

CSC470: Software Engineering Final Report
TESS: The Extraordinary Sudoku Solver

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v1.1

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1 Executive Summary

Have you ever played a Sudoku game that you weren't able to solve? Have you spent hours trying to solve a specific puzzle, but something never quite added up? This is where we come in. with The Extraordinary Sudoku Solver, or as everyone in the lab calls it, TESS. TESS isn't a normal sudoku game, it allows normal game play much like any sudoku game will; however, it has an added feature that makes it stand out from the rest of the apps currently on the market. TESS allows a user to input the given values from a sudoku puzzle and work its magic to find a solution for you. David and Joseph are currently working on TESS to get her up and running. The goal of TESS is to allow a user to play different sudoku games, much like most of the apps currently out there, but also allow a user to input a sudoku puzzle they have been working on elsewhere and get an instant solution. There are a few major problems that the developers are facing. One of the biggest problems is the time efficiency. TESS needs to be able to solve the entire game in under 5 seconds and even though that may seem like a long time, going through all the possible solutions won't be fast enough. The developers are currently working on an algorithm that will work in $O(N^5)$ which is roughly 3 billion computations; however, with pruning and better algorithms, they will be able to get the algorithm to solve it much faster. Another major problem the young developers face is the allotted time to finish the project, they only have about a month to finish this massive project. They might be able to finish the project on time, if they dedicate enough time towards this project and focus on it more than the previous projects they worked on. The design will be rather simple much like any sudoku game out there; however, the color scheme will be different with a nice black and neon green coloring pattern. There will be a few buttons such as choosing to play a game as well as the ability to access the solver to solve a sudoku puzzle the user might have. The goals of this project is to allow the user to play a sudoku game. The user should be able to pick a game from the our database and be able to play it. It will require the developers to manage different difficulty levels as well as storing games in the database. Another goal for this project is to allow the user to check how they are doing so far. This will require the developers to write testers that will test if the current numbers are valid or invalid. The major goal of this project is to completely solve the sudoku puzzle that the user inputs. Some problems that will arise are due to the time constraint. Brute force will take too long; however, if depth first search is used along with pruning, there is a good chance it will finish in time. The system design is like how most games would be structured. The user can select play or solve at the very beginning. If the user decides to play a game, then they will be able to choose a difficulty they would like to play. There will be options for a hint; however, the hint function might not be released with the first version, since that isn't the main priority with the project. There will be a check option to check if there are any errors in the current state of the puzzle as well as a solve option to solve the rest of the puzzle. The following description is outlined in figure 2. The sequence diagram (Figure 3) illustrates the flow of logic when a user decides to play the game. Finally, the activity diagram

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(Figure 4) greatly outlines the dynamic aspects of the proposed sudoku game. The test plan for this project is based on the bottom-up approach. We, the developers, will be focusing on utility, reliability, robustness, and performance to ensure this project is functional and well as enjoyable to the user.

2 Introduction

This section will provide the introduction to the final report document as well as roughly highlight the project on hand.

2.1 Purpose

The purpose of this document is to give a detailed and overall description of The Extraordinary Sudoku Solver (TESS) app. The overall purpose of this project is to help the avid Sudoku players to have a platform to enjoy the game on as well as get help when they are unable to solve a puzzle. This app is intended to be used by both amateurs and professionals, as well as anyone in-between. This will be a free platform for anyone to have access to it as well as modify it in any way the like. Sudoku is an amazing game and the hopes of this project is to expand the entertainment and excitement of Sudoku to anyone willing to try this app.

2.2 Definitions, acronyms, and abbreviations

| Term | Definition |
|------|----------------------------------------------------------------|
| DESC | Description |
| DFS | Depth First Search Algorithm |
| Grid | This is where all the values are stored for the player to see. |
| ID | Identification |
| PW | Priority Weights |
| User | Whoever will be using the app |

3 Goals

There are a few major goals that needed to be accomplished in this project. The main overarching goal was to create an intuitive Sudoku game UI and combine it with a Sudoku game solving component. This goal was thus broken into smaller pieces: create a user friendly UI for a user to be able to play a Sudoku game and create a efficient and fast Sudoku solver to solve any given puzzle. This program also needed to have a few additional components as well. The program must include some sort of searching algorithm and because of the complexity of the problem, it also needs to include some sort of pruning technique to minimize the operations needed to solve the entire game. The program also have some sort of database component to store all the puzzles in along with the current puzzle

the user is working on. Another major goal was to turn this program into a mobile app that will run on Android devices and eventually on other systems as well. These were the main goals of the project that helped drive the focus of the project and its workers.

4 Specific Requirements

This section will cover the specific requirements of the project including functional and non-functional requirements. The functional requirements are identified with R followed by a number and nonfunctional requirements are identified with RQ followed by a number. All the functional requirements are marked with a PW (Priority Weight) which refer to the priority of that specific requirement with 5 being the highest priority and 1 being the lowest.

4.1 Functional Requirements

This section will cover the functional requirements associated with the project along with the following tags: ID, TITLE, DESC, and PW.

ID:R1

TITLE: Play Game Option

DESC: The user first opens up the app, they should be able to choose the option to play a Sudoku puzzle. They user should be able to stay as long as they want to on this screen.

PW: 3

ID:R2

TITLE: Select Difficulty

DESC: The user should be able to select a difficulty setting that better suites needs at any time. There should be 5 difficulty options for the user to choose from. 1 being the easiest all the way down to 5 being the hardest.

PW: 2

ID:R3

TITLE: Back Option

DESC: The user should be able to return to the main screen from the select difficulty screen if they don't select a difficulty. The user can remain on the select difficulty as long as the want to.

PW: 1

ID:R4

TITLE: Continue Game

DESC: The user should be able to continue a game that has been previously started whether or not the app has been closed. All of the user's input should be saved so they could be brought up again should the user want to continue a

game.
PW: 4

ID:R5

TITLE: Get Puzzle

DESC: When the user selects a difficulty, a puzzle with the selected difficulty should be retrieved from the database for the user to be able to play it and enjoy the game.

PW: 2

ID:R6

TITLE: Solver Option

DESC: On started, the user should be able to select the Solver option in the app to go straight to the solver part of the app.

PW: 5

ID:R7

TITLE: Input Sudoku Puzzle To Solve

DESC: The user needs to be able to input any sort of Sudoku puzzle that the user has, with or without any extra numbers the user wishes to input.

PW: 5

ID:R8

TITLE: Check Current Board

DESC: The user should be able to check the status of the current puzzle they are working on. The user should be able to view the inputs that are conflicting with each other. They should be marked in some way for the user to be able to see them clearly.

PW: 4

ID:R9

TITLE: Delete an Input Value

DESC: The user should be able to delete an input value that they put in previously or a value that the system put in automatically.

PW: 5

ID:R10

TITLE: Clear Board

DESC: The user should be able to clear the entire board easily and effortlessly.

PW: 3

ID:R11

TITLE: Solve Current Board

DESC: The user should be able to have the option to solve the current board that they are working on. It should use the input the system put in as well as the inputs the user decided to add.

PW: 5

ID:R12

TITLE: Play Sudoku Game

DESC: The user should be able to play a Sudoku game by selecting certain boxes and input a value into them.

PW: 4

ID:R13

TITLE: Hint Option

DESC: The user should have the option to get a hint on the current Sudoku game they are playing. The hint should display any correct value on the given board.

PW: 1

ID:R14

TITLE: Download Mobile Application

DESC: The user should be able to download the mobile application either from the Play Store or via Email to their Android phone. The download should be free.

PW: 5

4.2 Non-Functional Requirements

This section will cover the non-functional requirements associated with the project along with the following tags: ID, TITLE, and DESC.

ID:RQ1

TITLE: System Availability

DESC: The system needs to be available to the user 99.9% of the time, whether or not the system is being used. The system can only be down for 0.1% of the time for updates or maintenance.

ID:RQ2

TITLE: Solve Time

DESC: The app should be able to solve a given Sudoku puzzle, whether there is or isn't a solution in under 5 seconds.

ID:RQ3

TITLE: Search Algorithm

DESC: The Suduko solver must utilize some search algorithm such as depth first search or breadth first search or any other searching algorithm.

ID:RQ4

TITLE: Pruning Technique

DESC: There must be some sort of pruning technique with solving the problem because 9^{81} is not feasible.

ID:RQ5

TITLE: Database Storage

DESC: The Database needs be stored locally on the device and new puzzles should be added to the device through updates or pulled from an external database.

ID:RQ6

TITLE: Easy to Use

DESC: The app should be very simple to use to any player with some general idea of how Sudoku puzzles work.

ID:RQ7

TITLE: Private Information

DESC: The app should not keep any personal information about the user. There app should not ask the user for any passwords.

4.3 Version

This is version 1.1 or v1.1, which is also the most current version of the system. Version 1.0 came out on the April 7, 2017; however, after tests were conducted there were a few design flaws that needed to be worked around. Version 1.0 was not able to solve difficult Sudoku puzzles within the allotted and many of the beta testers were not pleased with this. After some thought, v1.0 was pulled off the market and developers continued to improve the algorithm to solve the more difficult problems. In v1.1, the developers finally came up with a fast enough algorithm to solve it within the time limit. This new and updated version will be available on the market soon; however, it still remains in its early stages of development.

4.4 System Model

This section will cover the general system model. This section includes the actors, use cases, use case diagram, prototyping and the traceability matrix.

4.4.1 Actors

The section covers the primary actors that are involved with the system directly or indirectly.

- Player: This is the primary actor who will be using the app as well as interacting with it.

- Database: This is the datastore that is on the device that contains all the Sudoku puzzles for the user to play.

4.4.2 Use Cases

This section covers the use cases that are most prominent in the Sudoku app that describe how the user shall interact with the app. Each use case will contain the following components: ID, Title, Actors, and Description.

ID:UC1

TITLE: Select Play Game

ACTORS: Player

DESC: Player opens up the app and selects to play a Sudoku puzzle.

ID:UC2

TITLE: Select Solver

ACTORS: Player

DESC: Player opens up the app and selects the Solver option to solve a Sudoku puzzle they might have.

ID:UC3

TITLE: Selecting a difficulty

ACTORS: Player and Database

DESC: Player selects a difficulty from the options available and a Sudoku board is filled with a puzzle similar to the difficulty the Player selected.

ID:UC4

TITLE: Quitting Time

ACTORS: Player and Database

DESC: When Player decides to quit the puzzle they are currently working on, the puzzle is saved to the database so Player can continue playing it.

ID:UC5

TITLE: Continuing

ACTORS: Player and Database

DESC: When Player decides to play a game again and selects the continue option to bring up the previously saved game they were playing.

ID:UC6

TITLE: Give me a hint

ACTORS: Player

DESC: The Player is unsure of any other moves, so Player decides to select the hint option in order to receive a hint about the current Sudoku puzzle they are working on.

ID:UC7

TITLE: Solve the Puzzle

ACTORS: Player

DESC: The Player is tired of playing and wants to see the solution to the Sudoku puzzle, so they decided to tap the solve button to get all the answers.

ID:UC8

TITLE: Clear the Board

ACTORS: Player

DESC: The Player decides to start a new puzzle, so the Player hits the clear button to erase everything on the board.

ID:UC9

TITLE: Playing the game

ACTORS: Player

DESC: The Player enjoys playing a Sudoku game by clicking the buttons and entering the numbers that they might think will solve the puzzle.

4.4.3 Use Case Diagram

Figure 1 depicts the the use case diagram used by the app as well as the develops to design a proper system.

4.4.4 Traceability Matrix

The traceability matrix, as shown in Figure 2, shows the priority weight of each use case based on the requirements that it meets. As per the figure, use case 9 had one of the highest priorities, which is consequently one of the most important use cases as well.

5 System Design

This is the system design section.

5.1 Desgin Overview

Provide an overview of the design, including diagrams, key design subsections, and how they relate or connect to one another (e.g., Interaction, structural models).

5.2 Realistic Constraints and Professional Standards

Identify and discuss realistic constraints on the problem, such that constraints may include economic, environmental, social, ethical, health and safety, manufacturability, policy issues, etc.

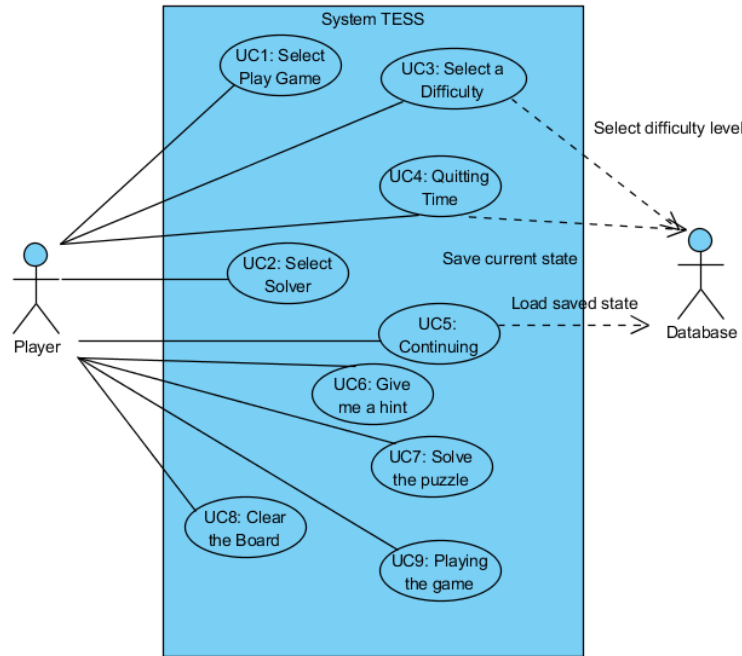


Figure 1: Use case diagram of the TESS System.

5.2.1 System Constraints

The application design for Android smartphones requires to be implemented in Java. In addition to the programming language requirements, Android application development requires Android Studio IDE to be installed on the development computer. The IDE enables the developer to program and test the app on the same computer.

The IDE itself requires the developer to have a basic understanding of Android application development. It also requires the developer to configure an Android Virtual Device to run and test the app that is currently being developed.

*We have outlined the six system constraints of TESS below.

ID:C1

TITLE: Memory Space

DESC: The app should have a small footprint. The entire app should take up less than 5MBs of memory, this is including with future updates as well.

ID:C2

| REQs | PW | UC1 | UC2 | UC3 | UC4 | UC5 | UC6 | UC7 | UC8 | UC9 |
|----------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| R1 | 3 | X | | X | | | | | | |
| R2 | 2 | | | X | | | | | | X |
| R3 | 1 | | | X | X | X | | | | |
| R4 | 4 | | | X | X | X | | | | |
| R5 | 2 | | | X | | | | | | |
| R6 | 5 | | X | | | | | | | X |
| R7 | 5 | | | | | | | X | | X |
| R8 | 4 | | | | | | X | X | | X |
| R9 | 5 | | | | | | | | | X |
| R10 | 3 | | | | | | | | X | X |
| R11 | 5 | | | | | | | X | | X |
| R12 | 4 | | | | | | X | X | X | X |
| R13 | 1 | | | | | | X | | | X |
| R14 | 5 | X | X | | | | | | | |
| Max PW | | 5 | 5 | 4 | 4 | 4 | 4 | 5 | 4 | 5 |
| Total PW | | 8 | 10 | 12 | 5 | 5 | 9 | 18 | 7 | 32 |

Figure 2: Traceability Matrix of the TESS System.

TITLE: Internet Connection for Updates

DESC: The app must have an internet connection established to be able to retrieve updated information from a master database.

ID:C3

TITLE: Programming Language

DESC: The app must be written in mainly Java, there may be other languages within the program, but the main part of it should be in Java.

ID:C4

TITLE: Android Device Only

DESC: The system must work on Android Devices, specifically the Galaxy Note 5 first, the following versions will include other phone models.

ID:C5

TITLE: Time to Solve

DESC: The app should take less than 5 seconds to output the solved Sudoku puzzle or report that it can't be solved.

ID:C6

TITLE: Database Usage

DESC: The app must utilize some sort of database to hold the stored puzzles.

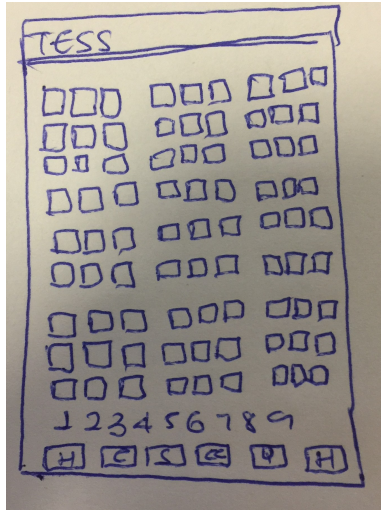


Figure 3: User constraints of the TESS System.

5.3 Alternative Designs and Design Choices

Describe alternative designs that were considered during execution of the project. Discuss how design choices were guided by constraints and other factors. E.g., architectural design models – Layered or Client-server and details shown using activity diagram as shown in Figure 4 (Context model), sequence diagram (Interaction model), class diagram (Structural model).

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6 System Implementation

This is the system implementation section.

Describe the technical details for each of the subsystems or a the system-level and provide sequence diagrams or station/activity diagrams for your system implementation.

7 System Testing

This section will describe the testing plan for TESS and the different tests that will be conducted on it. This section will also display the results of the tests.

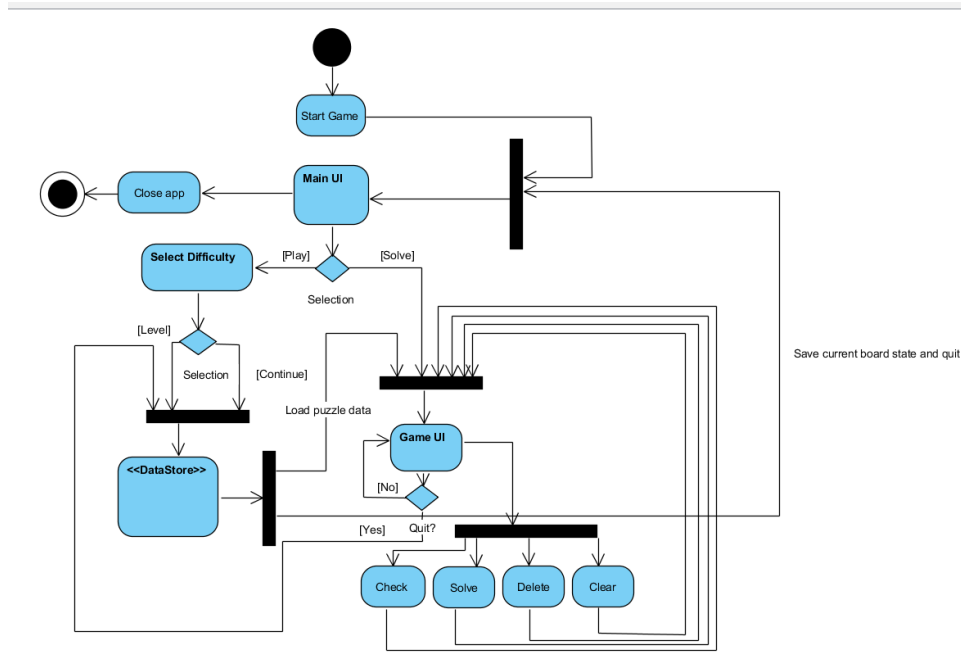


Figure 4: Activity diagram of the TESS system.

7.1 Test Plan

This section will describe the testing plan for the system. Due to the nature of the project, the testing phase is only applicable to a small portion of the project. Since there is no input directly from the user and there are only buttons available for the user to use, the testing will be rather minimal. The project was created in such a way as to reduce the chance of errors, so the developers chose to use only buttons in the UI. There are a few major methods that do require testing, they are: `solveHorizontal()`, `solveVertical()`, `solveBox()`, and `solveRecur()`. For the first three methods there will be 2 tests each, one showing where it solves the expected square and the other where there is no way for it solve it. These cases are simple and are only used to solve the easy cases in the app in order to cut down the time of having the DFS run through the different possibilities. For the final method, `solveRecur()`, there will be 5 tests run, one from each difficulty to show that those puzzles can be solved and also 1 test case where the input is invalid. All of the aforementioned tests are unit tests, specifically Black-box tests. This specific type of test involves giving the program a set of input and testing it with the expected output. The other kind of unit tests are called White-box tests, in which there are multiple tests within a single unit test. For this project there is only one applicable place where White-box testing is necessary. In the solve function, `solve()`, that solves the entire puzzle, it relies on all four of the aforementioned methods as well as a secondary function

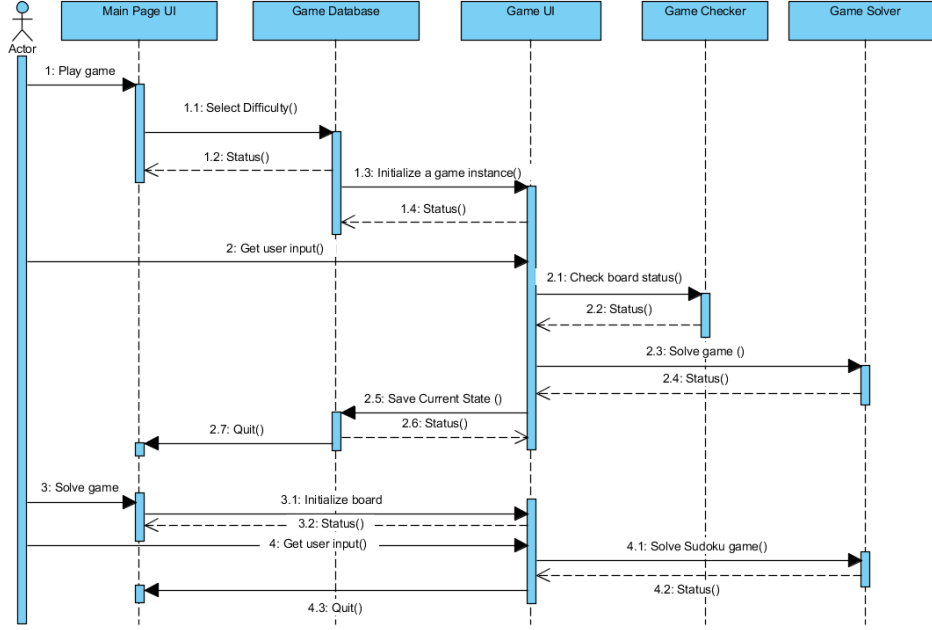


Figure 5: Sequence diagram of the TESS system.[1]

that the `solveRecur()` calls on recursively, `solveRecurCheck()`. There will be 1 White-box test where each method is directly dependent on the other in order to produce the correct solution and also 1 other White-box test to perform the same test on invalid input. Due to the nature of the project, the integration testing is directly associated with the unit testing. The two different testing phases are intertwined within each other, so the aforementioned tests are also the integration tests as well. The integration tests are based on the bottom-up approach. There will be one specific system test that will be written because the only test that will need to be performed on the app is the performance test and this will be tested by using one of the most difficult Sudoku puzzles known to man. The test will check whether the app can solve it within the 5 second limit. There aren't any other system tests to create due to the nature of the app. These are all the tests that will need to be created and run to make sure the app works properly. Since this is still in the beta stages, there will be user testing and the app will be provided to select individuals to run the app and report back with their findings.

7.2 Test Results

This section will describe the test results in detail. The test results went as expected. As seen in Figure 6, all the tests passed. In Figure 7 is an example of the many unit and integration tests that were written. The two different types

of tests are interweaved so there aren't specific tests for one type. Most of these tests were written with the Black-box test design; however, the solve function was written with White-box test design in mind. These tests were created to make sure individual methods were working properly. Since the system is minimalistic and avoids any security risks there was only one main system test to design, this was the performance tests. As depicted in Figure 8, the system test uses a time limit approach where it records the start time and the finish time. Then it converts the difference into seconds and returns whether the program solves it under the time constraint. This is one of the more important tests due to the system constraints mentioned earlier. As shown per Figure 6, the performance test is under the time allotted for the program to solve any puzzle. The user tests are still in progress and there have not been any known issues yet. Overall, the tests were a success.

| Test Name | Duration |
|---------------------------|----------|
| UnitTest (max.sudoku) | 703ms |
| solveRecurCorrect0 | 78ms |
| solveRecurCorrect1 | 0ms |
| solveRecurCorrect2 | 0ms |
| solveRecurCorrect3 | 0ms |
| solveRecurCorrect4 | 250ms |
| solveRecurCorrect5 | 140ms |
| solveHorizontalNotCorrect | 0ms |
| whiteBoxTestNotCorrect | 0ms |
| solveRecurNotCorrect | 0ms |
| solveBoxCorrect | 0ms |
| solveVerticalNotCorrect | 0ms |
| performanceTest | 63ms |
| whiteBoxTestCorrect | 172ms |
| solveBoxNotCorrect | 0ms |
| solveHorizontalCorrect | 0ms |
| solveVerticalCorrect | 0ms |

Figure 6: Results of test cases

[illegible]

Figure 7: Test: solveHorizontalTest()

8 Conclusions

This is the conclusions section.


```

@Test
public void performanceTest() throws Exception{
    m.gridVal=new int[9][9];
    String s = "800000000003600000070090200050007000000045700000100030001000069008500010090000400";
    for(int i=0;i<9;i++){for(int j=0;j<9;j++){
        m.gridVal[j][i]=Integer.parseInt(s.charAt(i*9+j)+"");
    }
    long startTime = System.currentTimeMillis();
    boolean t = m.solveRecur(0,0);
    long endTime = System.currentTimeMillis();
    assertEquals(true, t&&(endTime-startTime)/1000<5);
}

```

Figure 8: Test: performanceTest()

Overall summary of design methodologies, key creative approaches and potential contribution/impact. [2]

References

- [1] K. Fakhroutdinov, “Android camera,” *UML graphical notation overview, examples, and reference*, 2015.
- [2] J. Mammo, “Hahahahaha,” *Computer Networks*, vol. 71, pp. 1–30, 2017.