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CS 480 Spring 2023 Programming Assignment #02

Due: **Sunday, April 16, 2023, 11:59 PM CST**
Points: **100**

Instructions:

1. Place **all your deliverables (as described below) into a single ZIP** file named:

```
LastName_FirstName_CS480_Programming02.zip
```

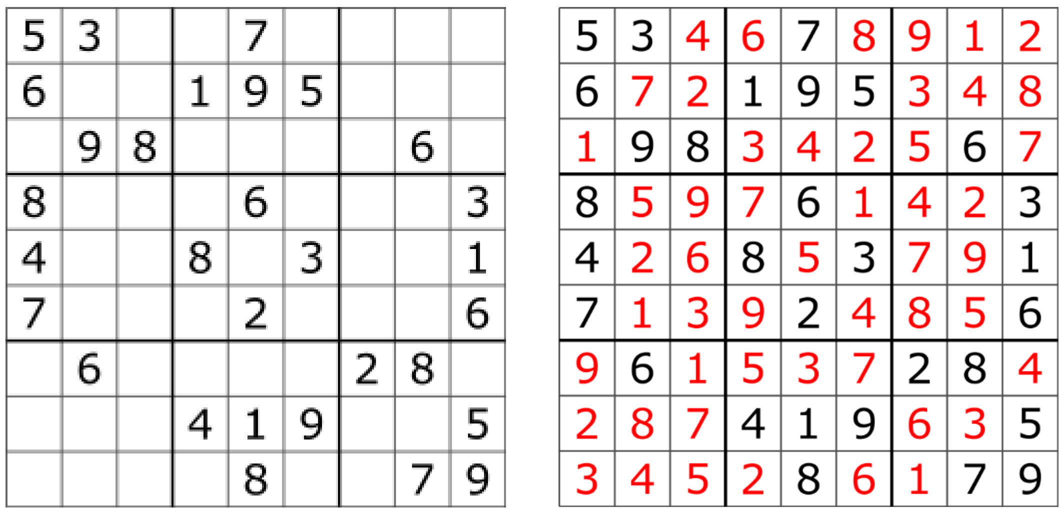
2. Submit it to Blackboard Assignments section before the due date. **No late submissions will be accepted**.

Objectives:

1. (100 points) Implement and evaluate a constraint satisfaction problem algorithm.

Problem description:

Sudoku is a logic-based, combinatorial, number-placement puzzle. In classic Sudoku, the objective is to fill a 9 × 9 grid with digits so that each column, each row, and each of the nine 3 × 3 subgrids that compose the grid contain all of the digits from 1 to 9. The puzzle setter provides a partially completed grid, which for a well-posed puzzle has a single solution (see Figure 1). [source: Sudoku - Wikipedia].



a) unsolved Sudoku puzzle

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

b) solved Sudoku puzzle

5	3	4	6	7	8	9	1	2
6	7	2	1	9	5	3	4	8
1	9	8	3	4	2	5	6	7
8	5	9	7	6	1	4	2	3
4	2	6	8	5	3	7	9	1
7	1	3	9	2	4	8	5	6
9	6	1	5	3	7	2	8	4
2	8	7	4	1	9	6	3	5
3	4	5	2	8	6	1	7	9

Figure 1: Sudoku puzzle: (a) unsolved, (b) solved [source: Sudoku - Wikipedia].

Your task is to implement in Python the following constraint satisfaction problem algorithms**(refer to lecture slides and/or your textbook for details and pseudocode)**:

- Brute force (exhaustive) search algorithm,
- Constraint Satisfaction Problem (CSP) back-tracking search,
- CSP with forward-checking and MRV heuristics,

and apply them to solve the puzzle (provided in a CSV file).

Your program should:

- Accept two (2) command line arguments, so your code could be executed with

  ```
  python cs480_P02_AXXXXXXXX.py FILENAMEMODE
  ```

  where:

  - `cs480_P02_AXXXXXXXX.py`is your python code file name,
  - `FILENAME`is the input CSV file name (unsolved or solved sudoku puzzle),
  - `MODE`is mode in which your program should operate
    - `1` – brute force search,
    - `2` – Constraint Satisfaction Problem back-tracking search,
    - `3` – CSP with forward-checking and MRV heuristics,
    - `4` – test if the completed puzzle is correct.

  Example:

  ```
  python cs480_P02_A11111111.py testcase4.csv2
  ```

  If the number of arguments provided is NOT two (none, one, or more than two) or arguments are invalid (incorrect file, incorrect mode) your program should display the following error message:

  ```
  ERROR: Not enough/too many/illegal input arguments.
  ```

  and exit.

- Load and process input data file specified by the `FILENAME` argument (<u>assume that input data file is ALWAYS in the same folder as your code</u> - this is REQUIRED!).

- Run an algorithm specified by the `MODE` argument to solve the puzzle (or test if the solution is valid – `MODE 4`),

- Report results on screen in the following format:

  ```
  Last Name, First Name, AXXXXXXXX solution:
  ```

```
Input file: FILENAME.CSV
Algorithm: ALGO_NAME

Inputpuzzle:

X,6,X,2,X,4,X,5,X
4,7,X,X,6,X,X,8,3
X,X,5,X,7,X,1,X,X
9,X,X,1,X,3,X,X,2
X,1,2,X,X,X,3,4,X
6,X,X,7,X,9,X,X,8
X,X,6,X,8,X,7,X,X
1,4,X,X,9,X,X,2,5
X,8,X,3,X,5,X,9,X


Number of search tree nodes generated: AAAA
Search time: T1 seconds

Solved puzzle:

8,6,1,2,3,4,9,5,7
4,7,9,5,6,1,2,8,3
3,2,5,9,7,8,1,6,4
9,5,8,1,4,3,6,7,2
7,1,2,8,5,6,3,4,9
6,3,4,7,2,9,5,1,8
5,9,6,4,8,2,7,3,1
1,4,3,6,9,7,8,2,5
2,8,7,3,1,5,4,9,6
```

where:

- `AXXXXXXXX`is your IIT A number,
- `FILENAME.CSV`input file name,
- `ALGO_NAME`is the algorithm name (`TEST` for mode `4`),
- `AAAA` is the number of search tree nodes generated (`0` for mode `4`),
- `T1`is measured search time in seconds (`0` for mode `4`),

- Save the solved puzzle to `INPUTFILENAME_SOLUTION.csv` file.

- In `MODE 4` (test) your program should display the input puzzle along with a message

```
This is a valid, solved, Sudoku puzzle.
```

if the solution is correct and

```
ERROR: This is NOT a solvedSudoku puzzle.
```

if it is not correct.

Input data file:

Your input data file is a single CSV (comma separated values) file containing the Sudoku puzzlegrid (see Programming Assignment #02 folder in Blackboard for sample files). The file structure is as follows:

```
X,6,X,2,X,4,X,5,X
4,7,X,X,6,X,X,8,3
X,X,5,X,7,X,1,X,X
9,X,X,1,X,3,X,X,2
X,1,2,X,X,X,3,4,X
6,X,X,7,X,9,X,X,8
X,X,6,X,8,X,7,X,X
1,4,X,X,9,X,X,2,5
X,8,X,3,X,5,X,9,X
```

You **CANNOT** modify nor rename input data files. Rows and columns in those files represent individual rows and columns of the puzzle grid as shown on Figure 1. You can assume that file structure is correct without checking it.

CSV file data is either:

- a character `X` corresponding unassigned (empty) grid cell,
- a positive integer (from the {1, 2, 3, 4, 5, 6, 7, 8, 9} set) corresponding to an assigned grid cell value.

Deliverables:

Your submission should include:

- Python code file(s). Your py file should be named:

  `cs480_P02_AXXXXXXXX.py`

  where`AXXXXXXXX` is your IIT A number (this is REQUIRED!). If your solution uses multiple files, makes sure that the main (the one that will be run to solve the problem) is named that way and others include your IIT A number in their names as well.
- this document with your results and conclusions. You should rename it to:

  `LastName_FirstName_CS480_Programming02.doc`or `pdf`

Use`testcase1.csv`input data file and run all three algorithms to solve the puzzle. Repeat this search ten (10) times for each algorithm and calculate corresponding averages. Report your findings in the Table A below.

Table A

Algorithm	Number of generated nodes	Average search time in seconds
Brute force search	864	0.003553462
CSP back-tracking	639	0.001298952
CSP with forward-checking and MRV heuristics	71(Note this is dynamic so the number of generated nodes might vary)	0.001897907

Testing:

I have performed the algorithm on testcase4 and noted the result.

Execution Times:

Executiom Time	Brute	CSP Backtrack	MRV Forward Checking
t1	0.005632162	0.001030922	0.001996756
t2	0.003968239	0.001031637	0.002897739
t3	0.000999689	0.00099659	0.001027107
t4	0.001034737	0.000998497	0.001996756
t5	0.001997709	0.00199604	0.000997782
t6	0.002927303	0.001014233	0.00337553
t7	0.003180742	0.002199173	0.00266695
t8	0.004638433	0.000995398	0.001029253
t9	0.007246494	0.001685858	0.001994371
t10	0.003909111	0.001041174	0.000996828
Avg	0.003553462	0.001298952	0.001897907

What are your conclusions? Which algorithm performed better? What is the time complexity of each algorithm. Write a summary below

Conclusions
To conclude, the best approach among brute force, CSP backtracking, and CSP with forward-checking and MRV heuristics depends on the specific problem's characteristics, such as problem size, constraints, and efficiency requirements. In case of the Sudoku problem the best method is CSP with forward-checking and MRV heuristics followed by CSP back-tracking and Brute force is simple to implement but inefficient for large problems. CSP backtracking is optimized and suitable for problems with many constraints and moderate size. CSP with forward-checking and MRV heuristics is further optimized and suitable for larger problems with complex constraints. As we can see in our results the number of nodes generated are 71 for CSP with Forward Checking and MRV heuristics, 639 for CSP back-tracking and 864 for brute force search for testcase4.csv. Moreover CSP algorithms performs better than Brute Force, even CSP Forward Checking and Back Tracing takes almost same time we ended up solving lesser number of nodes in CSP with Forward Checking.

The Big O complexity depends upon the number of empty cells in the Sudoku grid and the constraints or already filled cells. Almost in the worst case scenarios algorithm will take O(9^81) but using CSP back-tracking & CSP with forward-checking and MRV heuristics it will be almost less than O(9^81).