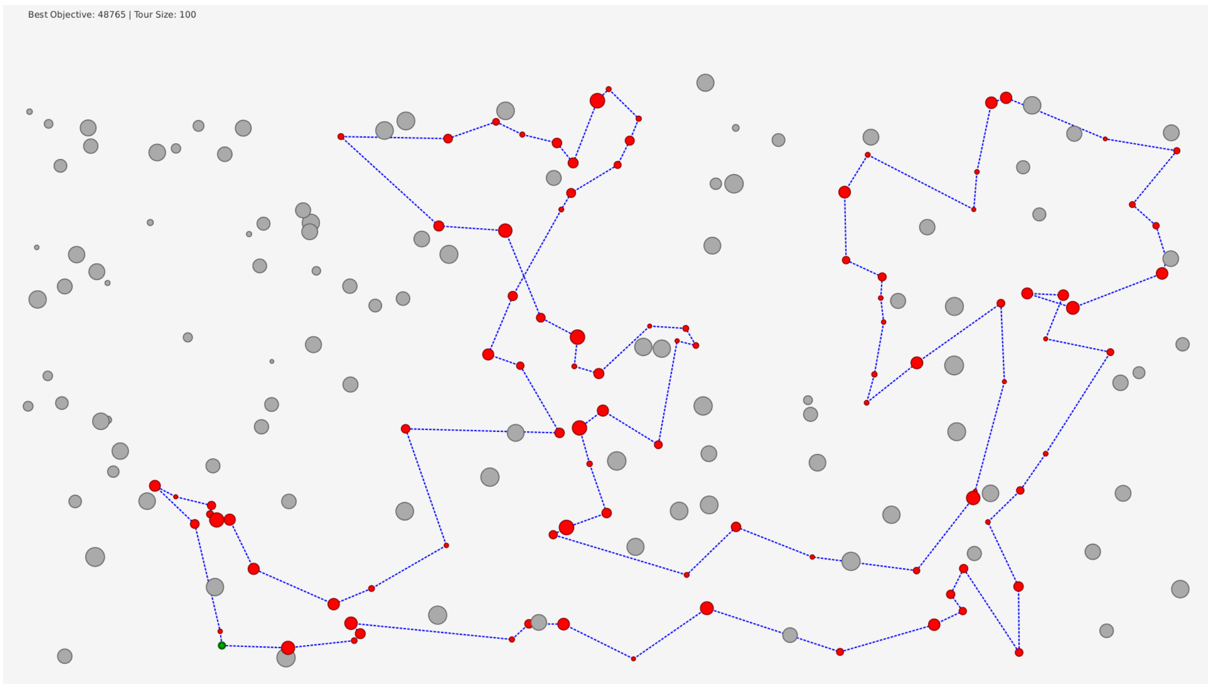
    - Instance B:



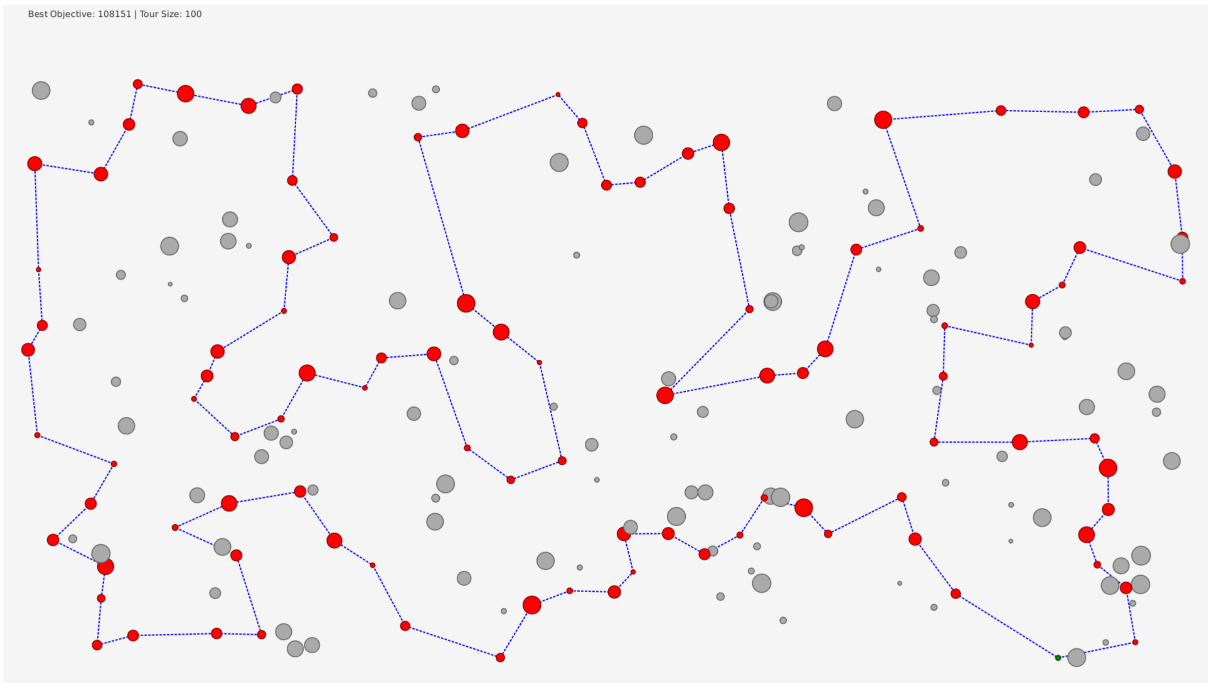
- Greedy Cycle
  - Instance A:



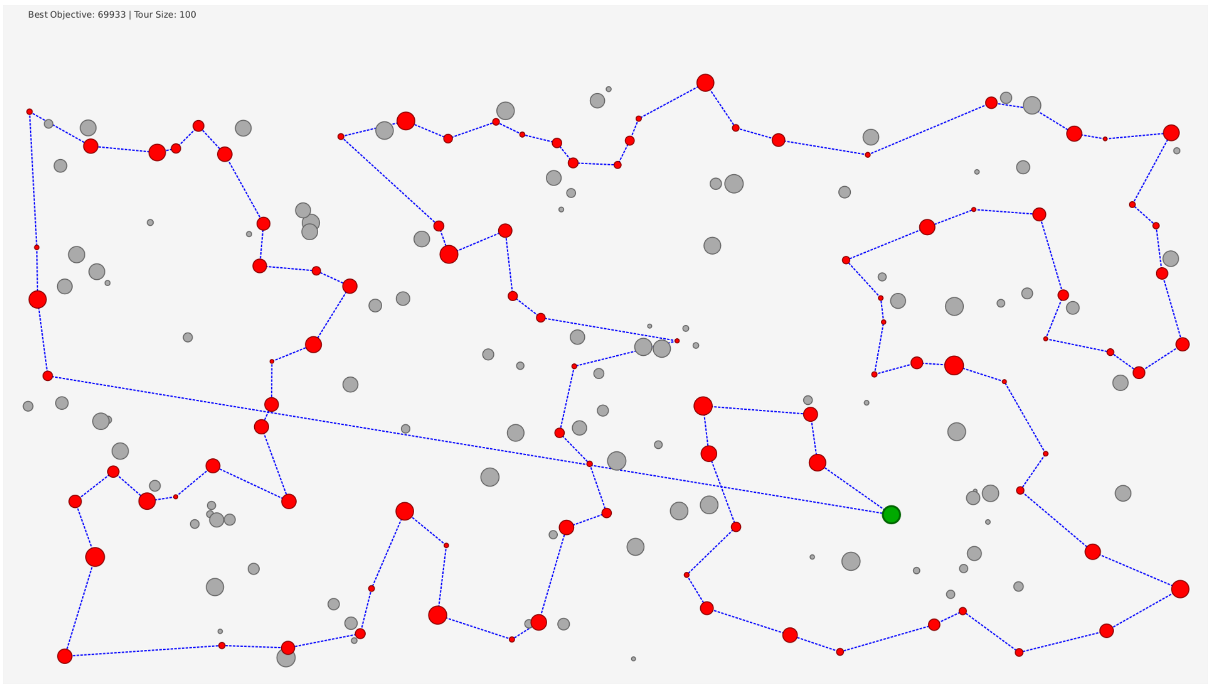
  - Instance B:



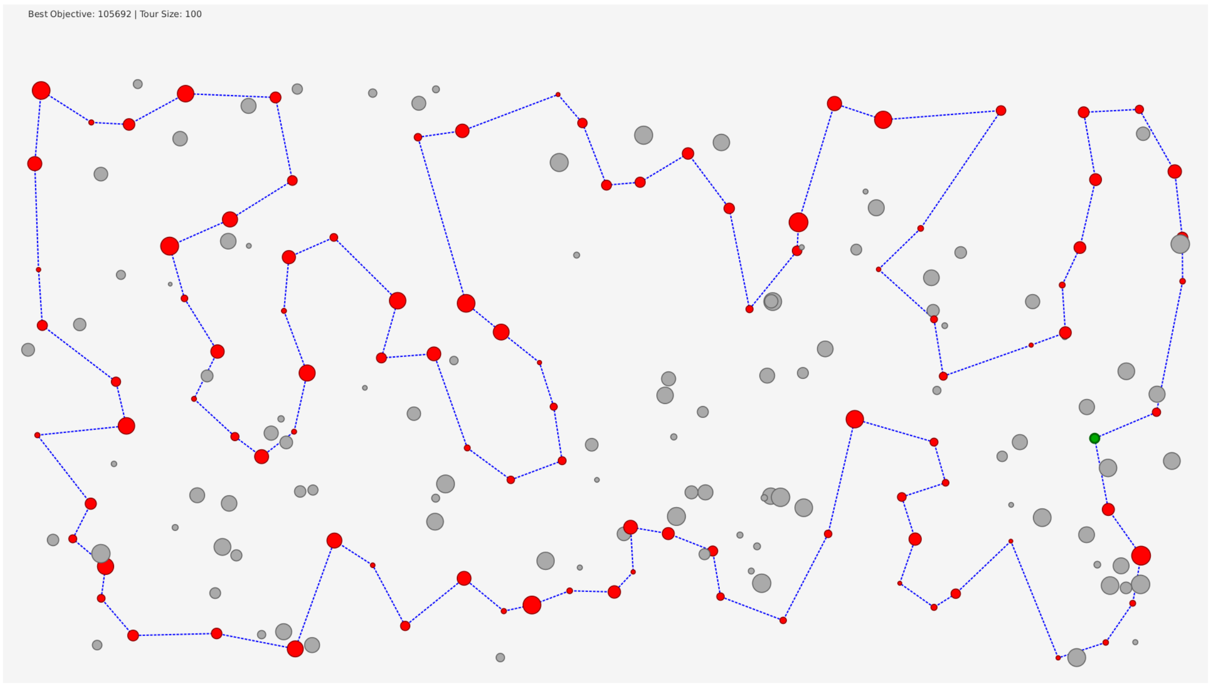
- Nearest Neighbour all-positions with 2-regret
    - Instance A:



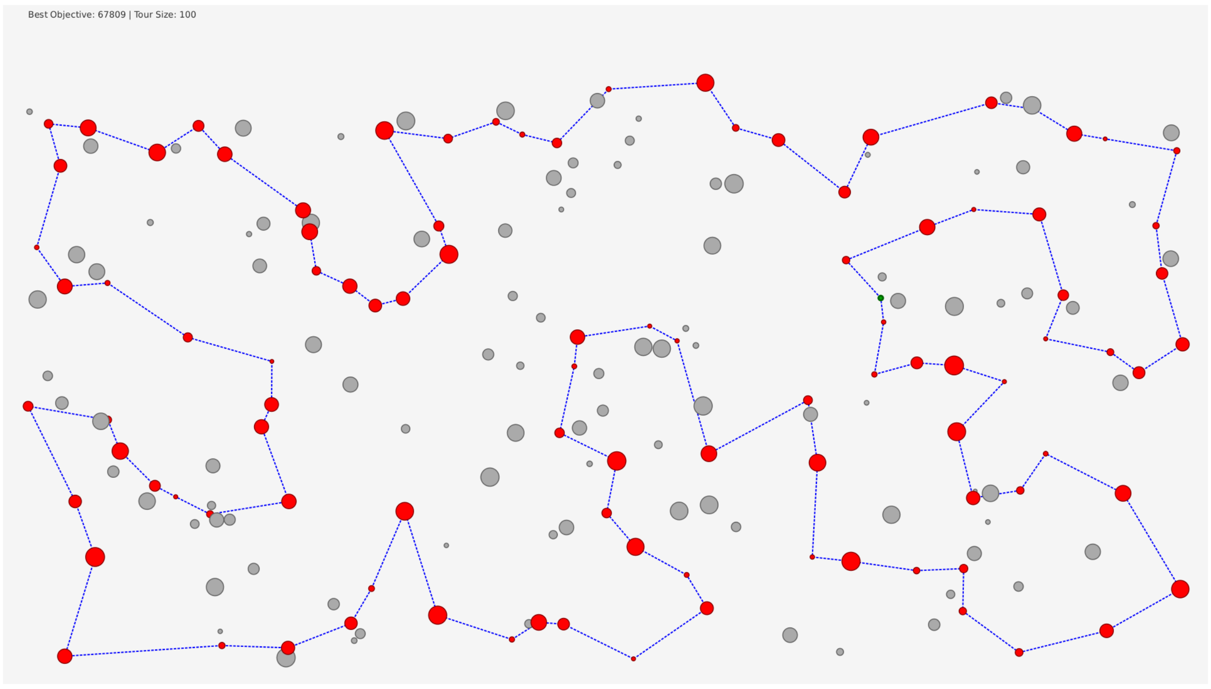
    - Instance B:



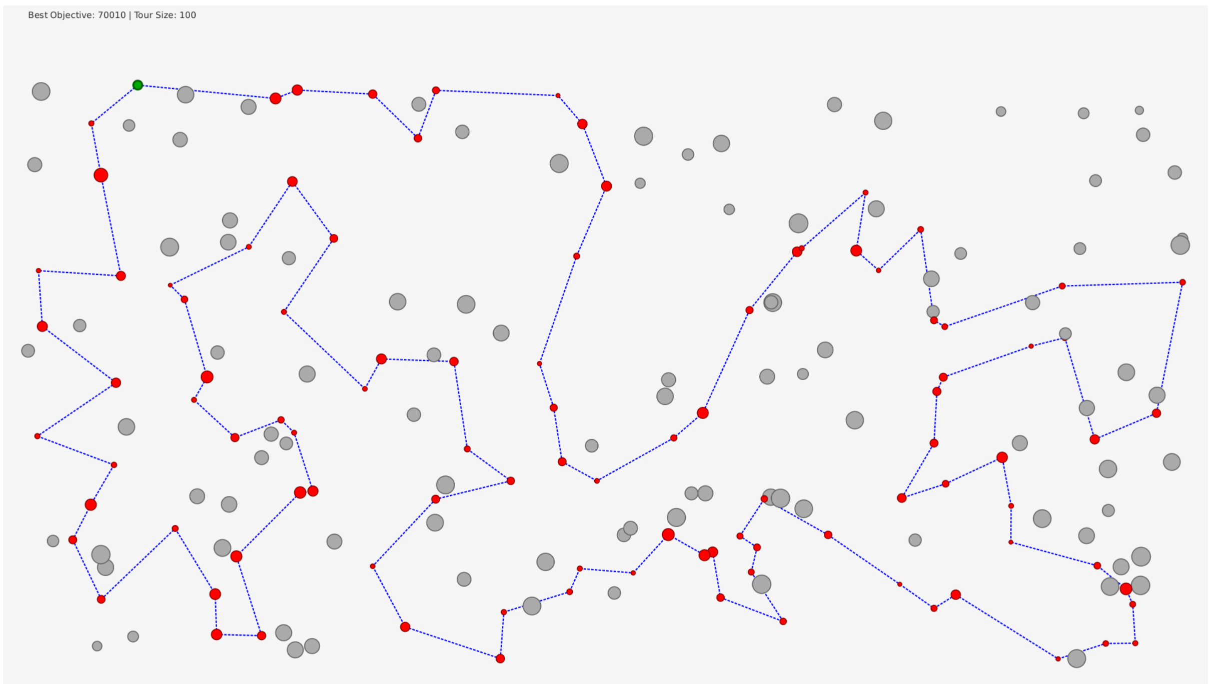
- Greedy Cycle with 2-regret
    - Instance A:



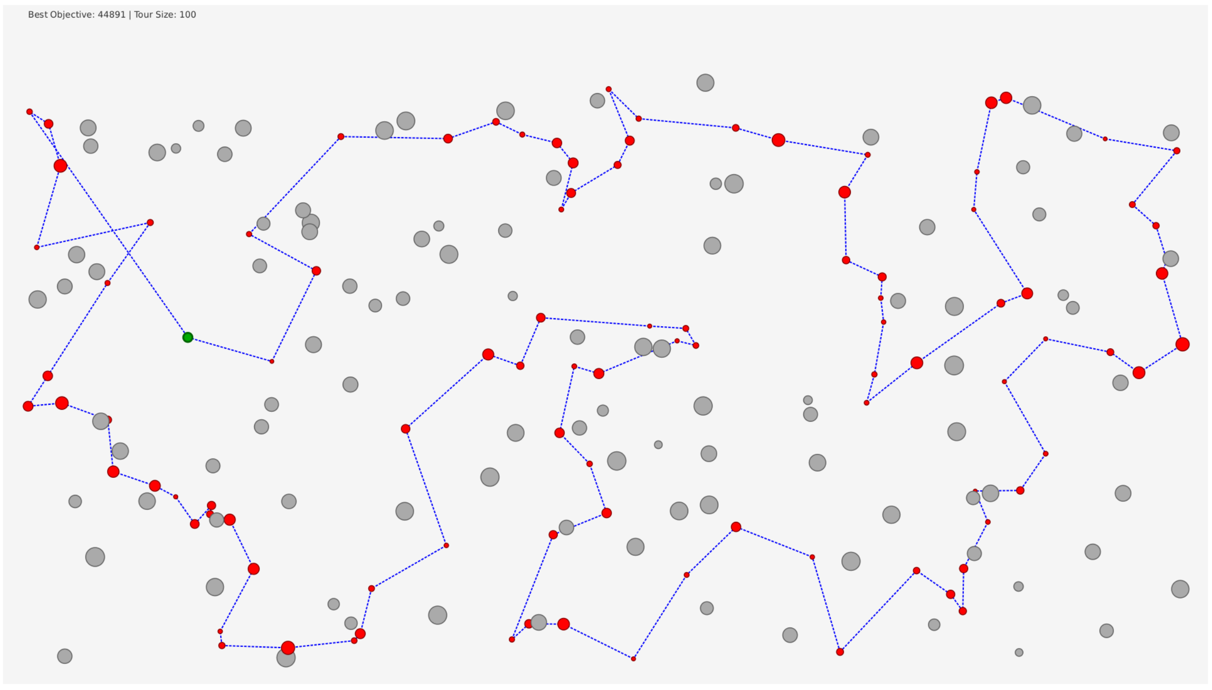
    - Instance B:



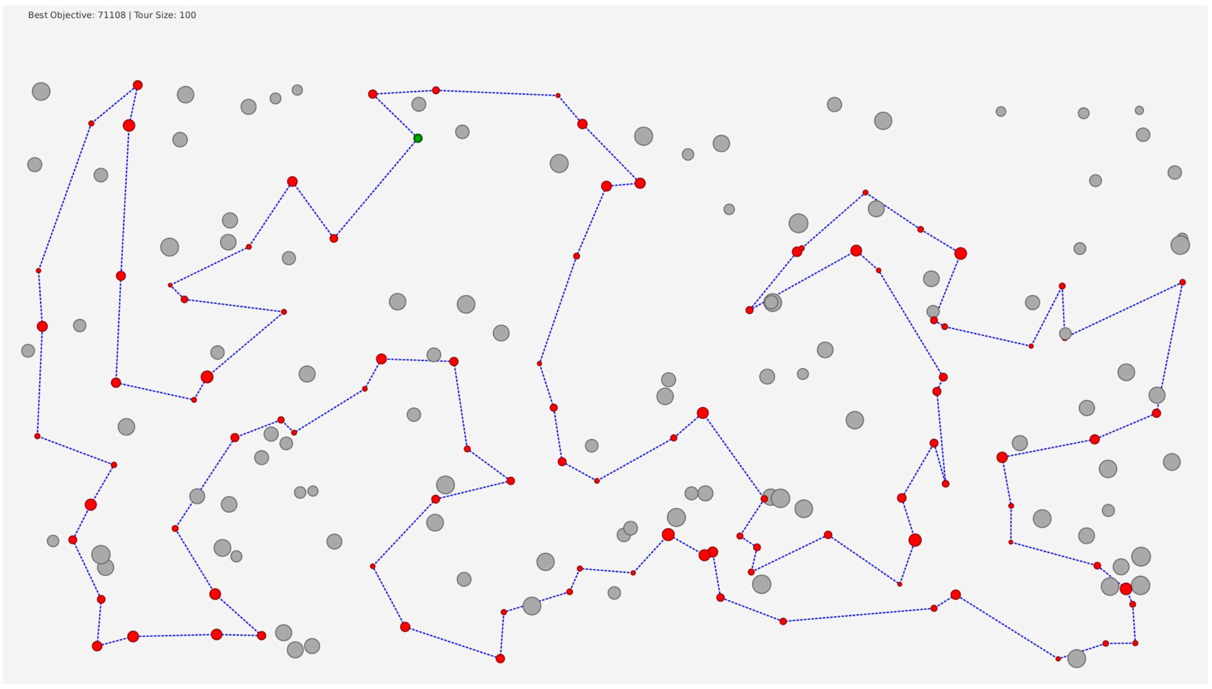
- Nearest Neighbour all-positions with 2-regret weighted
    - Instance A:



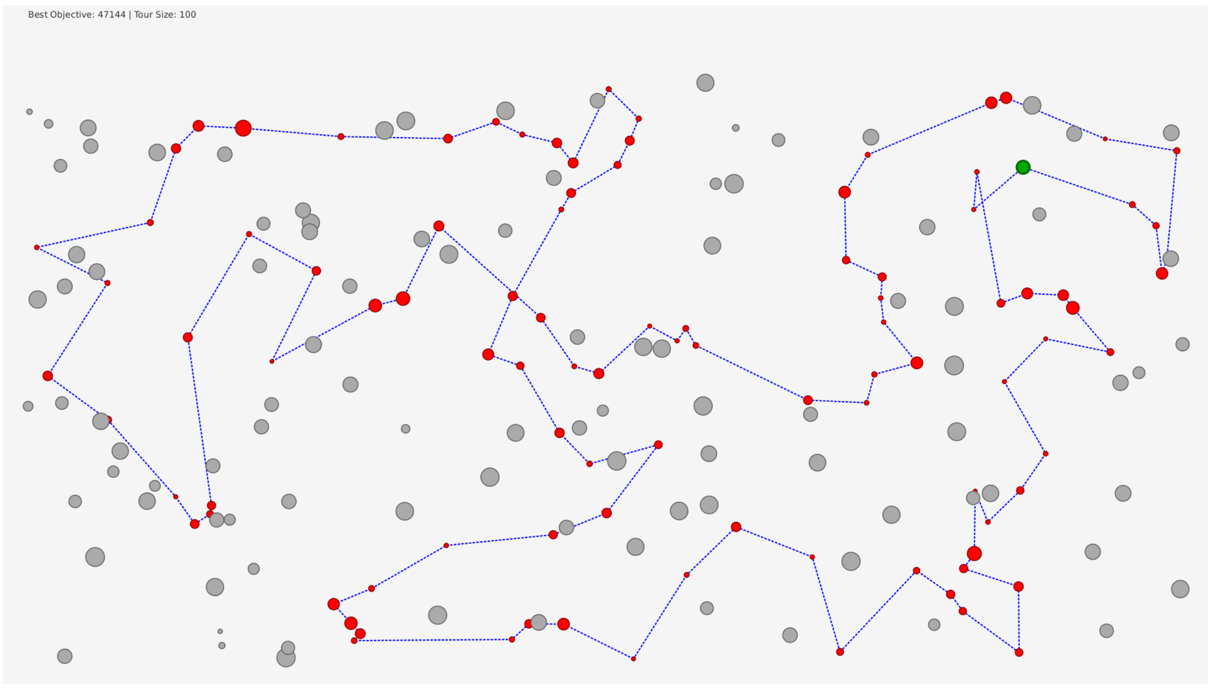
    - Instance B:



- Greedy Cycle with 2-regret weighted
  - Instance A:



  - Instance B:



Best Solutions

- Random algorithm
    - Instance A: 34, 30, 144, 54, 89, 103, 181, 97, 135, 76, 64, 2, 171, 43, 85, 136, 66, 156, 141, 51, 197, 158, 41, 101, 42, 88, 179, 154, 84, 77, 177, 53, 195, 3, 60, 188, 25, 165, 132, 46, 105, 20, 199, 118, 166, 124, 86, 70, 80, 139, 63, 92, 9, 187, 178, 27, 15, 109, 137, 98, 58, 18, 56, 31, 26, 95, 28, 57, 16, 184, 186, 29, 94, 65, 142, 12, 190, 23, 78, 35, 194, 10, 7, 185, 91, 38, 82, 176, 1, 167, 160, 48, 62, 110, 127, 145, 151, 116, 161, 11
    - Instance B: 196, 149, 50, 95, 105, 122, 41, 25, 119, 87, 26, 66, 169, 61, 35, 134, 42, 31, 175, 111, 17, 84, 143, 1, 10, 60, 67, 151, 120, 198, 63, 100, 170, 124, 185, 22, 38, 173, 160, 13, 154, 98, 180, 171, 46, 78, 15, 83, 130, 101, 159, 140, 8, 90, 2, 172, 158, 11, 136, 21, 116, 131, 139, 161, 146, 165, 104, 30, 70, 52, 137, 82, 88, 65, 135, 49, 36, 24, 178, 68, 162, 177, 45, 55, 181, 179, 18, 183, 62, 110, 166, 109, 168, 99, 6, 81, 37, 79, 89, 121

- Nearest Neighbour end-only
    - Instance A: 124, 94, 63, 53, 180, 154, 135, 123, 65, 116, 59, 115, 139, 193, 41, 42, 160, 34, 22, 18, 108, 69, 159, 181, 184, 177, 54, 30, 48, 43, 151, 176, 80, 79, 133, 162, 51, 137, 183, 143, 0, 117, 46, 68, 93, 140, 36, 163, 199, 146, 195, 103, 5, 96, 118, 149, 131, 112, 4, 84, 35, 10, 190, 127, 70, 101, 97, 1, 152, 120, 78, 145, 185, 40, 165, 90, 81, 113, 175, 171, 16, 31, 44, 92, 57, 106, 49, 144, 62, 14, 178, 52, 55, 129, 2, 75, 86, 26, 100, 121
    - Instance B: 16, 1, 117, 31, 54, 193, 190, 80, 175, 5, 177, 36, 61, 141, 77, 153, 163, 176, 113, 166, 86, 185, 179, 94, 47, 148, 20, 60, 28, 140, 183, 152, 18, 62, 124, 106, 143, 0, 29, 109, 35, 33, 138, 11, 168, 169, 188, 70, 3, 145, 15, 155, 189, 34, 55, 95, 130, 99, 22, 66, 154, 57, 172, 194, 103, 127, 89, 137, 114, 165, 187, 146, 81, 111, 8, 104, 21, 82, 144, 160, 139, 182, 25, 121, 90, 122, 135, 63, 40, 107, 100, 133, 10, 147, 6, 134, 51, 98, 118, 74

- Nearest Neighbour all-positions
    - Instance A: 196, 81, 90, 165, 119, 40, 185, 106, 178, 3, 14, 144, 62, 9, 148, 102, 49, 52, 55, 57, 92, 129, 152, 97, 1, 101, 100, 53, 180, 154, 135, 70, 127, 123, 162, 149, 131, 65, 116, 43, 184, 35, 84, 112, 4, 190, 10, 177, 30, 54, 48, 160, 34, 146, 22, 18, 108, 69, 159, 181, 42, 5, 41, 193, 139, 68, 46, 115, 59, 118, 51, 151, 133, 176, 0, 117, 143, 183, 89, 23, 137, 80, 79, 63, 94, 26, 86, 75, 2, 120, 44, 25, 16, 171, 175, 113, 56, 31, 78, 145
    - Instance B: 63, 135, 122, 131, 121, 51, 90, 191, 147, 6, 188, 169, 132, 13, 70, 3, 15, 145, 195, 168, 139, 11, 182, 138, 33, 160, 29, 0, 109, 35, 143, 106, 124, 62, 18, 55, 34, 170, 152, 183, 140, 4, 149, 28, 20, 60, 148, 47, 94, 66, 179, 185, 22, 99, 130, 95, 86, 166, 194, 176, 180, 113, 103, 114, 137, 127, 89, 163, 187, 153, 81, 77, 141, 91, 36, 61, 21, 82, 111, 144, 8, 104, 177, 5, 45, 142, 78, 175, 162, 80, 190, 136, 73, 193, 31, 54, 117, 198, 156, 1

- Greedy Cycle
  - Instance A: 0, 117, 143, 183, 89, 186, 23, 137, 176, 80, 79, 63, 94, 124, 152, 97, 1, 101, 2, 120, 129, 55, 49, 102, 148, 9, 62, 144, 14, 178, 106, 165, 90, 81, 196, 40, 119, 185, 52, 57, 92, 179, 145, 78, 31, 56, 113, 175, 171, 16, 25, 44, 75, 86, 26, 100, 53, 154, 180, 135, 70, 127, 123, 162, 133, 151, 51, 118, 59, 65, 116, 43, 184, 35, 84, 112, 4, 190, 10, 177, 30, 54, 48, 160, 34, 146, 22, 18, 108, 69, 159, 181, 42, 5, 115, 41, 193, 139, 68, 46
  - Instance B: 80, 162, 175, 78, 142, 36, 61, 91, 141, 97, 187, 165, 127, 89, 103, 137, 114, 113, 194, 166, 179, 185, 99, 130, 22, 66, 94, 47, 148, 60, 20, 28, 149, 4, 140, 183, 152, 170, 34, 55, 18, 62, 124, 106, 128, 95, 86, 176, 180, 163, 153, 81, 77, 21, 87, 82, 8, 56, 144, 111, 0, 35, 109, 29, 160, 33, 49, 11, 43, 134, 147, 6, 188, 169, 132, 13, 161, 70, 3, 15, 145, 195, 168, 139, 182, 138, 104, 25, 177, 5, 45, 136, 73, 164, 31, 54, 117, 198, 193, 190

- Nearest Neighbour all-positions with 2-regret
  - Instance A: 16, 175, 56, 31, 38, 157, 17, 196, 91, 57, 52, 106, 185, 8, 165, 39, 90, 27, 71, 164, 7, 21, 132, 14, 102, 128, 167, 111, 130, 148, 15, 64, 114, 186, 23, 89, 183, 153, 0, 141, 66, 176, 79, 133, 151, 109, 118, 59, 197, 116, 43, 42, 5, 96, 115, 198, 46, 68, 93, 36, 67, 108, 69, 199, 20, 22, 146, 103, 34, 160, 48, 30, 104, 177, 10, 190, 4, 112, 35, 184, 166, 131, 24, 123, 127, 70, 6, 154, 158, 53, 136, 121, 100, 97, 152, 87, 2, 129, 82, 25
  - Instance B: 129, 119, 159, 37, 41, 81, 77, 97, 146, 187, 165, 127, 137, 75, 93, 76, 194, 166, 86, 110, 128, 124, 62, 18, 34, 174, 183, 9, 99, 185, 179, 172, 57, 66, 47, 148, 23, 20, 59, 28, 4, 152, 184, 155, 84, 3, 15, 145, 13, 132, 169, 188, 6, 150, 147, 134, 2, 43, 139, 11, 0, 33, 104, 8, 82, 87, 79, 36, 7, 177, 123, 5, 78, 162, 80, 108, 196, 42, 156, 30, 117, 151, 173, 19, 112, 121, 116, 98, 51, 125, 191, 178, 10, 133, 44, 72, 40, 63, 92, 38

- Greedy Cycle with 2-regret
  - Instance A: 196, 157, 188, 113, 171, 16, 78, 25, 44, 120, 82, 129, 92, 57, 172, 2, 75, 86, 26, 121, 182, 53, 158, 154, 6, 135, 194, 127, 123, 24, 156, 4, 190, 177, 104, 54, 48, 34, 192, 181, 146, 22, 20, 134, 18, 69, 67, 140, 68, 110, 142, 41, 96, 42, 43, 77, 65, 197, 115, 198, 46, 60, 118, 109, 151, 133, 79, 80, 176, 66, 141, 0, 153, 183, 89, 23, 186, 114, 15, 148, 9, 61, 73, 132, 21, 14, 49, 178, 52, 185, 119, 165, 39, 95, 7, 164, 71, 27, 90, 81
  - Instance B: 18, 34, 174, 183, 9, 99, 185, 179, 172, 57, 66, 47, 60, 20, 59, 28, 4, 53, 170, 184, 155, 84, 70, 132, 169, 188, 6, 192, 134, 2, 74, 118, 98, 51, 120, 71, 178, 10, 44, 17, 107, 100, 63, 102, 135, 131, 121, 112, 19, 173, 31, 117, 198, 24, 1, 27, 42, 196, 108, 80, 162, 142, 5, 123, 7, 36, 79, 91, 141, 97, 77, 58, 82, 68, 104, 33, 49, 29, 0, 41, 143, 119, 153, 186, 163, 103, 127, 137, 75, 93, 48, 166, 194, 180, 64, 86, 110, 128, 124, 62

- Nearest Neighbour all-positions with 2-regret weighted

    - Instance A: 108, 18, 199, 159, 22, 146, 181, 34, 160, 48, 54, 177, 184, 84, 4, 112, 35, 131, 149, 65, 116, 43, 42, 5, 41, 193, 139, 68, 46, 115, 59, 118, 51, 151, 133, 162, 123, 127, 70, 135, 154, 180, 53, 121, 100, 26, 86, 75, 101, 1, 97, 152, 2, 120, 44, 25, 16, 171, 175, 113, 56, 31, 78, 145, 179, 92, 129, 57, 55, 52, 185, 40, 196, 81, 90, 165, 106, 178, 14, 49, 102, 144, 62, 9, 148, 124, 94, 63, 79, 80, 176, 137, 23, 89, 183, 143, 0, 117, 93, 140
    - Instance B: 131, 121, 51, 90, 147, 6, 188, 169, 132, 13, 168, 195, 145, 15, 70, 3, 155, 184, 152, 170, 34, 55, 18, 62, 124, 106, 128, 95, 130, 183, 140, 4, 149, 28, 20, 60, 148, 47, 94, 66, 57, 172, 179, 185, 86, 166, 194, 176, 113, 103, 127, 89, 163, 187, 153, 81, 77, 141, 91, 61, 36, 21, 82, 8, 104, 33, 160, 0, 35, 109, 29, 11, 138, 182, 25, 177, 5, 78, 175, 162, 80, 190, 136, 73, 31, 54, 193, 117, 198, 156, 1, 16, 27, 38, 135, 122, 63, 100, 107, 40

- Greedy Cycle with 2-regret weighted
    - Instance A: 0, 117, 143, 183, 89, 186, 23, 137, 176, 80, 79, 63, 94, 124, 152, 97, 1, 101, 2, 120, 82, 129, 57, 92, 55, 52, 49, 102, 148, 9, 62, 144, 14, 138, 178, 106, 185, 165, 40, 90, 81, 196, 179, 145, 78, 31, 56, 113, 175, 171, 16, 25, 44, 75, 86, 26, 100, 121, 53, 180, 154, 135, 70, 127, 123, 162, 133, 151, 51, 118, 59, 65, 116, 43, 184, 84, 112, 4, 190, 10, 177, 54, 48, 160, 34, 146, 22, 18, 108, 69, 159, 181, 42, 5, 115, 41, 193, 139, 68, 46
    - Instance B: 199, 183, 140, 95, 130, 99, 22, 179, 185, 86, 166, 194, 113, 176, 26, 103, 114, 137, 127, 89, 163, 187, 153, 81, 77, 141, 91, 61, 36, 175, 78, 142, 45, 5, 177, 21, 82, 111, 8, 104, 138, 182, 139, 168, 195, 145, 15, 3, 70, 13, 132, 169, 188, 6, 147, 115, 10, 133, 122, 63, 135, 38, 1, 117, 193, 31, 54, 131, 90, 51, 121, 118, 74, 134, 11, 33, 160, 29, 0, 109, 35, 143, 106, 124, 128, 62, 18, 55, 34, 170, 152, 4, 149, 28, 20, 60, 94, 66, 47, 148

Conclusions

- The Random algorithm serves only as a non-deterministic baseline, performing drastically worse than all other methods, with average objective values over 264,000 and 212,000 for Instances A and B, respectively.
- The basic greedy heuristics that allow for flexible insertion (NN all-positions and Greedy Cycle) significantly outperformed the constrained NN end-only method. For Instance A, the average result improved from 85,108.5 (NN end-only) to approximately 72,000 (insertion-based).
- The pure 2−regret variations (NN all-pos 2-regret and Greedy Cycle 2-regret) performed poorly, with average objective values much worse than the basic greedy methods (e.g., averages around 117,000 for Instance A). This suggests that prioritizing the difference between the two best moves (regret) over the absolute best cost-of-insertion leads to locally bad decisions.
- The weighted 2-regret approach, combining both regret and minimum cost, proved highly effective. The NN all-positions 2-regret weighted (0.5, 0.5) achieved the best

overall performance for both instances, yielding the lowest minimum and lowest average objective values (Min: 70,010 for Instance A, 44,891 for Instance B).