Sudoku Game

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1. Introduction

This project presents an implementation of a **Sudoku game and solver** using the **Imperative Programming Paradigm**.

The purpose of this implementation is to demonstrate:

- Object-Oriented Programming (OOP)
- Mutable program state
- Explicit control flow using loops
- Iterative backtracking algorithm
- Use of higher-order functions via callbacks

The Sudoku solver modifies the game state directly and solves the puzzle step by step using commands and loops, which clearly reflects imperative programming principles.

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2. Sudoku Problem Description

Sudoku is a logic-based puzzle played on a **9×9 grid**, divided into **nine 3×3 subgrids**.

The objective is to fill the grid so that:

- Each row contains numbers from 1 to 9 exactly once
- Each column contains numbers from 1 to 9 exactly once
- Each 3×3 subgrid contains numbers from 1 to 9 exactly once

Empty cells are represented by the value **0**.

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3. Programming Paradigm Used

This implementation follows the **Imperative Paradigm**, which is characterized by:

- Explicit instructions that change program state
- Step-by-step execution control
- Mutable variables and data structures
- Commands that directly modify memory

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4. System Design

4.1 Object-Oriented Structure

The system is implemented using a single class:

`SudokuGame`

This class encapsulates:

- The Sudoku board (mutable state)
- Game logic
- Validation logic
- Solving logic
- User interaction

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5. Board Representation

The Sudoku board is represented as a **2D list (9×9 matrix)**:

- Numbers (1–9): filled cells
- Zero (0): empty cells

The board is stored internally as:

```
self.board
```

This state is **mutable** and modified directly during gameplay and solving.

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6. Core Methods Explanation

6.1 `print_board()`

This method prints the Sudoku board in a formatted way:

- Uses dots (`.`) to represent empty cells
- Adds visual separators for rows and columns
- Improves readability for the user

This method only displays state and does not modify it.

6.2 `is_valid(row, col, num)`

This method checks whether a number can be placed in a given position.

Validation steps:

1. Check the row
2. Check the column
3. Check the corresponding 3×3 subgrid

Returns:

- `True` if the move follows Sudoku rules
- `False` otherwise

6.3 `is_complete()`

This method checks whether the puzzle is fully solved.

- If no cell contains 0 → puzzle is complete
- Otherwise → puzzle is incomplete

6.4 `find_empty_cell()`

This method scans the board and returns the position of the first empty cell.

- Returns `(row, col)` if found
- Returns `None` if the board is full

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7. Iterative Sudoku Solver (AI)

7.1 Algorithm Overview

The solver uses an **ITERATIVE BACKTRACKING ALGORITHM** instead of recursion.

Main steps:

1. Collect all empty cells at the start
2. Traverse empty cells using an index variable
3. Try numbers from 1 to 9 for each cell
4. If no number fits → explicitly backtrack
5. Continue until the board is solved or no solution exists

This approach provides full control over execution using loops.

7.2 `solve_sudoku(callback=None)`

The `solve_sudoku` method performs the automated solving process.

Key characteristics:

- Uses `while` and `for` loops
- Directly mutates `self.board`
- Implements backtracking explicitly using index manipulation
- No recursion is used

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8. Higher-Order Function Usage (Callback)

The solver demonstrates the use of a **higher-order function** through the `callback` parameter.

A higher-order function:

- Accepts another function as an argument

In this project:

- `solve_sudoku` receives a `callback`
- The callback is called after each significant board modification
- This enables visualization or logging without changing the solving logic

Example use case:

- Visualizing the solving process step by step
- Debugging algorithm behavior
- Separating logic from presentation

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9. Manual Gameplay

The program allows the user to play Sudoku manually.

`play()` Method

- Prompts user to enter row, column, and number
- Validates inputs
- Prevents overwriting filled cells
- Updates board state directly (imperative style)
- Ends when the puzzle is solved or user exits

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10. Execution Modes

At runtime, the user can choose:

1. **Manual Play** – user solves the puzzle
2. **AI Solve with Visualization** – solver with callback visualization
3. **AI Solve Fast Mode** – solver without visualization

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11. Key Imperative Programming Characteristics

This implementation clearly demonstrates:

- Mutable shared state
- Explicit step-by-step control
- In-place state modification
- Loop-based algorithm design
- Side effects during execution
- Higher-order function usage

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12. Conclusion

This project provides a clear example of solving Sudoku using **Imperative Programming**.

The iterative backtracking algorithm highlights the importance of:

- Explicit control flow
- State management
- Mutable data structures

The addition of higher-order functions improves flexibility by separating logic from visualization, making the design more modular while remaining imperative in nature.