By Christian Micklisch 🏇 Manoj Krishna Mohan

N-Queens problem formulation

The N-Queens problem is a NP-Complete problem. The problem is to find the arrangement of N queens on an NxN chess board, such that no queen can attack any other queens on the board. The chess queens can attack in any direction as horizontal, vertical, horizontal and diagonal way. The attacks can also be direct or indirect.

```
{ 0,  👑,  0,  0}
{ 0,  0,  0,  👑}
{ 👑,  0,  0,  0}
{ 0,  0,  👑,  0}
```

The above board represents a 4x4 board such that no queens attack each other. In our project, we have tried to use the column-wise movement, sideways movement method and also the Random restart methodologies to achieve the solution.

The Program structure

The programs for defining and generating the NxN chess board and also the other files which include the hill-climbing algorithms and the test cases are listed as below. All the functions are called inside of the main.py file which runs once the test cases are generated. The logic for hillclimbing is defined in the hill_climbing.py and the generated state is once again evaluated by the evaluate.py file. The subfolder test_files contains all the respective test cases that run before the User inputs the values for generating the N-Queens board.

```
├──test_files
│   ├── test.py
│   ├── test_evaluate.py
│   ├── test_generate.py
│   └── test_hill_climbing.py
├── evaluate.py
├── generate_nxn.py
├── hill_climbing.py
└── main.py
```

hill-climbing-search

Hill climbing search is an optimization technique which belongs to category of Informed Search strategy. It is an iterative algorithm that starts with an arbitrary solution to a problem, then attempts to find a better solution by making incremental changes to the solution. If the increment produces a better solution, it proceeds with the incrementing until the best solution is found.

The steps involved in a Hill Climbing Search is as follows: - Evaluate the initial state, if it is goal state then return success and Stop - Loop Until a solution is found or there is no new operator left to apply - Select and apply an operator to the current state - Check new state: - - If it is goal state, then return success and quit - - If it is better than the current state then assign new state as a current state - - If not better than the current state, then proceed to the next loop or iteration until solution is found

Global Variables

In this project, we define few Global Variables that require input from the USER. We first ask the USER, if he wants to run a Evaluation on the 8-QUEENS puzzle or if he wants to run a *Hill Climibing Search* on a single matrix of values. We also let the USER input his own size for which the search has to be performed. In the Evaluation, we have a fixed amount of runs, i.e **100** and the number of **sideways_move** as mentioned in the lecture to be limited to **100**. The board size is also fixed to be a 8x8 board with **8 Queens**.

```
def run_evaluation():

    amount = 100
    sideways_amount = 25
    restarts = 25
    board_size = 8
    print("Running evaluation for 8-queens problem at,", amount,"unique cases")
    run_hill_climbing(amount, board_size)
    run_hill_climbing_sideways(amount, sideways_amount, board_size)
    run_hill_climbing_random_restart(amount, restarts, board_size)
    run_hill_climbing_random_restart_sideways(amount, restarts, board_size)
```

The Single run function is as defined below with several parameters that is required as input. We get the **size** of the board from USER and also the **number of restarts** that are required to find the solution:

```
def get_size_input():
    size = int(input("What is the size you want to test?:"))
    amount = int(input("How many restarts do you want to have?:"))
    run_hill_climbing_random_restart(1, amount, size)
```

Hill Climbing Implementation and Procedures

The Implementations of our Algorithms are divided as follows: We have the `generate_nxn.py` file which is used for generating the initial state of the board. We use the random library in the python modules and use it to generate the NxN board by placing queens in a random fashion, but making sure there is only one queen per column/per row. We later use the `generate_successors` method to generate the succesor states of the initial generated matrix.

Later we evaluate the same generated matrix with the methods that can be found in the `evaluate.py` file. The evaluation is done by counting the number of attacks that a Queen is vulnerable to in a *row-wise, column-wise,diagonally as well as in the reverse diagonal* manner. Based on this evaluation we do a Hill Climbing Search to get the next state and repeat the same until a state is acheived where no queens attack each other. We also define another method to `generate_sideways_successors` board in order to increase the rate of success. We also have the Random Restart method in the `hill_climbing.py` file. This file contains our main algorithm for performing the hill climbing search. We define a class create a Node and which additionally creates the additional nodes/states. The Random-restart hill climbing as defined in the method `climb_random_restart` takes in the number of restarts and the state of the board as the arguments. It is used for conducting a series of hill-climbing searches from randomly generated initial states with the number of restarts limit. If it reaches a limit then it means the solution could not be achieved. The random restart is again improvised with the `climb_random_restart_sideways` move available too.

The actual rate of success without sideways move is around 14%. Whereas with sideways included, the rate of success increases to 94%

Analysis:

```
Running evaluation for 8-queens problem at, 100 unique cases
Running 100 case(s) for hill climbing
Rate of success:  0.11
Rate of failure:  0.89
Average steps for success:  5.0
Average steps for failure:  4.033707865168539
Running 100 case(s) for sideways move with 25 steps
Rate of success:  0.9
Rate of failure:  0.1
Average steps for success:  23.6
Average steps for failure:  65.9
Average steps for success sideways:  6.411111111111111
Running 100 case(s) for random restart move with 100 restarts
Rate of success:  1.0
Rate of failure:  0.0
Average steps for success:  30.43
Average steps for failure:  Unknown
Average steps for success restarts:  5.13
Running 100 case(s) for random restart move with 100 restarts and sideways moves
Rate of success:  1.0
Rate of failure:  0.0
Average steps for success:  33.6
Average steps for failure:  Unknown
Average steps for success sideways:  6.08
Average steps for success restarts:  0.44
```

```
Running evaluation for 8-queens problem at, 200 unique cases
Running 200 case(s) for hill climbing
Rate of success:  0.19
Rate of failure:  0.81
Average steps for success:  5.157894736842105
Average steps for failure:  3.8950617283950617
Running 200 case(s) for sideways move with 25 steps
Rate of success:  0.9
Rate of failure:  0.1
Average steps for success:  25.055555555555557
Average steps for failure:  66.45
Average steps for success sideways:  7.0777777777777775
Running 200 case(s) for random restart move with 100 restarts
Rate of success:  1.0
Rate of failure:  0.0
Average steps for success:  32.33
Average steps for failure:  Unknown
Average steps for success restarts:  5.61
Running 200 case(s) for random restart move with 100 restarts and sideways moves
Rate of success:  1.0
Rate of failure:  0.0
Average steps for success:  35.735
Average steps for failure:  Unknown
Average steps for success sideways:  6.915
Average steps for success restarts:  0.535
```

```
Running evaluation for 8-queens problem at, 300 unique cases
Running 300 case(s) for hill climbing
Rate of success:  0.18333333333333332
Rate of failure:  0.8166666666666667
Average steps for success:  4.709090909090909
Average steps for failure:  4.09795918367347
Running 300 case(s) for sideways move with 25 steps
Rate of success:  0.9333333333333333
Rate of failure:  0.06666666666666667
Average steps for success:  23.72142857142857
Average steps for failure:  65.25
Average steps for success sideways:  6.560714285714286
Running 300 case(s) for random restart move with 100 restarts
Rate of success:  1.0
Rate of failure:  0.0
Average steps for success:  34.27
Average steps for failure:  Unknown
Average steps for success restarts:  6.086666666666667
Running 300 case(s) for random restart move with 100 restarts and sideways moves
Rate of success:  1.0
Rate of failure:  0.0
Average steps for success:  36.163333333333334
Average steps for failure:  Unknown
Average steps for success sideways:  6.89
Average steps for success restarts:  0.57
```

```
Running evaluation for 8-queens problem at, 400 unique cases
Running 400 case(s) for hill climbing
Rate of success:  0.1125
Rate of failure:  0.8875
Average steps for success:  5.066666666666666
Average steps for failure:  4.042253521126761
Running 400 case(s) for sideways move with 25 steps
Rate of success:  0.9225
Rate of failure:  0.0775
Average steps for success:  24.905149051490515
Average steps for failure:  65.6774193548387
Average steps for success sideways:  6.91869918699187
Running 400 case(s) for random restart move with 100 restarts
Rate of success:  1.0
Rate of failure:  0.0
Average steps for success:  31.6175
Average steps for failure:  Unknown
Average steps for success restarts:  5.49
Running 400 case(s) for random restart move with 100 restarts and sideways moves
Rate of success:  1.0
Rate of failure:  0.0
Average steps for success:  36.99
Average steps for failure:  Unknown
Average steps for success sideways:  7.155
Average steps for success restarts:  0.58
```

```
Running evaluation for 8-queens problem at, 500 unique cases
Running 500 case(s) for hill climbing
Rate of success:  0.132
Rate of failure:  0.868
Average steps for success:  5.166666666666667
Average steps for failure:  4.0368663594470044
Running 500 case(s) for sideways move with 25 steps
Rate of success:  0.928
Rate of failure:  0.072
Average steps for success:  24.29310344827586
Average steps for failure:  66.05555555555556
Average steps for success sideways:  6.762931034482759
Running 500 case(s) for random restart move with 100 restarts
Rate of success:  1.0
Rate of failure:  0.0
Average steps for success:  32.468
Average steps for failure:  Unknown
Average steps for success restarts:  5.63
Running 500 case(s) for random restart move with 100 restarts and sideways moves
Rate of success:  1.0
Rate of failure:  0.0
Average steps for success:  36.072
Average steps for failure:  Unknown
Average steps for success sideways:  6.824
Average steps for success restarts:  0.554
```

Below is the results that were obtained with the hill climbing algorithm:

Hill Climbing Results

```
Running 100 cases for hill climbing
Rate of success:  0.15
Rate of failure:  0.85
Average steps for success:  5.0
Average steps for failure:  3.988235294117647
```

Sideways Move Results

```
Running 100 cases for sideways move with 25 steps
Rate of success:  0.88(This varies with every run, since it is at random)
Rate of failure:  0.12
Average steps for success:  22.579545454545453
Average steps for failure:  65.41666666666667
```

Random Restart Results

```
Running 100 cases for random restart move with 25 restarts
Rate of success:  0.99
Rate of failure:  0.01
Average steps for success:  30.363636363636363
Average steps for failure:  108.0
```

Results:

The number of steps taken for a hill climibing search for 25-Queens and the rate of success is given below:

```
- - - - - - - - - - - - - - - - - - - - Q - - - - - -
- - Q - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - - Q - - -
- - - - - Q - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - Q - - - - - - -
- - - - - - - - - - - - - - - - - Q - - - - - - - - -
- - - - - - Q - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - Q - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - Q - - - - - -
- - - - - - - - - - - - - - - - - - - Q - - - - - - -
- - - Q - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - Q - - - -
- - - - - - - - - - - - - - - - - - - - - - - - - - Q
- - - - - - - - - - Q - - - - - - - - - - - - - - - -
- Q - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - - - - - Q -
Q - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - - - Q - - - - - - - - - - - - - - -
- - - - Q - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - Q - - - - - - - - - - - - - - - - - - -
- - - - - - - - - Q - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - - - Q - - - - -
- - - - - - - - - - - - Q - - - - - - - - - - - - - -
- - - - - - - - - Q - - - - - - - - - - - - - - - - -
- - - - - - - - - - - - - - - - - - - Q - - - - - - -
```

Rate of success: 1.0 Rate of failure: 0.0 Average steps for success: 411.0

Hill Climbing search without Sideways moves for a 8-Queen puzzle

```
Running evaluation for 8-queens problem at, 100 unique cases
Running 100 case(s) for hill climbing
Moves for initial state:
- - - Q - - - -
Q - - - - - - -
- - - - - - - -
- Q - - - - - Q
- - - - - - - -
- - - - Q - Q -
- - - - - Q - -
- - Q - - - - -
Move:  1

- - - Q - - - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - Q
- - - - - - - -
- - - - - - Q -
- - - - - Q - -
- - Q - - - - -

Move:  2

- - - Q - - - -
Q - - - - - - -
- - - - Q - - -
- - - - - - - Q
- Q - - - - - -
- - - - - - Q -
- - - - - Q - -
- - Q - - - - -

Move:  3

- - - Q - - - -
Q - - - - - - -
- - - - Q - - -
- - - - - - - Q
- Q - - - - - -
- - - - - - Q -
- - - - - - - -
- - Q - - Q - -

Move:  4

- - - Q - - - -
Q - - - - - - -
- - - - Q - - -
- - - - - - - Q
```

```
- Q - - - - - -
- - - - - - Q -
- - Q - - - - -
- - - - - Q - -
```

```
Moves for initial state:
- Q - - - - - -
- - - - - - - Q
- - - - - - - -
- - - - - - - -
- - - - Q - Q -
- - - - - - - -
- - - - - - - -
Q - Q Q - Q - -
Move:  1

- Q - - - - - -
- - - - - - - Q
- - - - - - - -
Q - - - - - - -
- - - - Q - Q -
- - - - - - - -
- - - - - - - -
- - Q Q - Q - -

Move:  2

- Q - - - - - -
- - - - - - - Q
- - - Q - - - -
Q - - - - - - -
- - - - Q - Q -
- - - - - - - -
- - - - - - - -
- - Q - - Q - -

Move:  3

- - - - - - - -
- - - - - - - Q
- - - Q - - - -
Q - - - - - - -
- - - - Q - Q -
- Q - - - - - -
- - - - - - - -
- - Q - - Q - -

Move:  4

- - - - Q - - -
- - - - - - - Q
- - - Q - - - -
Q - - - - - - -
- - - - - - Q -
- Q - - - - - -
```

```
- - - - - - - -
- - Q - - Q - -

Move:  5

- - - - Q - - -
- - - - - - - Q
- - - Q - - - -
Q - - - - - - -
- - - - - - Q -
- Q - - - - - -
- - - - - Q - -
- - Q - - - - -
```

```
Moves for initial state:
- - - - - - - -
- - Q - - Q - Q
- - - - - - Q -
Q - - Q - - - -
- - - - - - - -
- - - - - - - -
- Q - - - - - -
- - - - Q - - -
Move:  1

- - - - - Q - -
- - Q - - - - Q
- - - - - - Q -
Q - - Q - - - -
- - - - - - - -
- - - - - - - -
- Q - - - - - -
- - - - Q - - -

Move:  2

- - - - - Q - -
- - Q - - - - Q
- - - - - - Q -
- - - Q - - - -
Q - - - - - - -
- - - - - - - -
- Q - - - - - -
- - - - Q - - -

Move:  3

- - - - - Q - -
- - Q - - - - -
- - - - - - Q -
- - - Q - - - -
Q - - - - - - -
- - - - - - - Q
- Q - - - - - -
- - - - Q - - -
```

```
Moves for initial state:
Q - - Q - - - -
- Q - - - - - -
- - - - - - Q -
- - - - - - - -
- - Q - - - - -
- - - - Q Q - -
- - - - - - - -
- - - - - - - Q
Move:  1

- - - Q - - - -
- Q - - - - - -
- - - - - - Q -
Q - - - - - - -
- - Q - - - - -
- - - - Q Q - -
- - - - - - - -
- - - - - - - Q

Move:  2

- - - Q - - - -
- - - - - - - -
- - - - - - Q -
Q - - - - - - -
- - Q - - - - -
- - - - Q Q - -
- Q - - - - - -
- - - - - - - Q

Move:  3

- - - - - - - -
- - - Q - - - -
- - - - - - Q -
Q - - - - - - -
- - Q - - - - -
- - - - Q Q - -
- Q - - - - - -
- - - - - - - Q

Move:  4

- - - - - Q - -
- - - Q - - - -
- - - - - - Q -
Q - - - - - - -
- - Q - - - - -
- - - - Q - - -
```

```
- Q - - - - - -
- - - - - - - Q
```

Hill Climbing Search with Sideways Moves for a 8-Queen puzzle

```
Running 100 case(s) for sideways move with 25 steps
Moves for initial state:
- Q - - - Q - -
- - - - - - - -
Q - - - Q - - -
- - - - - - - -
- - - - - - Q -
- - Q - - - - -
- - - Q - - - Q
- - - - - - - -
Move:  1

- - - - - Q - -
- - - - - - - -
Q - - - Q - - -
- - - - - - - -
- - - - - - Q -
- - Q - - - - -
- - - Q - - - Q
- Q - - - - - -

Move:  2

- - - - - Q - -
Q - - - - - - -
- - - - Q - - -
- - - - - - - -
- - - - - - Q -
- - Q - - - - -
- - - Q - - - Q
- Q - - - - - -

Move:  3

- - - Q - Q - -
Q - - - - - - -
- - - - Q - - -
- - - - - - - -
- - - - - - Q -
- - Q - - - - -
- - - - - - - Q
- Q - - - - - -

Move:  4

- - - Q Q - - -
Q - - - - - - -
- - - - - Q - -
- - - - - - - -
- - - - - - Q -
```

```
- - Q - - - - -
- - - - - - - Q
- Q - - - - - -

Move:  5

- - - - Q - - -
Q - - - - - - -
- - - - - Q - -
- - - Q - - - -
- - - - - - Q -
- - Q - - - - -
- - - - - - - Q
- Q - - - - - -

Move:  6

- - Q - - - - -
Q - - - - - - -
- - - - - Q - -
- - - Q - - - -
- - - - - - Q -
- - - - Q - - -
- - - - - - - Q
- Q - - - - - -

Move:  7

- - - - Q - - -
Q - - - - - - -
- - - - - Q - -
- - - Q - - - -
- - - - - - Q -
- - Q - - - - -
- - - - - - - Q
- Q - - - - - -

Move:  8

- - - - Q - - -
Q - - - - - - -
- - - - - Q - -
- - - Q - - - -
- - - - - - Q -
- Q - - - - - -
- - - - - - - Q
- - Q - - - - -

Move:  9

- - - - Q - - -
```

```
- - - Q - - - -
- - - - - Q - -
Q - - - - - - -
- - - - - - Q -
- Q - - - - - -
- - - - - - - Q
- - Q - - - - -

Move:  10

- - - - Q - - -
- - - - - - - -
- - - - - Q - -
Q - - - - - - -
- - - - - - Q -
- Q - Q - - - -
- - - - - - - Q
- - Q - - - - -

Move:  11

- - - - Q - - -
- Q - - - - - -
- - - - - Q - -
Q - - - - - - -
- - - - - - Q -
- - - Q - - - -
- - - - - - - Q
- - Q - - - - -
```

```
Moves for initial state:
Q - Q - - - Q -
- Q - - Q - - Q
- - - - - - - -
- - - - - - - -
- - - Q - - - -
- - - - - - - -
- - - - - Q - -
- - - - - - - -
Move:  1

Q - Q - - - Q -
- - - - Q - - Q
- - - - - - - -
- Q - - - - - -
- - - Q - - - -
- - - - - - - -
- - - - - Q - -
- - - - - - - -

Move:  2

Q - - - - - Q -
- - - - Q - - Q
- - - - - - - -
- Q - - - - - -
- - - Q - - - -
- - - - - - - -
- - - - - Q - -
- - Q - - - - -

Move:  3

Q - - - - - Q -
- - - - Q - - -
- - - - - - - -
- Q - - - - - -
- - - Q - - - -
- - - - - - - Q
- - - - - Q - -
- - Q - - - - -

Move:  4

Q - - - - - - -
- - - - Q - - -
- - - - - - Q -
- Q - - - - - -
- - - Q - - - -
- - - - - - - Q
```

```
- - - - - Q - -
- - Q - - - - -

Move:  5

Q - - - - - - -
- - - - Q - - -
- - - - - - - Q -
- - - Q - - - -
- Q - - - - - -
- - - - - - - Q
- - - - - Q - -
- - Q - - - - -

Move:  6

Q - - - - - - -
- - - - Q - - -
- - - - - - - Q -
- - - - - Q - -
- Q - - - - - -
- - - - - - - Q
- - - Q - - - -
- - Q - - - - -

Move:  7

Q Q - - - - - -
- - - - Q - - -
- - - - - - - Q -
- - - - - Q - -
- - - - - - - -
- - - - - - - Q
- - - Q - - - -
- - Q - - - - -

Move:  8

- Q - - - - - -
- - - - Q - - -
- - - - - - - Q -
- - - - - Q - -
Q - - - - - - -
- - - - - - - Q
- - - Q - - - -
- - Q - - - - -

Move:  9

- Q - - - - - -
- - - - Q - - -
```

```
- - - - - - Q -
- - - - - - - -
Q - - - - - - -
- - - - - Q - Q
- - - Q - - - -
- - Q - - - - -

Move:  10

- Q - - - - - -
Q - - - - - - -
- - - - - - Q -
- - - - - - - -
- - - - Q - - -
- - - - - Q - Q
- - - Q - - - -
- - Q - - - - -

Move:  11

- - - - - - - -
Q - - - - - - -
- - - - - - Q -
- Q - - - - - -
- - - - Q - - -
- - - - - Q - Q
- - - Q - - - -
- - Q - - - - -

Move:  12

- - - - - Q - -
Q - - - - - - -
- - - - - - Q -
- Q - - - - - -
- - - - Q - - -
- - - - - - - Q
- - - Q - - - -
- - Q - - - - -

Move:  13

- - - - - Q - -
Q - - - - - - -
- - - - - - - Q
- Q - - - - - -
- - - - Q - - -
- - - - - - Q -
- - - Q - - - -
- - Q - - - - -
```

```
Move:  14

- - - - - Q - Q
Q - - - - - - -
- - - - - - - -
- Q - - - - - -
- - - - Q - - -
- - - - - - Q -
- - - Q - - - -
- - Q - - - - -

Move:  15

- - - - Q Q - -
Q - - - - - - -
- - - - - - - -
- Q - - - - - -
- - - - - - - Q
- - - - - - Q -
- - - Q - - - -
- - Q - - - - -

Move:  16

- - - - - Q - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q
- - - - - - Q -
- - - Q - - - -
- - Q - - - - -

Move:  17

- - - - - Q - -
- - - Q - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q
- - - - - - Q -
Q - - - - - - -
- - Q - - - - -

Move:  18

- - - - - Q - -
- - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - Q - - - Q
```

```
- - - - - - Q -
Q - - - - - - -
- - Q - - - - -

Move:  19

- - - - - Q - -
- - - - - - - Q
- - - - Q - - -
- Q - - - - - -
- - - Q - - - -
- - - - - - Q -
Q - - - - - - -
- - Q - - - - -

Move:  20

- - - - - - Q -
- - - - - - - Q
- - - - Q - - -
- Q - - - - - -
- - - Q - - - -
- - - - - Q - -
Q - - - - - - -
- - Q - - - - -

Move:  21

- - - - - - - -
- - - - - - - Q
- - - - Q - - -
- Q - - - - - -
- - - Q - - - -
- - - - - Q Q -
Q - - - - - - -
- - Q - - - - -

Move:  22

- - - - - Q - -
- - - - - - - Q
- - - - Q - - -
- Q - - - - - -
- - - Q - - - -
- - - - - - Q -
Q - - - - - - -
- - Q - - - - -

Move:  23

- - - - - Q - -
```

```
- - - - - - - Q
- - - - Q - - -
- Q - - - - - -
- - - Q - - - -
- - - - - - Q -
- - Q - - - - -
Q - - - - - - -

Move:  24

- - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- Q - - - - - -
- - - Q - - - -
- - - - - - Q -
- - Q - - - - -
Q - - - - - - -

Move:  25

Q - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- Q - - - - - -
- - - Q - - - -
- - - - - - Q -
- - Q - - - - -
- - - - - - - -

Move:  26

Q - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- Q - - - - - -
- - - Q - - - -
- - - - - - Q -
- - - - - - - -
- - Q - - - - -

Move:  27

- - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- Q - - - - - -
- - - Q - - - -
- - - - - - Q -
Q - - - - - - -
- - Q - - - - -
```

```
Move:  28

- - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- Q - - - - - -
Q - - - - - - -
- - - - - - Q -
- - - Q - - - -
- - Q - - - - -

Move:  29

Q - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- Q - - - - - -
- - - - - - - -
- - - - - - Q -
- - - Q - - - -
- - Q - - - - -

Move:  30

Q - - - - - - -
- - - - - - - Q
- - - - Q Q - -
- Q - - - - - -
- - - - - - - -
- - - - - - Q -
- - - Q - - - -
- - Q - - - - -

Move:  31

Q - - - - - - -
- - - - - - - Q
- - - - Q Q - -
- - - - - - Q -
- - - - - - - -
- Q - - - - - -
- - - Q - - - -
- - Q - - - - -

Move:  32

Q - - - - - - -
- - - - - - - Q
- - - - Q Q - -
- - - - - - - -
```

```
- - - - - - Q -
- Q - - - - - -
- - - Q - - - -
- - Q - - - - -

Move:  33

Q - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- - - - - - - -
- - - - - - Q -
- Q - - - - - -
- - - Q - - - -
- - Q - - - - -

Move:  34

Q - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- - Q - - - - -
- - - - - - Q -
- Q - - - - - -
- - - Q - - - -
- - - - - - - -

Move:  35

Q - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- - - - - - Q -
- - Q - - - - -
- Q - - - - - -
- - - Q - - - -
- - - - - - - -

Move:  36

Q - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- - - - - - - -
- - Q - - - - -
- Q - - - - - -
- - - Q - - - -
- - - - - - Q -

Move:  37
```

```
- - - - Q - Q -
- - - - - - - Q
- - - - - Q - -
- - - - - - - -
- - Q - - - - -
- Q - - - - - -
- - - Q - - - -
Q - - - - - - -

Move:  38

- - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- - - - - - - -
- - Q - - - Q -
- Q - - - - - -
- - - Q - - - -
Q - - - - - - -

Move:  39

- - - - Q - - -
- - - - - - - Q
- - - - - Q - -
- - Q - - - - -
- - - - - - Q -
- Q - - - - - -
- - - Q - - - -
Q - - - - - - -

Move:  40

- - - Q - - - -
- - - - - - - Q
- - - - - Q - -
- - Q - - - - -
- - - - - - Q -
- Q - - - - - -
- - - - Q - - -
Q - - - - - - -

Move:  41

- - - Q - - - -
- - - - - - - Q
- - - - - - - -
- - Q - - - - -
- - - - - Q Q -
- Q - - - - - -
- - - - Q - - -
```

```
Q - - - - - - -

Move:  42

- - - Q - - - -
- - - - - - - Q
- - - - - - Q -
- - Q - - - - -
- - - - - Q - -
- Q - - - - - -
- - - - Q - - -
Q - - - - - - -

Move:  43

- - - Q - - - -
- - - - - - - Q
- - Q - - - - -
- - - - - - Q -
- - - - - Q - -
- Q - - - - - -
- - - - Q - - -
Q - - - - - - -

Move:  44

- - - Q - - - -
- - - - - - - Q
- - Q - - - - -
- - - - - - - -
- - - - - Q - -
- Q - - - - - -
- - - - Q - - -
Q - - - - - Q -

Move:  45

- - - - - - Q -
- - - - - - - Q
- - Q - - - - -
- - - - - - - -
- - - - - Q - -
- Q - - - - - -
- - - - Q - - -
Q - - Q - - - -

Move:  46

- - - Q - - Q -
- - - - - - - Q
- - Q - - - - -
```

```
- - - - - - - -
- - - - - Q - -
- Q - - - - - -
- - - - Q - - -
Q - - - - - - -

Move:  47

- - - Q - - - -
- - - - - - - Q
- - Q - - - - -
- - - - - - - -
- - - - - Q - -
- Q - - - - - -
- - - - Q - - -
Q - - - - - Q -

Move:  48

- - - Q - - - -
- - - - - Q - -
- - Q - - - - -
- - - - - - - -
- - - - - - - Q
- Q - - - - - -
- - - - Q - - -
Q - - - - - Q -

Move:  49

- - - Q - - - -
- - - - - - - -
- - Q - - - - -
- - - - - Q - -
- - - - - - - Q
- Q - - - - - -
- - - - Q - - -
Q - - - - - Q -

Move:  50

- - - Q - - - -
- - - - - - - -
- - Q - - - - -
- - - - - - Q -
- - - - - - - Q
- Q - - - - - -
- - - - Q - - -
Q - - - - Q - -

Move:  51
```

```
- - - Q - - - -
- - - - - - - Q
- - Q - - - - -
- - - - - - Q -
- - - - - - - -
- Q - - - - - -
- - - - Q - - -
Q - - - - Q - -

Move:  52

- - - Q - Q - -
- - - - - - - Q
- - Q - - - - -
- - - - - - Q -
- - - - - - - -
- Q - - - - - -
- - - - Q - - -
Q - - - - - - -

Move:  53

- - - - - Q - -
- - - - - - - Q
- - Q - - - - -
- - - - - - Q -
- - - Q - - - -
- Q - - - - - -
- - - - Q - - -
Q - - - - - - -

Move:  54

- - - - - Q - -
- - - - - - - Q
- - - Q - - - -
- - - - - - Q -
- - Q - - - - -
- Q - - - - - -
- - - - Q - - -
Q - - - - - - -

Move:  55

- - Q - - Q - -
- - - - - - - Q
- - - Q - - - -
- - - - - - Q -
- - - - - - - -
- Q - - - - - -
```

```
- - - - Q - - -
Q - - - - - - -

Move:  56

- - Q - - - - -
- - - - - - - Q
- - - Q - - - -
- - - - - - Q -
- - - - - - - -
- Q - - - - - -
- - - - Q Q - -
Q - - - - - - -

Move:  57

- - Q - - - - -
- - - - - - - Q
- - - - - - Q -
- - - Q - - - -
- - - - - - - -
- Q - - - - - -
- - - - Q Q - -
Q - - - - - - -

Move:  58

- - Q - - - - -
- - - - - - - Q
- - - - - - Q -
- - - Q - - - -
- Q - - - - - -
- - - - - - - -
- - - - Q Q - -
Q - - - - - - -

Move:  59

- - Q - - - - -
- - - - - - - Q
- - - - - - Q -
- - - Q - - - -
- - - - Q - - -
- - - - - - - -
- Q - - - Q - -
Q - - - - - - -

Move:  60

- - Q - - - - -
- - - - Q - - Q
```

```
- - - - - - Q -
- - - Q - - - -
- - - - - - - -
- - - - - - - -
- Q - - - Q - -
Q - - - - - - -

Move:  61

- - Q - - - - -
- - - - Q - - Q
- - - - - - Q -
- - - Q - - - -
Q - - - - - - -
- - - - - - - -
- Q - - - Q - -
- - - - - - - -

Move:  62

- - Q - - - - -
- - - - Q - - Q
- - - - - - Q -
- - - Q - - - -
Q - - - - - - -
- - - - - - - -
- Q - - - - - -
- - - - - Q - -

Move:  63

- - Q - - - - -
- - - - - - - Q
- - - - - - Q -
- - - Q - - - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - Q - -

Move:  64

- - Q - - - - -
- - - - - - - Q
- - - - - - Q -
- - - - - Q - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - Q - - - -
```

```
Move:  65

- - Q - - Q - -
- - - - - - - Q
- - - - - - Q -
- - - - - - - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - Q - - - -

Move:  66

- - Q - - Q - -
- - - - - - - Q
- - - - - - Q -
Q - - - - - - -
- - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - Q - - - -

Move:  67

- - - - - Q - -
- - - - - - - Q
- - - - - - Q -
Q - - - - - - -
- - Q - - - - -
- - - - Q - - -
- Q - - - - - -
- - - Q - - - -

Move:  68

- - - - - Q - -
- - Q - - - - -
- - - - - - Q -
Q - - - - - - -
- - - - - - - Q
- - - - Q - - -
- Q - - - - - -
- - - Q - - - -

Move:  69

- - - - - Q - -
- - Q - - - - -
- - - - - - Q -
Q - - - - - - -
- - - - - - - Q
```

```
- Q - - - - - - -
- - - - Q - - -
- - - Q - - - -

Move:  70

- - - - - Q - -
- - Q Q - - - -
- - - - - - Q -
Q - - - - - - -
- - - - - - - Q
- Q - - - - - -
- - - - Q - - -
- - - - - - - -

Move:  71

- - - - - Q - -
- - - Q - - - -
- - - - - - Q -
Q - - - - - - -
- - - - - - - Q
- Q - - - - - -
- - - - Q - - -
- - Q - - - - -
```

```
Moves for initial state:
- - - - - - - -
Q - Q - - Q Q -
- - - - - - - -
- - - - - - - -
- - - - - - - Q
- - - Q Q - - -
- - - - - - - -
- Q - - - - - -
Move:  1

Q - - - - - - -
- - Q - - Q Q -
- - - - - - - -
- - - - - - - -
- - - - - - - Q
- - - Q Q - - -
- - - - - - - -
- Q - - - - - -

Move:  2

Q - Q - - - - -
- - - - - Q Q -
- - - - - - - -
- - - - - - - -
- - - - - - - Q
- - - Q Q - - -
- - - - - - - -
- Q - - - - - -

Move:  3

Q - Q - - - - -
- - - - - Q Q -
- - - Q - - - -
- - - - - - - -
- - - - - - - Q
- - - - Q - - -
- - - - - - - -
- Q - - - - - -

Move:  4

- - Q - - - - -
- - - - - Q Q -
- - - Q - - - -
Q - - - - - - -
- - - - - - - Q
- - - - Q - - -
```

```
- - - - - - - -
- Q - - - - - -

Move:  5

- - Q - - - - -
- - - - - Q - -
- - - Q - - - -
Q - - - - - - -
- - - - - - - Q
- - - - Q - - -
- - - - - - Q -
- Q - - - - - -

Move:  6

- - - Q - - - -
- - - - - Q - -
- - Q - - - - -
Q - - - - - - -
- - - - - - - Q
- - - - Q - - -
- - - - - - Q -
- Q - - - - - -

Move:  7

- - - - - - - -
- - - - - Q - -
- - Q Q - - - -
Q - - - - - - -
- - - - - - - Q
- - - - Q - - -
- - - - - - Q -
- Q - - - - - -

Move:  8

- - Q - - - - -
- - - - - Q - -
- - - Q - - - -
Q - - - - - - -
- - - - - - - Q
- - - - Q - - -
- - - - - - Q -
- Q - - - - - -
```

```
Moves for initial state:
- - Q - - - - -
Q - - - - - - -
- Q - - - - Q Q
- - - - Q - - -
- - - - - - - -
- - - Q - Q - -
- - - - - - - -
- - - - - - - -
Move:  1

- - Q - - - - -
Q - - - - - - -
- - - - - - Q Q
- - - - Q - - -
- Q - - - - - -
- - - Q - Q - -
- - - - - - - -
- - - - - - - -

Move:  2

- - Q Q - - - -
Q - - - - - - -
- - - - - - Q Q
- - - - Q - - -
- Q - - - - - -
- - - - - Q - -
- - - - - - - -
- - - - - - - -

Move:  3

Q - - Q - - - -
- - Q - - - - -
- - - - - - Q Q
- - - - Q - - -
- Q - - - - - -
- - - - - Q - -
- - - - - - - -
- - - - - - - -

Move:  4

- - - Q - - - -
- - Q - - - - -
- - - - - - Q Q
- - - - Q - - -
- Q - - - - - -
- - - - - Q - -
```

```
Q - - - - - - -
- - - - - - - -

Move:  5

- - Q Q - - - -
- - - - - - - -
- - - - - - Q Q
- - - - Q - - -
- Q - - - - - -
- - - - - Q - -
Q - - - - - - -
- - - - - - - -

Move:  6

- - Q Q - - - -
- - - - - - - -
- - - - - - - Q
- - - - Q - - -
- Q - - - - - -
- - - - - Q - -
Q - - - - - - -
- - - - - - Q -

Move:  7

- - Q Q - - - -
- - - - - - - -
- - - - - - - Q
- - - - Q - - -
Q - - - - - - -
- - - - - Q - -
- Q - - - - - -
- - - - - - Q -

Move:  8

- - Q Q - - - -
- - - - - - - -
- - - - - - Q -
- - - - Q - - -
Q - - - - - - -
- - - - - Q - -
- Q - - - - - -
- - - - - - - Q

Move:  9

- - Q Q - - - -
- - - - - - - -
```

```
- - - - - - Q -
- - - - - Q - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q

Move:  10

- - - Q - - - -
- - Q - - - - -
- - - - - - - Q -
- - - - - Q - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q

Move:  11

- - Q - - - - -
- - - Q - - - -
- - - - - - - Q -
- - - - - Q - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q

Move:  12

- - Q Q - - - -
- - - - - - - -
- - - - - - - Q -
- - - - - Q - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q

Move:  13

- - - Q - - - -
- - Q - - - - -
- - - - - - - Q -
- - - - - Q - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q
```

```
Move:  14

- - - Q - - - -
- - - - - - Q -
- - Q - - - - -
- - - - - Q - -
Q - - - - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q

Move:  15

- - - Q - - - -
- - - - - - Q -
- - - - - - - -
- - - - - Q - -
Q - Q - - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q

Move:  16

- - - Q - - - -
Q - - - - - - -
- - - - - - - -
- - - - - Q - -
- - Q - - - Q -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q

Move:  17

- - - Q - - - -
Q - - - - - - -
- - - - - - Q -
- - - - - Q - -
- - Q - - - - -
- - - - Q - - -
- Q - - - - - -
- - - - - - - Q

Move:  18

- - - Q - - - -
Q - - - - - - -
- - - - - - Q -
- - - - - Q - -
- - Q - - - - -
```

```
- Q - - - - - - -
- - - - Q - - -
- - - - - - - - Q

Move:  19

- - - Q - - - -
Q - - - - - - -
- - - - - - - Q -
- - - - - Q - -
- - - - - - - -
- Q Q - - - - -
- - - - Q - - -
- - - - - - - Q

Move:  20

- - - Q - - - -
Q - - - - - - -
- - - - - - - Q -
- - - - - - - -
- - - - - Q - -
- Q Q - - - - -
- - - - Q - - -
- - - - - - - Q

Move:  21

- - - Q - - - -
Q - - - - - - -
- - - - - - - Q -
- - - - - - - -
- - Q - - - - -
- Q - - - Q - -
- - - - Q - - -
- - - - - - - Q

Move:  22

- - - Q - - - -
Q - - - - - - -
- - - - - - - Q -
- - - - Q - - -
- - Q - - - - -
- Q - - - Q - -
- - - - - - - -
- - - - - - - Q

Move:  23

- - - Q - - - -
```

```
Q - - - - - - -
- - - - - - Q -
- - - - Q - - -
- Q Q - - - - -
- - - - - Q - -
- - - - - - - -
- - - - - - - Q

Move:  24

- - - Q - - - -
- - - - - - Q -
Q - - - - - - -
- - - - Q - - -
- Q Q - - - - -
- - - - - Q - -
- - - - - - - -
- - - - - - - Q

Move:  25

- - - Q - - - -
- - - - - - Q -
Q - - - - - - -
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Move:  26

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Move:  27

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Move:  28

- - - - - Q - -
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- Q - - - - - -
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Move:  29

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Move:  30

- - - - - Q - -
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Move:  31

- - - Q - - - -
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Q Q - - - - - -
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Move:  32

- - - Q - - - -
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Q - - - - - - -
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- Q - - - - Q -
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Move:  33

- - - Q - - - -
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Move:  34

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Move:  35

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Move:  36

- - - Q - - - -
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Move:  37
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- - - - - Q Q -
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Move:  38

- - - Q - - - -
- - - - - Q Q -
- - - - Q - - -
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- Q - - - - - -
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- - Q - - - - -
- - - - - - - Q

Move:  39

- - - Q - - - -
- - - - - Q Q -
- - - - Q - - -
- Q - - - - - -
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- - Q - - - - -
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Move:  40

- - - Q - - - -
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- Q - - - - - -
- - - - - Q - -
Q - - - - - - -
- - Q - - - - -
- - - - - - - Q
```

References and Citations:

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