ITCS 3153: Introduction to Artificial Intelligence
In-class assignment
Local Search

Implement a Simulated Annealing algorithm to solve the N-queens problem. You may use the nqueens.py script in Canvas files that provides a Board class, number of attacking queens heuristic cost function, and getSuccessorStates function.

Guidelines:

1. Use an linear scheduling function: f(T) = T*decay_rate where decay_rate is a constant in range (0,1). **Note that this function is taking the current temperature as the input, not the time value "t".** At each iteration, pass in T to your scheduling function and return a new T value. Do not use the "t" value shown in the textbook.

2. Set initial T=100.

3. Terminate the algorithm if T is smaller than a threshold value, e.g., 0.00001.
    a. Note that this is not the only termination condition.

4. Try different pairs of decay_rate and the threshold for T to terminate the loop:
    a. decay_rate=0.9, T=0.000001
    b. decay_rate=0.75, T=0.0000001
    c. decay_rate=0.5, T=0.00000001

Create a loop to run 10 simulated annealing executions with each of the above decay rate and T threshold pairs (4a-4c). Each run should have a random starting board of the same size. For each run, print the following information to console:

a) Initial state and its h-value
b) Final state and its h-value

For each pair of decay rate and T threshold values, print out:

c) Decay rate
d) Threshold for T
e) Average h-value of the final solutions over all 10 runs

Then, create another loop to increase the board size. Use the following board sizes: 4, 8, and 16.

Example final output: (your output should be readable and organized, but doesn't need to be exactly like this)

```
**********
Board size: 4
**********
##########
Decay rate 0.9 T Threshold: 1e-06
##########
Run 0
Initial board:
[1, 0, 0, 0]
[0, 0, 1, 0]
[0, 0, 0, 1]
[0, 0, 0, 1]
h-value: 6
Final board h value: 2
[0, 0, 1, 0]
[0, 1, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
Run 1
Initial board:
[0, 0, 1, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
[0, 1, 0, 0]
h-value: 6
Final board h value: 2
[0, 0, 0, 1]
[1, 0, 0, 0]
[0, 0, 1, 0]
[0, 1, 0, 0]
Run 2
Initial board:
[0, 0, 1, 0]
[1, 0, 0, 0]
[0, 1, 0, 0]
[1, 0, 0, 0]
h-value: 6
```

Final board h value: 0
[0, 0, 1, 0]
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
Run 3
Initial board:
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 0, 0, 1]
[0, 0, 1, 0]
h-value: 4
Final board h value: 0
[0, 1, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
[0, 0, 1, 0]
Run 4
Initial board:
[0, 0, 1, 0]
[0, 0, 1, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
h-value: 6
Final board h value: 0
[0, 1, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
[0, 0, 1, 0]
Run 5
Initial board:
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
[1, 0, 0, 0]
h-value: 4
Final board h value: 2
[0, 0, 0, 1]
[1, 0, 0, 0]

[0, 0, 1, 0]
[0, 1, 0, 0]
Run 6
Initial board:
[0, 1, 0, 0]
[0, 0, 1, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
h-value: 6
Final board h value: 0
[0, 0, 1, 0]
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
Run 7
Initial board:
[1, 0, 0, 0]
[0, 1, 0, 0]
[0, 1, 0, 0]
[0, 1, 0, 0]
h-value: 8
Final board h value: 2
[1, 0, 0, 0]
[0, 0, 1, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
Run 8
Initial board:
[0, 1, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
[1, 0, 0, 0]
h-value: 2
Final board h value: 2
[0, 1, 0, 0]
[0, 0, 1, 0]
[1, 0, 0, 0]
[0, 0, 0, 1]
Run 9

Initial board:
[1, 0, 0, 0]
[0, 0, 1, 0]
[0, 1, 0, 0]
[0, 1, 0, 0]
h-value: 4
Final board h value: 2
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
[0, 0, 1, 0]
Average h-cost of final solutions: 1.2
##
Decay rate 0.75 T Threshold: 1e-07
##
Run 0
Initial board:
[0, 1, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
[1, 0, 0, 0]
h-value: 4
Final board h value: 2
[0, 1, 0, 0]
[0, 0, 1, 0]
[1, 0, 0, 0]
[0, 0, 0, 1]
Run 1
Initial board:
[1, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[0, 1, 0, 0]
h-value: 8
Final board h value: 2
[0, 0, 1, 0]
[1, 0, 0, 0]
[0, 1, 0, 0]
[0, 0, 0, 1]

Run 2
Initial board:
[0, 0, 0, 1]
[0, 0, 1, 0]
[0, 0, 1, 0]
[0, 0, 0, 1]
h-value: 8
Final board h value: 2
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
[0, 0, 1, 0]
Run 3
Initial board:
[0, 1, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
[0, 1, 0, 0]
h-value: 6
Final board h value: 0
[0, 0, 1, 0]
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
Run 4
Initial board:
[0, 0, 1, 0]
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 0, 0, 1]
h-value: 2
Final board h value: 2
[0, 1, 0, 0]
[0, 0, 0, 1]
[0, 0, 1, 0]
[1, 0, 0, 0]
Run 5
Initial board:
[0, 0, 0, 1]

[0, 1, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
h-value: 4
Final board h value: 0
[0, 0, 1, 0]
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
Run 6
Initial board:
[1, 0, 0, 0]
[1, 0, 0, 0]
[0, 0, 1, 0]
[0, 1, 0, 0]
h-value: 6
Final board h value: 2
[0, 0, 0, 1]
[1, 0, 0, 0]
[0, 0, 1, 0]
[0, 1, 0, 0]
Run 7
Initial board:
[1, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
h-value: 12
Final board h value: 2
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
[0, 0, 1, 0]
Run 8
Initial board:
[0, 1, 0, 0]
[1, 0, 0, 0]
[1, 0, 0, 0]
[0, 1, 0, 0]

h-value: 8
Final board h value: 2
[0, 0, 0, 1]
[0, 1, 0, 0]
[1, 0, 0, 0]
[0, 0, 1, 0]
Run 9
Initial board:
[0, 1, 0, 0]
[0, 0, 0, 1]
[0, 0, 1, 0]
[0, 1, 0, 0]
h-value: 8
Final board h value: 0
[0, 1, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
[0, 0, 1, 0]
Average h-cost of final solutions: 1.4
##
Decay rate 0.5 T Threshold: 1e-08
##
Run 0
Initial board:
[0, 1, 0, 0]
[1, 0, 0, 0]
[0, 0, 1, 0]
[0, 1, 0, 0]
h-value: 6
Final board h value: 2
[0, 1, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
[0, 0, 0, 1]
Run 1
Initial board:
[0, 0, 0, 1]
[0, 0, 1, 0]
[1, 0, 0, 0]

[0, 0, 1, 0]
h-value: 4
Final board h value: 2
[0, 0, 0, 1]
[0, 1, 0, 0]
[1, 0, 0, 0]
[0, 0, 1, 0]
Run 2
Initial board:
[1, 0, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
[0, 1, 0, 0]
h-value: 6
Final board h value: 2
[0, 0, 1, 0]
[1, 0, 0, 0]
[0, 1, 0, 0]
[0, 0, 0, 1]
Run 3
Initial board:
[0, 1, 0, 0]
[0, 1, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
h-value: 4
Final board h value: 4
[0, 0, 1, 0]
[0, 0, 1, 0]
[0, 1, 0, 0]
[0, 0, 0, 1]
Run 4
Initial board:
[0, 0, 1, 0]
[0, 0, 1, 0]
[0, 1, 0, 0]
[0, 1, 0, 0]
h-value: 6
Final board h value: 4

[1, 0, 0, 0]
[0, 0, 1, 0]
[0, 1, 0, 0]
[0, 0, 0, 1]
Run 5
Initial board:
[1, 0, 0, 0]
[0, 1, 0, 0]
[0, 0, 1, 0]
[0, 0, 1, 0]
h-value: 8
Final board h value: 4
[0, 0, 1, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
[0, 0, 0, 1]
Run 6
Initial board:
[0, 1, 0, 0]
[1, 0, 0, 0]
[0, 1, 0, 0]
[1, 0, 0, 0]
h-value: 10
Final board h value: 2
[1, 0, 0, 0]
[0, 0, 0, 1]
[0, 1, 0, 0]
[0, 0, 1, 0]
Run 7
Initial board:
[0, 0, 0, 1]
[0, 0, 0, 1]
[0, 0, 0, 1]
[0, 0, 1, 0]
h-value: 8
Final board h value: 0
[0, 1, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]

[0, 0, 1, 0]
Run 8
Initial board:
[0, 0, 0, 1]
[0, 0, 0, 1]
[0, 0, 1, 0]
[0, 1, 0, 0]
h-value: 8
Final board h value: 4
[0, 0, 0, 1]
[0, 1, 0, 0]
[0, 0, 1, 0]
[1, 0, 0, 0]
Run 9
Initial board:
[0, 0, 1, 0]
[0, 1, 0, 0]
[0, 0, 1, 0]
[0, 0, 0, 1]
h-value: 10
Final board h value: 2
[0, 0, 1, 0]
[0, 1, 0, 0]
[0, 0, 0, 1]
[1, 0, 0, 0]
Average h-cost of final solutons: 2.6
****
Board size: 8
****
##
Decay rate 0.9 T Threshold: 1e-06
##
…

Continue with the rest of the board sizes...