

To run this program, you must have python 3.7 or higher installed.

<https://www.python.org/downloads/>

Next, install matplotlib and numpy using pip. <https://pip.pypa.io/en/stable/quickstart/>

Then, you can run test.py. By default it will run on the the 98th, 99th, 100th, and 101st boards in sudoku_small.csv. The first two boards can/will be solved with AC3, while the last two boards can/will be solved with backtracking. The program will create a graph of the queue lengths at each step in the AC3 algorithm, for each sudoku it solves. This graph is saved in the queue_length.png file.

Input is taken from sudoku_small.csv. The format of that file is that the first line contains "quizzes,solutions\n" while all of the following lines contain two comma separated lists of numbers. The numbers represent the board, with zeros representing empty spaces. The board is arranged by filling in the rows from left to right and then top to bottom with the numbers.

```

import sudoku_board
import numpy as np
import matplotlib.pyplot as plt
from typing import Tuple, Set, Dict

def PrepBoard(path: str = r"A2\sudoku_small.csv", n: int = 1) -> Tuple["np.ndarray[np.int8]",
                                                                    Set[Tuple[Tuple[int, int],
                                                                    Tuple[int, int]
                                                                    ]],
                                                                    Dict[Tuple[int, int],
                                                                    Set[int]]]:
    """
    Loads the nth board, generates the constraints and domains

    Args:
        board: Board to be printed
        empty_value: Values to be printed if cell is empty
    Print:
        NO_SOL => There is no solution
        FAIL => There is a implementation error
        SOLVED => The board has been fully solved
        PARTIAL_SOLVE => The board has been partial solved
    """
    board = sudoku_board.load_file(path=path, n=n)[-1]
    constraints = sudoku_board.create_constraint_set()
    domains = sudoku_board.create_domain_set(board)
    return board, constraints, domains

def testBoard(n: int = 1) -> None:
    """
    Prints the nth board, applies AC-3 to nth board, prints the board and

    Args:
        board: Board to be printed
        empty_value: Values to be printed if cell is empty
    Print:
        NO_SOL => There is no solution
        FAIL => There is a implementation error
        SOLVED => The board has been fully solved
        PARTIAL_SOLVE => The board has been partial solved
    """
    pre, constraints, domains = PrepBoard(n)
    post_Domains = sudoku_board.AC3(constraints, domains)

    print(f"Sudoku Board #{n}")
    sudoku_board.pretty_print_board(pre)

    if not post_Domains:
        print("NO_SOL: AC-3 has identified board #{n} has no solution")
    elif not sudoku_board.validSolve(pre, sudoku_board.domains2Board(post_Domains)):
        print("FAIL: AC-3 has been implemented incorrectly")

```

```

    for key, val in post_Domains.items():
        print(f"{key} | {val}")
elif sudoku_board.solved(post_Domains):
    print("SOLVED: AC-3 has fully solved the board")
    sudoku_board.pretty_print_board(sudoku_board.domains2Board(post_Domains))
else:
    print("PARTIAL_SOLVE: AC-3 has partially solved the board")

    for key, val in post_Domains.items():
        print(f"{key} | {val}")

post_Domains = sudoku_board.backtracking_search(post_Domains)

if not post_Domains:
    print("NO_SOL: BackTrack has identified board #{n} has no solution")
elif not sudoku_board.validSolve(pre, sudoku_board.domains2Board(post_Domains)):
    print("FAIL: BackTrack has been implemented incorrectly")
    for key, val in post_Domains.items():
        print(f"{key} | {val}")
elif sudoku_board.solved(post_Domains):
    print("SOLVED: BackTrack has fully solved the board")
    sudoku_board.pretty_print_board(sudoku_board.domains2Board(post_Domains))
else:
    print("NO_SOL: BackTrack has partially solved the board")

def solve(pre: "np.ndarray[np.int8]") -> bool:
    """
    Takes in a board and tries to solve it using AC-3 and BackTracking

    Args:
        board: Board to be printed
    Print:
        Prints out the solved board or which algorithm failed and the domain set of the failed
        board
    """

    constraints = sudoku_board.create_constraint_set()
    domains = sudoku_board.create_domain_set(pre)

    post_Domains, qlen = sudoku_board.AC3(constraints, domains, True)

    plt.plot(qlen)
    plt.xlabel("Step #")
    plt.ylabel("Queue Length")
    plt.savefig("queue_length")

    if not post_Domains:
        print("Board is not valid")
        return False
    elif sudoku_board.solved(post_Domains):
        print("Board solved with AC3")
        sudoku_board.pretty_print_domain(post_Domains)

```

```

    return True
elif not sudoku_board.validDomains(post_Domains):
    print("AC-3 has created an invaild board")
    for key, val in post_Domains:
        print(f"{key} | {val}")
    raise ValueError("AC-3 has created an invaild board")
else:
    print("AC-3 did not solve the board. Attepting to solve with backtracking...")
    post_Domains = sudoku_board.backtracking_search(domains)
    if not post_Domains:
        print("Board is not vaild")
        return False
    elif not sudoku_board.solved(post_Domains):
        print("Backtracking has not solved the board")
        for key, val in post_Domains:
            print(f"{key} | {val}")
        raise ValueError("Backtracking has not solved the board")
    elif not sudoku_board.validDomains(post_Domains):
        print("AC-3 has created an invaild board")
        for key, val in post_Domains:
            print(f"{key} | {val}")
        raise ValueError("AC-3 has created an invaild board")
    else:
        print("Solved with backtracking:")
        sudoku_board.pretty_print_domain(post_Domains)

#solve(sudoku_board.load_file(path =r"A2\sudoku_small.csv",n=1)[-1])

for i in range(98,102):
    solve(sudoku_board.load_file(path =r"A2\sudoku_small.csv",n=i)[-1])

```

```

import numpy as np

from typing import List, Tuple, Set, Dict, Union
from collections import deque
from itertools import chain
from copy import deepcopy

EMPTY_ENTRY = 0
CHAR_WIDTH_OF_BOARD = 21
SIZE_OF_BOARD = 9
BLOCK_SIZE = SIZE_OF_BOARD // 3
ALL_CELLS = [(i, j) for i in range(SIZE_OF_BOARD) for j in range(SIZE_OF_BOARD)]

def pretty_print_board(board: "np.ndarray[np.int8]", empty_value: str = " ") -> None:
    """
    Takes a in a board and pretty prints it

    Args:
        board: board to be printed
        empty_value: value to be printed if cell is empty
    Print:
        board with empty_value if the cell is empty
    """

    print("-"*CHAR_WIDTH_OF_BOARD)
    for row in range(SIZE_OF_BOARD):
        print("|", end="")
        print(("{} {} {}| "*3).format(*
                                     map(lambda x: x if x != 0 else empty_value, board[row])))
        if row % 3 == 2:
            print("-"*CHAR_WIDTH_OF_BOARD)

def pretty_print_domain(domains: Dict[Tuple[int, int], Set[int]], empty_value: str = " ") ->
None:
    """
    Takes in domains, converts into a board and pretty prints it. If there are multiple values
    in the domain of a cell, it prints empty_value

    Args:
        domains: A dictionary with key: ALL_CELLS val: domain set of cell
    Prints:
        The board with empty_value if the domain of a cell has multiple values
    """
    pretty_print_board(domains2Board(domains), empty_value)

def domains2Board(domains: Dict[Tuple[int, int], Set[int]]) -> "np.ndarray[np.int8]":
    """
    Takes in domains and returns a board. If there are multiple values in the domain of a cell,
    it sets the value to 0.

```

Args:

domains: A dictionary with key: ALL_CELLS val: domain set of cell

Returns:

board: the domain as a board

```
"""
# Unpacks one element sets and sets multi element sets to 0
domains = {cell: 0 if len(domain) != 1 else next(iter(domain)) for cell, domain in domains.
items()}

# convert dictionary to ndarray
return np.reshape(np.asarray(list(map(lambda x: domains[x[0]],
                                     sorted(list(domains.items())))), np.int8),
                 (-1, SIZE_OF_BOARD))
```

```
def validSolve(pre: "np.ndarray[np.int8]", post: "np.ndarray[np.int8]") -> bool:
```

```
"""
Takes in a board before and after an algorithm has been applied and checks if the board
is still an valid sudoku. Assumes that the pre algo board was valid.
```

Args:

pre: board before change

post: board with new cell value for testing

Returns:

True if new boards are valid, else False

```
"""
# Check if there are duplicates or invalid characters in each row
for row in post:
    domain = set(range(1, SIZE_OF_BOARD+1))
    for val in row:
        if val not in domain and val != 0:
            return False
        elif val != 0:
            domain.remove(val)
# Check if there are duplicates or invalid characters in each col
for col in post.transpose():
    domain = set(range(1, SIZE_OF_BOARD+1))
    for val in col:
        if val not in domain and val != 0:
            return False
        elif val != 0:
            domain.remove(val)
BLOCK_TOP_LEFT = [(x, y) for x in range(0, 9, 3) for y in range(0, 9, 3)]

# Check if there are duplicates or invalid characters in each block
for block_cell in BLOCK_TOP_LEFT:
    domain = set(range(1, SIZE_OF_BOARD+1))
    x_coord, y_coord = block_cell
    for val in map(
        lambda x: post[x],
        {(x_coord // BLOCK_SIZE * BLOCK_SIZE + x_val, y_coord // BLOCK_SIZE * BLOCK_SIZE +
         y_val)
         for x_val in range(BLOCK_SIZE) for y_val in range(BLOCK_SIZE)} - {block_cell}):
```

```

    if val not in domain and val != 0:
        return False
    elif val != 0:
        domain.remove(val)

```

```

# Check if any of filled cells in pre are changed

```

```

return np.all(np.any((pre == post, pre == np.zeros((SIZE_OF_BOARD, SIZE_OF_BOARD))), axis=0))

```

```

def validDomains(domains: Dict[Tuple[int, int], Set[int]]) -> bool:

```

```

    """

```

```

    Takes in a board before and after an algorithm has been applied and checks if the board
    is still an valid sudoku. Assumes that the pre algo board was valid.

```

```

    Takes in domains and checks if it's valid domain

```

```

    Args:

```

```

        domains: A dictionary with key: ALL_CELLS val: domain set of cell

```

```

    Returns:

```

```

        True if new boards are valid, else False

```

```

    """

```

```

# Check if any cell has domain length 0

```

```

if any(map(lambda x: not len(x), domains.values())):
    return False

```

```

# Check if the constraining cells of any cell (with domain length one) has the same value

```

```

for cell in ALL_CELLS:
    if len(
        domains[cell]) == 1 and any(
            map(lambda x: domains[x] == set(domains[cell]),
              constrained_variables(cell))):
        return False

```

```

return True

```

```

def solved(domains: Dict[Tuple[int, int], Set[int]]) -> bool:

```

```

    """

```

```

    Takes in a domain and checks if the board has been solved

```

```

    Args:

```

```

        domains: A dictionary with key: ALL_CELLS val: domain set of cell

```

```

    Returns:

```

```

        True if board was been solved, else False

```

```

    """

```

```

return all(map(lambda x: len(x) == 1, domains.values()))

```

```

def load_file(path: str = r"A2\sudoku_small.csv", n: int = 1) -> List["np.ndarray[np.int8]"]:

```

```

    """

```

```

    Reads file at path and constructs board

```

```

    Args:

```

```

        path: location of the file with sudoku boards. The first row is the column titles. All

```

others of the
 form " 'partial sudoku', 'solved sudoku' " . A partial sudoku is 81 character
 string, containing
 integers between 0 and 9 inclusive. The integer 0 implies that the cell is
 blank.

n: integer number of how many boards to create

Returns:

boards: a list of boards

"""

fv = open(path, "r")

_ = fv.readline()

boards = []

for i in range(n):

ln = fv.readline()

if "," in ln:

partial, solved = ln.split(",")

else:

partial = ln.strip("\n")

boards.append(np.reshape(np.asarray(list(partial), np.int8), (-1, SIZE_OF_BOARD)))

return boards

def constrained_variables(coord: Tuple[int, int]) -> Set[Tuple[int, int]]:

"""

When given coordinates for a cell, returns all of the coordinates of cells which constrain
 that cell

Args:

coord: A 2-tuple with integers between 0 and 8 inclusive, representing the coordinate
 of the cell

Returns:

A list of coordinates, which act as constraints for the coord cell,
 i.e. the coordinates of all of the cells in the same row, column, or block as the given
 cell coord

"""

x_coord = coord[0]

y_coord = coord[1]

variables = {

(x_coord, val) for val in range(SIZE_OF_BOARD)} | {

(val, y_coord) for val in range(SIZE_OF_BOARD)} | {

(x_coord // BLOCK_SIZE * BLOCK_SIZE + x_val, y_coord // BLOCK_SIZE * BLOCK_SIZE + y_val)

for x_val in range(BLOCK_SIZE) for y_val in range(BLOCK_SIZE)}

cell does not constrain itself

return variables - {coord}

def create_constraint_set() -> Set[Tuple[Tuple[int, int], Tuple[int, int]]]:

"""

Generates initialized constraint_set for blank sudoku board. A cell's value can not be same
 as the

value of any cell in it's row, column or block.

Returns:

constraints: a set of constraints. A constraint is a 2-tuple of cell coords. Constraint (Xi,Xj) implies that Xi != Xj.

"""

```
return set(chain(*map(lambda cell: {(cell, diff) for diff in constrained_variables(cell)},
ALL_CELLS)))
```

```
def create_domain_set(board: "np.ndarray[np.int8]") -> Dict[Tuple[int, int], Set[int]]:
```

"""

Generates a domains from a board. If cell has a set value, it's domain is just that value, else the domain is all integers from 1 to 9 inclusive.

Args:

board: a board with either a value for each cell or 0 if it has no value

Returns:

domains: A dictionary with key: ALL_CELLS val: domain set of cell

"""

```
return {cell: set(range(1, 10)) if not board[cell] else {board[cell]} for cell in ALL_CELLS}
```

```
def AC3(constraints: Set[Tuple[int, int]],
```

```
domains: Dict[Tuple[int, int],
```

```
Set[int]], returnQueueLength = False) -> Union[Union[Dict[Tuple[int, int],
Set[int]], bool], Tuple[Union[Dict[Tuple[int, int], Set[int]], bool], List[
int]]]:
```

"""

Takes in a Constraint Satisfaction Problem (CSP) and makes it arc-constraint

Args:

constraints: a set of all relationship between variables. Constraint (x,y) => x != y

domains: a dictionary with key: ALL_CELLS val: domain set of cell

returnQueueLength: if true, this function returns a list of the length of the queue at each step

Returns:

domains: A dictionary with key: ALL_CELLS val: domain set of cell

queue_lengths: a list of the length of the queue at each step (if returnQueueLength == True)

"""

```
queue = deque(constraints)
```

```
qlen = []
```

```
while queue:
```

```
    qlen.append(len(queue))
```

```
    Xi, Xj = queue.popleft()
```

```
    revised, domains = revise(Xi, Xj, domains)
```

```
    if revised:
```

```
        if not domains[Xi]:
```

```
            return False
```

```
            queue.extend(set((Xk, Xi) for Xk in constrained_variables(Xi)))
```

```
if returnQueueLength:
```

```

    return domains, qlen
else:
    return domains

def revise(Xi: Tuple[int, int],
          Xj: Tuple[int, int],
          domains: Dict[Tuple[int, int],
                        Set[int]]) -> Tuple[bool, Dict[Tuple[int, int],
                                                         Set[int]]]:
    """
    Takes in an arc and makes it arc consistent

    Args:
        Xi: variable's whose domain is to be adjusted
        Xj: variables's whose being checked against Xi
        domains: A dictionary with key: ALL_CELLS val: domain set of cell

    Returns:
        revised: was Xi's domain changed
        domains: A dictionary with key: ALL_CELLS val: domain set of cell
    """
    revised = False
    removed = set()
    for val in domains[Xi]:
        if not (domains[Xj] - set([val])):
            revised = True
            removed.add(val)
    domains[Xi] -= removed
    return revised, domains

def select_unassigned_variable(domains: Dict[Tuple[int, int],
                                              Set[int]]) -> Tuple[int, int]:
    """
    Takes in domains and selects the domain with lowest number of options which hasn't be
    assigned

    Args:
        domains: a dictionary with key: ALL_CELLS val: domain set of cell

    Returns:
        The coord of the domain with lowest number of options which hasn't be assigned
    """
    return min(filter(lambda cell: len(domains[cell]) > 1, domains.keys()), key = lambda cell: len(
        domains[cell]))

def backtracking_search(
    domains: Dict[Tuple[int, int],
                  Set[int]]):
    """
    Takes in a sudoku Constraint Satisfaction Problem (CSP) and searches solution using
    backtracking,
    starting from the last arc-consistent step of an unsuccessful AC-3 attempt.

    Args:

```

constraints: a set of all relationship between variables. Constraint $(x,y) \Rightarrow x \neq y$
 domains: a dictionary with key: ALL_CELLS val: domain set of cell

Returns:

A solution to the board, else False.

"""

return backtracking_search_aux(select_unassigned_variable(domains), domains)

def backtracking_search_aux(currCell: Tuple[int, int], domains: Dict[Tuple[int, int], Set[int]]):

"""

Recursive auxiliary assist for backtracking_search

Args:

currCell: a tuple containing coordinates of current cell we're working with

constraints: a set of all relationship between variables. Constraint $(x,y) \Rightarrow x \neq y$

domains: a dictionary with key: ALL_CELLS val: domain set of cell

board: array containing board values. If there are multiple values in the domain of a cell, value is 0.

Returns:

A solution domain as board, else False.

"""

if solved(domains):

return domains

for testVal **in** domains[currCell]:

newDomains = deepcopy(domains)

newDomains[currCell] = set([testVal])

for cell **in** constrained_variables(currCell):

newDomains[cell] -= set([testVal])

if validDomains(newDomains):

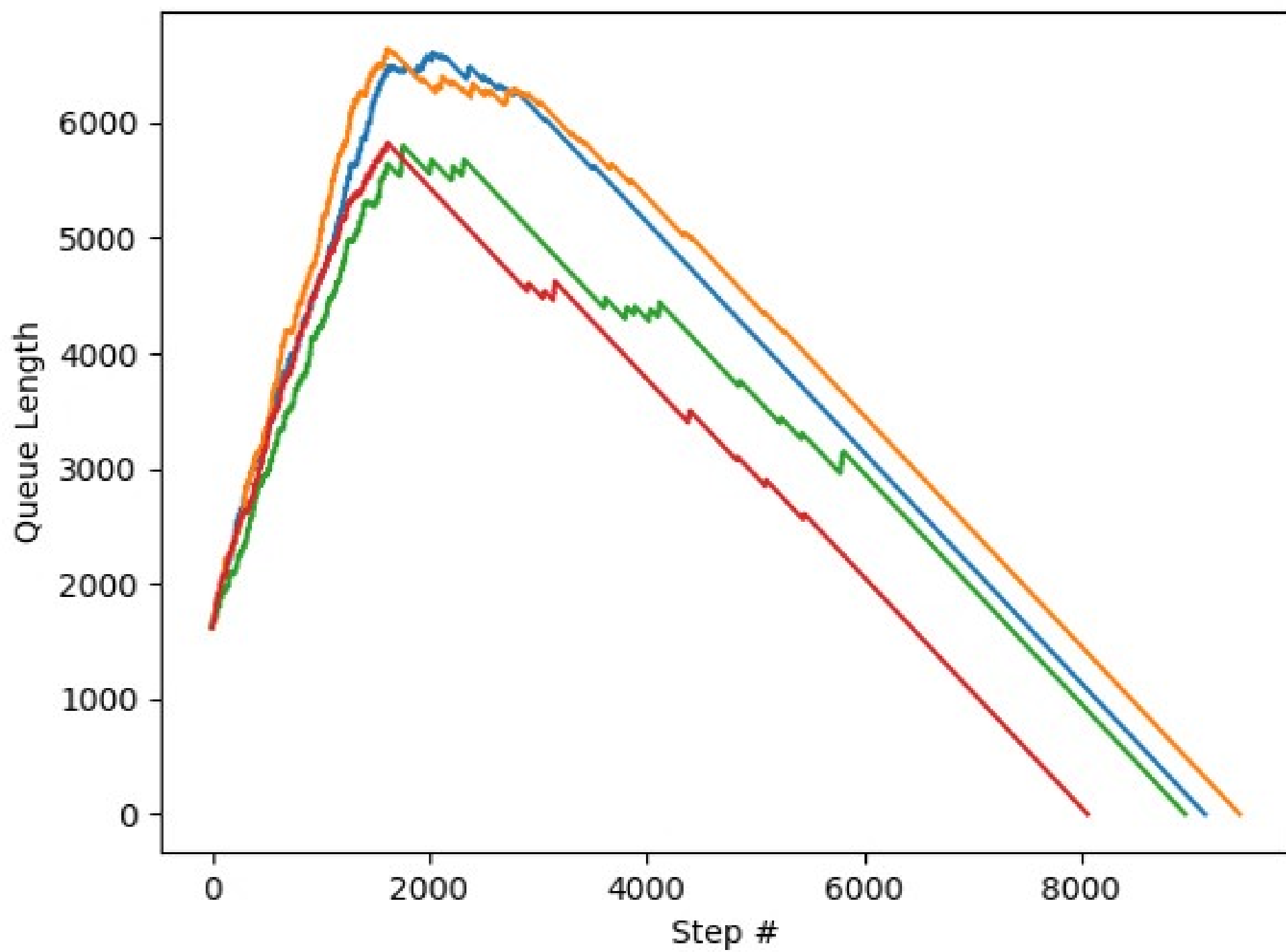
ret = backtracking_search_aux(select_unassigned_variable(domains), newDomains)

if ret:

return ret

else:

return False



quizzes, solutions

004300209005009001070060043006002087190007400050083000600000105003508690042910300,864371259325849
761971265843436192587198657432257483916689734125713528694542916378
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