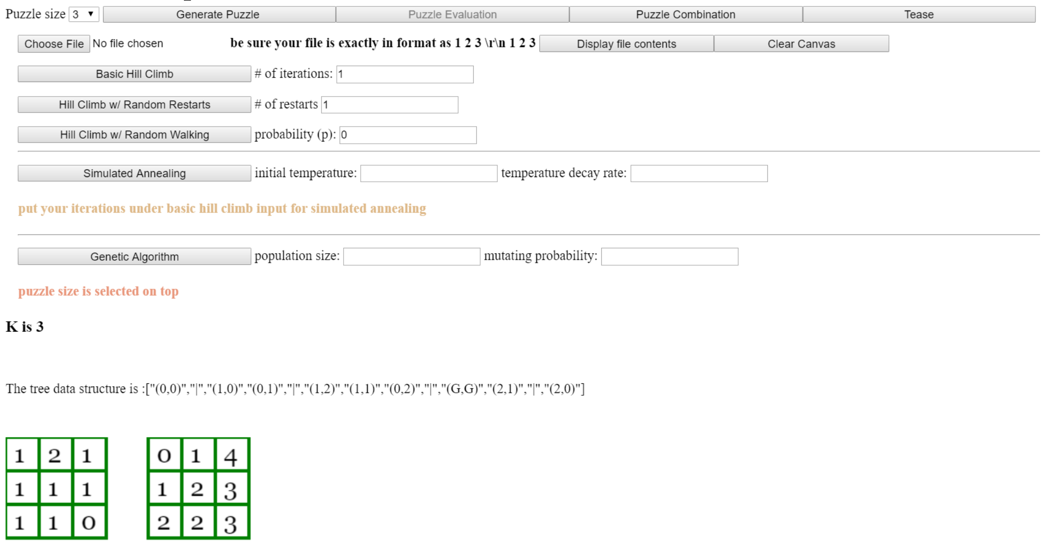
Assignment 1 Local Search Report
By Brandon Young and Ruicheng Wu

Task 1. Puzzle Representation

GUI Example 1:



Puzzle size: 3

No file chosen

be sure your file is exactly in format as 1 2 3 \r\n 1 2 3

# of iterations: 1

# of restarts: 1

probability (p): 0

initial temperature: temperature decay rate:

put your iterations under basic hill climb input for simulated annealing

population size: mutating probability:

puzzle size is selected on top

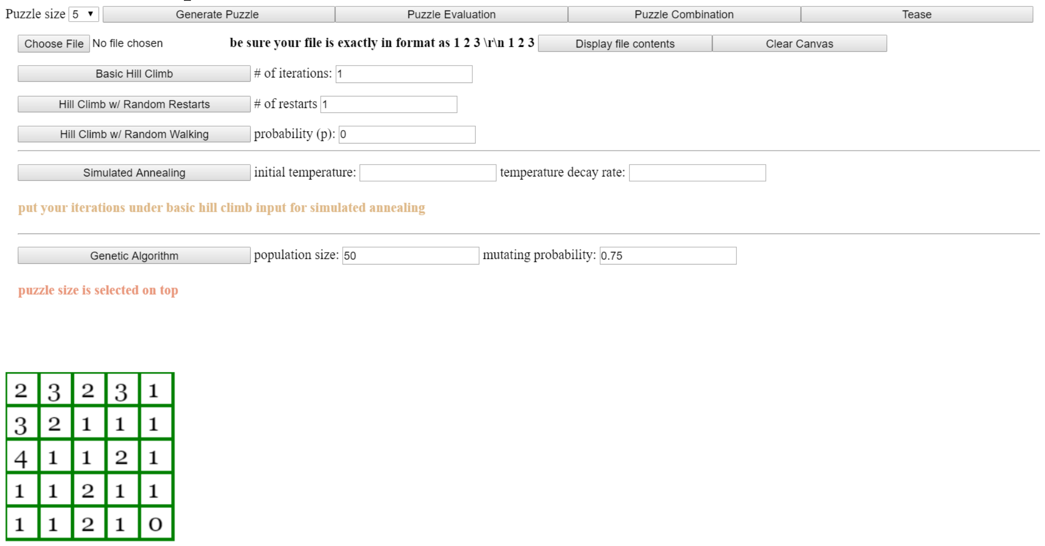
K is 3

The tree data structure is :["(0,0)","|","(1,0)","(0,1)","|","(1,2)","(1,1)","(0,2)","|","(G,G)","(2,1)","|","(2,0)"]

1	2	1
1	1	1
1	1	0

0	1	4
1	2	3
2	2	3

GUI Example 2:



Puzzle size: 5

No file chosen

be sure your file is exactly in format as 1 2 3 \r\n 1 2 3

# of iterations: 1

# of restarts: 1

probability (p): 0

initial temperature: temperature decay rate:

put your iterations under basic hill climb input for simulated annealing

population size: 50 mutating probability: 0.75

puzzle size is selected on top

2	3	2	3	1
3	2	1	1	1
4	1	1	2	1
1	1	2	1	1
1	1	2	1	0

Task 2. Puzzle Evaluation

The puzzle is on the left, while the BFS output is on the right. The following shows 2 puzzles for each possible size, one that is solvable and one that is unsolvable

1. 5x5 (Solvable):

1	1	4	1	1
1	1	2	1	1
4	1	1	2	1
1	3	1	1	1
2	1	1	1	0

0	1	2	5	5
1	2	3	5	4
2	3	4	4	3
X	4	4	5	4
5	4	3	4	5

2. 5x5 (Unsolvable):

3	4	2	1	1
3	2	1	1	1
2	3	2	1	1
4	1	2	1	2
3	2	1	2	0

0	X	2	1	2
6	4	3	2	3
4	6	3	3	4
1	5	3	4	2
5	5	4	5	X

3. 7x7 (Solvable):

1	3	1	4	5	3	1
6	1	1	2	1	2	2
1	4	4	3	1	1	1
1	4	1	3	2	2	1
4	4	2	3	1	1	2
6	2	1	3	1	1	1
3	1	3	2	1	1	0

0	1	7	5	2	X	X
1	5	6	4	3	4	2
6	6	7	5	4	5	4
5	2	6	4	5	3	3
6	X	7	5	4	5	4
5	7	X	4	3	4	5
7	6	7	5	4	5	5

4. 7x7 (Unsolvable):

4	1	5	4	2	1	5
1	3	1	1	3	1	1
4	3	1	1	3	3	2
6	4	3	1	1	1	1
1	2	4	1	1	2	1
6	2	2	1	3	3	4
2	1	1	1	3	2	0

0	3	2	7	1	6	2
X	4	7	6	5	5	4
X	3	6	5	2	5	4
2	5	4	4	5	4	3
1	2	4	3	4	5	4
2	4	3	4	3	6	3
4	3	4	5	6	6	X

5. 9x9 (Solvable):

8	1	3	7	1	3	1	5	4
2	2	5	7	7	5	4	6	2
5	1	4	1	6	4	1	1	3
4	3	3	3	4	4	1	1	5
1	3	2	3	4	4	1	5	3
1	1	1	2	2	1	3	4	3
8	4	6	4	1	1	1	3	5
6	1	6	1	1	4	5	2	5
5	6	1	4	6	5	6	1	0

0	5	4	3	2	3	X	X	1
4	5	5	6	3	X	4	6	3
7	6	7	6	5	5	5	6	4
2	4	5	5	3	3	6	7	4
6	4	8	6	5	3	7	8	2
7	7	7	6	6	6	5	8	5
8	5	6	5	5	6	7	6	7
3	5	5	4	4	4	4	7	3
1	6	X	5	4	2	6	6	5

6. 9x9 (Unsolvable):

6	3	1	1	4	3	5	3	4
4	1	3	1	1	3	3	5	1
5	6	5	1	1	2	4	5	1
1	2	4	1	4	2	2	3	2
5	6	6	1	2	1	3	3	3
7	3	3	4	1	1	1	3	2
4	2	1	1	1	4	1	4	1
5	1	4	3	3	1	2	3	6
4	5	1	1	6	5	1	4	0

0	2	5	6	3	4	1	7	4
5	4	5	5	6	6	4	6	6
2	5	5	4	5	3	X	4	7
6	3	5	4	5	5	6	6	6
7	5	5	4	4	4	3	5	5
6	4	5	4	3	3	2	3	7
1	4	4	3	2	3	3	4	X
3	4	5	4	3	4	4	4	5
6	5	6	5	6	5	6	4	X

7. 11x11 (Solvable):

4	9	7	7	4	1	7	10	9	9	1
3	5	5	1	6	1	7	1	2	5	9
4	5	3	1	4	1	3	2	3	7	8
1	5	6	6	7	3	4	3	1	5	5
10	1	2	5	1	6	4	1	1	1	6
10	3	5	2	2	1	2	1	5	1	7
1	5	8	7	3	5	1	1	4	1	6
3	2	1	5	3	1	4	4	1	1	7
1	2	2	7	1	3	4	1	6	1	1
1	7	6	3	5	3	6	1	7	6	6
4	7	1	5	7	4	6	1	3	5	0

0	X	5	9	1	7	7	7	2	6	7
X	8	9	8	7	6	7	10	11	X	8
7	5	8	7	6	5	6	11	4	7	X
X	6	6	7	3	6	5	6	5	6	6
1	X	7	3	2	3	6	5	4	5	2
7	6	4	6	3	7	4	5	5	6	7
6	7	7	5	7	5	7	6	7	7	6
7	5	6	6	4	X	5	5	7	8	6
6	7	7	8	8	9	7	10	8	7	7
5	4	6	4	8	X	5	9	3	7	8
6	5	5	6	4	4	9	8	6	5	3

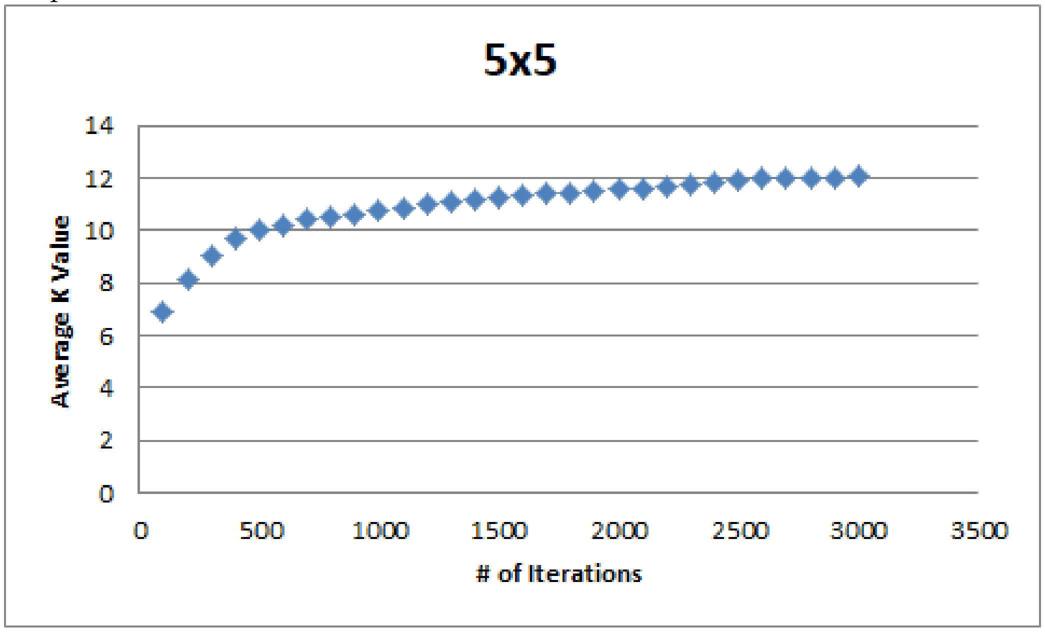
8. 11x11 (Unsolvable):

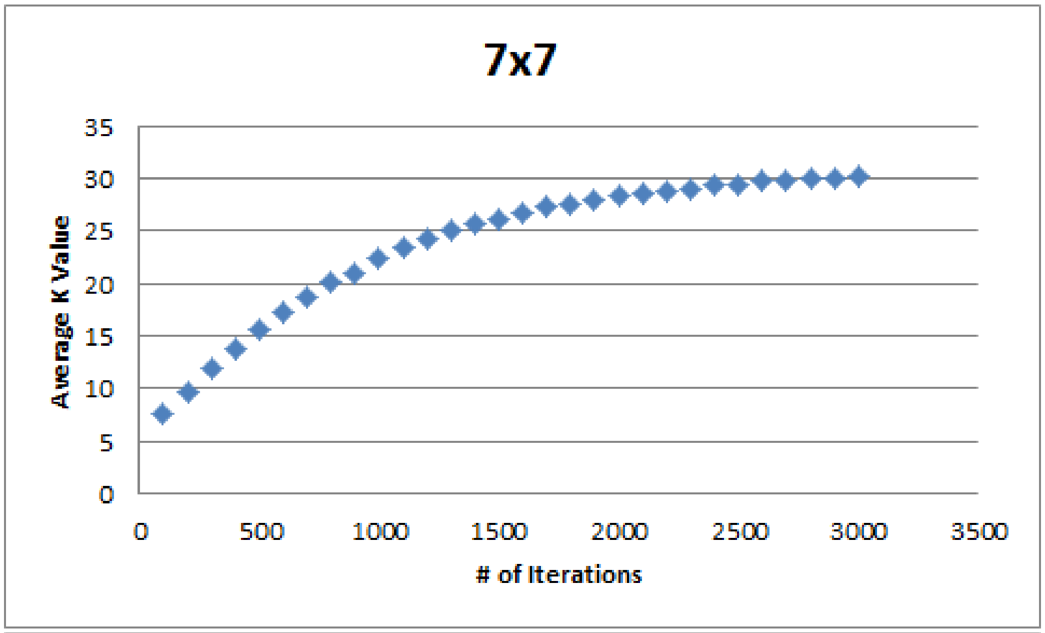
2	1	4	9	10	7	7	1	5	4	5
10	1	9	1	2	8	1	6	3	3	4
6	1	1	7	8	2	2	4	1	5	2
4	1	1	7	6	6	2	3	2	5	8
6	9	1	2	1	3	1	5	1	6	8
3	4	2	1	1	3	1	1	5	1	3
4	5	7	1	1	5	3	4	1	3	5
10	3	8	4	2	1	4	1	5	1	8
5	1	8	4	2	1	6	3	2	3	1
5	1	1	7	3	1	4	1	7	2	2
4	6	2	3	4	7	6	1	6	7	0

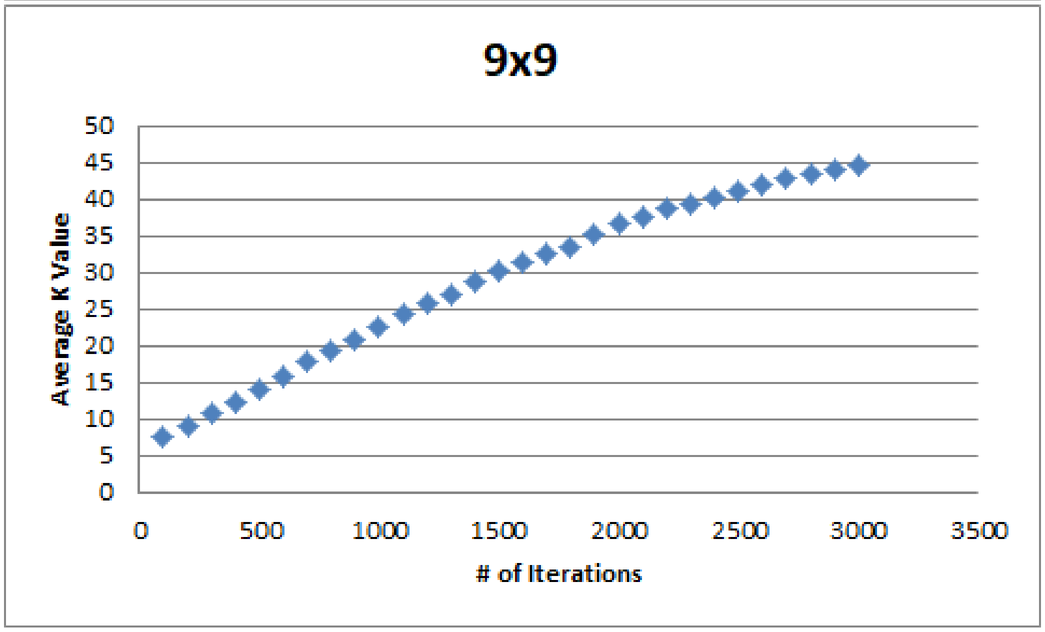
0	7	1	7	X	7	2	X	6	X	6
7	6	5	X	X	5	5	6	4	X	7
1	5	4	4	3	6	2	4	3	4	5
3	4	3	4	4	6	4	X	4	7	5
8	3	2	3	5	4	3	4	5	6	4
4	X	3	5	4	5	4	5	5	7	7
6	X	5	4	5	5	5	5	X	6	6
4	8	4	5	5	4	3	6	6	5	4
2	7	5	X	4	3	4	6	X	6	6
7	6	6	5	5	4	5	5	6	7	6
5	7	6	5	4	5	6	6	5	7	X

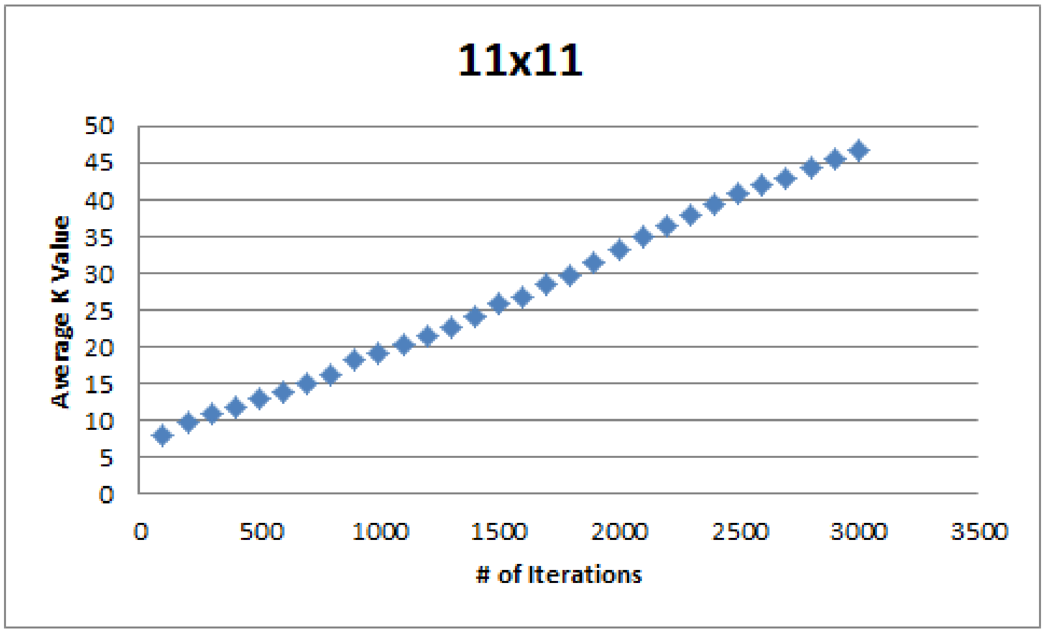
Task 3. Basic Hill Climb

To get the following plots we ran hill climb 50 times for 3000 iterations and at every 100th iteration we took the K value at that interval. Then we averaged the K values at each interval to get the data for the following scatterplots:



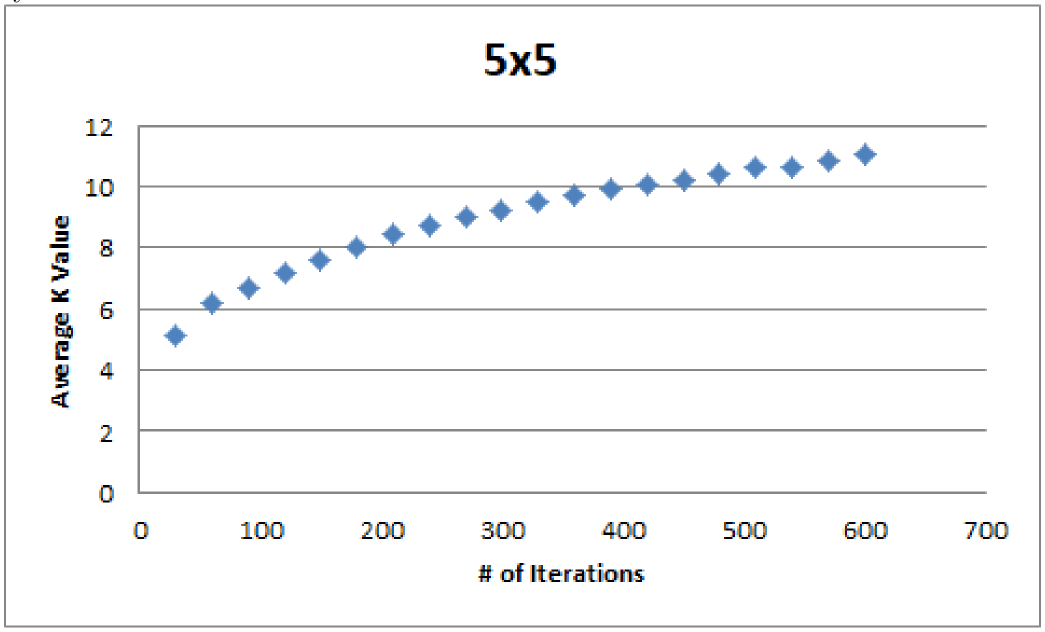

7x7
Average K Value
# of Iterations
0
5
10
15
20
25
30
35
0
500
1000
1500
2000
2500
3000
3500

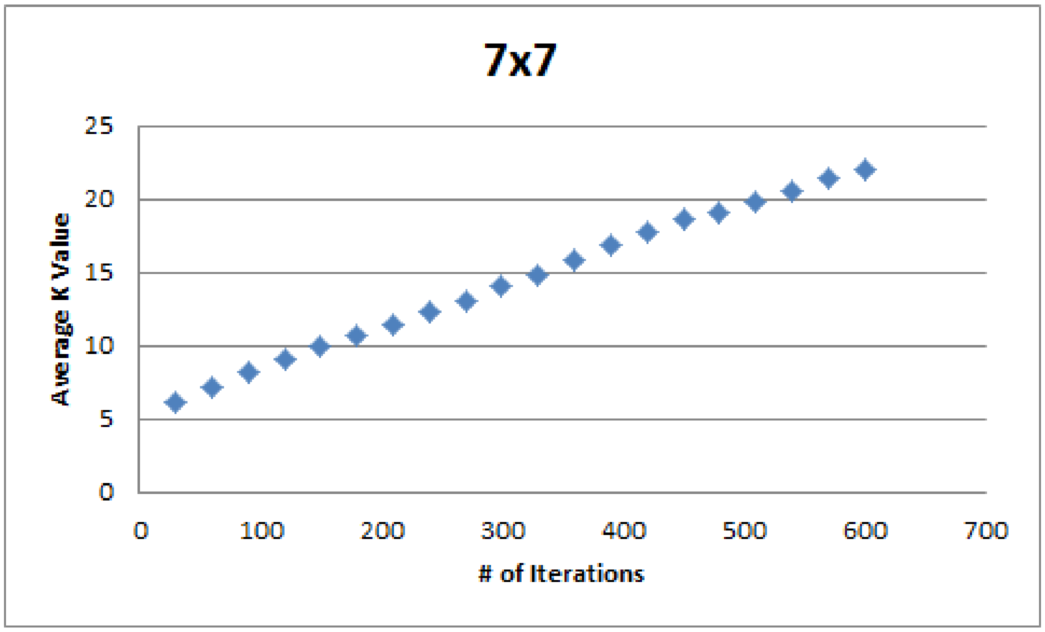

9x9
Average K Value
# of Iterations
0
5
10
15
20
25
30
35
40
45
50
0
500
1000
1500
2000
2500
3000
3500

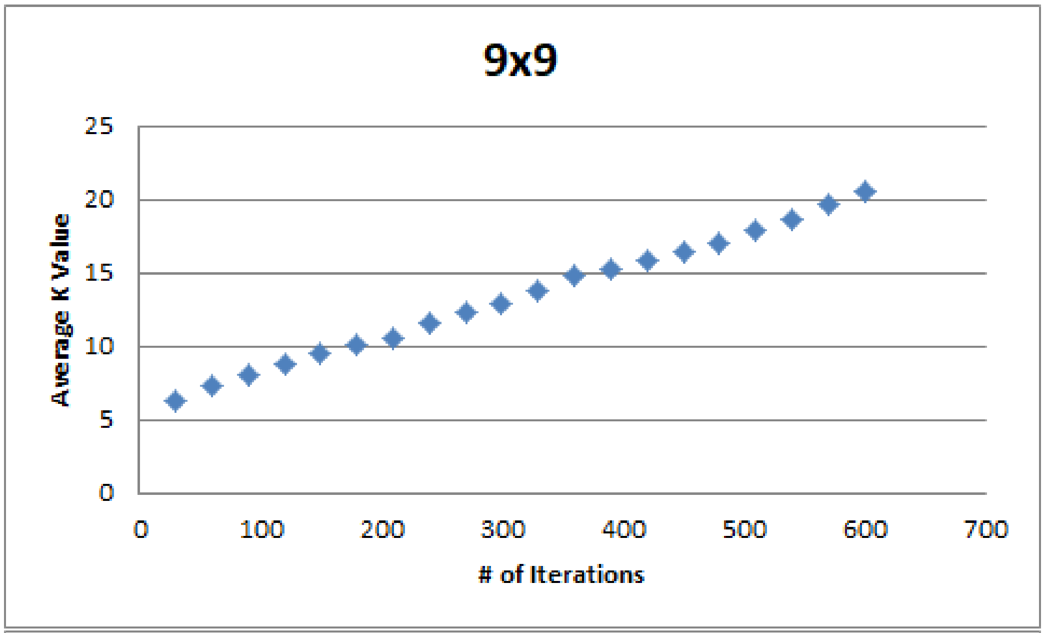

11x11
Average K Value
# of Iterations
0
5
10
15
20
25
30
35
40
45
50
0
500
1000
1500
2000
2500
3000
3500

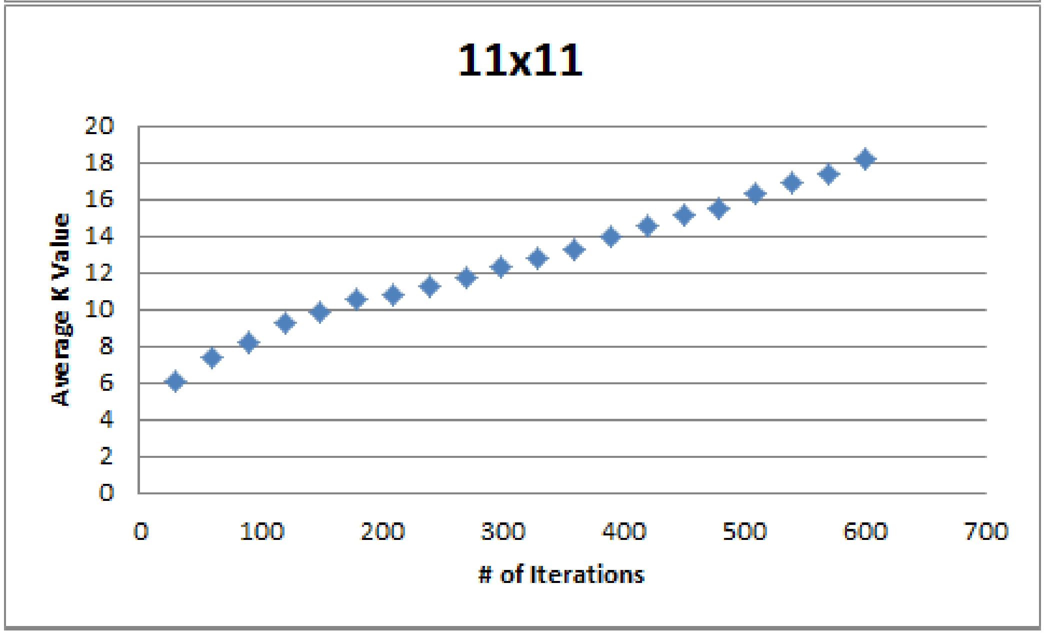
Task 4. Hill Climbing with Random Restarts

For hill climbing with random restarts, using 600 iterations and 5 restarts, the best individual hill climb was picked and its K values were recorded at every 100th iteration:







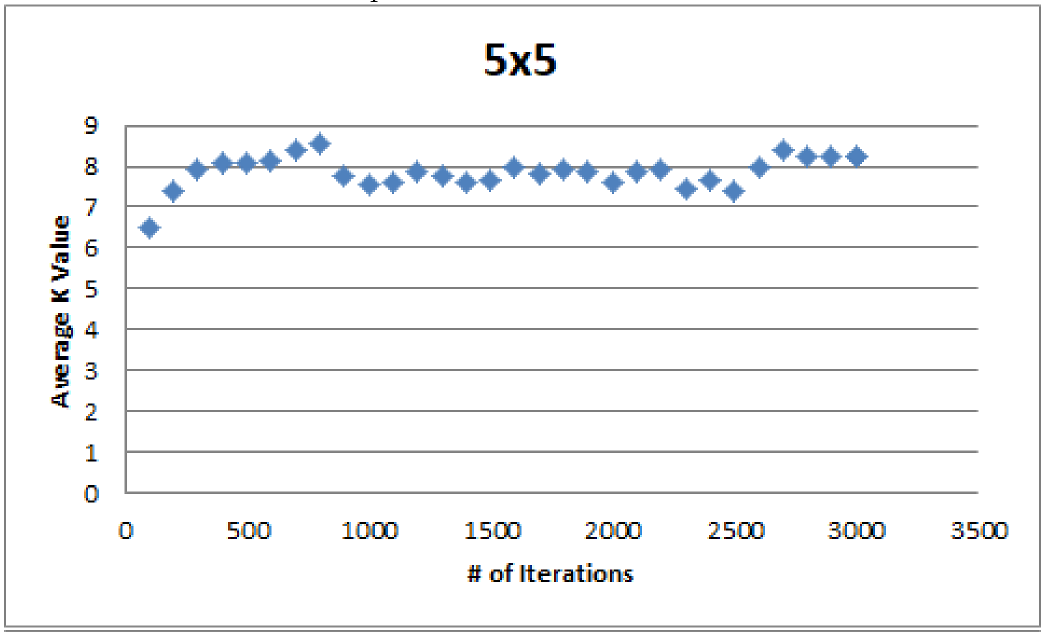


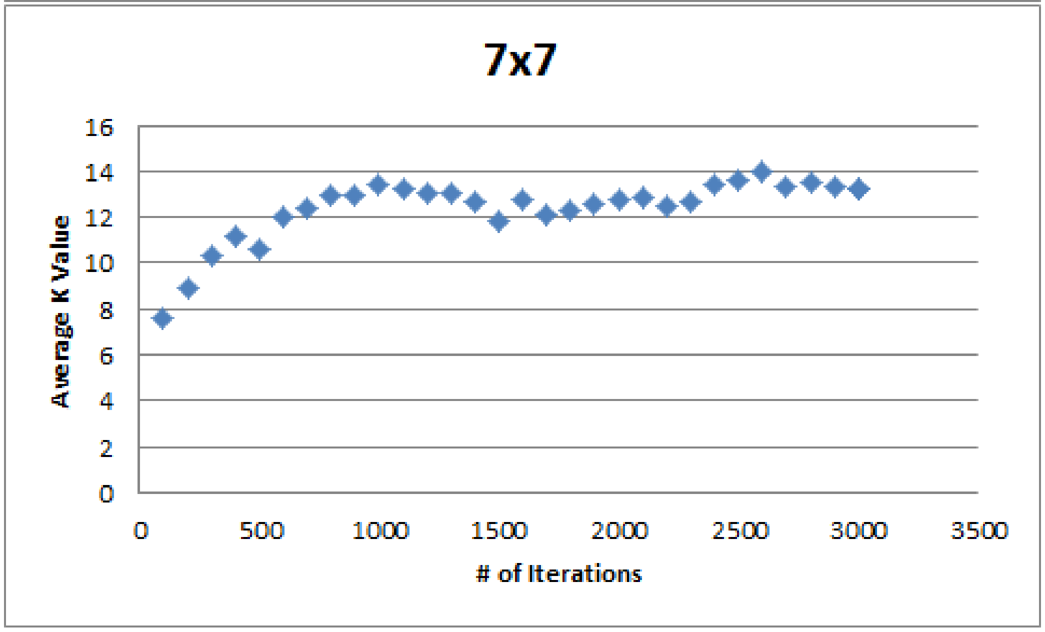
Compared to basic hill climbing, hill climbing with restarts appears to do worse. On the 5x5 plots, for example, restarts only reaches K = 11 at most, but basic hill climb reaches K = 12.

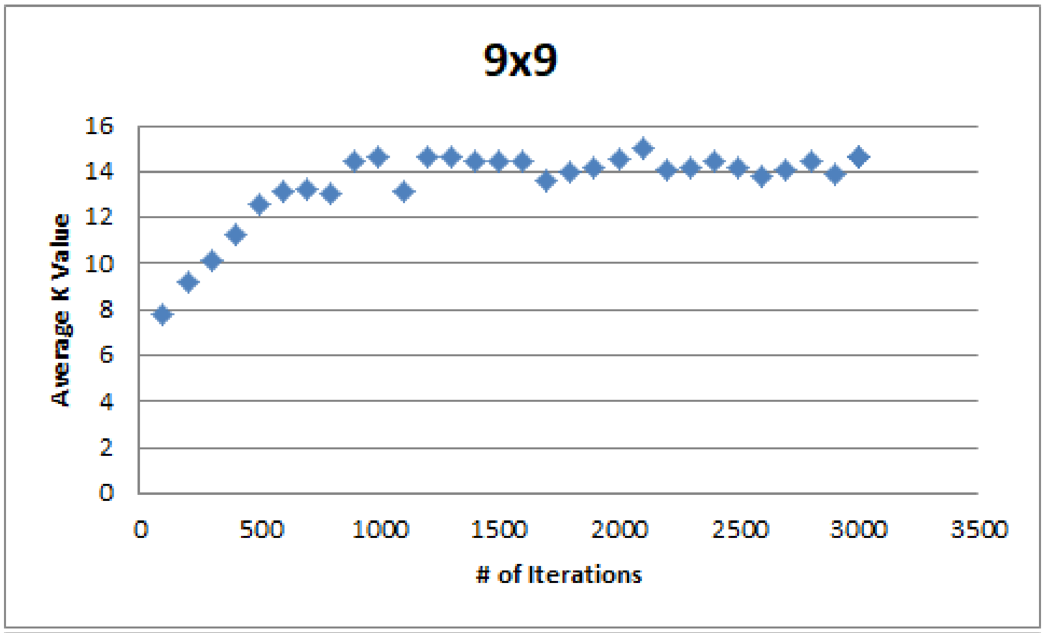
For the number of restarts, more than 2 restarts are preferred, to differentiate from basic hill climb. Yet the number of restarts should not be too high, or the hill climb process will be too short to be effective compared to basic hill climb. So 5 restarts was chosen for the plots above.

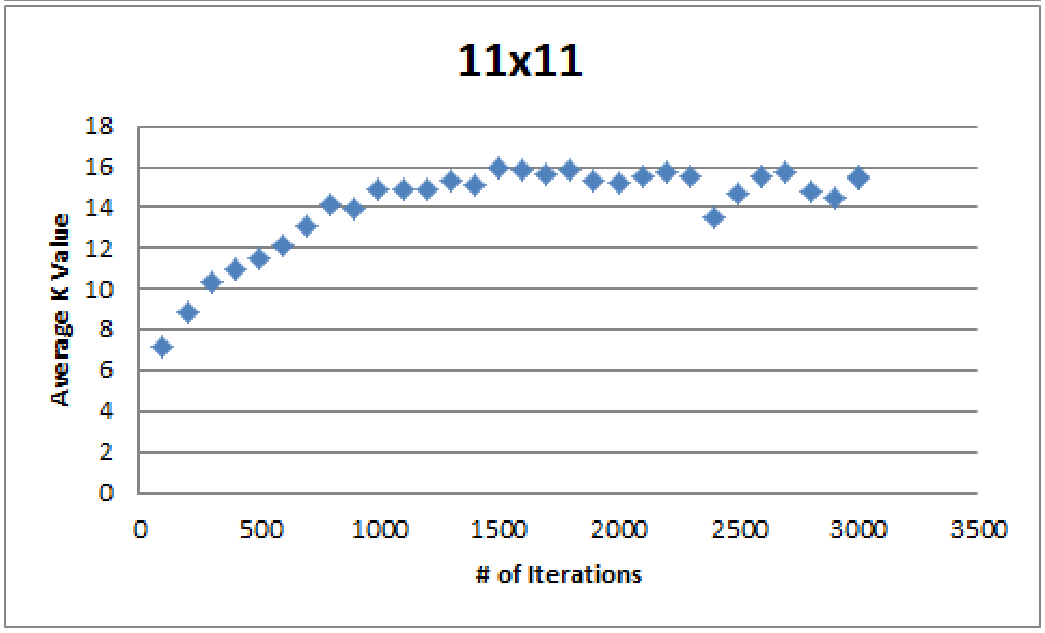
Task 5. Hill Climbing with Random Walking

For hill climbing with random walking, p = 0.01, where p is the probability of allowing downhill movement. A similar process with basic hill climbing was used to obtain the scatterplots below:







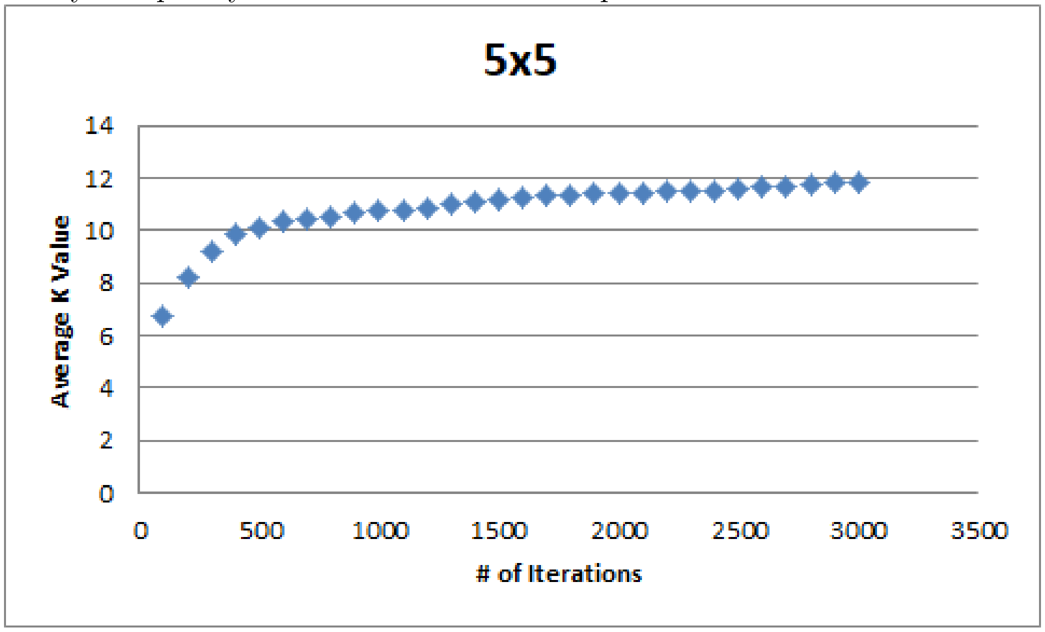


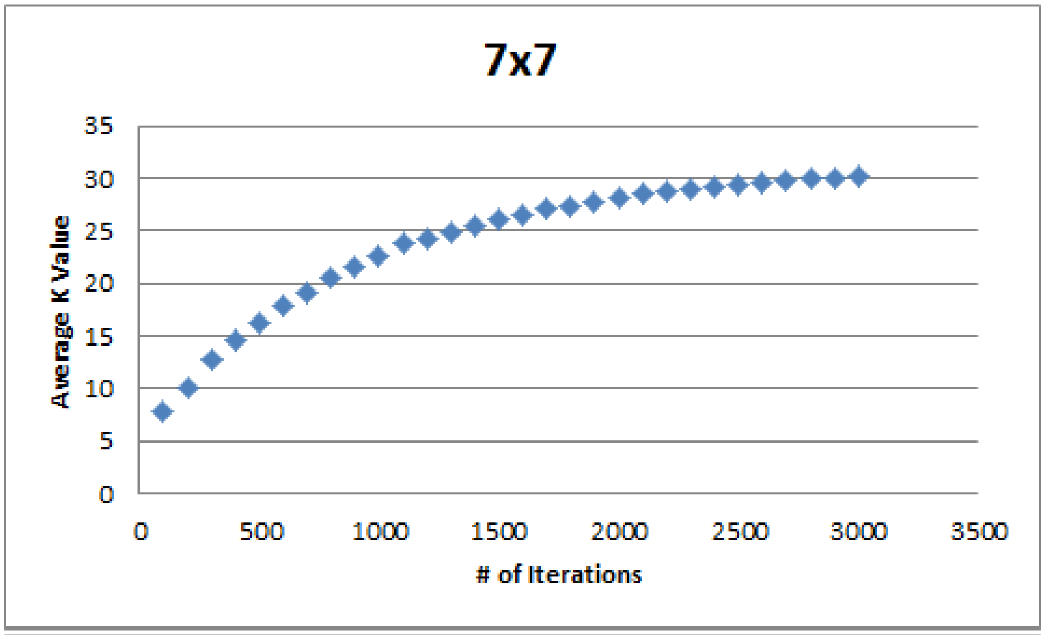
Random walk does appear to work, however, the dips caused by downhill movement can be too severe to recover from. This is why p was set to 0.01, but it looks like it could be set even lower to retain the effectiveness of basic hill climbing.

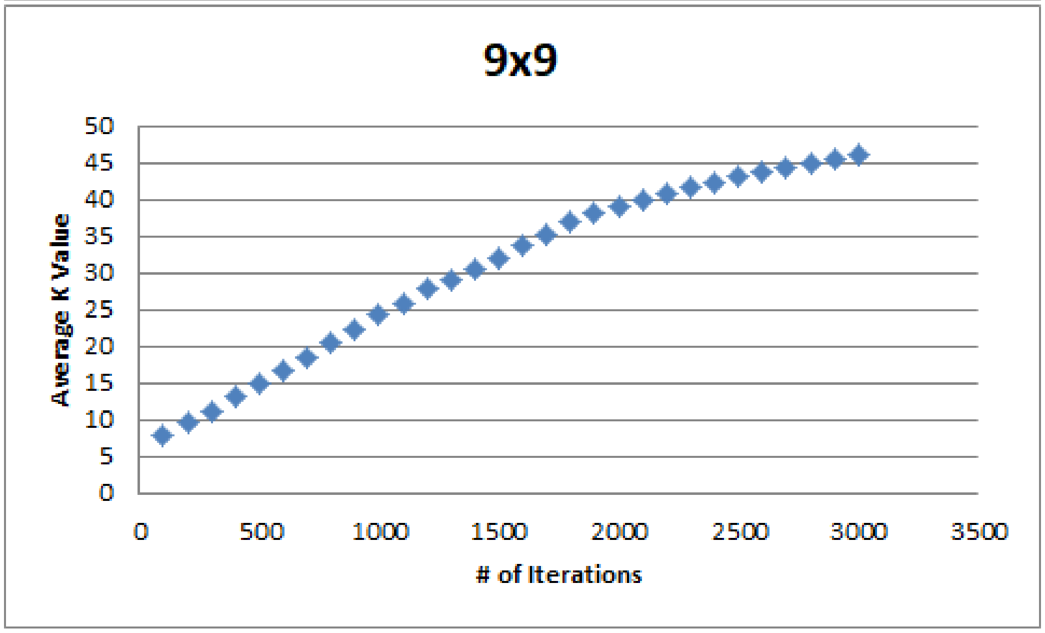
Compared to plain hill climbing and climbing with restarts, random walk performs much worse, reaching a high of about K = 8.5 for 5x5 puzzles while the other 2 methods surpassed 10. However, this may be caused by the averaging of data points, since at some points in the plots, there can be a jump in K values (such as from iterations 800 to 900 on the 9x9 plot).

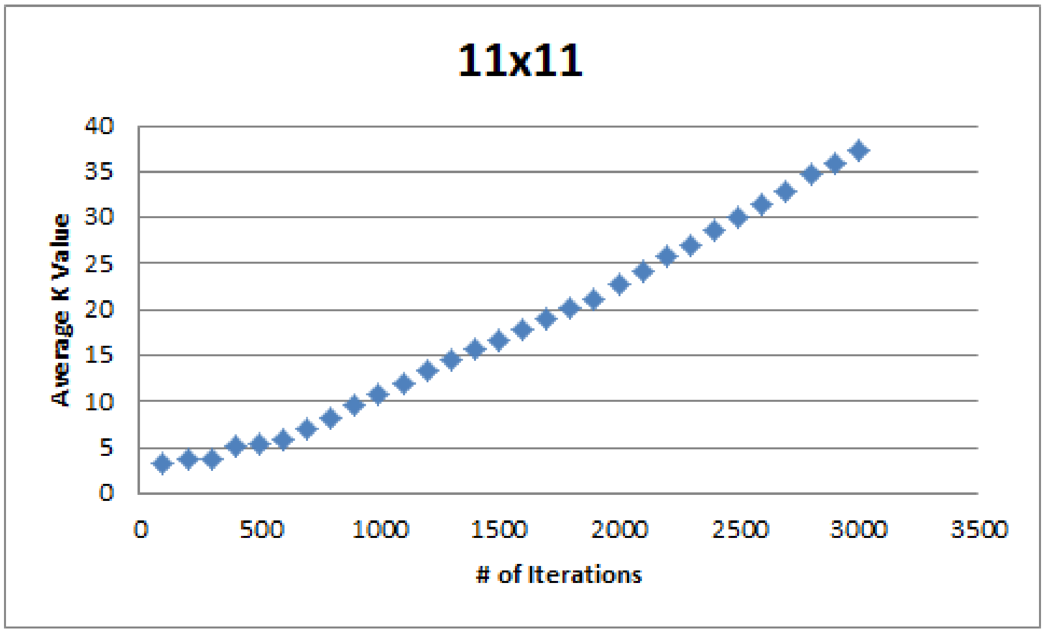
Task 6. Simulated Annealing

The parameters used for simulated annealing were: T (initial temperature)= 1000, decay rate = 0.99 with 3000 iterations and every 100th iteration being recorded. The decay rate was picked so that the temperature would not decay too quickly or the results would end up the same as random walk's.




7x7
Average K Value
# of Iterations
0
5
10
15
20
25
30
35
0
500
1000
1500
2000
2500
3000
3500


9x9
Average K Value
# of Iterations
0
5
10
15
20
25
30
35
40
45
50
0
500
1000
1500
2000
2500
3000
3500

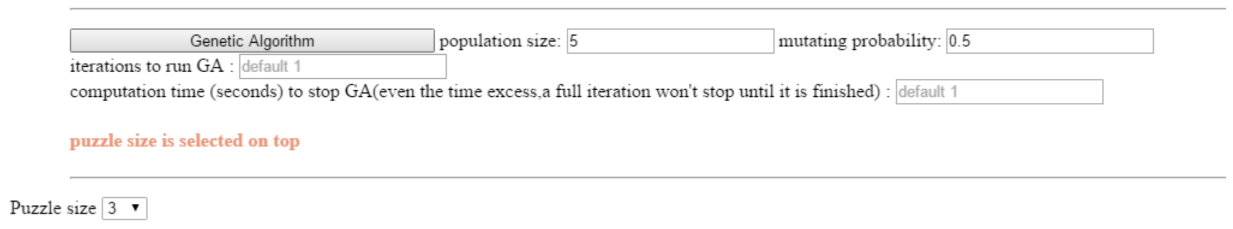


Compared to random walk, simulated annealing (SA) is much more successful, reaching a max K of 12 at the 3000th iteration compared to random walk's 8.5. Simulated annealing achieved maximum K values of about 12, 30, 46 and 37 for 5x5, 7x7, 9x9 and 11x11 puzzles respectively. In comparison, in the same total number of iterations, hill climbing with random restarts obtained K values of about 11, 22, 21 and 18. Simulated annealing performs objectively better.

However, compared to basic hill climbing, simulated annealing performs about the same, with the exception of 11x11 puzzles where simulated annealing has a lower maximum K value. This may be caused by the randomness due to the probability of downhill movement, but it shows that basic hill climbing is the most reliable out of the four methods.

Task 7. Genetic Algorithms

In order to run Genetic Algorithm, you need those two sections:
Except Computation Time(It is used by us to record the time before,the feature is unable to use right now), You have a default population size 5,default mutating probability 0.5,and default iteration 1


Genetic Algorithm population size: 5 mutating probability: 0.5
iterations to run GA : default 1
computation time (seconds) to stop GA(even the time excess,a full iteration won't stop until it is finished) : default 1

puzzle size is selected on top

Puzzle size 3

Our implementation of GA is to take a final optimized puzzle(With highest fitness value, K) among all these iterations(default 1).For each iteration, this method will create puzzle set of population size p and then evaluate each individual puzzle with fitness function. We select a descent amount of two puzzle groups according to each individuals' fitness value(Some puzzle may not be chosen at all while some may be chosen repeatedly). After selection, we randomly choose one row of puzzles in same group and do this for every group. Then process to cross-over,that is swap Part A of first puzzle with Part A of second puzzle in same group.So now each group should have $PartA - PuzzleOne - PartB - PuzzleTwo$ $PartA - PuzzleTwo - PartB - PuzzleOne$ like structure. The last step is mutating, with corresponding mutating probability,each individual puzzle will have a chance to mutate a randomly selected row(Or may not mutate at all).

(Here, all puzzles are verified and guaranteed to be valid)

1,Generating: randomly generate population size p puzzles,store in a Three-Dimensional Array,2D array represents each puzzle.

2.Fitness Evaluation and Selection: process each puzzle with fitness function and store corresponding k into an array. Will calculate the total k sum and the proportion of each puzzle, for instance, a k group : $[4, 3, 2, 1]$, the puzzle with $k = 4$ will be 40 percent and puzzle with $k = 1$ will be 10 percent. These probability will be mapping along one line with range $[0, 1)$, in this case,$[0, 0.4), [0.4, 0.7), [0.7, 0.9), [0.9, 1)$. After storing and mapping k, we use $Math.random()$ to determine the selection. In $Javascript$, $Math.random()$ will generate a number randomly between 0(inclusive),1(exclusive).We check which interval it is located.Do this twice for each selection iteration(an inner loop).According to the combinatorial theory, we decide to run this selection loop until we have either $C(p, 2)$ group with no duplicate matrix or this loop has iterated more than population size p(In case the loop stuck when some puzzles with extreme high k being choosing repeatedly or just the order being swapped like $A - B$ and $B - A$).After this loop, we should have a descent amount of group with two puzzles each.

(Note : in order to keep a good start, we sort out any puzzle with negative value.)

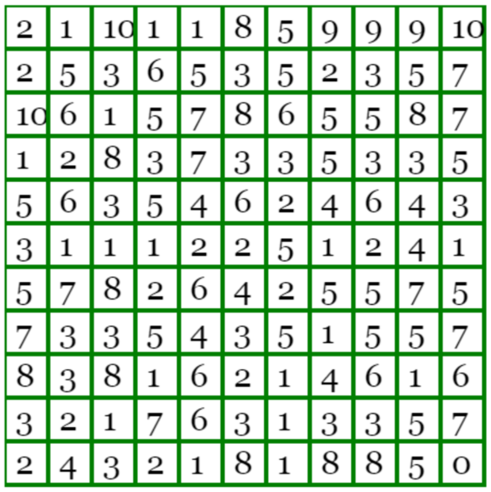
3.Random Pick and Crossing-Over: for each group , use an advanced random number trick to pick a row to cut off and cross over, each group will only need one random number bases their total row numbers. We didn't choose to pick column because it is easier to get entire row than column when we coded(Or if you visualize the $2d$ array as column-row,that is another story).When cross-over, PartA of 1st puzzle will be joined with PartB of 2nd puzzle to make a new puzzle with exact same size as before.And the rest part joined together. Apply this operation to each group, a group of new crossover puzzle is presenting.

4.Mutating and Find Best K: Going through all operations before, in our code,randomly pick a row for each puzzle first, then we use random trick again to decide if their chosen rows are going to be mutated or not(We choose to mutate one row instead of one cell).After mutating has done, we present all these puzzles to being evaluated again and capture the puzzle with highest K and draw it and its visualizing matrix on the screen presenting with other data.

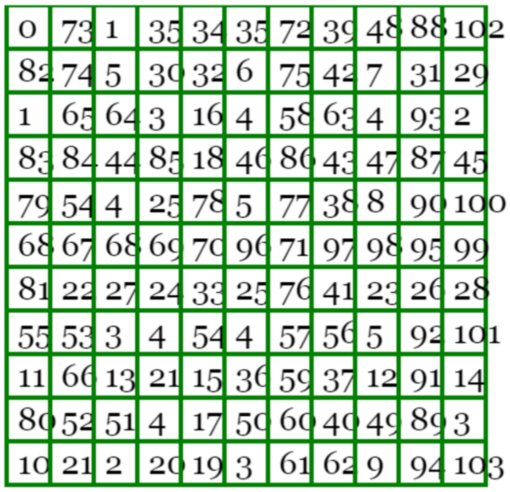
5.Grand Outer Loop and Harvesting: All operations above are just one run of GA. So we take iteration number to go through GA and harvest the puzzle with highest value K and present it and its visualizing matrix on the screen.

Task 8. Hardest Puzzle

To create the hardest puzzle, we used basic hill climb, since it gave reliable results. By running many iterations on a random 11x11 puzzle, we found the following puzzle with K = 103 (actual puzzle is one the left, evaluation matrix is on the right):



2	1	10	1	1	8	5	9	9	9	10
2	5	3	6	5	3	5	2	3	5	7
10	6	1	5	7	8	6	5	5	8	7
1	2	8	3	7	3	3	5	3	3	5
5	6	3	5	4	6	2	4	6	4	3
3	1	1	1	2	2	5	1	2	4	1
5	7	8	2	6	4	2	5	5	7	5
7	3	3	5	4	3	5	1	5	5	7
8	3	8	1	6	2	1	4	6	1	6
3	2	1	7	6	3	1	3	3	5	7
2	4	3	2	1	8	1	8	8	5	0



0	73	1	35	34	35	72	39	48	88	102
82	74	5	30	32	6	75	42	7	31	29
1	65	64	3	16	4	58	63	4	93	2
83	84	44	85	18	46	86	43	47	87	45
79	54	4	25	78	5	77	38	8	90	100
68	67	68	69	70	96	71	97	98	95	99
81	22	27	24	33	25	76	41	23	26	28
55	53	3	4	54	4	57	56	5	92	101
11	66	13	21	15	36	59	37	12	91	14
80	52	51	4	17	50	60	40	49	89	3
10	21	2	20	19	3	61	62	9	94	103