

Solving the N -Queens Problem with Local Search

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This vignette provides example code for a combinatorial problem: the *N-Queens Problem*.

1 The problem

The goal is to place N queens on a chess-board of size $N \times N$ in such a way that no queen is attacked. A queen may move vertically, horizontally and on a diagonal. So whenever there is more than one queen on any row, column or diagonal, the position is invalid. To solve the problem with a Local Search (LS), we need three components:

1. a way to represent a solution (i.e. a position on the chessboard);
2. a way to evaluate such a solution;
3. and, since we use a LS, a method to modify a solution.

We start by attaching the package and fixing a seed.

```
> library("NMOF")  
> set.seed(134577)
```

2 Representing a solution

Since on any row there cannot be more than one queen, we may store a position as a vector of columns on which the queens are placed. (In chess, rows would be called ranks and columns would be files, but we prefer matrix terminology.) Thus, a candidate solution p (p for position) could look as follows:

```
> N <- 8          ## board size  
> p <- sample.int(N) ## a random solution  
> data.frame(row = 1:N, column = p)
```

	row	column
1	1	1
2	2	7
3	3	2
4	4	4
5	5	3
6	6	8
7	7	5
8	8	6

Or (a very bad solution):

```
> p <- rep(1, N)  
> data.frame(row = 1:N, column = p)
```

	row	column
1	1	1
2	2	1
3	3	1
4	4	1
5	5	1
6	6	1
7	7	1
8	8	1

We will also want to visualise a position, for which we write the function `print_board`.

```
> print_board <- function(p, q.char = "Q", sep = " ") {
  n <- length(p)
  row <- rep("-", n)
  for (i in seq_len(n)) {
    row_i <- row
    row_i[p[i]] <- q.char

    cat(paste(row_i, collapse = sep))
    cat("\n")
  }
}
> print_board(p)
```

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

3 Evaluating a solution

We need to compute on what row, column, diagonal (top left to bottom right) or reverse diagonal (top right to bottom left) a queen stands. Rows and columns are simple; we label the diagonals as follows.

```
> mat <- array(NA, dim = c(N,N)) ## diagonals
> for (r in 1:N)
  for (c in 1:N)
    mat[r,c] <- c - r
> mat
```

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]	[,8]
[1,]	0	1	2	3	4	5	6	7
[2,]	-1	0	1	2	3	4	5	6
[3,]	-2	-1	0	1	2	3	4	5
[4,]	-3	-2	-1	0	1	2	3	4
[5,]	-4	-3	-2	-1	0	1	2	3
[6,]	-5	-4	-3	-2	-1	0	1	2
[7,]	-6	-5	-4	-3	-2	-1	0	1
[8,]	-7	-6	-5	-4	-3	-2	-1	0

```
> mat <- array(NA, dim = c(N,N)) ## reverse diagonals
> for (r in 1:N)
  for (c in 1:N)
    mat[r,c] <- c + r - (N + 1)
> mat
```

	[,1]	[,2]	[,3]	[,4]	[,5]	[,6]	[,7]	[,8]
[1,]	-7	-6	-5	-4	-3	-2	-1	0
[2,]	-6	-5	-4	-3	-2	-1	0	1
[3,]	-5	-4	-3	-2	-1	0	1	2
[4,]	-4	-3	-2	-1	0	1	2	3
[5,]	-3	-2	-1	0	1	2	3	4
[6,]	-2	-1	0	1	2	3	4	5
[7,]	-1	0	1	2	3	4	5	6
[8,]	0	1	2	3	4	5	6	7

Note that for reverse diagonals, the $N + 1$ would not be necessary; it serves only to shift the diagonal labels so that the main diagonal is zero.

Thus for a given solution p , we know the row, column, diagonal and reverse diagonal for each queen. We define the quality of a solution by the number of attacks that happen: for a valid solution, that number should be zero.

```
> n_attacks <- function(p) {
  ## more than one Q on a column?
  sum(duplicated(p)) +

  ## more than one Q on a diagonal?
  sum(duplicated(p - seq_along(p))) +

  ## more than one Q on a reverse diagonal?
  sum(duplicated(p + seq_along(p)))
}
> n_attacks(p)
[1] 7
```

4 Changing a solution

A given position may be modified by picking one row randomly and then moving the queen there to the left or right. We allow for moves up to step squares, which we set to 3 in the example.

```
> neighbour <- function(p) {
  step <- 3
  i <- sample.int(N, 1)
  p[i] <- p[i] + sample(c(1:step, -(1:step)), 1)

  if (p[i] > N)
    p[i] <- 1
  else if (p[i] < 1)
    p[i] <- N
  p
}
```

```
> print_board(p)
```

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

```
> print_board(p <- neighbour(p))
```

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

```
> print_board(p <- neighbour(p))
```

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

5 Solving the model

We use three different LS methods: a ‘classical’ Stochastic Local Search (LSopt), Threshold Accepting (TAopt) and Simulated Annealing (SAopt).

```
> p0 <- rep(1, N) ## or a random initial solution: p0 <- sample.int(N)
> print_board(p0)
```

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

```
> sol <- LSopt(n_attacks, list(x0 = p0,
                              neighbour = neighbour,
                              printBar = FALSE,
                              nS = 10000))
```

```
Local Search.
Initial solution: 7
Finished.
Best solution overall: 1
```

```
> print_board(sol$xbest)
```

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

```
> sol <- TAopt(n_attacks, list(x0 = p0,
                              neighbour = neighbour,
                              printBar = FALSE,
                              nS = 1000))
```

```
Threshold Accepting

Computing thresholds ... OK
Estimated remaining running time: 0.19 secs

Running Threshold Accepting ...
Initial solution: 7
```

```
Finished.  
Best solution overall: 0
```

```
> print_board(sol$xbest)
```

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

```
> sol <- SAopt(n_attacks, list(x0 = p0,  
                               neighbour = neighbour,  
                               printBar = FALSE,  
                               nS = 1000))
```

```
Simulated Annealing.  
  
Calibrating acceptance criterion ... OK  
Estimated remaining running time: 0.185 secs.  
  
Running Simulated Annealing ...  
Initial solution: 7  
Finished.  
Best solution overall: 0
```

```
> print_board(sol$xbest)
```

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

References

Manfred Gilli, Dietmar Maringer, and Enrico Schumann. *Numerical Methods and Optimization in Finance*. Elsevier/Academic Press, 2011. URL <http://enricoschumann.net/NMOF>.