Intelligent Systems Project 3

Constraint Satisfaction Problems (CSP)
Map Coloring Problem

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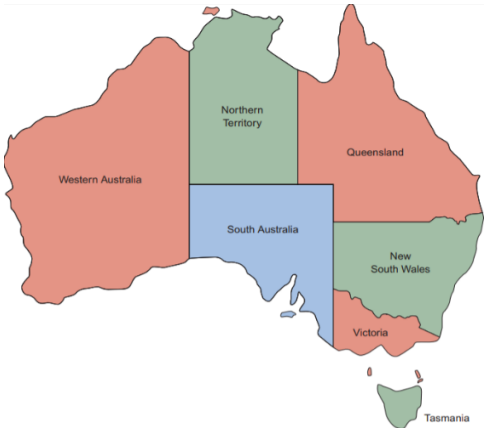
1.1 Constraint Satisfaction Problems

Constraint satisfaction problems (CSPs) are mathematical questions defined as a set of objects whose state must satisfy a few constraints or limitations. CSPs represent the entities in a problem as a homogeneous collection of finite constraints over variables, which is solved by constraint satisfaction methods. CSP on finite domains are typically solved using a form of search.

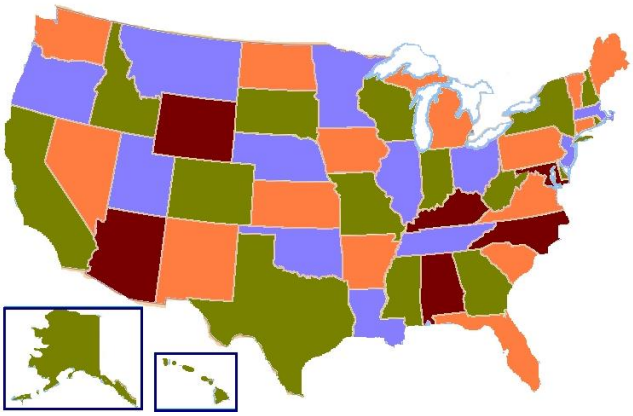
Examples of simple problems that can be modeled as a constraint satisfaction problem include:

- N-queens puzzle
- Map coloring problem
- Sudoku, Crosswords, Futoshiki, Kakuro (Cross Sums), Numbrix, Hidato and many other logic puzzles

Here, we are considering the Map Coloring problem for Australia and USA.



Australia with map coloring



USA with map coloring

1.2 Backtracking

Backtracking is a general algorithm for finding all (or some) solutions to some computational problems, notably constraint satisfaction problems, that incrementally builds candidates to the solutions, and abandons a candidate ("backtracks") as soon as it determines that the candidate cannot possibly be completed to a valid solution.

Backtracking can be applied only for problems which admit the concept of a "partial candidate solution" and a relatively quick test of whether it can possibly be completed to a valid solution. It is useless, for example, for locating a given value in an unordered table.

Backtracking is an important tool for solving constraint satisfaction problems, such as crosswords, verbal arithmetic, Sudoku, and many other puzzles. It is often the most convenient technique for parsing, for the knapsack problem and other combinatorial optimization problems. It is also the basis of the so-called logic programming languages such as Icon, Planner and Prolog.

We typically solve constraint satisfaction problems by drawing a search tree whose nodes contain partial solutions. That way, the task of solving the problem is equivalent to the task of searching a tree where in each branch represents a value that we tentatively assign to a variable which we later backtrack. To make the search more intelligent, we try to prune as many branches as we can from the tree, so that we avoid dead ends.

Three different strategies are used to perform the search:

- Depth First Search Only:

  This strategy is the most basic approach; it doesn't prune any branches. It checks whether all the values assigned so far are consistent with each other or not.

  To perform depth first search only – After a value has been assigned to a variable, examine them to ensure the values are consistent with the constraints. If they aren't, then backtrack.

- Depth first search + forward checking:

  This strategy eliminates impossible options from the neighboring variables.

  To perform DFS + Forward Checking [FC]:

  1. [DFS] Once a value is assigned to a variable, examine all the variables to ensure values are consistent with the constraints. If they aren't, backtrack.

  2. [FC] After you assign a value to a variable, consider all its neighbors. Eliminate any options from its neighbors that are incompatible with the value assigned.

- Depth first search + forward checking + propagation through singleton domains:

  This strategy eliminates impossible options from neighboring variables. Then, if any of those neighboring variables have only one option left, it looks ahead to see what else it can eliminate.

  1. [DFS] Once a value is assigned to a variable, examine all the variables assigned values so far to ensure values are consistent with the constraints. If they aren't, backtrack.

  2. [FC] Once a value is assigned to a variable, consider all its neighbors. Eliminate any options from its neighbors that are incompatible with the value you just assigned.

  3. [PROP-1] If you eliminate options from a neighbor in the previous step, and that neighbor has only one option left, add that neighbor to the list of variables to propagate. Propagate all the variables in the list.

The following three heuristics are utilized in the search :

- Minimum Remaining Values (MRV): It is a heuristic function which chooses the variable with the fewest legal values.

- Least-constraining value heuristic: Choose a value that rules out the smallest number of values in variables connected to the current variable by constraints.

- Degree heuristic: Assign a value to the variable that is involved in the largest number of constraints on other unassigned variables.

OUTPUT:

File - Main

```
D:\Java\jdk1.8.0_102\bin\java.exe "-javaagent:D:\IntelliJ IDEA Community
Edition 2019.2\lib\idea_rt.jar=58340:D:\IntelliJ IDEA Community Edition 2019
.2\bin" -Dfile.encoding=UTF-8 -classpath D:\Java\jdk1.8.0_102\jre\lib\
charsets.jar;D:\Java\jdk1.8.0_102\jre\lib\deploy.jar;D:\Java\jdk1.8.0_102\
jre\lib\ext\access-bridge-32.jar;D:\Java\jdk1.8.0_102\jre\lib\ext\cldrdata.
jar;D:\Java\jdk1.8.0_102\jre\lib\ext\dnsns.jar;D:\Java\jdk1.8.0_102\jre\lib\
ext\jaccess.jar;D:\Java\jdk1.8.0_102\jre\lib\ext\jfxrt.jar;D:\Java\jdk1.8.
0_102\jre\lib\ext\localedata.jar;D:\Java\jdk1.8.0_102\jre\lib\ext\nashorn.
jar;D:\Java\jdk1.8.0_102\jre\lib\ext\sunec.jar;D:\Java\jdk1.8.0_102\jre\lib\
ext\sunjce_provider.jar;D:\Java\jdk1.8.0_102\jre\lib\ext\sunmscapi.jar;D:\
Java\jdk1.8.0_102\jre\lib\ext\sunpkcs11.jar;D:\Java\jdk1.8.0_102\jre\lib\ext
\zipfs.jar;D:\Java\jdk1.8.0_102\jre\lib\javaws.jar;D:\Java\jdk1.8.0_102\jre\
lib\jce.jar;D:\Java\jdk1.8.0_102\jre\lib\jfr.jar;D:\Java\jdk1.8.0_102\jre\
lib\jfxswt.jar;D:\Java\jdk1.8.0_102\jre\lib\jsse.jar;D:\Java\jdk1.8.0_102\
jre\lib\management-agent.jar;D:\Java\jdk1.8.0_102\jre\lib\plugin.jar;D:\Java
\jdk1.8.0_102\jre\lib\resources.jar;D:\Java\jdk1.8.0_102\jre\lib\rt.jar;D:\
IntelliJ_Projects\Project03_IS\out\production\Project03_IS is.assignment3.
main.CSPDriver
*** Run started ***
############################################################
Australia Map Coloring
############################################################
No Heuristics  used
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 20.0
Time taken = 1.0 ms
############################################################
No Heuristics & Forward Checking
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 20.0
Time taken = 0.5 ms
############################################################
No Heuristics & Forward Checking with propagation through singleton domains
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks = 12.0
Time taken = 0.0 ms
############################################################
MRV
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 20.0
Time taken = 1.0 ms
############################################################
```

```
MRV & Forward Checking
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 0.0
Time taken = 0.5 ms
############################################################
MRV & Forward Checking with propagation through singleton domains
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks = 0.0
Time taken = 0.15 ms
############################################################
Degree Constraint
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 0.0
Time taken = 0.25 ms
############################################################
Degree Constraint & Forward Checking
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 0.0
Time taken = 0.25 ms
############################################################
Degree Constraint & Forward Checking with propagation through singleton
domains
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks = 0.0
Time taken = 0.15 ms
############################################################
Least Constraining Value
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 0.0
Time taken = 0.0 ms
############################################################
Least Constraining Value & Forward Checking
------------------------------------------------------------
A run completed
```

```
A run completed
A run completed
A run completed
Total No of backtracks is 0.0
Time taken = 0.25 ms
############################################################
Least Constraining Value & Forward Checking with propagation through
singleton domains
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks = 0.0
Time taken = 0.15 ms
############################################################
Number of Runs for Australia = 4

No Heuristics:
Avg No of Backtracks = 20.000000
Avg Time in Milliseconds = 1.000000 ms

No Heuristics & Forward Checking:
Avg No of Backtracks = 20.000000
Avg Time in Milliseconds = 0.500000 ms

MRV:
Avg No of Backtracks = 20.000000
Avg Time in Milliseconds = 1.000000 ms

LCV & Forward Checking & propagation through singleton domains:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.250000 ms

No Heuristics & Forward Checking & propagation through singleton domains:
Avg No of Backtracks = 20.000000
Avg Time in Milliseconds = 0.000000 ms

Degree Constraint & Forward Checking & propagation through singleton domains
:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.250000 ms

LCV & Forward Checking:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.250000 ms

MRV & Forward Checking & propagation through singleton domains:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.250000 ms

Degree Constraint & Forward Checking:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.250000 ms

LCV:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.000000 ms
```

```
MRV & Forward Checking:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.500000 ms

Degree Constraint:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.250000 ms
############################################################
USA Map Coloring
############################################################
No Heuristics  used
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 1.2328615E7
Time taken = 20214.25 ms
############################################################
No Heuristics & Forward Checking
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 1.2328615E7
Time taken = 19345.25 ms
############################################################
No Heuristics & Forward Checking with propagation through singleton domains
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks = 7397169.0
Time taken = 11580.3 ms
############################################################
MRV
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 1.2328615E7
Time taken = 22398.25 ms
############################################################
MRV & Forward Checking
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 0.0
Time taken = 0.5 ms
############################################################
MRV & Forward Checking with propagation through singleton domains
------------------------------------------------------------
```

```
A run completed
A run completed
A run completed
A run completed
Total No of backtracks = 0.0
Time taken = 0.15 ms
############################################################
Degree Constraint
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 0.0
Time taken = 0.5 ms
############################################################
Degree Constraint & Forward Checking
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 0.0
Time taken = 0.5 ms
############################################################
Degree Constraint & Forward Checking with propagation through singleton
domains
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks = 0.0
Time taken = 0.44999999999999996 ms
############################################################
Least Constraining Value
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 0.0
Time taken = 0.0 ms
############################################################
Least Constraining Value & Forward Checking
------------------------------------------------------------
A run completed
A run completed
A run completed
A run completed
Total No of backtracks is 0.0
Time taken = 0.25 ms
############################################################
Least Constraining Value & Forward Checking with propagation through
singleton domains
------------------------------------------------------------
A run completed
A run completed
```

```
A run completed
A run completed
Total No of backtracks = 0.0
Time taken = 0.15 ms
############################################################
Number of Runs for USA = 4

No Heuristics:
Avg No of Backtracks = 12328615.000000
Avg Time in Milliseconds = 20214.250000 ms

No Heuristics & Forward Checking:
Avg No of Backtracks = 12328615.000000
Avg Time in Milliseconds = 19345.250000 ms

MRV:
Avg No of Backtracks = 12328615.000000
Avg Time in Milliseconds = 22398.250000 ms

LCV & Forward Checking & propagation through singleton domains:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.250000 ms

No Heuristics & Forward Checking & propagation through singleton domains:
Avg No of Backtracks = 12328615.000000
Avg Time in Milliseconds = 19300.500000 ms

Degree Constraint & Forward Checking & propagation through singleton domains
:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.750000 ms

LCV & Forward Checking:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.250000 ms

MRV & Forward Checking & propagation through singleton domains:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.250000 ms

Degree Constraint & Forward Checking:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.500000 ms

LCV:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.000000 ms

MRV & Forward Checking:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.500000 ms

Degree Constraint:
Avg No of Backtracks = 0.000000
Avg Time in Milliseconds = 0.500000 ms

*** Run complete ***
```

```
Process finished with exit code 0
```