Term Project

CP468
December 2nd 2019

Austin Bursey , Aaron Exley, Tim McGill, Joseph Myc

1 How to install/compile/execute our code

To install the app simply download the .zip file and extract the files wherever you would like to keep them. Our code is written in python so no pre-compilation required. However, Python 3.6 or greater is required to run the code.

We are using some external libraries that need to be installed. To install these libraries use the following command. The libraries include numpy for faster and easier array calculations and matplotlib to plot graphs

```
pip install -r requirements.txt
```

The code can be executed in multiple different ways from command prompt with different arguments:

–n [n] for specifying n-queens, 8 otherwise.

–file [file] file as input for the initial board state, random otherwise.

–maxsteps [steps] the amount queens to move until program should quit looking for a solution, 4000 otherwise.

Ex:
To run random 8-queens examples:

```
python n-queens.py
```

To run random n-queens

```
python n-queens.py –n 'n-value here'
or
python n-queens.py 'n-value'
```

To run a specific n-queens

```
python n-queens.py –file 'file name here'
```

The format for the input file are as follows; a single digit per line representing the row for the queen. The queens are then filled in from descending order of the text file into the furthest left column of the board all the way to the furthest right in order.

2 Design and Implementation choices

We used structures like numpy arrays and dictionaries to improve performance. We also created two classes One called Queen which contains two variables; row and col for the row and column value respectively. And Puzzle which contains an array of type Queen which contains all the queens on the belonging to the current board state named 'queens' an array of type queens which contains all the queens currently attacking another queen and a count of all attacking pairs of queens.

2.1 Design

1. When initializing a random board state we designed it in such a way that the next queen will be placed in one of the rows that will cause the least amount of conflicting queens (row will be chosen randomly among minimums if there's multiple).

2. After initialization, we count conflicting pairs of queens and store it in the Puzzle object as a variable.

3. From there we check if the board is solved. If it is a solution, ie no conflicting queens exist, the board state is printed (for small N -values) and the user is informed a solution has been found. If the board state after generation is not a solution we call the local search algorithm.

4. The local search algorithm takes in 3 parameters; the puzzle in its current state, the maximum number of steps you would like to the algorithm to run for. And the value of N of the current board size. From there the algorithm picks a conflicting queen from the array of conflicting queens and finds the possible positions to move that queen that will cause the minimum conflicts (if there is multiple minimums we pick randomly).

5. If a local minimum occurs we save the position of all the conflicting queens and force the program to find a minimum that does not involve moving a queen to a position it has already visited during this local minimum, which forces side-ways moves in a single direction.

2.2 Implementation

1. In order to maintain a linear run time, we had to be careful about how we went about counting the total amount of conflicts. The algorithm we went with was first to store the queens in an array of length N. Then in order to count the number of conflicts, we store 3 arrays one of size N that stores the number of queens in each row, and 2 of size 2N that store the number of queens in each of the 2 diagonals. We then loop through the N queens and increment each of the arrays by 1 as follows, $row[row\_of\_queen], backslashDiagonal[row + col], forwardslashDiagonal[N - row + col]$. Then to count the total amount of we loop through these arrays and for every element we add $(x(x-1))/2$ conflicts to the total since every queen conflicts with each other which makes it a connected graph. We then use the same idea to find the minimum conflict spots when trying to move a queen.

2. We also used numpy arrays and operations when ever we could as numpy is super optimized c code under the hood which would make the array operations we are doing not only easier to do, but also more efficient.

3 Performance for Different values of N

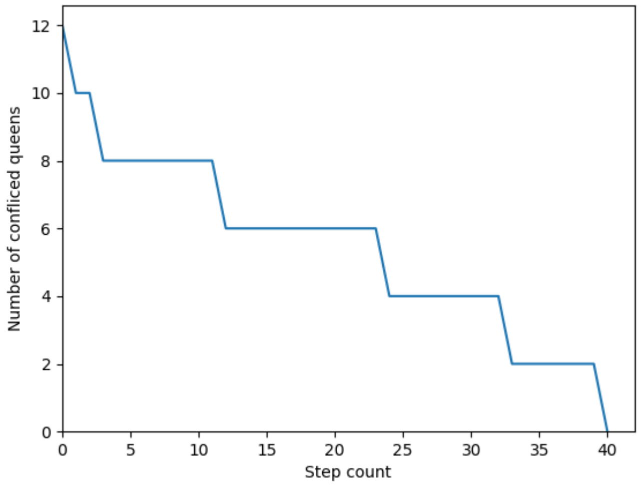
Due to our design choices and implementation the board generation is the most computationally heavy part of the program, The graphs below shows how board generation and subsequently the entire program runs for different values of n. As you can see, the time increase for large values up to 100 000 is basically done in linear time, We begin to see quadratic run-time for any value of n larger than 100 000.

4 Graphs For n= 1 000 000

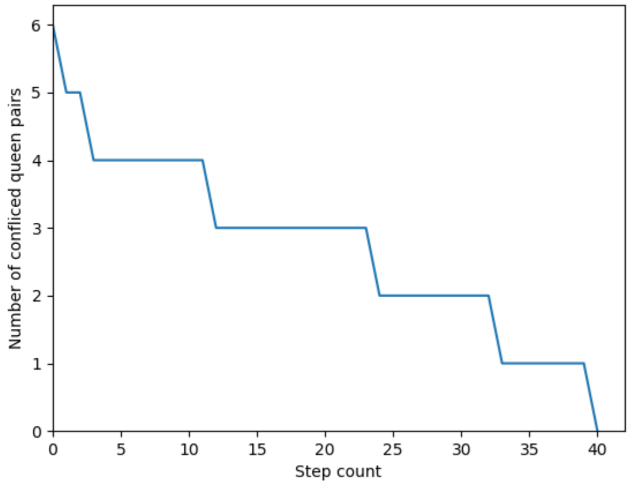
The output of the program:

```
python n-queens.py 1000000
Generating board
Progress: 999000/1000000
Board Generated in 5985.30265s
Initial Pairs = 6
BenchMark: 0
Time: 230.99690s
====================SOLUTION FOUND IN 40 STEPS=====================
Pairs = 0
```

The graph for the number of conflicting queens per move:



The graph for the number of pairs of conflicting queens per move:

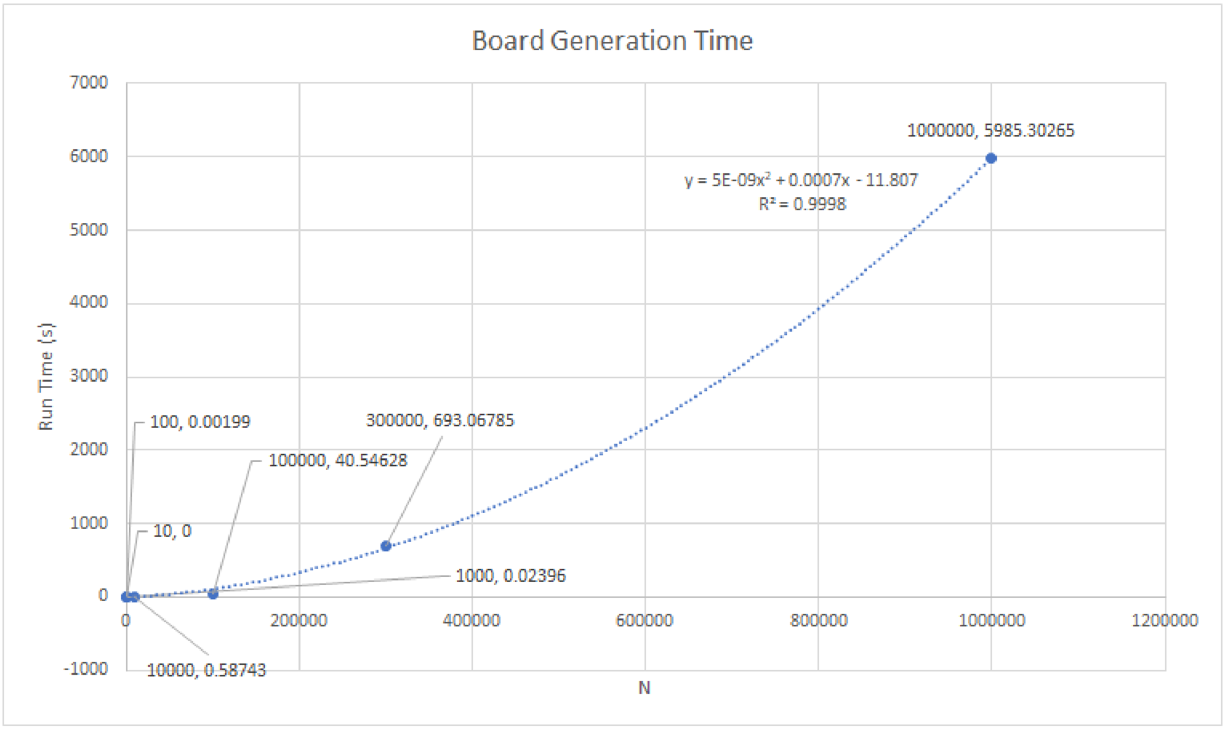


5 Results for test runs on different n-values

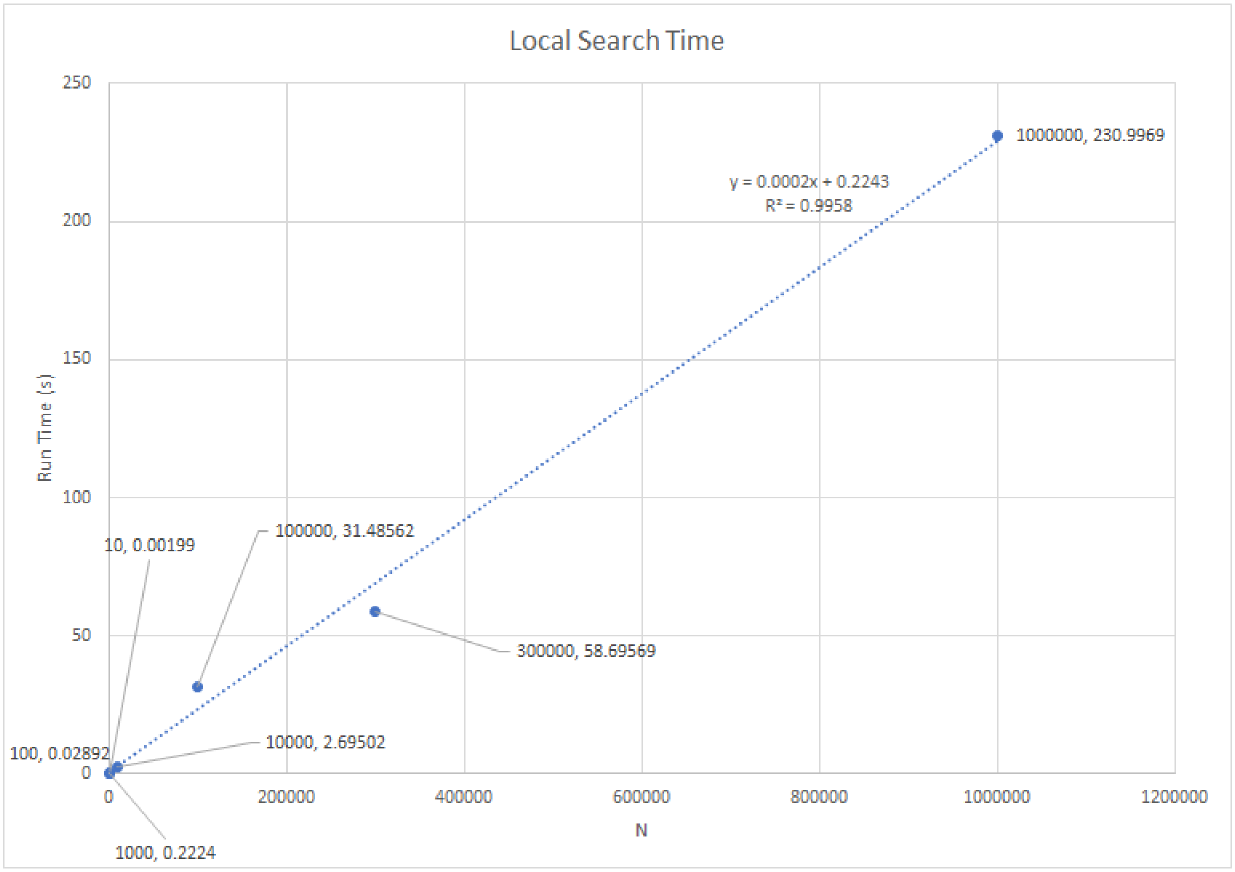
Run Times

n	Run Time (s)			n	Board Generation (s)
10	0.00199			10	0
100	0.02892			100	0.00199
1000	0.2224			1000	0.02396
10000	2.69502			10000	0.58743
100000	31.48562			100000	40.54628
300000	58.69569			300000	693.06785
1000000	230.9969			1000000	5985.30265

Board Generation run-time graph:



Local Search run-time graph



6 Code

```
from random import randint
from operator import add
import time
import sys
import argparse
from PIL import Image
from PIL import ImageDraw
from PIL import ImageFont

import numpy as np  # pip install numpy
import matplotlib.pyplot as plt # pip install matplotlib

class Queen:
    def __init__(self, col ,row, pairs=0):
        self.col = col
        self.row = row
        self.pairsCount = pairs

    def __str__(self):
        return '\nCol={}, Row={}'.format(self.col, self.row)
    def __repr__(self):
        return '\nCol={}, Row={}'.format(self.col, self.row)

    def __eq__(self,other):
        return self.col == other.col

    def __ne__(self,other):
        return not self.__eq__(other)

class puzzle:
    def __init__(self, n, array=None):

        self.queens = []

        #If parameters for the positions of the queens are passed in,
        #add these positions to the puzzle
        if array is not None:
            n = len(array)
            for i in range(n):
                self.queens.append(Queen(i, array[i]))

        #If parameters for the queens positions are not passed in, create a random minimized board.
        else :
            self.queens = createBoard(n)

        self.conflictQueens = []
        self.pairsCount = countPairs(self, n)

    def __str__(self):
        return '\n Pairs = {}\n conflicted Queens = {}'.format(self.pairsCount, self.conflictQueens)

    def __repr__(self):
        return '\n Pairs = {} conflicted Queens = {}'.format(self.pairsCount, self.conflictQueens)

def createBoard(N):
    '''
    Creates the inital state of the board by adding the next queen to the spot
    with the least conflicts O(2n^2)
    ---------------------------
    Params:
        n: the size of the board
    returns:
        puzzle: a 1-d list of size n containing a queen at each column
    '''

    #Queen location in the row
    row = np.zeros(N, dtype=np.int16)

    #Top left to bottom right diagonal array
    ld = np.zeros(N + N, dtype=np.int16)

    #Top right to bootm left diagonal array
    rd = np.zeros(N + N, dtype=np.int16)
    r = np.random.randint(0, N)

    #Add initial queens constraints to the board
    row[r] = 1
    ld[r] = 1
    rd[N - r] = 1

    #Add initial queen to the board
    queens = [Queen(0, r)]

    for col in range(1, N): # O(N)

        #Print progress check every so often
        if N >= 100000:
            if col % 1000 == 0:
                print("Progress: {}/{}".format(col, N), end='\r')

        #Get diagonal array of collision counts
        p = ld[col: col + N]
        q = (rd[col + 1: col + N + 1])[::-1]
        #Get array of all collision counts
        total = row + p + q # O(N)

        #Get positions with the minimum number of collisions
        minT = np.where(total == total.min())[0] # O(N)

        #Pick random location with minimum number of collisions
        r = np.random.randint(0, minT.shape[0])
        r = minT[r]

        #Add constraints to the board
        row[r] += 1
        ld[r + col] += 1
        rd[N - r + col] += 1

        #Add queen to the board
        queens.append(Queen(col, r))
    print()
    return queens

def countPairs(puzzle, n):
    '''
    Counts the total number of pairs in the board O(4n)
    ---------------------------
    Params:
        puzzle: A puzzle for the current state
        n: the size of the board
    returns:
        counts: the count of the pairs
    '''
    count = 0
    f_row = [0] * n
    f_mdiag = [0] * (n + n)
    f_sdiag = [0] * (n + n)
```

```
queens = puzzle.queens
puzzle.conflictQueens = []

cRow = dict({})
cmD = dict({})
csD = dict({})

#Count how many queens are in each row, and diagonal
for i in range(n): # O(n)

    row = queens[i].row

    f_row[row] += 1
    if f_row[row] > 1:
        cRow[row] = True

    f_mdiag[row + i] += 1
    if f_mdiag[row + i] > 1:
        cmD[row + i] = True

    f_sdiag[n - row + i] += 1
    if f_sdiag[n - row + i] > 1:
        csD[n - row + i] = True

#Count total number of pairs
for i in range(n + n): # O(2n)
    x, y, z = 0, 0, 0

    if i < n:
        x = f_row[i]
    y = f_mdiag[i]
    z = f_sdiag[i]
    count += (x * (x - 1)) // 2
    count += (y * (y - 1)) // 2
    count += (z * (z - 1)) // 2

#Count the number of queen conflicts in the puzzle object and add it to
# the puzzle's array conflictQueens
for q in queens: # O(n)
    if q.row in cRow or q.row + q.col in cmD or n - q.row + q.col in csD:
        puzzle.conflictQueens.append(q)

return count
```

```python
def localSearch(puzzle, maxSteps, n):
    '''
    Performs min conflics local search of the puzzle O(6n)
    ---------------------------
    Params:
        puzzle: A puzzle for the current state
        maxSteps: The maximum number of steps to try before aborting
        n: the size of the board
    returns:
        The finished puzzle
        The number of steps
        If it was solved
    '''
    global conflicts
    global conflictspair
    savedInstances = dict({})
    blacklistedQueens = []
    lastCount = 0
    thisCount = 1
    for i in range(maxSteps): # O(k)
        if i % 100 == 0:
            print("Amount of Steps: {:5}".format(i), end='\r')

        #If a local minimum is hit, mark all queens that have colissions for moving/adjusting.
        if lastCount == thisCount:
            for queen in puzzle.conflictQueens:
                if (queen.col, queen.row) not in savedInstances:
                    savedInstances[(queen.col,queen.row)] = True
        else :
            savedInstances = dict({})

        m = len(puzzle.conflictQueens)

        index = randint(0, m - 1)
        currentQueen = puzzle.conflictQueens[index]

        #Get new location to move the queen to O(2n)
        pairMin, minRow = findMinimum(currentQueen.row,currentQueen.col, puzzle,n,savedInstances)

        #If the row to adjust is not the current row, move to the row and save the new instance
        if (minRow != currentQueen.row):
            puzzle.queens[currentQueen.col].row = minRow
            puzzle.queens[currentQueen.col].pairsCount = pairMin
            if (currentQueen.col, currentQueen.row) not in savedInstances:
                savedInstances[(currentQueen.col,currentQueen.row)] = True
        #Otherwise, just save the instance

        puzzle.pairsCount = countPairs(puzzle,n) # O(4n)
        lastCount = thisCount
        thisCount = puzzle.pairsCount
        #append count to conflict(s) array
        conflicts.append(len(puzzle.conflictQueens))
        conflictspair.append(puzzle.pairsCount)
        if puzzle.pairsCount == 0:
            print()
            return puzzle, i, True
    print()
    return puzzle, i, False

def findMinimum(cRow, cCol, puzzle, n, savedInstances):
    '''
    Finds the next move to do for a given queen that will minimize the conflicts O(2n)
    ---------------------------
    Params:
        row: The row of the current queen
        col: The column of the current queen
        puzzle: A puzzle for the current state
        n: the size of the board
        savedInstance: A small buffer of previous moves used for dealing with plateaus
    returns:
        The new count for the conflicts
        The row to move the queen too
    '''

    total = np.zeros(n)
    queens = puzzle.queens

    for i in range(n): # O(n)

        #count the collisions in each row except for the current row
        row = queens[i].row
        if i != cCol:
            total[row] += 1

        #Count collisions in the diagonals that pass through the current column
        if cCol <= row + i <= cCol + (n - 1):
            total[row + i - cCol] += 1
        if cCol + 1 <= n - row + i <= n + cCol:
            total[abs((n - row + i) - (n + cCol))] += 1

    mins = np.where(total == total.min())[0] # O(n)

    i = np.random.randint(0, mins.shape[0])
    r = mins[i]

    #Check that the move has not already been made
    while len(mins) > 1 and (cCol, r) in savedInstances:
        mins = np.delete(mins, i)
        i = randint(0, len(mins) - 1)
        r = mins[i]

    if len(mins) == 1:
        return total[mins[0]], mins[0]
    else:
        return total[mins[i]], mins[i]
```

```
def saveBoardToImage(puzzle, n):

  img = Image.new('RGB', (6500, 7400), (255, 255, 255))
  d = ImageDraw.Draw(img)

  font = ImageFont.truetype("Courier Prime Code.ttf", 200)
  d.text((6500 // 2 - 500, 20), "1000-Queens", fill=(0, 0, 0), font=font)

  arr = puzzle.queens
  for i in range(n-1, -1, -1):#rows
      board = ""
      for j in range(n):#column
          if arr[j].row == i:
              board += "Q"
          else:
              board += "."
      d.text((250, (n - i - 1) * 7 + 300), board, fill=(0, 0, 0))

  img.save("large.png")

def printBoard(puzzle):
    '''
    Prints the board with index 0, 0 at the botton left corner
    ---------------------------
    Params:
        puzzle: A puzzle for the current state
    prints:
        prints the board
    '''
    arr = puzzle.queens
    for i in range(n-1, -1, -1):#rows
        for j in range(n):#column
            if arr[j].row == i:
                print("Q|",end = "")
            else :
                print(".|",end="")
        print()
    print("Pairs = {}".format(puzzle.pairsCount))

conflicts=[]
conflictspair=[]
if __name__ == "__main__":

    parser = argparse.ArgumentParser(description="Solve n-queens")

    parser.add_argument("--n", default=-1, type=int, help="The size of the board (nxn) with n queens
    parser.add_argument("--file", default=None, help="Read initial state of the board from a file")
    parser.add_argument("--maxsteps", default=4000, type=int, help="The maximum amout of steps to try
    parser.add_argument('args', nargs='*', help="if an integer is put here it will be used as n if n

    args = parser.parse_args()
```

```
if args.n != -1:
    n = args.n
elif len(args.args) > 0:
    n = int(args.args[0])
else:
    n = 8

if args.file is not None:
    initialPos = []
    with open(args.file, 'r') as f:
        for line in f:
            initialPos.append(int(line))
    n = len(initialPos)
    newPuzzle = puzzle(n, initialPos)
else:
    print("Generating board")
    t = time.time()
    newPuzzle = puzzle(n)
    print("Board Generated in {:.5f}s".format(time.time() - t))

if n < 17:
    printBoard(newPuzzle)
else:
    print("Initial Pairs = {}".format(newPuzzle.pairsCount))

if newPuzzle.pairsCount != 0:

    t = time.time()
    solution, i, solved = localSearch(newPuzzle, args.maxsteps, n)
    print("Time: {:.5f}s".format(time.time() - t))
    if solved:
        print("=====================SOLUTION FOUND IN {} STEPS=====================".format(i))
        if n < 17:
            printBoard(solution)
        else:
            print("Pairs = {}".format(newPuzzle.pairsCount))

        if n <= 1000:
            saveBoardToImage(solution, n)
        # else :
            # print(solution)
    else:
        print("=====================NO SOLUTION FOUND AFTER {} STEPS=====================".format
        if n < 17:
            printBoard(solution)
        else:
            print("Pairs = {}".format(newPuzzle.pairsCount))

#ploting the conflict count
plt.plot(conflicts)
plt.xlim(left=0)
plt.ylim(bottom=0)
plt.ylabel('Number of confliced queens')
plt.xlabel('Step count')
plt.savefig('n-queens-conflict-count-plot.png')
plt.close()
#ploting the conflict pair count
plt.plot(conflictspair)
plt.xlim(left=0)
plt.ylim(bottom=0)
plt.ylabel('Number of confliced queen pairs')
plt.xlabel('Step count')
plt.savefig('n-queens-conflict-pair-count-plot.png')
plt.close()
```