

Homework 1 Group 33
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Our team has used our program `map_generation.py` to generate ten maps of size (750 x 750) as it takes heuristic one (value zero) roughly 30 seconds to solve them. The raw data for each of the heuristics solving these ten maps can be found at the end of this writeup. We have assured that heuristics 1-5 provide the same solution, and therefore score. The table below outlines the average count of nodes expanded, branching factor, program runtime, and memory usage for each of the heuristics.

Heuristic	Avg No. Nodes	Avg Branching Factor	Avg Time (s)	Avg Memory (Mb)
1	846163	2.657	29.518	604.4
2	664635	2.676	25.649	587.3
3	599914	2.635	22.561	577
4	485737	2.636	18.797	563.5
5	484409	2.636	20.816	563.4
6	7925	3.347	3.39	519.9

Heuristic	% Faster than Heuristic Above	% Less Memory than Heuristic Above
1	xxx	xxx
2	15.08	2.91
3	13.69	1.79
4	20.02	2.40
5	-9.70	0.02
6	514.04	8.37

Because the solutions between the first five heuristics are identical, runtime and memory usage are suitable metrics for program efficiency. The percent decrease in time and memory for adjacent heuristics is shown in the table above. Heuristics make considerable progress in speed while changes in memory are minimal. Heuristic six runs five times faster than heuristic five on average but provides robot pathing solutions that are 8% longer on average. On a practical level, this tradeoff seems worthwhile even though heuristic six is not admissible.

It was determined experimentally that heuristic five can be expected to finish 1000 x 1000 size maps in roughly 30 seconds. By finding the equation of best fit between runtime and map size, we obtained a theoretical map size of 1170 x 1170 that heuristic five finishes in 30

seconds on average. The relationship between time and memory as a function of square map size is shown below for each heuristic.

Heuristic	Time(Map Size)	Memory(Map Size)
1	$y = 5E-05x^2 + 0.0028x - 0.3964$	$y = 0.0012x^2 - 0.0927x + 3.1858$
2	$y = 4E-05x^2 + 0.003x + 0.0251$	$y = 0.0012x^2 - 0.1031x + 4.8726$
3	$y = 3E-05x^2 + 0.005x - 0.3278$	$y = 0.0011x^2 - 0.0904x + 3.8543$
4	$y = 4E-06x^2 + 0.0248x - 1.4313$	$y = 0.001x^2 - 0.0269x + 0.5003$
5	$y = 6E-07x^2 + 0.0281x - 1.989$	$y = 0.0011x^2 - 0.0805x + 3.4649$
6	$y = 6E-06x^2 + 0.0002x - 0.0278$	$y = 0.001x^2 - 0.0691x + 3.2089$

From these equations we can calculate the runtime and max size map that could be completed with 16Gb of memory for each of the heuristics:

Heuristic	Max Size n x n with Memory 16GB	Time (s)
1	3689	690
2	3694	556
3	3850	463
4	4013	162
5	4034	101
6	4373	115

Lastly, we compared how much memory a program running 24 hours would require by comparing memory as a function of time and memory as a function of map size. We obtained an average value of 13660 Gb for heuristic six and 2133 Gb for heuristic five. Heuristic six consumes much more memory as its runtime is often much shorter than the other heuristics while its memory usage is only ~10% less.

Time (s)	Heuristic	Memory Based on Time (Gb)	Memory Based on Size (Gb)	Avg memory (Gb)
86400	6	12934	14387	13660.5
86400	5	1893	2373	2133

Raw Data								
Map	Heuristic	Depth	Actions	Score	Nodes	Branching	Memory (Mb)	Time (s)
0	1	353	424	-1359	884642	2.67	610	30.69
1	1	379	486	-1330	784270	2.64	601	27.18
2	1	309	366	-1186	654192	2.62	584	22.83
3	1	371	474	-1265	1133484	2.66	633	39.65
4	1	455	537	-1751	1185266	2.66	651	39.77
5	1	387	448	-1541	612105	2.69	585	21.82
6	1	234	298	-834	722616	2.66	581	25.93
7	1	340	394	-1394	765111	2.67	597	26.74
8	1	331	419	-1184	909497	2.66	606	31.22
9	1	313	389	-1122	810449	2.64	596	29.35
0	2	353	424	-1359	756044	2.69	594	27.72
1	2	379	486	-1330	683038	2.63	588	24.89
2	2	309	366	-1186	515610	2.66	566	19.1
3	2	371	474	-1265	995110	2.65	617	35.27
4	2	455	537	-1751	1023456	2.72	629	36.1
5	2	387	448	-1541	48591	2.73	567	18.03
6	2	234	298	-834	543371	2.68	563	20.41
7	2	340	394	-1394	585060	2.71	573	21.05
8	2	329	419	-1184	823120	2.64	596	29.42
9	2	313	389	-1122	672950	2.65	580	24.5
0	3	353	424	-1359	584932	2.63	585	24.7
1	3	379	486	-1330	467382	2.62	576	22.12
2	3	311	366	-1186	793557	2.59	561	17.9
3	3	371	474	-1265	966654	2.68	593	29.22
4	3	455	537	-1751	442126	2.61	625	34.4
5	3	387	448	-1541	374100	2.62	564	16.57
6	3	235	298	-834	528275	2.65	549	14.92

7	3	340	394	-1394	679147	2.64	568	19.39
8	3	331	419	-1184	581486	2.68	579	25.08
9	3	313	389	-1122	581486	2.63	570	21.31
0	4	353	424	-1359	509095	2.64	567	19.75
1	4	379	486	-1330	531947	2.6	570	20.43
2	4	311	366	-1186	368717	2.63	551	14.79
3	4	371	474	-1265	628272	2.64	576	24.22
4	4	455	537	-1751	761627	2.65	598	27.69
5	4	387	448	-1541	358326	2.64	553	14.35
6	4	235	298	-834	283857	2.64	541	12.17
7	4	340	394	-1394	401727	2.67	553	15.6
8	4	329	419	-1184	561735	2.63	568	21.35
9	4	313	389	-1122	452076	2.62	558	17.62
0	5	353	424	-1359	507016	2.64	567	28.65
1	5	379	486	-1330	530505	2.6	569	30.74
2	5	311	366	-1186	367465	2.63	551	14.59
3	5	371	474	-1265	627088	2.64	576	24.37
4	5	455	537	-1751	759480	2.65	598	28.18
5	5	387	448	-1541	357182	2.64	553	14.15
6	5	234	298	-834	282983	2.64	541	12.08
7	5	340	394	-1394	400475	2.67	553	15.87
8	5	329	419	-1184	560744	2.63	568	21.84
9	5	313	389	-1122	451159	2.62	558	17.69
0	6	352	431	-1514	6372	3.34	520	3.44
1	6	363	457	-1448	4367	3.57	520	3.27
2	6	289	353	-1235	4940	3.4	519	3.27
3	6	328	418	-1432	6030	3.09	520	3.37
4	6	430	496	-1884	30340	2.6	524	4.15
5	6	377	438	-1643	7237	3.36	520	3.5
6	6	208	247	-899	2263	3.85	518	3.15

7	6	322	363	-1455	10814	2.86	520	3.44
8	6	306	395	-1320	2382	4.03	519	3.03
9	6	290	364	-1243	4510	3.37	519	3.28

Map size n x n	Heuristic	Nodes	Branching	Memory (Mb)	Time (s)
8	6	5	4.6	0.082	0.001282
8	6	1	7	0.078	0.001159
8	6	12	4.92	0.082	0.001743
32	6	58	5.48	0.898	0.007821
32	6	130	4.22	0.922	0.01042
32	6	2	6.5	0.86	0.004525
128	6	509	4.56	14.39	0.088
128	6	15	6	14.11	0.067
128	6	238	4.52	14.18	0.0769
256	6	100	5.63	56.33	0.382
256	6	164	4.39	56.33	0.387
256	6	68	4.72	56.304	0.0392
512	6	577	5.66	225.6	1.63
512	6	1188	4.97	226	1.7102
512	6	2641	3.45	225.79	1.85
750	6	6372	3.34	520	3.44
750	6	4367	3.57	520	3.27
750	6	4940	3.4	519	3.27
750	6	6030	3.09	520	3.37
750	6	30340	2.6	524	4.15
750	6	7237	3.36	520	3.5
750	6	2263	3.85	518	3.15
750	6	10814	2.86	520	3.44
750	6	2382	4.03	519	3.03
750	6	4510	3.37	519	3.28
8	5	30	4.23	0.0859	0.002136

8	5	10	4.9	0.08203	0.001459
8	5	12	5	0.078125	0.001382
32	5	788	3.19	0.941	0.034039
32	5	63	4.7	0.875	0.007411
32	5	742	2.92	0.9179	0.029151
128	5	303799	2.56	16	1.039
128	5	39	5	14.085	0.068
128	5	2	6.5	14.07	0.07
256	5	38735	2.73	58.7	1.721
256	5	61242	2.68	60.77	2.53
256	5	47795	2.61	59.66	2
512	5	162246	2.62	237.27	7.77
512	5	20577	2.7	225.94	2.402
512	5	463710	2.58	269.3	19.2
1000	5	918876	2.61	951	36.35
1000	5	103566	2.63	865	8.86
1000	5	285579	2.67	882	15.25
1000	5	278544	2.69	881	15.5
1000	5	374580	2.63	890	18.04
1000	5	1256364	2.58	1003	50.13
750	5	507016	2.64	567	28.65
750	5	530505	2.6	569	30.74
750	5	367465	2.63	551	14.59
750	5	627088	2.64	576	24.37
750	5	759480	2.65	598	28.18
750	5	357182	2.64	553	14.15
750	5	282983	2.64	541	12.08
750	5	400475	2.67	553	15.87
750	5	560744	2.63	568	21.84

750	5	451159	2.62	558	17.69
8	4	13	4.54	0.082	0.0018
8	4	5	6	0.0781	0.0014
8	4	9	4.67	0.082	0.00141
32	4	156	3.06	0.88	0.011
32	4	478	3	0.91	0.022
32	4	285	2.98	0.89	0.014
128	4	4101	2.83	14.3	0.195
128	4	9713	2.76	14.6	0.368
128	4	2485	2.94	14.3	0.144
256	4	50431	2.6	60	2
256	4	139658	2.6	66.5	5.06
256	4	16867	2.62	57	0.95
512	4	117753	2.69	234	5.8
512	4	741477	2.6	295	29
512	4	268013	2.65	247	12
750	4	509095	2.64	567	19.75
750	4	531947	2.6	570	20.43
750	4	368717	2.63	551	14.79
750	4	628272	2.64	576	24.22
750	4	761627	2.65	598	27.69
750	4	358326	2.64	553	14.35
750	4	283857	2.64	541	12.17
750	4	401727	2.67	553	15.6
750	4	561735	2.63	568	21.35
750	4	452076	2.62	558	17.62
8	3	14	5.21	0.0859	0.0017
8	3	33	3.76	0.082	0.0022
8	3	37	4	0.0898	0.0029
32	3	909	3.02	0.9375	0.037

32	3	684	3.28	0.94	0.031
32	3	1595	2.88	0.96	0.0581
128	3	25488	2.72	15.14	0.89
128	3	610	3.25	14.17	0.088
128	3	634	3.32	14.18	0.093
256	3	17048	2.76	57	0.917
256	3	27609	2.76	57.4	1.254
256	3	170811	2.62	68.5	6.31
512	3	46183	2.63	266	18.7
512	3	257669	2.69	245	11.3
512	3	107435	2.65	233	5.54
750	3	584932	2.63	585	24.7
750	3	467382	2.62	576	22.12
750	3	793557	2.59	561	17.9
750	3	966654	2.68	593	29.22
750	3	442126	2.61	625	34.4
750	3	374100	2.62	564	16.57
750	3	528275	2.65	549	14.92
750	3	679147	2.64	568	19.39
750	3	581486	2.68	579	25.08
750	3	581486	2.63	570	21.31
8	2	48	3.35	0.082	0.00283
8	2	22	5.09	0.082	0.00205
8	2	16	4.44	0.082	0.00166
32	2	1224	2.89	0.9375	0.0462
32	2	2771	2.52	0.988	0.0949
32	2	393	3.49	0.90625	0.019
128	2	22252	2.68	14.8	0.77
128	2	16874	2.79	14.63	0.614
128	2	32587	2.61	15.55	1.144

256	2	141740	2.63	66	4.9
256	2	112885	2.69	63	4.06
256	2	122779	2.65	64	4.31
512	2	278656	2.65	247	11.85
512	2	267653	2.71	245	11.06
512	2	291935	2.74	250	12.06
750	2	756044	2.69	594	27.72
750	2	683038	2.63	588	24.89
750	2	515610	2.66	566	19.1
750	2	995110	2.65	617	35.27
750	2	1023456	2.72	629	36.1
750	2	48591	2.73	567	18.03
750	2	543371	2.68	563	20.41
750	2	585060	2.71	573	21.05
750	2	823120	2.64	596	29.42
750	2	672950	2.65	580	24.5
8	1	18	3.78	0.0859	0.0019
8	1	36	3.36	0.082	0.00232
8	1	2	5	0.082	0.0012
32	1	133	3.29	0.875	0.00936
32	1	483	3.41	0.9336	0.021
32	1	14469	2.82	0.953	0.0507
128	1	122	4.2	14	0.07
128	1	29211	2.68	15	0.98
128	1	31363	2.63	15.65	1.02
256	1	62297	2.71	59	2.36
256	1	19451	2.71	57	1
256	1	57441	2.69	59.6	2.22
512	1	29735	2.74	226	2.7
512	1	389583	2.66	255	15.49
512	1	773529	2.59	313	29.35

750	1	884642	2.67	610	30.69
750	1	784270	2.64	601	27.18
750	1	654192	2.62	584	22.83
750	1	1133484	2.66	633	39.65
750	1	1185266	2.66	651	39.77
750	1	612105	2.69	585	21.82
750	1	722616	2.66	581	25.93
750	1	765111	2.67	597	26.74
750	1	909497	2.66	606	31.22
750	1	810449	2.64	596	29.35