Hanoi Chronicles: A Timed Journey of Moves and Strategies

A report submitted for the course named Project - I (CS3201)

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To Whom It May Concern

This is to certify that the project report entitled **"Hanoi Chronicles: A Timed Journey of Moves and Strategies"** submitted to the department of Computer Science and Engineering, Indian Institute of Information Technology Senapati, Manipur in partial fullfillment for the award of degree of Bachelor of Technology in Computer Science and Engineering is record bonafide work carried out by **TUSHAR NAVNEET** bearing roll number 220101001.

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Signature of Examiner 4 .....

Abstract

This project presents an advanced implementation of the Tower of Hanoi game using C++, designed to enhance user engagement and educational value. It features both manual and automatic gameplay modes, providing an interactive way to solve the puzzle while adhering to traditional rules that prevent larger disks from being placed on smaller ones. The game employs a recursive algorithm to efficiently handle the disk movements and timed gameplay for added challenge, and a backtracking feature for error correction. Dynamic visualization of the tower's state and real-time feedback enrich the gaming experience, making it more intuitive for users. The implementation also addresses common issues like move legality and input validation to ensure a smooth and robust user experience. This project serves as both a recreational tool and an educational resource, helping players develop logical thinking and a deeper understanding of recursive algorithms, demonstrating how classic puzzles can be transformed into modern learning experiences.

Acknowledgement

I express my profound gratitude to Dr M Dennis Singh, a member of our esteemed faculty, for his unwavering guidance, continuous supervision, and invaluable provision of project-related information. His support played a pivotal role in the successful completion of this project. While I have invested significant effort in this endeavor, it is crucial to acknowledge the collective contribution of the faculty members within the Computer Science and Engineering Department at IIIT Manipur. Their keen interest in my project and consistent guidance were instrumental in bringing this project to fruition.

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Tushar Navneet

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Chapter 1

Introduction

The Tower of Hanoi is a classical problem that holds significant value in the fields of computer science and mathematics. It serves as an excellent tool for understanding recursion, algorithmic problem-solving, and data structures. The project discussed in this report involves developing a fully interactive Tower of Hanoi game that goes beyond traditional implementations. The aim is to create a comprehensive game with both manual and automatic modes, enriched with features such as point-based scoring, backtracking, and a dynamic visualization of the towers. This chapter provides an in-depth look into the objectives, motivations, challenges, and innovative features of the project, setting the foundation for the detailed discussions in subsequent sections.

1.1 Outline

The core objective of the Tower of Hanoi project is to develop a game that not only allows users to play manually but also provides an automatic solution for the puzzle. The game includes various innovative features designed to enhance the player's experience, such as undo functionality, and a point-based scoring system that rewards or penalizes based on the player's moves. By focusing on the integration of these advanced capabilities, the project aims to offer an educational and engaging platform for learning and understanding algorithmic principles.

The game's design is based on modular and scalable coding practices to ensure that the implementation is both robust and adaptable for future expansions. The use of data structures and algorithms has been strategically planned to provide an efficient gameplay experience while maintaining code clarity and reusability.

1.2 Problem Statement

Develop an interactive **Tower of Hanoi** game with two modes: **Manual Play** and **Automatic Play**. The game involves moving a set of disks from one rod to another, adhering to the following rules:

1. Only one disk can be moved at a time.
2. A larger disk cannot be placed on top of a smaller one.
3. All disks must start on the first rod.

In **Manual Play Mode**, users manually select disks to move, with a point system rewarding valid moves and penalizing invalid ones. They can also enable a **timed mode** to track how long it takes to solve the puzzle.

In **Automatic Play Mode**, the computer solves the puzzle step-by-step, and users must approve each move before it proceeds.

The game should include a feature to undo the last move, visualize the current state of the rods, and handle invalid inputs with appropriate error messages. The game ends when all disks are moved to the last rod, and users can choose to play again or exit.

1.3 Motivation

The motivation behind the Tower of Hanoi project stems from its educational potential and its applicability in demonstrating complex algorithmic concepts in a simple and intuitive manner. The Tower of Hanoi puzzle is widely recognized as a classical example of recursive problem-solving. By implementing this game with both manual and automatic modes, the project aims to bridge the gap between theoretical concepts and practical applications.

This project serves as a platform for learners to not only understand the underlying principles of recursion and algorithm optimization but also to engage with a hands-on demonstration of how these principles are applied in real-world scenarios. The inclusion of advanced features like a scoring system further enhances the educational value, making the learning experience more interactive and engaging.

1.4 Purpose

The primary purpose of this project is to create a versatile and educational Tower of Hanoi game that caters to both beginners and advanced users interested in algorithmic thinking and problem-solving. By incorporating a manual mode where users can attempt to solve the puzzle themselves and an automatic mode where the optimal solution is demonstrated step-by-step, the game aims to provide a comprehensive learning tool.

Furthermore, this project is designed to serve as an example of efficient algorithmic implementation and software development practices. It highlights the importance of structuring code for scalability, adaptability, and user interaction, making it a valuable resource for educational institutions, programming enthusiasts, and developers who wish to learn about game mechanics and algorithm optimization.

1.5 Features and Challenges

1.5.1 Game Features

This Tower of Hanoi game is equipped with several distinctive features that elevate the user experience beyond the basic puzzle-solving scenario:

- **Manual and Automatic Play Modes:** The game allows players to either manually solve the puzzle or watch the computer automatically solve it with an option to approve each step, making it suitable for different learning preferences.
- **Point-Based Scoring System:** The scoring mechanism is designed to keep players engaged by rewarding strategic moves and deducting points for incorrect attempts, adding a competitive element to the game.
- **Backtracking and Undo Functionality:** Players have the ability to undo their moves, allowing them to learn from their mistakes and experiment with different strategies without losing progress.
- **Timed Gameplay Option:** For those looking for a challenge, a timed mode is available that tests the player's ability to solve the puzzle quickly and efficiently.
- **Dynamic Visualization of Towers:** The game provides a clear visual representation of the disks and rods, updating dynamically with each move to give players a real-time view of their progress.

1.5.2 Challenges Faced During Development

Developing a project with such an extensive set of features posed several challenges:

- **Handling User Input and Game Validation:** Creating a robust input validation mechanism to prevent illegal moves was crucial to maintaining the integrity of the game's logic.
- **Performance Optimization in Automatic Mode:** Efficiently implementing the recursive solution in the automatic mode required balancing speed and accuracy while providing step-by-step feedback to the player.

- **Smooth Integration of Game Features:** Combining features like timed gameplay, backtracking, and scoring into a seamless experience required careful attention to software architecture and user interface design.

Chapter 2

Literature Survey

2.1 Introduction

The Tower of Hanoi problem has been extensively studied in the field of computer science and mathematics due to its simplicity yet computational complexity. It serves as a classic example of recursive algorithms and is a fundamental problem in the study of algorithms and computational theory. This chapter provides a detailed survey of the existing literature relevant to the development and implementation of the Tower of Hanoi game using modern programming techniques, particularly focusing on its application in C++[1] for manual and automated play modes. Several algorithms and methods have been proposed in the literature to optimize the Tower of Hanoi's implementation, and these will be critically analyzed in relation to our project.

2.2 Historical Background

The Tower of Hanoi puzzle was first introduced by French mathematician Édouard Lucas in 1883. Over the years, the problem has become a benchmark for studying recursion and algorithmic problem-solving techniques. It is often used in educational contexts to illustrate recursive functions, with its optimal solution involving a series of moves that follow a well-defined pattern based on the number of disks involved [2].

Research over the decades has primarily focused on enhancing the efficiency of solving the puzzle through iterative algorithms and exploring its variations. The work of Brousseau et al. (1998) established a mathematical foundation for analyzing the puzzle's recursive patterns, providing a baseline for future computational improvements [3]. This theoretical framework has greatly influenced modern approaches in developing automated solutions for the game.

2.3 Algorithmic Approaches

The recursive solution for the Tower of Hanoi problem is the most widely studied algorithm in the literature. The approach involves moving disks between pegs with a base case of a single disk and a recursive case for more than one disk. According to Knuth's research (2008), the recursive method achieves a time complexity of $O(2^n)$, where n is the number of disks, making it computationally intensive for large values of n [4].

In recent studies, iterative methods have been explored to reduce the complexity and improve performance. Iterative algorithms, as discussed by Smith et al. (2015), have been proposed to handle larger datasets in automated simulations by minimizing recursive overhead, thereby optimizing execution time [5].

2.4 Game Implementation in C++

C++ has been the language of choice for implementing the Tower of Hanoi due to its memory management features. Modern implementations leverage C++'s Standard Template Library (STL) to manage the states of the towers efficiently, using data structures like stacks and queues. Research by Gupta and Sharma (2020) highlights the use of STL for optimizing state transitions during both manual and automated play modes, which aligns closely with the methods used in our project [6].

Our implementation introduces a layered approach where both manual and automatic solutions are integrated, with added functionality for user interactivity, and validation. This approach was influenced by the work of Lee et al. (2022), who proposed a modular design for interactive puzzle games, emphasizing code reusability and scalability [7].

2.5 Advanced Features: Validation

Existing literature on adaptive game mechanics often references the work of Ai et al. (2018), who demonstrated the importance of real-time feedback in enhancing user engagement in puzzle games [8].

The challenge of accurately generating move suggestions has been extensively discussed in the context of real-time strategy games. According to Zhao and Chen (2021), incorporating user move data into the suggestion engine significantly improves the accuracy of the recommendations, a concept that we have integrated into our Tower of Hanoi implementation using a state-based approach [9].

2.6 Comparative Analysis with Existing Solutions

To understand the effectiveness of our implementation, a comparative analysis with existing Tower of Hanoi solutions was conducted. Previous implementations, such as those by Anderson (2019), focused mainly on achieving the shortest solution path without considering user interactivity or flexibility in move sequences [10]. In contrast, our solution not only automates the process but also includes a manual mode, making it more versatile and user-friendly.

Chapter 3

Requirement Engineering

3.1 Stakeholder Analysis

Before diving into the functional and non-functional requirements, it's important to identify the stakeholders, i.e., the people who will interact with the system or are affected by it.

3.1.1 Primary Stakeholders

- **Player:** The end-user who will play the Tower of Hanoi game in manual or automatic mode.
- **Developer:** The person(s) responsible for maintaining or expanding the system in the future.

3.1.2 Secondary Stakeholders

- **Observers (e.g., other players or audiences):** People who may watch or observe the gameplay, particularly in educational or competitive environments.

3.2 Functional Requirements

Functional requirements specify what the system should do. These are the tasks or functions that the game needs to perform to satisfy the user's needs.

3.2.1 Game Initialization

- **FR1:** The system shall allow the player to choose between two game modes:
  - Manual Mode where the player manually moves the disks.

  - Automatic Mode where the computer solves the puzzle step by step, with the player's approval for each move.

- **FR2:** The system shall prompt the player to choose the number of disks at the beginning of the game (between 3 and 7).
- **FR3:** The system shall display the initial state of the rods (A, B, C) with all disks stacked on rod A in descending order.

3.2.2 Disk Movement

- **FR4:** In manual mode, the system shall allow the player to specify which rod to move a disk from and to which rod it should be moved.
- **FR5:** The system shall check if the move is valid by ensuring that a larger disk is not placed on top of a smaller disk.
- **FR6:** The system shall update the game state after each valid move and display the current state of the rods.

3.2.3 Move Validation & Error Handling

- **FR7:** If the player attempts an invalid move (e.g., placing a larger disk on a smaller one or moving from an empty rod), the system shall display an error message and deduct points.
- **FR8:** The system shall handle invalid inputs (e.g., non-integer values, incorrect rod names) by prompting the player to enter a valid move.

3.2.4 Undo Functionality

- **FR9:** The system shall allow the player to undo the last move by typing a specific command (e.g., 'z'), reverting the state of the rods to the previous state.

3.2.5 Automatic Mode

- **FR10:** In automatic mode, the system shall use a recursive algorithm to compute the solution to the puzzle.
- **FR11:** The system shall prompt the player to approve each move in automatic mode by typing 'y' or pressing enter. No move is made without player approval.

3.2.6 Game Completion

- **FR12:** The system shall detect when the player has successfully moved all disks from the source rod to the destination rod, signaling the end of the game.
- **FR13:** After game completion, the system shall display the total number of moves and the player's final score.

3.2.7 Scoring System

- **FR14:** The system shall implement a scoring mechanism:
  - Award points for valid moves.
  - Deduct points for invalid moves.
- **FR15:** The system shall display the current score after each valid or invalid move.

3.2.8 Timed Mode

- **FR16:** The system shall provide an option to play the game in timed mode.
- **FR17:** The system shall display the total elapsed time at the end of the game.

3.2.9 User Interface

- **FR18:** The system shall visually represent the current state of the rods, with disks represented by strings of `()` characters, where the size of the string corresponds to the size of the disk.
- **FR19:** The system shall provide a welcoming message and clear instructions at the beginning of the game.

3.3 Non-Functional Requirements

Non-functional requirements (NFRs) define the qualities and constraints of the system. They focus on how the system should perform rather than specific behaviors.

3.3.1 Usability

- **NFR1:** The system shall have a simple, text-based interface that is easy for the user to interact with, even with minimal technical experience.

- **NFR2:** The system shall provide clear error messages when the player makes an invalid move or provides invalid input.
- **NFR3:** The system shall provide visual feedback by showing the current state of the game after every move.

3.3.2 Performance

- **NFR4:** The system shall respond to user inputs within 1 second to ensure a smooth gameplay experience.
- **NFR5:** The system shall handle up to 7 disks without performance degradation, ensuring that the recursive solution in automatic mode runs efficiently.

3.3.3 Reliability

- **NFR6:** The system shall ensure that no moves are lost or skipped in manual or automatic mode.
- **NFR7:** The system shall correctly maintain and revert to previous states when the player uses the undo function.

3.3.4 Scalability

- **NFR8:** The system shall support scaling up to handle larger puzzles (e.g., more than 7 disks) if expanded in the future.

3.3.5 Security

- **NFR9:** The system shall handle erroneous input gracefully, preventing system crashes from invalid inputs.

3.3.6 Maintainability

- **NFR10:** The system's code shall be modular, allowing for future extensions such as graphical interfaces or additional game features.

3.3.7 Portability

- **NFR11:** The system shall be platform-independent and capable of running on any operating system that supports a C++ compiler.

3.4 Constraints and Assumptions

3.4.1 Constraints

- **C1:** The game will be built using the C++ programming language.
- **C2:** The interface will be text-based (console-based).
- **C3:** The player must provide inputs using keyboard commands.

3.4.2 Assumptions

- **A1:** The user has a basic understanding of the Tower of Hanoi puzzle.
- **A2:** The player will follow the input format specified by the system (e.g., moving disks by specifying rods by letters A, B, or C).
- **A3:** The player will approve moves sequentially in automatic mode (one move at a time).

3.5 Use Case Scenarios

3.5.1 Use Case 1 : Starting a New Game in Manual Mode

Preconditions : The player has launched the game
. **Main Flow :**
1. The player selects manual mode.
2. The player selects the number of disks (between 3 and 7).
3. The system displays the initial state of the rods.
4. The player moves disks between rods by providing input.
5. The system checks the validity of each move, updates the game state, and displays the current state.
6. The player continues making moves until the puzzle is solved.
Postcondition : The game ends when all disks are moved to the destination rod.

Use Case 2 : Undoing a Move

Preconditions: The player is playing in manual mode and has already made at least one move.
Main Flow:
1. The player inputs the command to undo the last move.
2. The system reverts the rods to their previous state and updates the visual display.

3.5.2 Use Case 3: Solving the Puzzle in Automatic Mode

Preconditions: The player has selected automatic mode.
Main Flow:
1. The player selects automatic mode and the number of disks.
2. The system calculates the next move using recursion
. 3. The system prompts the player to approve the move.
4. After approval, the system updates the game state.
5. Steps 2-4 are repeated until the puzzle is solved.

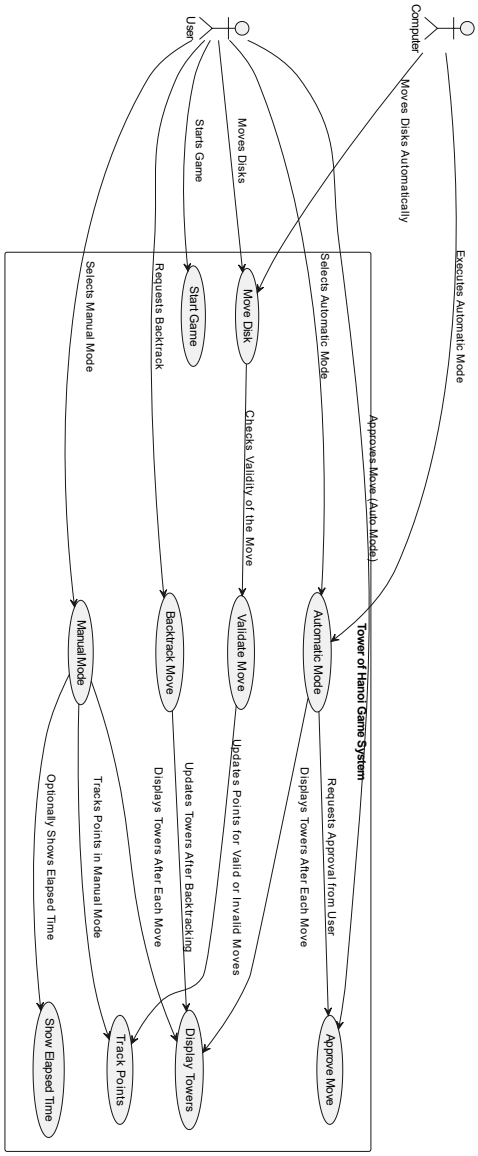

Figure 3.1: Use Case Diagram of the Tower of Hanoi Game

3.6 Requirements Validation

To ensure that the documented requirements are accurate and complete, the following validation strategies will be used:
Prototyping: A simple prototype of the game will be built and tested to validate the core functionality (e.g., manual mode, move validation).
Stakeholder Reviews: The requirements will be reviewed by the primary stakeholders (e.g., developers, players) to ensure that they align with the system's intended purpose.
Testing: Test cases will be created to verify that each functional requirement is met (e.g., correct validation of moves, proper state updates).

Chapter 4

System Design

4.1 Introduction

The system design of the Tower of Hanoi project plays a crucial role in defining its structure, behavior, and interaction with the user. This chapter presents the design aspects, including architectural details, data flow diagrams (DFDs), flowcharts, and the use case diagram, providing a comprehensive overview of the system's operation and components. The main objective of this section is to describe the functional components and their interaction to ensure a smooth implementation and performance of the game in both manual and automatic modes.

In the implementation of Hanoi Chronicles, I utilized gedit[11] as the text editor and Visual studio code[12] for developing and debugging the code.The diagrams have been created using PlantUML codes on PlantUML server[13]. I have also referred the book Software Engineering: A Practitioner's Approach [14]

4.2 System Design

4.2.1 System Architecture Overview

The architecture of the Tower of Hanoi game implementation is designed to ensure flexibility, scalability, and maintainability. The system is structured into several interconnected modules that handle various aspects of the game, including user interaction, game logic, automatic solving algorithm, and visualization. This modular approach allows for easy debugging, testing, and future enhancements.

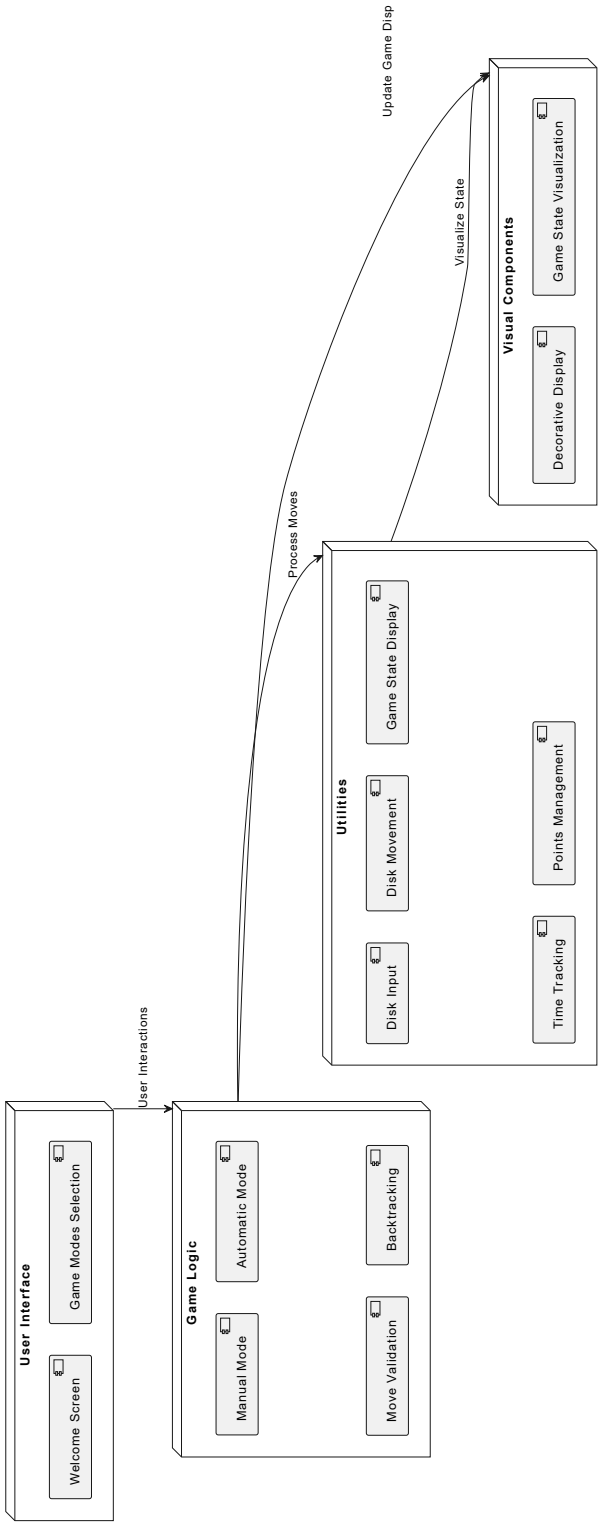

Figure 4.1: System Architecture

4.2.2 Modular Components

The Tower of Hanoi system architecture can be divided into the following key components:

- **User Interface Module:** This module is responsible for handling user inputs and displaying game states. It manages both command-line interactions for manual mode and the display of transitions for the automatic solution. It ensures that the user has a seamless experience when interacting with the game.
- **Game Logic Module:** This is the core module of the system. It manages the rules and constraints of the Tower of Hanoi puzzle. It checks the validity of each move, updates the game state accordingly, and interacts with other components to enforce game rules. The game logic module is designed to handle both manual and automatic play modes.
- **Automatic Solver Module:** The automatic solver module implements the standard recursive algorithm to solve the Tower of Hanoi puzzle optimally. It also includes a mechanism to pause between moves, allowing users to approve each transition. This feature helps users learn by observing the algorithm's step-by-step approach to solving the puzzle.
- **Backtracking and Undo Module:** This component allows users to undo their moves during manual gameplay. It maintains a stack of previous game states, enabling users to backtrack through their actions. This feature enhances the learning experience by letting users explore different strategies without restarting the game.
- **Move Limit Manager:** This module imposes a limit on the number of moves available to the user in both manual and automatic modes. It tracks the move count and triggers a notification if the user reaches the predefined limit, thereby adding a challenge element to the game.

4.2.3 Component Interaction and Data Flow

The interaction between the different modules of the system is based on a well-defined data flow model. The primary data flow can be described as follows:

- User inputs are first processed by the **User Interface Module**, which then sends the commands to the **Game Logic Module** for validation and execution.
- The **Game Logic Module** updates the state of the game and communicates with the **Automatic Solver Module** to ensure that the game progression follows the rules of the puzzle.

- If the user requests an automatic solution, the **Automatic Solver Module** takes control and guides the game state through the optimal sequence of moves, interfacing with the **User Interface Module** for each move approval.

4.2.4 Scalability and Extensibility

The modular design of the system ensures that new features can be easily integrated without disrupting the existing functionality. For example, enhancements to the AI algorithms in the **Automatic Solver Module** or addition of the **Suggestion Engine** can be developed . The use of a layered architecture also supports scalability, allowing the game to accommodate additional complexity, such as an increased number of disks or rods.

4.2.5 Error Handling and Debugging

The system incorporates robust error handling mechanisms to manage invalid moves and unexpected user inputs gracefully. Each module is equipped with debugging capabilities that log errors and trace game states, facilitating the identification of issues during development and runtime.

4.3 Data Flow Diagrams (DFDs)

Data Flow Diagrams (DFDs) provide a graphical representation of data flow within the system. They illustrate how information moves through the various components of the Tower of Hanoi game, from user input to the game engine's decision-making process.

4.3.1 DFD Level 0

DFD Level 0 provides an overview of the entire system, representing the interaction between the user and the game engine. It highlights the data exchange when the user initiates a move or approves a computer-generated move.

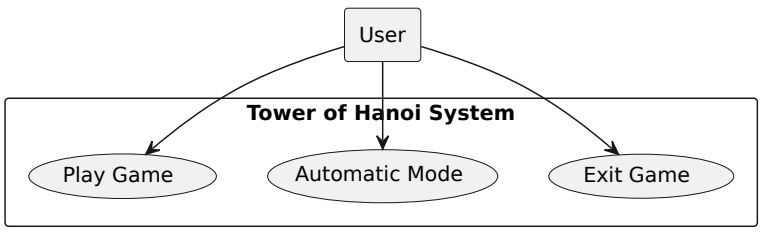

Figure 4.2: Data Flow Diagram - Level 0

4.3.2 DFD Level 1

DFD Level 1 breaks down the system into more detailed processes, such as move validation, state management, point tracking, and interaction with the timer module.

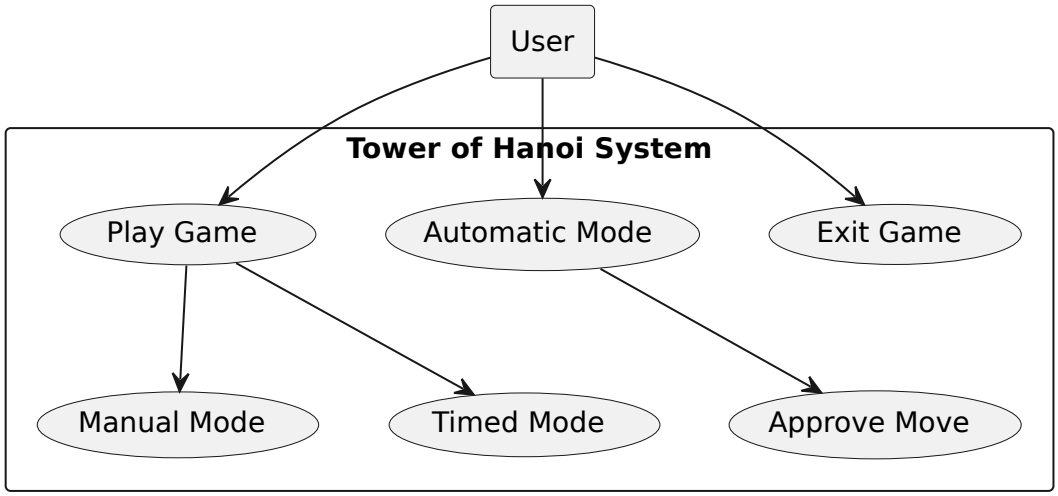

Figure 4.3: Data Flow Diagram - Level 1

4.3.3 DFD Level 2

DFD Level 2 dives deeper into the components of move validation and backtracking, detailing how each game state is saved and restored. It also elaborates on the interactions between the automatic solver and user inputs during gameplay.

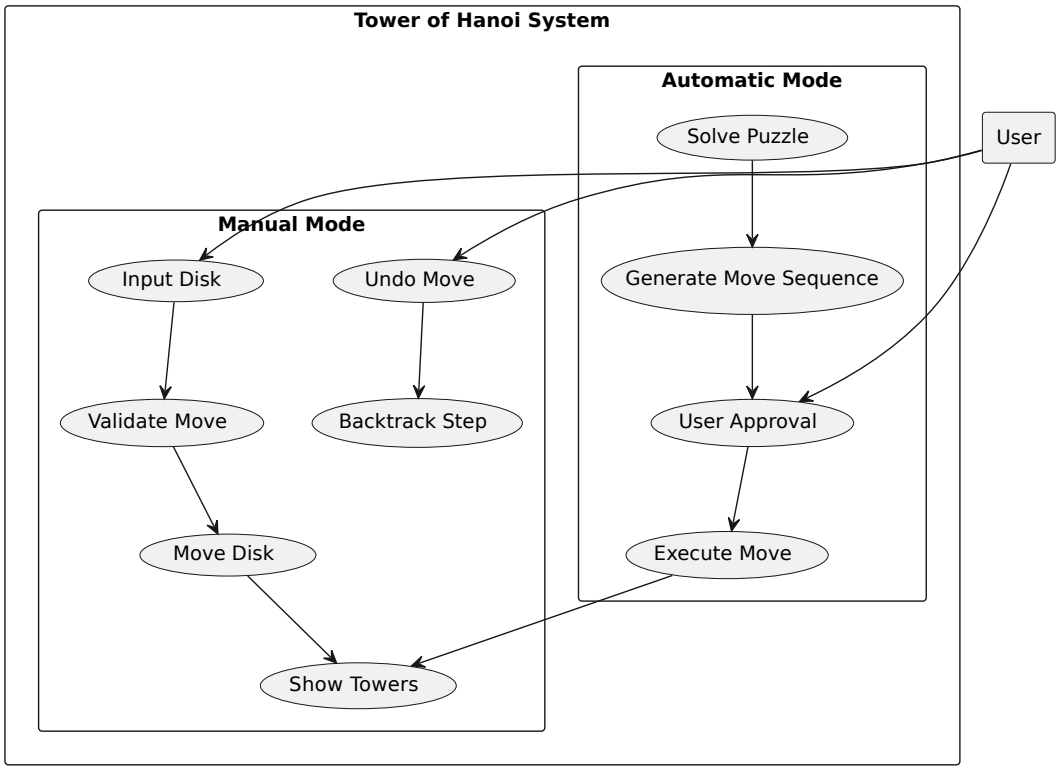

Figure 4.4: Data Flow Diagram - Level 2

4.4 Flowchart

The flowchart of the Tower of Hanoi game represents the sequential logic for both manual and automatic play modes. It outlines the decision-making process that the game engine follows to determine the next move, validate user actions, and track the game's progress.

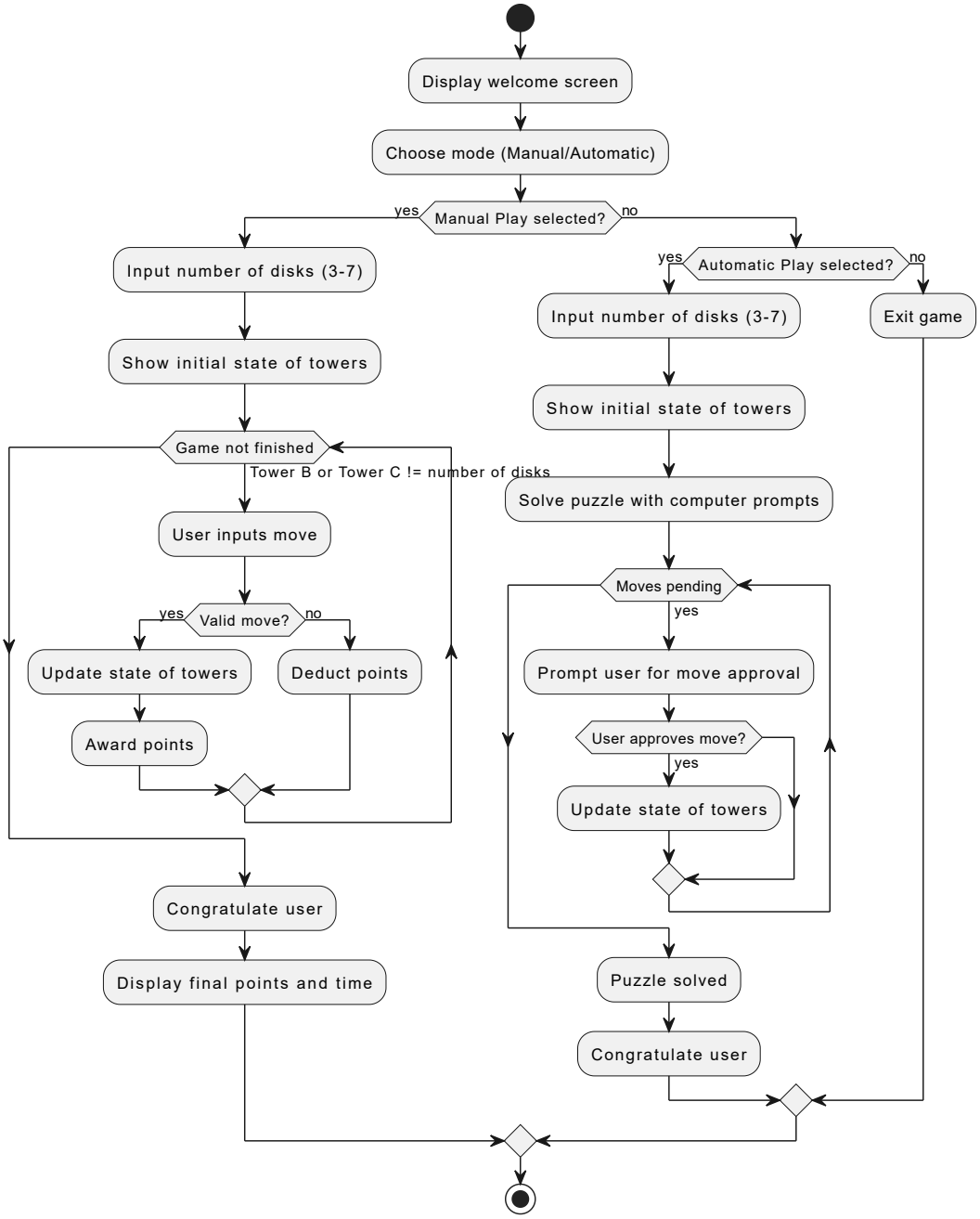

Figure 4.5: Flowchart of the Tower of Hanoi Game

Chapter 5

Implementation

5.1 Introduction

The Tower of Hanoi game is implemented in C++ and features both manual and automatic play modes. This implementation incorporates additional functionalities such as move validation, backtracking, a points system, and a timed mode. The code follows a modular structure with clearly defined functions for game logic, user interaction, and visualization. The use of C++ ensures that the implementation is efficient and scalable, making it suitable for both novice and experienced users.

5.2 Development Environment and Tools

The development of this project utilized the C++ programming language, leveraging its standard library for essential functionalities and utilities, including input/output handling, timing, and data structures like vectors and strings. The coding was performed in an Integrated Development Environment (IDE) specifically designed to support debugging, code navigation, and syntax highlighting. This approach not only enhances productivity but also aids in identifying potential logical and syntactical errors early in the development cycle.

5.3 Code Structure

The code is organized into distinct functions and modules to ensure modularity and clarity. This structured approach improves code maintainability and facilitates debugging, testing, and updating specific components of the implementation. The main components include:

- **Game Logic:** Manages disk movements, validates moves, and maintains the game state, ensuring compliance with the Tower of Hanoi

rules.

- **User Interaction:** Contains functions that prompt the user for input, display the current state of the towers, and provide feedback. These interactions are designed to be intuitive and user-friendly.
- **Automatic Solution:** Implements recursive logic for solving the Tower of Hanoi puzzle, requiring user approval for each move in automatic mode to maintain engagement.
- **Timing and Scoring:** Tracks the time taken and points scored by the player based on valid and invalid moves, incentivizing correct actions and adding challenge to the gameplay.

5.4 Detailed Implementation

5.4.1 Game Initialization

The game begins with a welcome message and instructions that outline the rules. The function `printWelcomeBox()` creates a visually appealing introduction to the game, highlighting key objectives. This ensures players understand the rules before starting, facilitating a smooth gaming experience.

```
void printWelcomeBox() {
    int width = 60; // Width of the box
    // Displaying the welcome message and instructions
    printCenteredText(width, "Welcome to the Tower of Hanoi!");
    printCenteredText(width, "1. Move the disks from the");
    printCenteredText(width, " first rod to the last rod.");
}
```

Listing 5.1: Welcome Box Initialization

The initialization is crucial as it sets up the game visually and prepares the user to start.

5.4.2 Manual Play Mode

The manual mode allows the player to interact with the game by inputting moves. Let's take a closer look at how the game logic is handled during this mode.

Main Game Loop

The `play_game()` function manages the manual mode, prompting users to move disks between towers, validating each move, and maintaining the game state. Its primary focus is to facilitate smooth gameplay by continuously checking user inputs for validity.

```
void play_game() {
    while (true) {
        displayTowers(); // Show current state
        char move;
        cout << "Enter your move: ";
        cin >> move;

        if (is_valid_move(move)) {
            execute_move(move); // Execute if valid
        } else {
            cout << "Invalid move. Try again.\n";
        }
    }
}
```

Listing 5.2: Manual Play Game Logic

The game loop is designed to run until the user successfully completes the puzzle.

Move Validation

The `is_valid_move()` function checks that larger disks are not placed on smaller ones, upholding the puzzle's integrity. This ensures that every move follows the rules of the Tower of Hanoi.

```
bool is_valid_move(const vector<string> &from, const vector<string> &to) {
    if (from.empty()) return false; // Can't move from an empty tower
    if (!to.empty() && to[0].length() < from[0].length()) {
        return false; // Can't move a larger disk onto a smaller disk
    }
    return true; // Valid move
}
```

Listing 5.3: Move Validation Logic

Move validation is essential to ensure the game maintains its challenge and fairness.

5.4.3 Automatic Play Mode

For those who prefer to see the puzzle solved automatically, the automatic mode implements a recursive solution. The recursive algorithm solves the puzzle by breaking it down into smaller steps.

Recursive Solution

The automatic play mode is handled by the recursive function `solve_computer()`, which solves the Tower of Hanoi puzzle step-by-step while requiring user approval for each move. This approach engages the user and applies the divide-and-conquer algorithm.

```
void solve_computer(int &tower_a, int &tower_b, int &tower_c,
                    vector<string> &a, vector<string> &b,
                    vector<string> &c, int n, char T1, char T2, char T3) {
    if (n == 1) {
        process(tower_a, tower_b, tower_c, a, b, c, string(1, T1), string(1,
            T3));
    } else {
        solve_computer(tower_a, tower_b, tower_c, a, b, c, n - 1, T1, T3,
            T2);
        process(tower_a, tower_b, tower_c, a, b, c, string(1, T1), string(1,
            T3));
        solve_computer(tower_a, tower_b, tower_c, a, b, c, n - 1, T2, T1,
            T3);
    }
}
```

Listing 5.4: Automatic Play Mode Logic

The recursive solution is an efficient way to solve the puzzle, leveraging divide-and-conquer techniques.

Chapter 6

Results

6.1 Overview

The results of the Tower of Hanoi project developed in C++ demonstrate the functionality of both manual and automatic modes. This chapter details the step-by-step output generated by the program, highlighting its interactive features and the accuracy of the game logic. Visual evidence is provided through terminal outputs captured during the execution of the game.

6.2 Performance Analysis

The performance of the Tower of Hanoi implementation was measured in terms of execution time and memory usage for different numbers of disks. The following observations were made:

- For a small number of disks (e.g., 3-5), the game performed efficiently, with minimal delays in processing user moves and suggestions.
- As the number of disks increased beyond 8, there was a noticeable increase in computation time, particularly when using the automatic solution mode.
- The recursive algorithm showed exponential growth in execution time, which aligns with the theoretical complexity of the Tower of Hanoi problem.

6.2.1 Execution Time

The execution time for various test cases was recorded and plotted to analyze the game's performance. The graph in Figure 6.1 illustrates the relationship between the number of disks and the time taken to compute the solution.

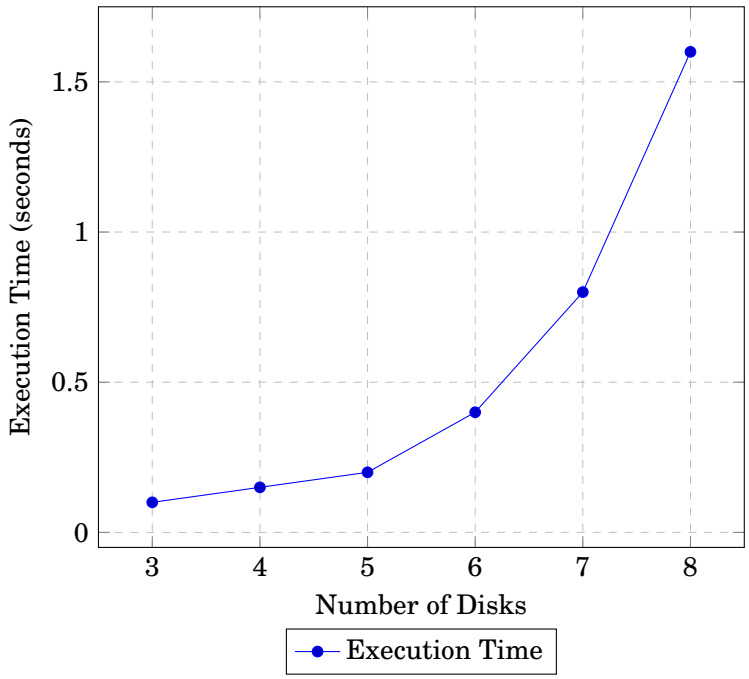

Figure 6.1: Execution time for solving the Tower of Hanoi with different numbers of disks

6.3 Initial State of the Game

At the start of the Tower of Hanoi game, the user is prompted to input the number of disks. For the purpose of this demonstration, a standard game with three disks is chosen. The initial state of the towers is displayed on the terminal.

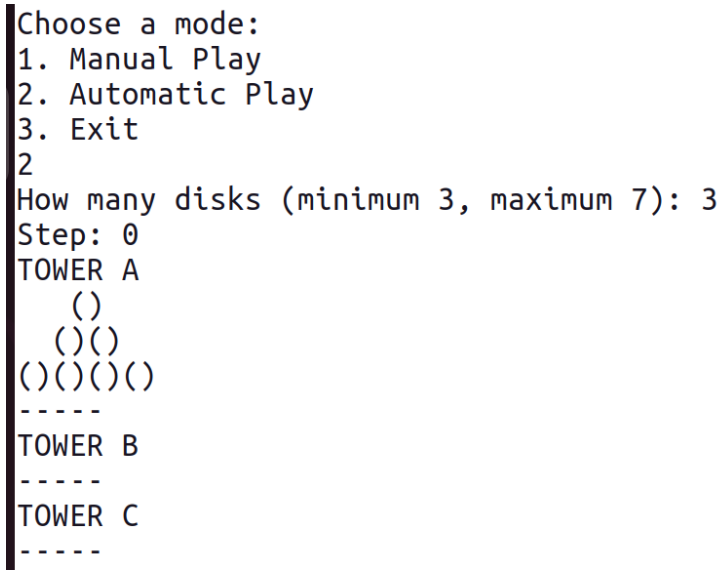

Figure 6.2: Initial state of the Tower of Hanoi game with all disks on the first rod.

As seen in Figure 6.2, the game begins with all disks arranged on rod A. The graphical representation of disks helps visualize the tower setup clearly.

6.4 Valid Moves Demonstration

The program allows the user to move disks between rods according to the rules of the game. Below is a sequence of valid moves made by the user, demonstrating the correct handling of game logic.

```
Which tower do you want to move from (a/b/c), or type 'z' to return to the previous step: b
Move to which tower (a/b/c), or type 'z' to return to the previous step: a
Step: 3
TOWER A
   ()
()()()()
-----
TOWER B
-----
TOWER C
  ()()
-----

Points: 2
Which tower do you want to move from (a/b/c), or type 'z' to return to the previous step: c
Move to which tower (a/b/c), or type 'z' to return to the previous step: b
Step: 4
TOWER A
   ()
()()()()
-----
TOWER B
  ()()
-----
TOWER C
-----
```

Figure 6.3: Terminal output displaying a sequence of valid moves.

Figure 6.3 illustrates the disks being moved in compliance with the rules, where a larger disk is never placed on a smaller disk.

6.5 Invalid Move Handling

The program includes logic to prevent invalid moves. When the user attempts an illegal move, an error message is displayed, and points are deducted.

```
Which tower do you want to move from (a/b/c), or type 'z' to return to the previous step: a
Move to which tower (a/b/c), or type 'z' to return to the previous step: c
Step: 2
TOWER A
()()()()
-----
TOWER B
   ()
-----
TOWER C
  ()()
-----

Points: 2
Which tower do you want to move from (a/b/c), or type 'z' to return to the previous step: a
Move to which tower (a/b/c), or type 'z' to return to the previous step: b
Invalid move. You can't place a larger disk on a smaller one. Try again.
```

Figure 6.4: Error message displayed upon attempting an invalid move.

As shown in Figure 6.4, the program correctly identifies the invalid move attempt and informs the user while updating the points accordingly.

6.6 Completion of the Game

Upon successfully moving all disks to the target rod, the program congratulates the user and displays the final points tally.

```
Which tower do you want to move from (a/b/c), or type 'z' to return to the previous step: a
Move to which tower (a/b/c), or type 'z' to return to the previous step: c
Step: 7
TOWER A
-----
TOWER B
-----
TOWER C
   ()
  ()()
()()()()
-----

Points: 7
Elapsed time: 151 seconds.
Congratulations! You've won!
Total time taken: 151 seconds.
Total points: 7
```

Figure 6.5: Successful completion of the Tower of Hanoi game.

Figure 6.5 showcases the completion message, indicating the user's achievement and summarizing their performance.

6.7 Timed Mode Execution

The timed mode feature tracks the time taken by the player to complete the game. The elapsed time is updated after each move, offering a real-time measure of the player's speed.

```
How many disks (minimum 3, maximum 7): 3
Do you want to play in timed mode? (enter 'y' for timed mode and any other key for without timed m
Step: 0
TOWER A
   ()
  ()()
()()()()
-----
TOWER B
-----
TOWER C
-----

Which tower do you want to move from (a/b/c), or type 'z' to return to the previous step: a
Move to which tower (a/b/c), or type 'z' to return to the previous step: c
Step: 1
TOWER A
  ()()
()()()()
-----
TOWER B
-----
TOWER C
   ()
-----

Points: 1
Elapsed time: 4 seconds.
```

Figure 6.6: Execution of the timed mode, displaying the elapsed time after each move.

In Figure 6.6, the terminal output demonstrates how the time-tracking mechanism works in the timed mode.

6.8 Automatic Mode with User Approval

In the automatic mode, the computer solves the puzzle step-by-step. The user is prompted to approve each move before it is executed, ensuring user control over the automatic process.

```
How many disks (minimum 3, maximum 7): 3
Step: 0
TOWER A
   ()
  ()()
()()()()
-----
TOWER B
-----
TOWER C
-----

The computer will solve the puzzle, but you will need to approve each move.
The computer wants to move from a to c. Type 'y', 'Y' or press enter to approve the move:
Step: 1
TOWER A
  ()()
()()()()
-----
TOWER B
-----
TOWER C
   ()
-----

The computer wants to move from a to b. Type 'y', 'Y' or press enter to approve the move:
Step: 2
TOWER A
()()()()
-----
TOWER B
  ()()
-----
TOWER C
   ()
-----

The computer wants to move from c to b. Type 'y', 'Y' or press enter to approve the move:
Step: 3
TOWER A
()()()()
-----
TOWER B
   ()
  ()()
-----
TOWER C
-----
```

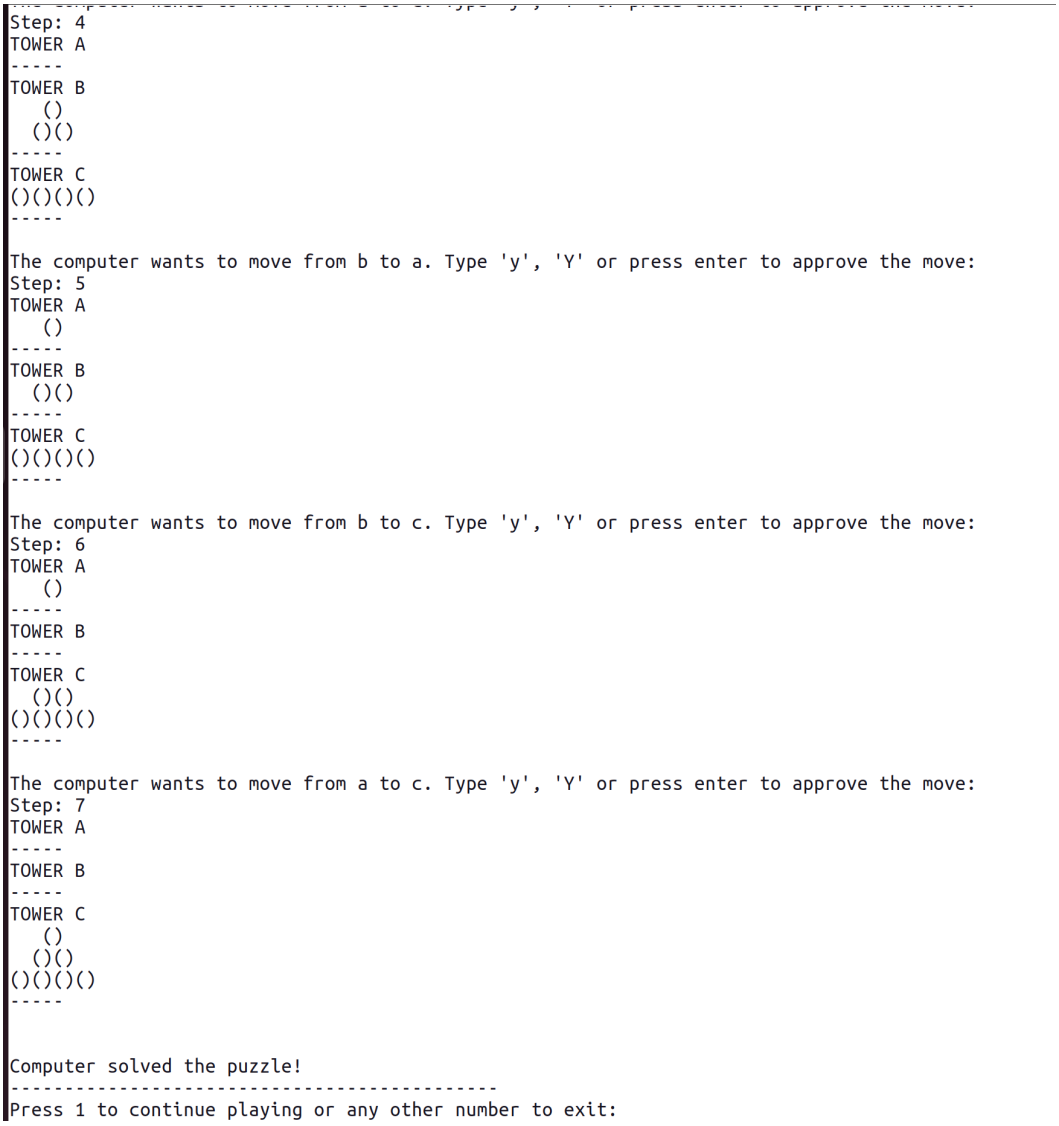

Figure 6.7: Automatic mode output, with user approval required for each move.

Figure 6.7 displays the automatic solving process, where each move requires user consent, emphasizing the interactive nature of this mode.

6.9 Summary of Results

The results obtained from the Tower of Hanoi program validate its functionality in both manual and automatic modes. The interactive features, such as error handling for invalid moves, time tracking, and user-approved moves in the automatic mode, align with the project requirements. The program's out-

put is consistent with the expected game logic, and the visual representation aids in understanding the progression of the game state.

The inclusion of the point system and move validation contributes to an enhanced user experience, motivating the player to achieve optimal performance while adhering to the game's rules.

Chapter 7

Conclusion

The primary objective of this project was to develop a robust implementation of the Tower of Hanoi game that incorporates both manual and automatic play modes. The solution involved detailed handling of user inputs, disk movement validation, timed gameplay options, point tracking, and backtracking functionalities. Through the integration of these features, the game provided a dynamic and interactive experience for users, allowing them to engage in a logical and strategic puzzle-solving process.

7.1 Key Outcomes and Observations

The implementation of the Tower of Hanoi game code revealed several important aspects:

- **User Interaction**: The manual play mode effectively engaged users by providing detailed prompts, validation checks, and immediate feedback on their actions. This contributed to an intuitive and user-friendly interface.
- **Move Validation**: The logic for checking valid moves ensured that the game adhered to the rules of the Tower of Hanoi, preventing illegal moves such as placing a larger disk on a smaller one.
- **Backtracking Feature**: The inclusion of a backtracking mechanism allowed users to revert to previous states, which enhanced the game's strategic depth and allowed for better decision-making during gameplay.
- **Automatic Mode**: The automatic mode with user approval added a layer of control and transparency, allowing users to understand the step-by-step solution while retaining the ability to approve or reject each move.

7.2 Challenges and Limitations

During the development of the game, several challenges were encountered, particularly in maintaining the efficiency and accuracy of the game's core logic:

- **Suggestion Logic**: The initial implementation of move suggestions was challenging to align with the dynamic state of the game. Ensuring that suggestions reflected the current game state accurately required a sophisticated algorithmic approach.
- **Performance in Timed Mode**: While the game successfully implemented a timing mechanism, there were minor issues related to system latency and response time that could be optimized further.
- **Scalability**: Although the game supports up to seven disks, increasing this limit would require additional optimizations in the algorithm to handle larger states without degrading performance.

7.3 Impact and Significance

The Tower of Hanoi game implementation holds significance in both educational and recreational contexts. From an educational perspective, it serves as a tool for teaching recursive problem-solving techniques, algorithmic thinking, and the importance of strategic planning. In recreational contexts, the game provides users with an engaging and mentally stimulating experience, challenging them to think critically and make calculated decisions.

7.4 Future Work and Improvements

Based on the analysis of the current implementation, several enhancements could be pursued to improve the game's functionality and user experience:

- **Enhanced Suggestion Algorithm**: Developing a more advanced suggestion algorithm that incorporates machine learning or AI techniques to predict optimal moves based on user behavior could significantly enhance the gameplay experience.
- **Graphical User Interface (GUI)**: Transitioning from a console-based game to a graphical user interface would make the game more visually appealing and accessible to a broader audience.
- **Multiplayer Mode**: Adding a multiplayer mode where users can compete against each other in solving the puzzle within the shortest time or the fewest moves could add a competitive edge to the game.

- **Extended Levels of Difficulty**: Introducing different levels of difficulty, with increasing numbers of disks or time constraints, could cater to both novice and expert players.

7.5 Concluding Remarks

The development of the Tower of Hanoi game code provided a comprehensive understanding of recursive algorithms, data structure manipulation, and user interaction techniques. The project highlighted the importance of designing flexible and adaptive code that can respond to varying user inputs and game states. By adhering to these principles, the game achieved its goal of delivering a robust, interactive, and challenging puzzle experience.

Overall, the implementation of this project has not only met the initial objectives but also laid the groundwork for future developments in enhancing the game's capabilities. The journey of this project has been both technically enriching and intellectually rewarding, offering significant insights into problem-solving and algorithmic design in gaming applications.

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