Norwegian University of Science and Technology

# Assignment 4 - Solving Constraint Satisfaction Problems

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October 2019

Appointed in
TDT4136 Introduction to Artificial Intelligence

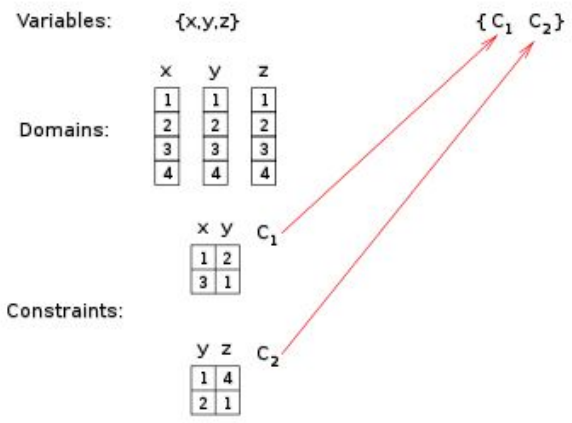


Figure 1: Constraint satisfaction dual problem

# 1 Solving CSPs with Backtracking Search and AC-3

Constrain satisfaction problem can be represented as a tuple (X,D,C). X is a set of variables, D is a set of their respective domains of values, and C is a set of constraints. See figure 1 for a illustration of the concept. In this assignment, backtracking search and AC-3 are implemented in the given skeleton code. To demonstrate that the CSP solver works, the program is used to solve the four Sudoku boards shown in figure 2, 3, 4 and 5.

The basic Sudoku problem can be modelled with constraint programming by a combination of alldifferent constraints. Soduku has 3x9 all-diff constraints, one over each set of variables in the same row, one over each set of variables in the same column, and one over each set of variables in the same sub-square.

## 1.1 Part 1

See my $_assignment.py for the source code with comments for a CSP solver based on backtracking search and AC-3, that is able to solve Sudoku boards.$

## 1.2 Part 2

Here are the program's solution for each of the four boards. The solutions can also be found in SudokuSolution.txt. The original boards can be seen in figures 2, 4, 6 and 8. The solutions can be seen in figures 3, 5, 7 and 9.

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

Figure 2: Easy board

```
easy
8 7 5 | 9 3 6 | 1 4 2
1 6 9 | 7 2 4 | 3 8 5
2 4 3 | 8 5 1 | 6 7 9
------+-------+------
4 5 2 | 6 9 7 | 8 3 1
9 8 6 | 4 1 3 | 2 5 7
7 3 1 | 5 8 2 | 9 6 4
------+-------+------
5 1 7 | 3 6 9 | 4 2 8
6 2 8 | 1 4 5 | 7 9 3
3 9 4 | 2 7 8 | 5 1 6
```

Figure 3: Easy board solution

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

Figure 4: Medium board

```
medium
7 8 4 | 9 3 2 | 1 5 6
6 1 9 | 4 8 5 | 3 2 7
2 3 5 | 1 7 6 | 4 8 9
------+-------+------
5 7 8 | 2 6 1 | 9 3 4
3 4 1 | 8 9 7 | 5 6 2
9 2 6 | 5 4 3 | 8 7 1
------+-------+------
4 5 3 | 7 2 9 | 6 1 8
8 6 2 | 3 1 4 | 7 9 5
1 9 7 | 6 5 8 | 2 4 3
```

Figure 5: Medium board solution

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

Figure 6: Hard board

```
hard
1 5 2 | 3 4 6 | 8 9 7
4 3 7 | 1 8 9 | 6 5 2
6 8 9 | 5 7 2 | 3 1 4
------+-------+------
8 2 1 | 6 3 7 | 9 4 5
5 4 3 | 8 9 1 | 7 2 6
9 7 6 | 4 2 5 | 1 8 3
------+-------+------
7 9 8 | 2 5 3 | 4 6 1
3 6 5 | 9 1 4 | 2 7 8
2 1 4 | 7 6 8 | 5 3 9
```

Figure 7: Hard board solution

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

Figure 8: Very hard board

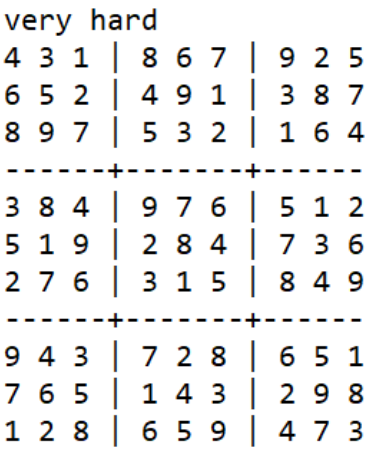


Figure 9: Very hard board solution

## 1.3 Part 3

Here are the number of times the BACKTRACK function was called, and the number of times the BACKTRACK function returned failure, for each of the four boards. A brief comment on these numbers for the four boards is included.

### Easy board

Calls: 3
Failures: 0

### Medium board

Calls: 1
Failures: 0

### Hard board

Calls: 12
Failures: 4

### Very hard board

Calls: 68
Failures: 56