VIETNAM NATIONAL UNIVERSITY HO CHI MINH CITY

UNIVERSITY OF SCIENCE

FACULTY OF INFORMATION TECHNOLOGY

LAB REPORT

Gem Hunter

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Contents

1.Introduction:

1.1.Lab description:

The Gem Hunter is a game following these rules:

- Players explore a grid to find hidden gems while avoiding traps
- Each tile with a number represents the number of traps surrouding it. (Number from 1-8)

To find the solution for this game, the problem is formulated as CNF constraints and solved it using logic. By assigining logical value (True/False) for each empty tile, the clauses are generated through a function created by programmer and solved via pysat library. Brute-force and backtracking algorithms are implemented to solve these clauses and compare their speed (by measuring running time, which is how long it takes for a ocmputer to perform a specific task) and their performance with using the library.

Objectives:

- Formulate logical contraints.
- Generate CNFs automatically.
- Apply pysat library to solve CNFs correctly.
- Program brute-force algorithm to compare with using library.
- Program backtracking algorithm to compare with using library.
- Provide at least 3 test cases with different (5x5, 11x11, 20x20) to check the solution.
- Comparing results and performance.

1.2.File structure:

Here is the file structure in “Source code":

```
.
└── Source code/
    ├── Data/
    │   ├── DataHandler.py  # This file handle the data (including input data and output data)
    │   └── Display.py  # This file supports display the result to the screen
    ├── Tasks
    │   ├── Backtracking.py  # Backtracking algorithm
    │   ├── Bruteforce.py  # Brute-force algorithm
    │   ├── CNFs_Generation.py  # Generate CNFs automatically
    │   └── PySat.py  # pysat library solves CNFs
    ├── testcases  # This folder contains all solvable test cases there corresponding output/
```

```
│   ├── input_1.txt
│   ├── input_2.txt
│   ├── input_3.txt
│   ├── output_1.txt
│   ├── output_2.txt
│   └── output_3.txt
├── UI/
│   ├── CommandLine.py   # Handle command line arguments
│   └── Execution.py  # Execute the corresponding command from command line arguments
├── main.py
├── readme.txt  # Contain the introduction to run the program
└── requirement.txt  # Contain all the libraries to install
```

1.3.Evaluation of requirements completion level:

Requirements	Completion Rate
Decribe the correct logical principles for generating CNFs	100%
Generate CNFs automatically	100%
Use pysat library to solve CNFs correctly	100%
Program brute-force algorithm to compare with using library	100%
Program backtracking algorithm to compare with using library	100%
Documents and other resources are used to write and analysis in report	100%

1.4.Youtube Demo Video Link:

Link: https://youtu.be/xV8ewsc04-8

2.Locigal principles for generating CNFs:

A CNF (Conjuctive Normal Form) is a formula which its clauses are connected to each other by conjuction (logical AND), each caluse consists of literals expressed by dijunction (logical OR).

E.g: $(l1 \lor l2 \lor l3) \land (\neg l2 \lor \neg l5 \lor \neg l6) \land (l4 \lor l10 \lor l8) \lor \ldots$

We already know that surrounding a tile containing a number 'k', there are exactly k Traps. Base on this rules, the principles is determined by two keys:

- There are at most k-Traps for all empty cells surrouding the number cell.
- There are at least k-Traps for all empty cells surrouding the number cell.

Handle exactly k-Traps:

- At most k-Traps: To make sure no more than k 'cells' are true, the program generates all combinations of k + 1 literals. For each such combination, it adds a clause to the CNF that **negates all literals in the combination**. If k + 1 literals were true simultaneously, one of these clauses would be violated. Thus, this ensures that at most k literals can be true.
- At least k-Traps: To ensure that at least k 'cells' are true, the program generates all combinations of n + 1 - k literals (where n is the total number of atomic sentences). For each combination, it adds a clause containing the **original literals.** If all literals in any of these combinations were false, the clause would be unsatisfied. This guarantees that at least k literals must be true.

3.Programming Implementation:

3.1.CNFs generation:

Pseudocode

Function generate_CNF_s(grid) return a 2D-list
    #grid is a 2D-list
    Clauses = **<empty_list>**
    For each cell(i, j) in grid:
        If cell(i, j) is not '_' and cell(i, j) is not '0':
            Clauses += make_clauses(grid, i, j)
    #Avoiding duplicate
    Unique_clauses = **<empty_list>**
    For each clause in Clauses:
        If clause not in Unique_clauses:
            Unique_clauses.add(clause)
    Clauses = Unique_clauses
    Return Clauses

Function make_clauses(grid, i, j) return a 2D list
    Number_of_rows = length(grid)
    Number_of_cols = length(grid[0])
    Integer_value = int(grid[i][j]) *# Enforce from string to integer*
 	
    Atomic_sentence = **<empty_list>**
    For **each cell** surrounding grid[i][j]:
        If **this cell** is an <empty_cell>:
            Atomic_sentence.add(**this_cell.get_row()** * Number_of_cols + **this_cell.get_column()** + 1)
 	
    At_most = list(**<Integer_value + 1>** - combinations of Atomic_sentence)
    At_least = list(**<length(Atomic_sentence) +1 – Integer_value>** - combinations of Atomic_sentence)

```
        Return list(At_most + At_least)
```

Explain:

- Whenever a number cell is found, **make_clauses** function is invoked to generate all CNF clauses surrounding this cell.
- Follow this formula: surrounding_cell_value = <its_current_row> * <length of colums> + <its_current_column> + 1.
- Add these surrounding cell's value into a list called Atomic_sentence:
  - At_most is the <number_cell_value + 1> - combinations of Atomic_sentence.
  - At_least is the <length(Atomic_sentence) - number_cell_value + 1> - combinations of Atomic_sentence.

3.2.Pysat:

Before implementing this bellow function, remember to **import** Solver **from** pysat.solvers,

```
Pseudocode
Function pySat(grid, cnf_s):
        s ← Solver()

        for each clause in cnf_s:

           s.add_clause(clause)

        solvable ← s.solve()

        if solvable == True:

           model ← s.get_model()

           grid ← fill_result(grid, model)  # Function fill 'T' and 'G' symbols to the grid
        delete s

        return grid, solvable
```

Explain: This above pseudocode simulates how pysat library works

3.3.Brute-force algorithm:

```
Pseudocode
Function brute_force_SAT(cnfs, current_row, literals, solvable=True):
      if current_row == lenth(cnfs):  # Base case

           return <empty_list>, solvable


        previous_state ← solvable
```

 # Finding all literals which is not set to be True/False

undecided_literals ←{i for i in cnfs[current_row] if i not in literals.keys()}

undecided_literals ← list(undecided_literals)

list_unit_clauses ← **<empty_list>**

if **undecided_literals** is not **empty**:

for i in range(len(**undecided_literals**)):

list_unit_clauses += list(**<i + 1>** - combinations of **undecided_literals**)

for i in range(len(**list_unit_clauses**)):

list_unit_clauses[i] += [**-lit** from **lit** in **undecided_literals** if lit not in **list_unit_clauses[i]**]

list_unit_clauses += [[**-i** from **i** in **undecided_literals**]]

additional ← **<empty_dictionaries>**

position ← 0

if ***undecided_literals*** is not **empty**:
for **each literal** in **each clause** in **list_unit_clauses:**
literals[literal] ← **True**

literals[-literal] ← **False**

current_state ← **check_cnf**(cnfs[current_row], literals)

 # The above function (check_cnf) is invoked to check wheter a clause is True or False

next_state ← **[True]** if **previous_state** and **current_state** are **True** else [**False]**

additional, solvable ← **brute_force_SAT**(cnfs, current_row + 1, literals, next_state) ***# Recursive call to reach to the next cnf clause***

if **solvable** is **True**:

```
                position = i
                break
            else:
                for each literal in each clause in list_unit_clauses:
                    delete literals[literal]
                    delete literals[-literal]
    else:
        current_state ← check_cnf(cnfs[current_row], literals)


        next_state ← [True] if previous_state and current_state are True else [False]


        additional, solvable = brute_force_SAT(cnfs, current_row + 1, literals,
next_state)


    if solvable:
        result ← <emtpy_list>
        if undecided_literals:
            for lit in list_unit_clauses[position]:
                result.add(lit)


        result.extend(additional)
        return result, solvable
    else:
return <empty_list>, False
```

Explain:

- Parmeter <literals>: this is an dictionaries storing all literals value (E.g: literals[2] = True, literals[-2] = False)
- The idea to implement brute-force is that the program traverses all clauses and check whether a clause is **True** or **False**.

- For each traversal, the program gains all literals which is not set to logical value (**True/False)** and generate all possible combinations from 1 to n (where n is the number of literal which is not set to logical value in that clause).
- Recursive call is invoked to reach to the next clause whenever all literals in current clause is set to be **True** or **False** and that clause is checked its logical value.
- Despite of a **False** clause, recursive call is still invoked until it reachs to the base case.
- The **check_cnf** function traverses all literals in the clause and returns **True** if one of these literals is **True**, else it returns **False.**

3.4.Backtracking algorithm:

Pseudocode

```
Function back_tracking_SAT(cnfs, current_row, literals):
    if current_row == length(cnfs):
        return <empty_list>, True


    clause ← cnfs[current_row]
    satisfied ← False
    undecided_literals ← <empty_list>


    for each literal in clause:
        val ← literals.get(literal)
        if val is True:
            satisfied ← True
            break
        elif val is None:
            undecided_literals.append(literal)


    if satisfied is True:
        return back_tracking_SAT(cnfs, current_row + 1, literals)


    if undecided_literals is not empty:
```

```
    for each literal in undecided_literals:
        literals[literal] ← True
        literals[-literal] ← False

        res, solvable ← back_tracking_SAT(cnfs, current_row + 1, literals)
        if solvable is True:
            res += [literal]
            return res, True

        literals[literal] ← False
        literals[-literal] ← True

        res, solvable ← back_tracking_SAT(cnfs, current_row + 1, literals)
        if solvable is True:
            res += [-literal]
            return res, True

        delete literals[literal]
        delete literals[-literal]

    return <empty_list>, False
else:
    return <empty_list>, False
```

Explain:

- This algorithm is enhanced from Brute-force algorithm. Instead of setting all literals to logical value for each clause, this algorithm only set one literal is **True** and its negation is **False**. This is possible because a clause is **True** if one of its literals is **True**. Then recursive call is invoked and continues checking logical value for the next clause.

- If the recursive call returns **False**, the algorithm inverses the logical value of the literal which has been set
    - E.g: Before recursive call: literals[2] = True, literals[-2] = False
    - If recursive call returns **False**: literals[2] = False, literals[-2] = True
- …and try another approach to the next literal which is not set to logical value
- If the all approach in that clause is **False** the function immediately terminates that branch of approach

4.Test cases and output:

4.1.Size 5x5:

```
***pysat library solves CNFs***
Before solving:   After solving:
1, _, 3, _, 2  |  1, T, 3, T, 2
_, 4, _, 5, _  |  G, 4, T, 5, T
2, _, _, _, 3  |  2, T, T, T, 3
_, 4, _, 5, _  |  T, 4, T, 5, T
1, _, 2, _, 2  |  1, G, 2, T, 2

===>Executed Time: 0.00011(s)

***Backtracking solves CNFs***
Before solving:   After solving:
1, _, 3, _, 2  |  1, T, 3, T, 2
_, 4, _, 5, _  |  G, 4, T, 5, T
2, _, _, _, 3  |  2, T, T, T, 3
_, 4, _, 5, _  |  T, 4, T, 5, T
1, _, 2, _, 2  |  1, G, 2, T, 2

===>Executed Time: 0.00009(s)

***Brute-force solves CNFs***
Before solving:   After solving:
1, _, 3, _, 2  |  1, T, 3, T, 2
_, 4, _, 5, _  |  G, 4, T, 5, T
2, _, _, _, 3  |  2, T, T, T, 3
_, 4, _, 5, _  |  T, 4, T, 5, T
1, _, 2, _, 2  |  1, G, 2, T, 2

===>Executed Time: 0.00408(s)
```

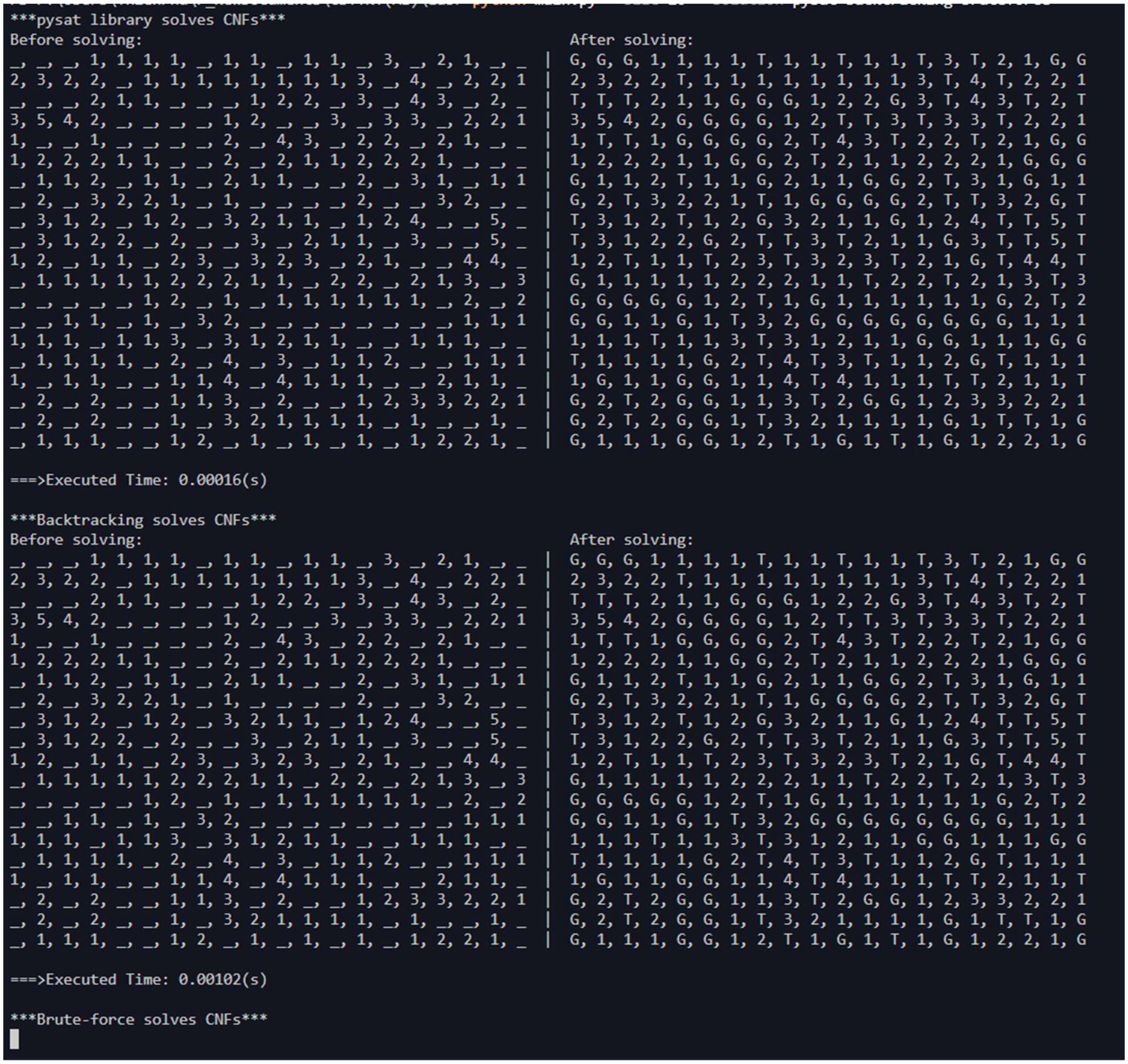
4.2.Size 11x11:

As Brute-force algorithm has to handle lots of cases (including the unsolvable cases), it would take a long time to find out the solution with this size.

```
***pysat library solves CNFs***
Before solving:                          After solving:
1, _, _, _, _, 1, 1, _, _, 1, _  |  1, G, T, G, G, 1, 1, G, T, 1, G
_, 2, 1, _, _, 1, _, 3, _, 2, _  |  T, 2, 1, G, G, 1, T, 3, G, 2, G
3, 4, _, 1, 1, 3, 3, 3, _, 1, _  |  3, 4, G, 1, 1, 3, 3, 3, T, 1, G
_, _, _, _, 1, _, _, 3, _, _, 1  |  T, T, T, G, 1, T, T, 3, G, G, 1
_, _, _, _, 2, 3, 2, 2, _, 2, _  |  T, T, G, G, 2, 3, 2, 2, T, 2, T
2, 3, _, 2, _, 2, 2, 3, 3, 3, 1  |  2, 3, G, 2, T, 2, 2, 3, 3, 3, 1
1, 2, _, _, 3, _, 2, _, _, 1, _  |  1, 2, T, G, 3, T, 2, T, T, 1, G
2, _, 3, _, _, 3, 3, 2, 2, 1, _  |  2, T, 3, T, G, 3, 3, 2, 2, 1, G
_, _, 4, 3, _, _, 2, 1, _, 1, 1  |  T, G, 4, 3, T, T, 2, 1, G, 1, 1
3, _, _, 3, 3, 4, _, _, 3, _, _  |  3, T, T, 3, 3, 4, T, G, 3, G, T
2, _, 3, _, _, 2, 2, _, _, _, 2  |  2, T, 3, G, T, 2, 2, T, T, T, 2

===>Executed Time: 0.00011(s)

***Backtracking solves CNFs***
Before solving:                          After solving:
1, _, _, _, _, 1, 1, _, _, 1, _  |  1, G, T, G, G, 1, 1, G, T, 1, T
_, 2, 1, _, _, 1, _, 3, _, 2, _  |  T, 2, 1, G, G, 1, T, 3, G, 2, G
3, 4, _, 1, 1, 3, 3, 3, _, 1, _  |  3, 4, T, 1, 1, 3, 3, 3, T, 1, G
_, _, _, _, 1, _, _, 3, _, _, 1  |  T, T, T, G, 1, T, T, 3, G, G, 1
_, _, _, _, 2, 3, 2, 2, _, 2, _  |  T, T, G, G, 2, 3, 2, 2, T, 2, T
2, 3, _, 2, _, 2, 2, 3, 3, 3, 1  |  2, 3, G, 2, T, 2, 2, 3, 3, 3, 1
1, 2, _, _, 3, _, 2, _, _, 1, _  |  1, 2, T, G, 3, T, 2, T, T, 1, G
2, _, 3, _, _, 3, 3, 2, 2, 1, _  |  2, T, 3, T, T, 3, 3, 2, 2, 1, G
_, _, 4, 3, _, _, 2, 1, _, 1, 1  |  T, T, 4, 3, T, T, 2, 1, G, 1, 1
3, _, _, 3, 3, 4, _, _, 3, _, _  |  3, T, T, 3, 3, 4, T, G, 3, G, T
2, _, 3, _, _, 2, 2, _, _, _, 2  |  2, T, 3, G, T, 2, 2, T, T, T, 2

===>Executed Time: 0.13044(s)

***Brute-force solves CNFs***
```

4.3.Size 20x20:

As Brute-force algorithm has to handle lots of cases (including the unsolvable cases), it would take a long time to find out the solution with this size.



5.References:

Generating CNF automatically: https://github.com/nguyentanhoangsa/CSAI-GemHunter/blob/master/source_code/createCNF.py

ChatGPT: https://chatgpt.com/

Pysat Documentation: https://pysathq.github.io/docs/html/

Video idea: https://youtu.be/WA_-mIzXGhw?si=Wg3Gp3pl6xNUr5zG