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364802751         22         26266         3548           562314780         22         21387         3525           561372084         22         17824         2752           075813624         22         20461         1536           654183270         22         17306         1878           083165724         22         16928         1763           124637580         22         22037         3196           261374085         22         1707         3122           023675148         22         16151         2264           617325840         22         16991         1956           830642157         22         15880         1114           473561028         22         14768         1285           271603854         22         18157         2105           541306872         22         18157         2105           541306872         22         18157         2105           541306872         22         15720         949           420136587         22         15730         490           037618452         22         15720         949           037618452         22		22		
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124637580   22   22037   3196	720168435			
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830642157         22         15880         1114           473561028         22         14768         1285           271603854         22         25165         2676           017564328         22         18157         2105           541306872         22         23740         2594           420136587         22         15534         2017           157684032         22         16464         2714           071836425         22         15720         949           037618452         22         20762         2067           340578126         22         14579         1507           074836152         22         1589         647           685274310         24         46748         3194           657403812         24         55631         2130           538264071         24         37286         1987           768514023         24         35959         1070           430127586         24         45946         1934           976485132         24         45946         1934           9781812         24         556444         3991           785802146         24	023675148			2264
473561028         22         14768         1285           271603854         22         25165         2676           017564328         22         18157         2105           541306872         22         23740         2594           420136587         22         15534         2017           157684032         22         16464         2714           071836425         22         20762         2067           340578126         22         14579         1507           074836152         22         15503         465           763245018         22         15859         647           68574310         24         46748         3194           687403812         24         55631         2130           538264071         24         37286         1987           073246581         24         3599         1070           430127586         24         45946         1934           976485132         24         45728         2256           735802146         24         56444         3991           781645023         24         45604         3591           781645023         24				
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541306872         22         23740         2594           420136587         22         15534         2017           157684032         22         16464         2714           071836425         22         15720         949           037618452         22         20762         2067           340578126         22         14579         1507           074836152         22         14579         1507           685274310         24         46748         3194           687403812         24         55631         2130           538264071         24         37286         1987           073246581         24         37328         645           768514023         24         3599         1070           430127586         24         45946         1934           976485132         24         45728         2256           735802146         24         56444         3991           781645023         24         45604         3591           782566187         24         45604         3591				
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037618452         22         20762         2067           340578126         22         14579         1507           074836152         22         15503         465           763245018         22         15859         647           685274310         24         46748         3194           657403812         24         55631         2130           538264071         24         37286         1987           073246581         24         37328         645           768514023         24         35959         1070           430127586         24         45946         1934           976485132         24         45728         2256           735802146         24         56444         3991           781645023         24         45604         3591           032546187         24         45874         4044				
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685274310         24         46748         3194           657403812         24         55631         2130           538264071         24         37286         1987           073246581         24         37328         645           768514023         24         35959         1070           430127586         24         45946         1934           076485132         24         45728         2256           735802146         24         56444         3991           781645023         24         45604         3591           052456187         24         45874         4044				
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270513486 24 31368 1781	032546187	24	45874	4044
	270513486	24	31368	1781

470561238	24	35304	3599
374815026	24	34419	2085
741385260	24	34972	3782
214703658	24	59846	7192
763258140	24	34342	1718
580261734	24	48056	3916
752601348	24	59124	8483
024738516	24	34220	3537
016723584	24	34603	3218
724508361	24	58205	4456
520738641	24	47530	4255
675401832	24	53321	4238
821534067	24	47950	5267
247865013	24	37542	2274
260873154	24	33045	509
820617354	24	47260	4471
426805317	24	55075	4072
275481036	24	35191	3492
520143867	24	49385	6292
726384150	24	35061	3103
528641730	24	35077	3748
350746218	24	37273	4389
267534018	24	35838	1980
075148263	24	46372	4986
870514326	24	31025	1071
280571346	24	35472	4304
850126743	24	45089	2805
658307142	24	54608	3511
568703214	24	50785	910
861425073	24	38424	4770
851674320	24	48587	4435
260541783	24	36125	3277
621538047	24	38015	4155
450817623	24	37390	5277
780316542	24	44130	2618
274836510	24	33294	1571
421706538	24	55305	7059
820613574	24	46146	1997
046158237	24	45485	3145
061243578	24	36800	5338
724356180	24	38610	3845
130547268	24	37503	3100
630827145	24	36048	2171
873502164	24	51065	1956
753426180	24	48077	2600

Test cases shown: 250

d	₩	A*(h1)	A*(h2)
4		12	12
6		17	17
8		48	28
10		86	31
12		227	71
14		629	137
16		1311	217
18		3417	470
20		7957	974
22		17819	1798
24		42873	3421

## Numbers are rounded

(Program can generate random puzzles with odd-numbered depths and depths greater than 24 as well, they were just omitted to keep the tables concise) This project was my first time implementing an AI algorithm, and it allowed me to apply my prior experience in object-oriented programming towards what I have learned in this class. My first step was to make a Node class containing variables for f, g, and h so my algorithm could iterate through the puzzles in the correct order (lowest f first). My next step was to implement functions returning h1 (number of misplaced tiles) and h2 (sum of Manhattan distances from correct position) for a given puzzle, as well as a function to evaluate whether a puzzle was solvable (even number of inversions). It was not too difficult designing each helper function but combining them all into one search function (A\*) was a tedious process. It was rewarding in the end, and I was delighted to see how efficiently the program could solve the puzzles.

The solutions that A\*(h1) and A\*(h2) generated contained the same number of steps for each random puzzle, and both algorithms returned an optimal solution (i.e. when testing the puzzles in Length20.txt, no solution generated took more than 20 steps). While both algorithms were successful, it was clear that A\*(h1) took longer than A\*(h2) by a huge margin. This is because h2 as a heuristic was more informational than h1. Counting misplaced tiles did not give any insight on how far each tile was from the correct spot, but summing up the Manhattan distances considered the horizontal and vertical movement of each tile.

The biggest lesson I learned from this project was to make sure I understand an algorithm before I try to implement it. Writing the Python code was the easy part, while understanding A\* took a few days. Furthermore, I learned that if I ever try to implement A\* elsewhere, it is good to experiment with several heuristics and not just one. In the case of this project, it made a huge difference in search cost.