## CP468 AI - ASSIGNMENT 2

## **NOVEMBER 11, 2019**

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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
                                                                                   111,
                                                                        Dict[Tuple[int, int],
                                                                             Set[int]]:
    11 11 11
   Loads the nth board, generrates 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")
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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
    ,, ,, ,,
   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 vaild")
        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:
    11 11 11
    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
    Arqs:
        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]":
    11 11 11
    Takes in domains and returns a board. If there are multiple values in the domain of a cell,
    it sets the value to 0.
```

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domains: A dictionary with key: ALL CELLS val: domain set of cell
    Returns:
       board: the domain as a board
    11 11 11
    # 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) \text{ for } x \text{ in range}(0, 9, 3) \text{ for } y \text{ 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
            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
       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
```

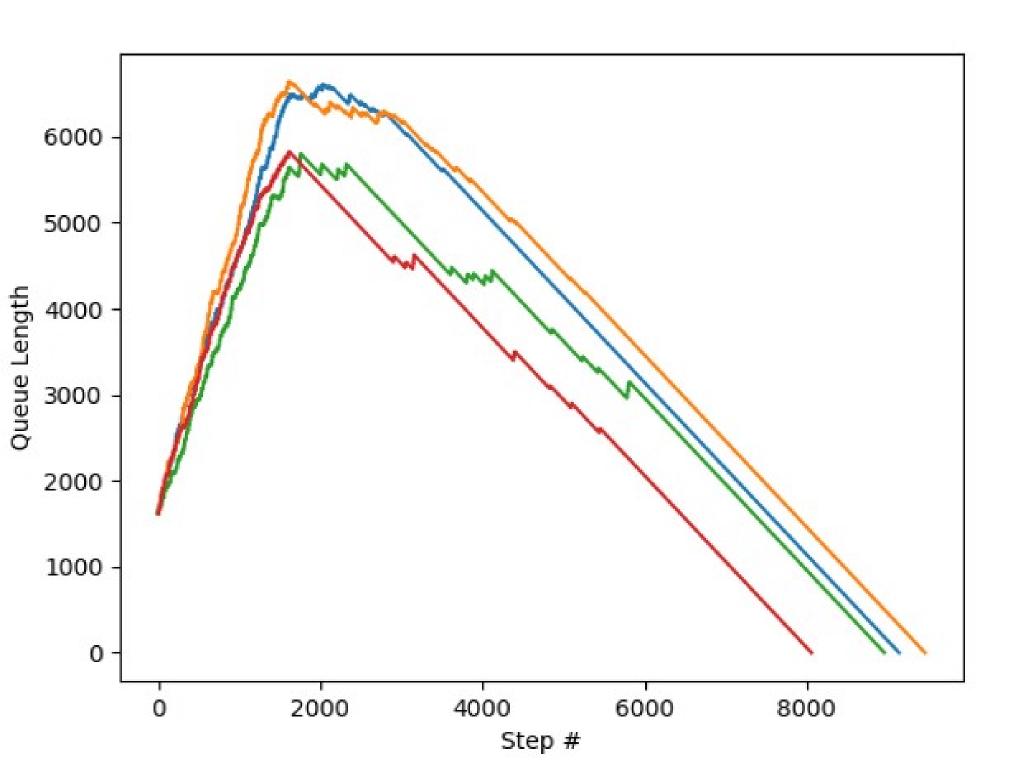
```
others of the
                form " 'partial sudoku', 'solved sudoku' " . A partial sudoku is 81 character
                string, containing
                intgers between 0 and 9 inclusive. The integer 0 implies that the cell is
                blank.
        n: integer number of how many boards 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
        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]]]:
    11 11 11
   Takes in a Constraint Satisfaction Problem (CSP) and makes it arc-constraint
   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
        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
   Aras:
        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]:
    11 11 11
   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:
```

return False

```
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
   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 auxilary 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) => x != 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:
```



```
quizzes, solutions
761971265843436192587198657432257483916689734125713528694542916378
04010005010700396052000800000000017000906800803050620090060543600080700250097100,346179258187523
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600120384008459072000006005000264030070080006940003000310000050089700000502000190,695127384138459
672724836915851264739273981546946573821317692458489715263562348197
49720000010040000500001609862030004030090000001072600002005870000600004530097061,497258316186439
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376713642895397164528482795631156823947541236789679418253238957164
005710329000362800004000000100000980083900250006003100300106000409800007070029500,865714329917362
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645469532781926153478741896532583724916674385129892617354315249867
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237531672489769231548453768921218459673175826394392147856846593712
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389381692574837564912692183457415927863123846795569371248748259136
08320009620003070400791500040239000801000406006987000000400007500060280070050900,183247596295638
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070490103003070590050000000000000061100749020024306008600980700012600000480007052,276495183843271
596951863247397528461168749325524316978635982714712654839489137652
830040096020010008904700030409002065308001070000603800507030020000506400002080100,831245796726319
548954768231419872365368451972275693814587134629193526487642987153
050400680090100000008059302007203000000600208604080005036004190100007000072800050,751432689293168
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078010609203009008410060052720106030000400700091305000932000400005720010000008006,578213649263549
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