COMP 424 - Artificial Intelligence - Homework #1

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1 Question 1 - Search

1. **Breadth First Search** Gare du Nord, Rogier, Yser, Ribaucourt, Simonis, Belgica, Pannenhuis, Bockstael, Stuybenbergh, Houba-Brugmann, Heysel, Roi Baudouin

   Uniform Cost Search Same as BFS given that all operators have unit costs. (Gare du Nord, Rogier, Yser, Ribaucourt, Simonis, Belgica, Pannenhuis, Bockstael, Stuybenbergh, Houba-Brugmann, Heysel, Roi Baudouin)

   Depth First Search Gare du Nord, Rogier, Botanique, Madou, Arts-Loi, Trone, Porte de Namur, Louise, Hotel des Monnaies, Porte de Hal, Gare du Midi, Clemenceau, Delacroix, Gare de l'Ouest, Beekkant, Osseghem, Simonis, Belgica, Pannenhuis, Bockstael, Stuyvenbergh, Houba-Brugmann, Heysel, Roi Baudouin

   Iterative Depth Search Gare du Nord, Rogier, Yser, Ribaucourt, Simonis, Belgica, Pannenhuis, Bockstael, Stuyvenbergh, Houba-Brugmann, Heysel, Roi Baudouin (implemented using limited depth search and increasing the maximum depth if a solution is not returned).

2. **BFS** Same as previous answer as BFS does not consider operator costs. (Gare du Nord, Rogier, Yser, Ribaucourt, Simonis, Belgica, Pannenhuis, Bockstael, Stuybenbergh, Houba-Brugmann, Heysel, Roi Baudouin)

   UCS The Python program I wrote to do this incorrectly returned a longer path than BFS, but this is due to how costs are sorted in the priority queue I chose to use. When it considered breaking ties between operators of the same cost, it chose via the clockwise order instead of a FIFO order like that of a BFS implemented with a queue.

   The correct answer should be the same path as BFS, because the path that should be taken would be along line 6, towards to left and then promptly up to Roi Baudouin.

   DFS Same as previous DFS answer because DFS also does not consider operator costs.

   IDS Same as previous IDS answer because IDS does not consider operator costs.

3. This heuristic is not admissible because the cost function does not depend on the length of the path but rather the line number. Thus, a path along line 4, 5, or 6 that redirects twice has the same cost as a path along line 1, 2, or 3. Thus, it's possible for the heuristic function to overestimate the cost of the path if the stations along the path lie on an older (1, 2, or 3) line.

4. This cost function is also not admissible because the driving distance between stations is strictly greater than or equal to the birds-flight distance.

2 Question 2 - Properties of Search Algorithms

Breadth-first search is a special case of uniform-cost search BFS is a special case of uniform-cost search when all operator costs are the same (or unit cost).

Depth-first search is a special case of best-first search DFS is not a special case of best-first search, because even if the heuristic function for all nodes is equal, best-first search is the same as breadth-first search.

Uniform-cost search is a special case of A* search Uniform-cost search is a special case of A* search, because A* search uses both the cost-so-far and the cost-to-go(heuristic function). Thus, if the cost that the heuristic function produces for all nodes is equal, then the only differing factor will be the "cost-so-far."

3 Question 3 - Optimization

1. See appendix for table and chart of hill climbing results.
2. See appendix for table and chart of simulated annealing results.

   The global maximum was near 1.65, so starting from lower numbers (1 to 4) is a good strategy. 0 is a poor starting point as negative x-values are outside the domain of the evaluation function. Additionally, smaller increments prove to be better than larger increments for reaching maxima.

   Interestingly, with hill climbing we were guaranteed to obtain the global maximum for starting points less than 4, while with simulated annealing it was possible to escape local maxima and reach the global maximum near 1.65.

   However, the simulated annealing sometimes escaped the global maximum when the starting point was less than 4.

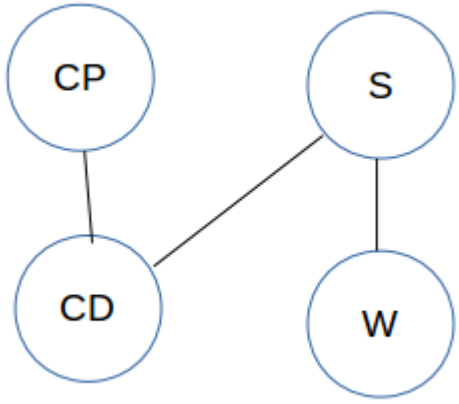
4 Question 4 - Constraint satisfaction

- Variables = X = {CP = Computer installation, CD = code download, S = sensor installation, W = wiring}

$$\text{Domain } = D = \{0, 5, 10, 15\}$$

$$\text{Constraints } = C = \{CP + 10 \leq CD, S + 5 \leq W, (CP + 10 \leq W \text{ or } W + 10 \leq CP)\}$$

Figure 1: Constraint Graph



Below is the search tree with backtracking, without forward checking.

$$D_{CP} = \{0, 5, 10, 15\}, D_{CD} = \{0, 5, 10, 15\}, D_S = \{0, 5, 10, 15\}, D_W = \{0, 5, 10, 15\}$$
$$CP = 0$$
$$D_{CP} = \{0, 5, 10, 15\}, D_{CD} = \{10, 15\}, D_S = \{0, 5, 10, 15\}, D_W = \{10, 15\}$$
$$CP = 0, CD = 10$$
$$D_{CP} = \{0\}, D_{CD} = \{10, 15\}, D_S = \{0, 5, 10, 15\}, D_W = \{10, 15\}$$
$$CP = 0, CD = 10, S = 0$$
$$D_{CP} = \{0\}, D_{CD} = \{10, 15\}, D_S = \{0\}, D_W = \{10, 15\}$$
$$CP = 0, CD = 10, S = 0, W = 10$$

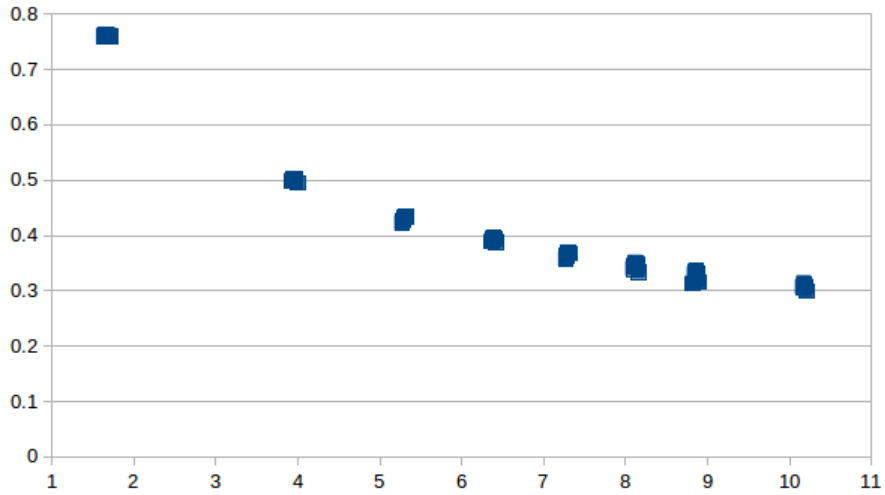
Finally the search tree below has backtracking and forward checking.

$$D_{CP} = \{0, 5, 10, 15\}, D_{CD} = \{0, 5, 10, 15\}, D_S = \{0, 5, 10, 15\}, D_W = \{0, 5, 10, 15\}$$
$$CP = 0$$
$$D_{CP} = \{0, 5, 10, 15\}, D_{CD} = \{10, 15\}, D_S = \{0, 5, 10, 15\}, D_W = \{10, 15\}$$
$$CP = 0, CD = 10$$
$$D_{CP} = \{0\}, D_{CD} = \{10, 15\}, D_S = \{0, 5, 10, 15\}, D_W = \{10, 15\}$$
$$CP = 0, CD = 10, S = 0$$
$$D_{CP} = \{0\}, D_{CD} = \{10, 15\}, D_S = \{0\}, D_W = \{10, 15\}$$
$$CP = 0, CD = 10, S = 0, W = 10$$

The search tree is identical because the order in which variables are assigned happened to be quite convenient.

5 Appendix

Figure 2: Hill Climbing Figure



5.1 Hill Climbing Table

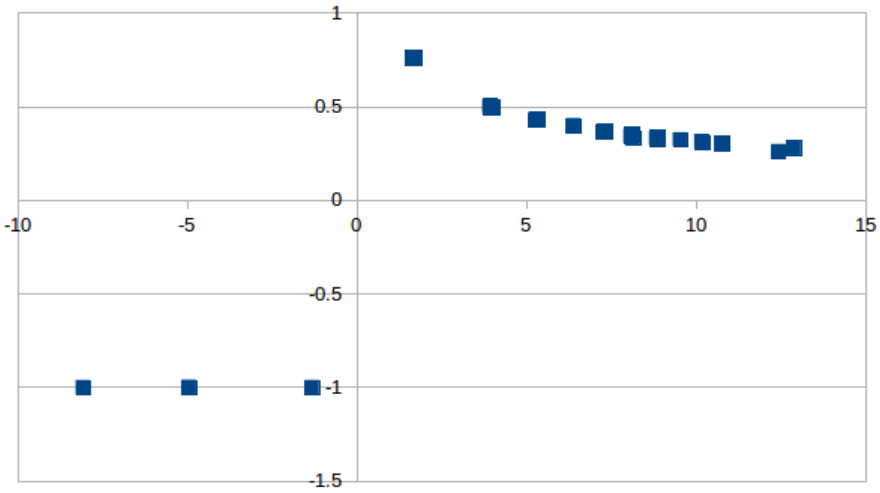
X position, height, depth of search

1.6700000000000013	0.7618221937920574	168
1.660000000000001	0.761740472199043	84
1.6800000000000013	0.7617119410997025	57
1.6800000000000008	0.7617119410997025	43
1.6500000000000008	0.7614695808369663	34
1.680000000000001	0.7617119410997025	29
1.680000000000001	0.7617119410997025	25
1.6800000000000004	0.7617119410997026	22
1.7100000000000004	0.7602018734642948	20
1.7000000000000004	0.760904485817884	18
1.6700000000000006	0.7618221937920574	68
1.6600000000000006	0.761740472199043	34
1.6600000000000006	0.761740472199043	23
1.6800000000000006	0.7617119410997024	18
1.6500000000000006	0.7614695808369661	14
1.6600000000000006	0.761740472199043	12
1.7000000000000006	0.760904485817884	11
1.6400000000000006	0.7610123592001171	9
1.6300000000000006	0.7603716791318267	8
1.7000000000000006	0.760904485817884	8

1.6700000000000013	0.7618221937920574	168
1.6699999999999997	0.7618221937920574	34
1.6599999999999997	0.761740472199043	18
1.6699999999999997	0.7618221937920574	12
1.6799999999999997	0.7617119410997025	9
1.6499999999999997	0.761469580836966	8
1.6399999999999997	0.7610123592001171	7
1.6499999999999997	0.761469580836966	6
1.6799999999999997	0.7617119410997025	5
1.6399999999999997	0.7610123592001171	5
1.6999999999999997	0.760904485817884	4
1.670000000000021	0.7618221937920573	134
1.6599999999999988	0.7617404721990428	68
1.6800000000000062	0.7617119410997025	45
1.6799999999999988	0.7617119410997026	34
1.6500000000000032	0.7614695808369663	28
1.6799999999999988	0.7617119410997026	23
1.670000000000002	0.7618221937920574	20
1.6399999999999988	0.761012359200117	18
1.6500000000000012	0.7614695808369661	16
1.6999999999999988	0.7609044858178841	14
3.960000000000001	0.5024752505561952	5
3.96	0.5024752505561952	3
3.97	0.5017098193857172	2
3.96	0.5024752505561952	2
3.95	0.502455225315548	2
3.94	0.5016537594984432	2
3.93	0.5000760678321541	2
3.92	0.49772853740965295	2
4	0.4946791233116909	1
4	0.4946791233116909	1
5.309999999999993	0.433631067901727	32
5.319999999999993	0.4335122961776068	17
5.3000000000000025	0.4325286076906744	11
5.32	0.4335122961776063	9
5.299999999999999	0.43252860769067386	7
5.299999999999998	0.43252860769067375	6
5.280000000000001	0.4266941275009493	5
5.32	0.4335122961776063	5
5.27	0.4219875062411762	4
5.299999999999999	0.43252860769067386	4
6.389999999999992	0.3955902249792521	40
6.379999999999992	0.39498471415288106	20
6.390000000000003	0.3955902249792519	14
6.4	0.39458173328744445	11
6.399999999999999	0.39458173328744484	9

1.6700000000000013	0.7618221937920574	168
6.359999999999998	0.3889682145498694	7
6.420000000000002	0.38772568075058056	7
6.4	0.39458173328744445	6
6.359999999999999	0.38896821454987024	5
6.399999999999999	0.39458173328744484	5
7.309999999999993	0.36982441275678335	32
7.299999999999994	0.36948265697393323	16
7.3000000000000025	0.36948265697393434	11
7.32	0.3681913705160748	9
7.299999999999999	0.36948265697393384	7
7.299999999999998	0.3694826569739338	6
7.280000000000001	0.3629140427055488	5
7.32	0.3681913705160748	5
7.27	0.35673273016255935	4
7.299999999999999	0.36948265697393384	4
8.119999999999997	0.35086432795616973	13
8.119999999999997	0.35086432795616973	7
8.119999999999997	0.35086432795616973	5
8.119999999999997	0.35086432795616973	4
8.100000000000001	0.34557854781088193	3
8.120000000000001	0.3508643279561698	3
8.14	0.34691838185400586	3
8.16	0.3337997964450457	3
8.09	0.3395218232610379	2
8.1	0.34557854781088104	2
8.860000000000003	0.33588865254310357	15
8.860000000000003	0.33588865254310357	8
8.850000000000003	0.33416390211797536	6
8.880000000000003	0.33143535825458986	4
8.849999999999998	0.33416390211797364	4
8.879999999999999	0.3314353582545914	3
8.86	0.33588865254310335	3
8.84	0.32982391433651126	3
8.82	0.3134772744141028	3
8.9	0.31655693367763404	2
10.179999999999996	0.3133563937889931	19
10.179999999999996	0.3133563937889931	10
10.179999999999996	0.3133563937889931	7
10.199999999999996	0.3078426794212617	6
10.200000000000003	0.3078426794212572	5
10.180000000000001	0.3133563937889934	4
10.21	0.30026658319792915	4
10.16	0.30592623378539363	3
10.18	0.31335639378899327	3
10.2	0.30784267942125926	3

Figure 3: Simulated Annealing Figure



5.2 Simulated Annealing Table

X position, height, depth of search

1.6700000000000013	0.7618221937920574	1875
1.660000000000001	0.761740472199043	1875
1.680000000000001	0.7617119410997025	1875
1.6800000000000008	0.7617119410997025	1875
1.650000000000001	0.7614695808369661	1875
1.6800000000000006	0.7617119410997024	1875
1.6800000000000008	0.7617119410997025	1875
-4.960000000000003	-1	1875
1.71	0.7602018734642948	1875
1.7000000000000002	0.760904485817884	1875
1.6700000000000006	0.7618221937920574	1875
1.6600000000000006	0.761740472199043	1875
1.6600000000000006	0.761740472199043	1875
1.6800000000000006	0.7617119410997024	1875
1.6500000000000006	0.7614695808369661	1875
1.6600000000000006	0.761740472199043	1875
5.340000000000002	0.42959743337673273	1875
7.320000000000006	0.3681913705160734	1875
1.6300000000000006	0.7603716791318267	1875
6.399999999999994	0.39458173328744567	1875
1.6699999999999995	0.7618221937920574	1875
1.6599999999999997	0.761740472199043	1875
1.6699999999999995	0.7618221937920574	1875

1.6700000000000013	0.7618221937920574	1875
1.6799999999999997	0.7617119410997025	1875
1.6499999999999995	0.7614695808369661	1875
1.6399999999999997	0.7610123592001171	1875
1.6499999999999995	0.7614695808369661	1875
1.6799999999999997	0.7617119410997025	1875
3.979999999999997	0.5001561397633886	1875
4.000000000000002	0.4946791233116903	1875
3.9599999999999795	0.502475250556196	1875
3.960000000000001	0.5024752505561952	1875
1.6800000000000062	0.7617119410997025	1875
1.6799999999999988	0.7617119410997026	1875
3.9499999999999966	0.5024552253155479	1875
3.9600000000000004	0.5024752505561952	1875
3.979999999999998	0.5001561397633884	1875
1.6399999999999988	0.761012359200117	1875
3.9899999999999984	0.49781266663212936	1875
1.6999999999999988	0.7609044858178841	1875
3.960000000000001	0.5024752505561952	1875
3.9599999999999995	0.5024752505561954	1875
3.97	0.5017098193857172	1875
3.96	0.5024752505561952	1875
3.95	0.502455225315548	1875
3.9399999999999995	0.501653759498443	1875
6.38000000000001	0.39498471415288355	1875
3.92	0.49772853740965295	1875
6.429999999999996	0.3818962481795434	1875
1.6999999999999975	0.7609044858178841	1875
5.309999999999993	0.433631067901727	1875
5.319999999999993	0.4335122961776068	1875
3.949999999999992	0.5024552253155476	1875
5.32	0.4335122961776063	1875
5.299999999999999	0.43252860769067386	1875
6.379999999999991	0.39498471415288094	1875
7.310000000000009	0.3698244127567823	1875
3.959999999999999	0.5024752505561954	1875
5.27	0.4219875062411762	1875
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6.389999999999992	0.3955902249792521	1875
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5.309999999999994	0.4336310679017271	1875
5.319999999999999	0.43351229617760634	1875
5.3000000000000025	0.4325286076906744	1875
6.359999999999998	0.3889682145498694	1875
7.330000000000005	0.3645868719916684	1875
1.6799999999999962	0.7617119410997026	1875

1.6700000000000013	0.7618221937920574	1875
7.349999999999998	0.3515300114792273	1875
8.099999999999993	0.34557854781087766	1875
7.309999999999993	0.36982441275678335	1875
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6.3999999999999995	0.3945817332874446	1875
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5.320000000000011	0.4335122961776055	1875
5.319999999999993	0.4335122961776068	1875
10.200000000000003	0.3078426794212572	1875
7.27	0.35673273016255935	1875
10.199999999999989	0.3078426794212659	1875
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8.119999999999997	0.35086432795616973	1875
8.119999999999997	0.35086432795616973	1875
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8.14	0.34691838185400586	1875
10.160000000000002	0.3059262337853951	1875
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8.860000000000003	0.33588865254310357	1875
8.860000000000003	0.33588865254310357	1875
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9.559999999999988	0.32008926036152924	1875
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10.800000000000015	0.2981923223357985	1875
8.86	0.33588865254310335	1875
8.12	0.35086432795616973	1875
8.82	0.3134772744141028	1875
10.799999999999994	0.29819232233581305	1875
10.179999999999996	0.3133563937889931	1875
9.54000000000001	0.3233999467949527	1875
10.179999999999996	0.3133563937889931	1875
10.799999999999983	0.29819232233582005	1875
8.849999999999984	0.33416390211796926	1875
9.519999999999996	0.3149740337040338	1875
8.109999999999992	0.34936955163261296	1875
8.879999999999999	0.3314353582545914	1875
12.879999999999995	0.26577861724148644	1875
14.299999999999985	0.2617347447142557	1875