Lab 10: Sudoku Game

Table of Contents

1. Single Sequential Mode

From the previous lab you should have observed that multithreading did not add much to the performance. For this phase, you must remove the different modes and keep only a single sequential mode for verification, which is sufficient.

2. Incomplete State

We will continue to assume that the game is sanitised. However, there is now an additional state: `INCOMPLETE`. This is represented on the board by `0` zero digited cells. For example, if we start from a valid Sudoku solution (a fully correct 9 × 9 board) and remove one value (which is represented by `0`) from the 81 cells, the verifier must report the state for this solution as `INCOMPLETE`.

Table 1. An example of empty sudoku board

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

The GUI would **not** display it as zeros; that functionality is restricted to the application layer.

3. Game Driver

3.1. Verfication

You must implement a Sudoku game driver that takes a **source solution**, which is supposed to be a valid, fully solved Sudoku board.

- The driver must **not** assume that the source solution is valid.
- It must first verify the source solution.
- If the source game is not `VALID` (i.e. it is `INVALID` or `INCOMPLETE`), you must raise an exception and propagate it to the presentation layer.

3.2. Difficulty Levels

You must support three difficulty levels: **Hard**, **Medium**, and **Easy**.

These are generated by removing a random number of cells from the solved board:

- Hard: remove **25** cells
- Medium: remove **20** cells
- Easy: remove **10** cells

The random positions to erase must be chosen using a seed based on the current time. The three levels **must** be generated at once.

Use `RandomPairs` class for this task.

```java
import java.util.ArrayList;
import java.util.HashSet;
import java.util.List;
import java.util.Random;
import java.util.Set;

public class RandomPairs {

    // Range 0..8 for both x and y
    private static final int MAX_COORD = 8;
    private static final int MAX_UNIQUE_PAIRS = (MAX_COORD + 1) * (MAX_COORD + 1);
    private final Random random;

    public RandomPairs() {
        this.random = new Random(System.currentTimeMillis());
    }

    /**
     * Generate n distinct random pairs (x, y) where 0 <= x <= 8 and 0 <= y <= 8.
     */
    public List<int[]> generateDistinctPairs(int n) {
        if (n < 0 || n > MAX_UNIQUE_PAIRS) {
            throw new IllegalArgumentException(
                "n must be between 0 and " + MAX_UNIQUE_PAIRS + " (inclusive)");
        }

        Set<Integer> used = new HashSet<>();
        List<int[]> result = new ArrayList<>(n);

        while (result.size() < n) {
            int x = random.nextInt(MAX_COORD + 1); // 0..8
            int y = random.nextInt(MAX_COORD + 1); // 0..8

            // Encode pair (x, y) as a single int to track uniqueness
            int key = x * (MAX_COORD + 1) + y;

            if (used.add(key)) {
                result.add(new int[] { x, y });
            }
        }

        return result;
    }
}
```

3.3. Storage

You must create a folder hierarchy for generated games and save each new game into one of three folders:

- `easy`
- `medium`
- `hard`

There must also be another folder that stores **only the currently played game**, regardless of its level. This is required so that, if the user closes the application and reopens it, you can ask whether they want to continue their last unfinished game.

- If a game becomes completely filled and is verified as valid, it must be removed permanently (deleted).

4. GUI Requirements

For this lab, you must provide a **GUI**.

At start-up, the presentation layer must get **game catalogue** method. This method returns two booleans:

1. Whether there is an unfinished game.
2. Whether there exists at least one game of each difficulty level: easy, medium, and hard (there must be at least one per level).

The logic is as follows:

- If the first boolean is `true` (there is an unfinished game), the presentation layer must call the loader to load that unfinished game.
- If the first boolean is `false`, it must then check the second boolean:
    - If the second boolean is `true`, the user is asked which difficulty they prefer (`easy`, `medium`, or `hard`), and then the loader is called to load a game of that type.

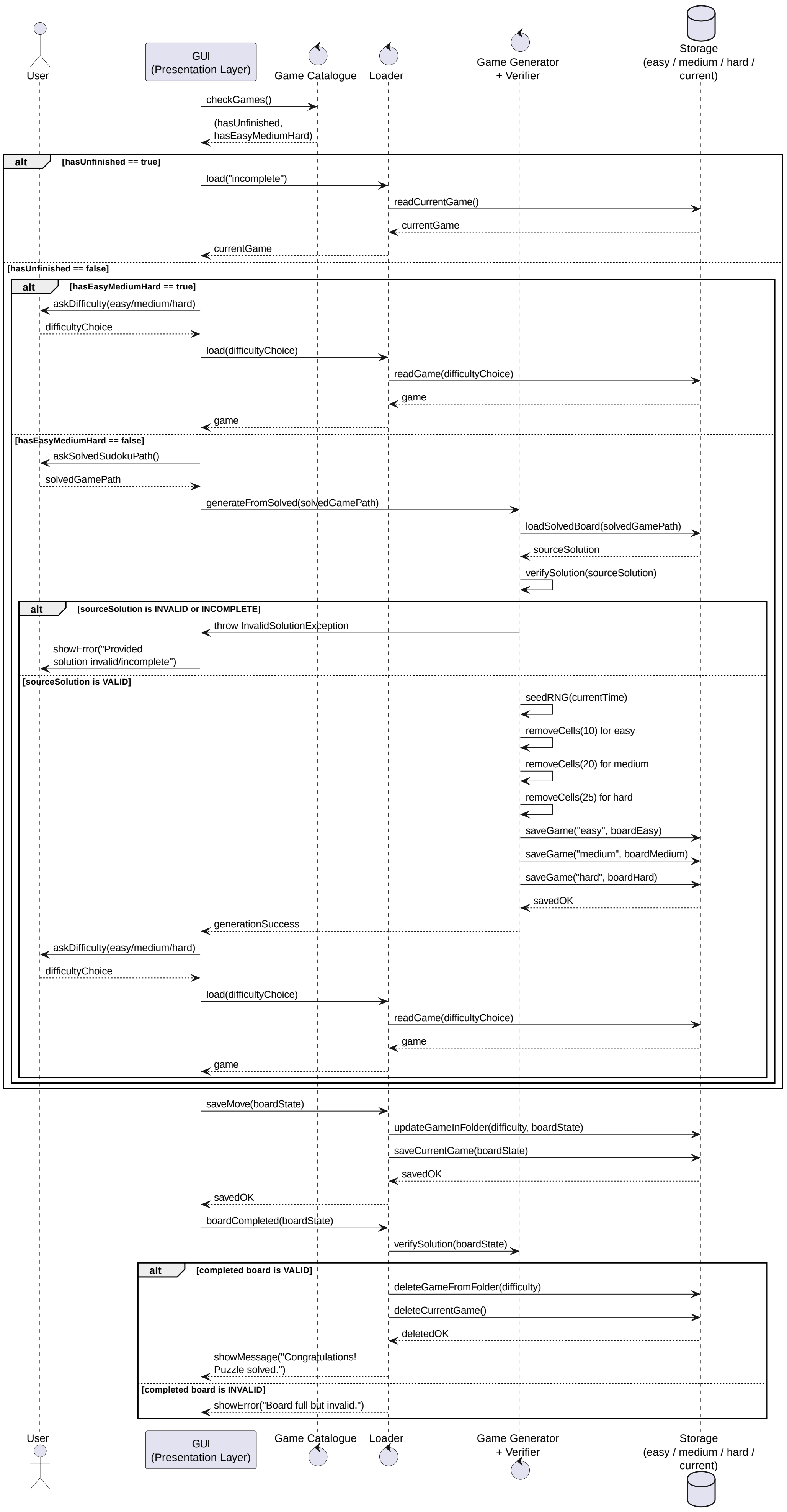
The **loader** is responsible for loading a game by type:

- `easy`
- `medium`
- `hard`
- `incomplete` (if there is one)

If the user has no incomplete game and there is not at least one game per difficulty level, the user must see a screen that asks them to provide a path to a solved Sudoku game file. This solved game will then be used to generate the different difficulty levels.

5. Verification, Difficulty, and Storage Flow

Sudoku - Verification, Difficulty, Storage, and GUI Flow


User
GUI (Presentation Layer)
Game Catalogue
Loader
Game Generator + Verifier
Storage (easy / medium / hard / current)
checkGames()
(hasUnfinished, hasEasyMediumHard)
alt
[hasUnfinished == true]
load("incomplete")
readCurrentGame()
currentGame
currentGame
[hasUnfinished == false]
alt
[hasEasyMediumHard == true]
askDifficulty(easy/medium/hard)
difficultyChoice
load(difficultyChoice)
readGame(difficultyChoice)
game
game
[hasEasyMediumHard == false]
askSolvedSudokuPath()
solvedGamePath
generateFromSolved(solvedGamePath)
loadSolvedBoard(solvedGamePath)
sourceSolution
verifySolution(sourceSolution)
alt
[sourceSolution is INVALID or INCOMPLETE]
throw InvalidSolutionException
showError("Provided solution invalid/incomplete")
[sourceSolution is VALID]
seedRNG(currentTime)
removeCells(10) for easy
removeCells(20) for medium
removeCells(25) for hard
saveGame("easy", boardEasy)
saveGame("medium", boardMedium)
saveGame("hard", boardHard)
savedOK
generationSuccess
askDifficulty(easy/medium/hard)
difficultyChoice
load(difficultyChoice)
readGame(difficultyChoice)
game
game
saveMove(boardState)
updateGameInFolder(difficulty, boardState)
saveCurrentGame(boardState)
savedOK
savedOK
boardCompleted(boardState)
verifySolution(boardState)
alt
[completed board is VALID]
deleteGameFromFolder(difficulty)
deleteCurrentGame()
deletedOK
showMessage("Congratulations! Puzzle solved.")
[completed board is INVALID]
showError("Board full but invalid.")
User
GUI (Presentation Layer)
Game Catalogue
Loader
Game Generator + Verifier
Storage (easy / medium / hard / current)

In order to integrate **GUI** (presentation layer) and **Controllers** (application layer) you have to follow `Design Guide`. we didn't add it to the flow (sequence diagram) for simplicity.

6. Design Guide

- The MVC model states that the **View**, **Controller** and **Model** should be kept separate.
- In this lab, it is required to implement two interfaces, one for each layer (presentation and application). These two interfaces must then be integrated so that the **View** can interact with the **Controller**.

```
class Catalog
{
    // True if there is a game in progress, False otherwise.
    bool current;

    // True if there is atleast one game available
    // for each difficulty, False otherwise.
    bool allModesExist;
}
```

```
class Game
{
    int[][] board;
    Game(int[][] board)
    {
        // IMPORTANT: DON'T COPY THE BOARD BY VALUE
        // USE REFERENCES
        this.board = board;
    }
    // Add methods and attributes if needed
}
```

`Viewable` is the interface of the controller representing the actions that are exposed to the viewer

```
interface Viewable
{
    Catalog getCatalog();

    // Returns a random game with the specified difficulty
    // Note: the Game class is the representation of the soduko game in the controller
    Game getGame(DifficultyEnum level) throws NotFoundException;

    // Gets a sourceSolution and generates three levels of difficulty
    void driveGames(Game sourceGame) throws SolutionInvalidException;
    // Given a game, if invalid returns invalid and the locates the invalid duplicates
    // if valid and complete, return a value
    // if valid and incomplete, returns another value
    // The exact repersentation as a string is done as you best see fit
    // Example for return values:
    // Game Valid -> "valid"
    // Game incomplete -> "incomplete"
    // Game Invalid -> "invalid 1,2 3,3 6,7"
    String verifyGame(Game game);

    // returns the correct combination for the missing numbers
    // Hint: So, there are many ways you can approach this, one way is
    // to have a way to map an index in the combination array to its location in the
board
    // one other way to to try to encode the location and the answer all in just one
int
    int[] solveGame(Game game) throws InvalidGame;

    // Logs the user action
    void logUserAction(String userAction) throws IOException;
}
```

`Controllable` is the interface of the viewer representing the actions that GUI components signal according to user actions on screen.

```
interface Controllable
{
    bool[] getCatalog();

    int[][] getGame(char level) throws NotFoundException;

    void driveGames(String sourcePath) throws SolutionInvalidException;

    // A boolean array which says if a specifc cell is correct or invalid
    bool[][] verifyGame(int[][] game);

    // contains the cell x, y and solution for each missing cell
    int[][] solveGame(int[][] game) throws InvalidGame;

    // Logs the user action
    void logUserAction(UserAction userAction) throws IOException;
}
```

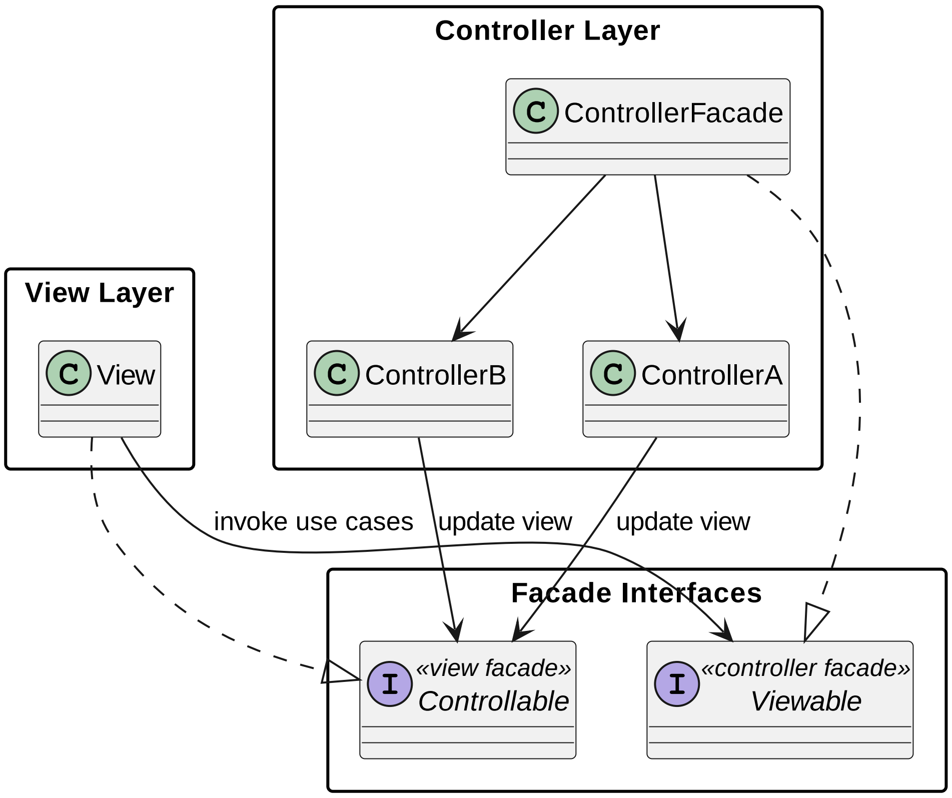
You must retain the types of the parameters and return value for each interface.

The `Game` and `Catalog` classes, and `DifficultyEnum` must only be defined and used on the controller side and not the viewer, however, `UserAction` should be defined and used only on viewer side.

The reason we use two separate interfaces is to simulate that the viewer and the controller are distinct entities, each with its own data representation and potentially different semantics.

The following diagram shows how the given interfaces should be used. Note: Since the two interfaces are incompatible, what component should be added between them to allow their integration? == MVC Architecture with External Facade Interfaces

7. View–Controller Architecture with External Facades



8. In-Game Behaviour: Verify, Solve, and Undo

In the “happy path” where a game is successfully loaded and presented to the player, the GUI must offer two buttons:

- `Verify`
- `Solve`

The `Solve` button must be **disabled** unless the number of remaining empty cells is **exactly 5**. At that point, it should become enabled.

You must also support **Undo** functionality.

Undo requires a **log file** stored in the same folder as the currently played game. Let this folder be called `incomplete`. This folder must always be in one of two states:

- Empty, or
- Containing exactly two files: the log file and the Sudoku game file.

Logging behaviour:

- Log entries must be written immediately.
- Suppose we have an empty cell at `(3, 5)` and the user enters the value `3`.
  - The log file should be appended with a record in the form `(x, y, val, prev)`.
  - In this example it would be: `(3, 5, 3, 0)`, where `prev` is the previous value (`0` in this case).

When the user performs `Undo`, you must:

- Remove the last line from the log file.
- Apply the inverse of that change to the board.

9. Solver Requirements

For the solver, you may **not** use any sophisticated or "smart" Sudoku-solving techniques. We do not want constraint propagation, backtracking optimisations, or any clever algorithms.

Instead, you must implement the solver using **permutations** only, with the following constraints:

- The solver is **bounded** to cases where there are exactly **5 remaining empty cells**.
- Each of the `5` positions initially has `9` possible values (`1`–`9`).
- This yields at most `9^5` possibilities (roughly `60,000` permutations).

You can think of this as verifying up to `60,000` different boards:

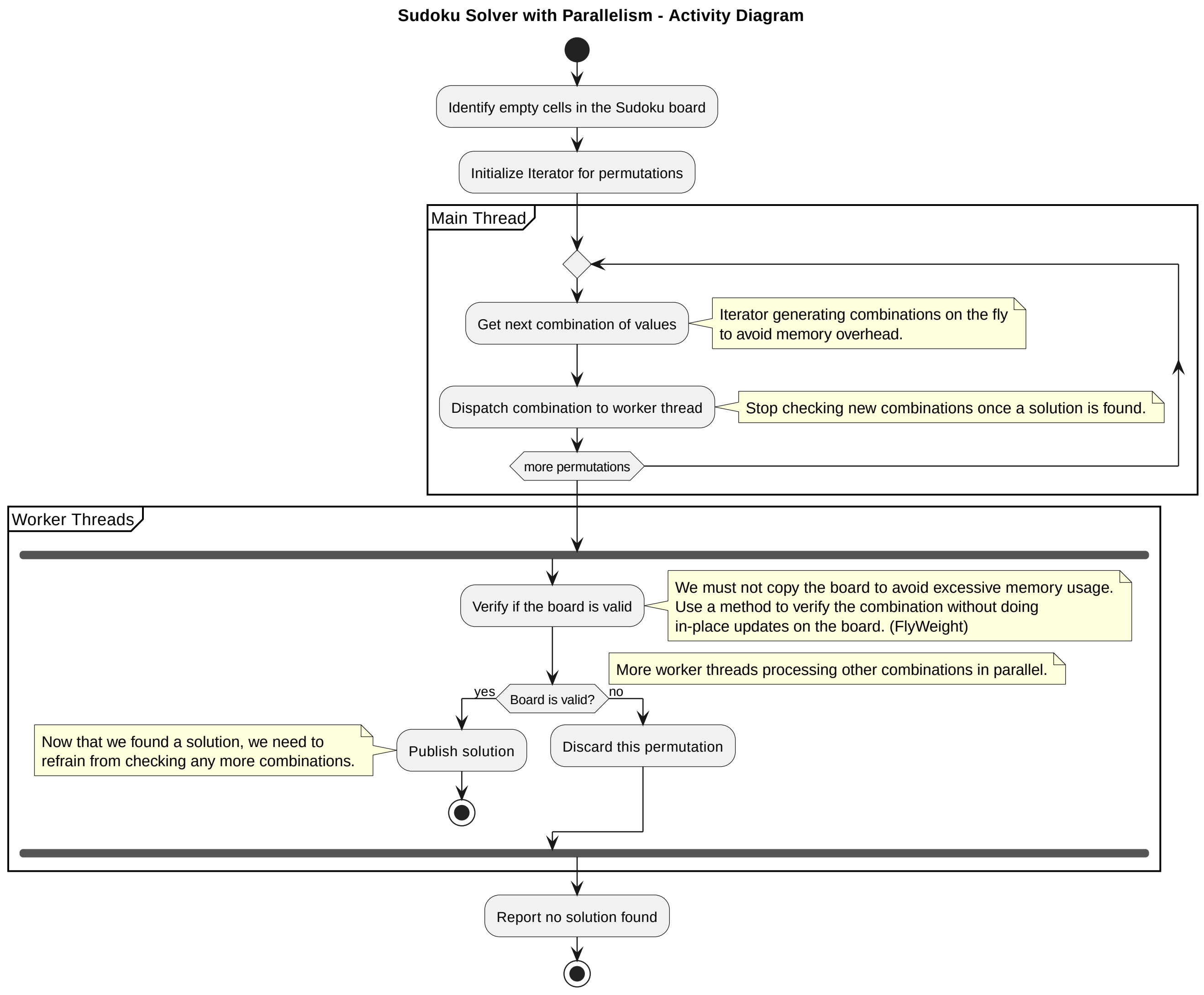
- For each permutation, you fill in the `5` empty cells with one of the combinations.
- For each resulting board, you verify whether it is a valid Sudoku.

You may stop as soon as you find a valid solution. On average, this is expected to require about half the checks (≈`30,000` verifications). Each verification is a relatively lightweight operation: a loop over `81` cells.

The main concern is **memory management** so that you do not run out of memory whilst handling all these permutations. You are expected to solve this using two design patterns:

- **Iterator**
- **Flyweight**

You must **not** use any of the Java concurrency keywords `synchronized`, `volatile` or thread-safe data structures at all.


Sudoku Solver with Parallelism - Activity Diagram
Identify empty cells in the Sudoku board
Initialize Iterator for permutations
Main Thread
Get next combination of values
Iterator generating combinations on the fly to avoid memory overhead.
Dispatch combination to worker thread
Stop checking new combinations once a solution is found.
more permutations
Worker Threads
Verify if the board is valid
We must not copy the board to avoid excessive memory usage. Use a method to verify the combination without doing in-place updates on the board. (FlyWeight)
More worker threads processing other combinations in parallel.
yes
Board is valid?
no
Now that we found a solution, we need to refrain from checking any more combinations.
Publish solution
Discard this permutation
Report no solution found

10. Design Patterns

We explicitly mentioned two design patterns, `Flyweight` and `Iterator`. The application encourages the use of additional design patterns (at least **two** more), which you should research independently. However, it is preferable to justify why certain patterns were not used, rather than introducing them unnecessarily or forcefully.

The primary objective is to **justify** and **argue** for your design decisions.

The `Command` and `Memento` patterns are outside the scope of this course. While they could be beneficial for logging purposes, you are not required to use them (they are not of any the **three** patterns mentioned before).