CHAPTER I

INTRODUCTION

1.1 Background

The integration of artificial intelligence (AI) in board games has seen remarkable advancements, contributing significantly to the fields of game theory and computational intelligence. Santorini, a strategy board game renowned for its blend of simplicity and strategic depth, presents an interesting case study for AI research. Prior works, including Jack Boreham's exploration into developing an AI capable of playing Santorini, have focused on leveraging traditional AI techniques to navigate the game's complex decision spaces effectively. However, these studies predominantly target the game's basic mechanics, overlooking the nuanced strategic layers introduced by the god system [1].

The god system in Santorini introduces unique powers and abilities, significantly diversifying gameplay and strategic considerations. This aspect of Santorini has been underexplored in AI research, representing a gap in our understanding of AI's potential to adapt to and leverage variable player powers in board games. Boreham's project, while providing a solid foundation in AI development for Santorini, does not delve into the complexities introduced by the god system, focusing instead on a basic version of the game [1].This gap highlights a broader trend in AI board game research, where the variability and strategic depth added by such systems are often overlooked.

This research aims to fill this gap by focusing on the integration of Means-End Analysis and heuristic functions to address the unique challenges posed by the god system in Santorini. By doing so, it seeks not only to enhance AI performance in a more complex version of Santorini but also to contribute to the broader discourse on AI adaptability in board games featuring variable player powers. Through a critical analysis of existing AI strategies, as illustrated by Boreham's work, and the development of novel MCTS adaptations, this research aims to illuminate AI potential in navigating variable player powers introduced by Santorini's god system [1].

1.2 Prior Research

This sub chapter reviews the existing research on artificial intelligence in board games, focusing on significant advancements and identifying gaps. While extensive studies have been conducted on classic games like chess and Go, the unique challenges posed by newer games such as Santorini have been less explored. This research extends beyond foundational work, such as that by Jack Boreham, by addressing the complexities introduced by Santorini's god system, which previous studies have largely overlooked.

The paper "Applying Machine Learning to the Board Game Pylos,"[2] which utilized machine learning algorithms to optimize gameplay strategies in a deterministic, zero-sum environment. While the Pylos study harnessed decision trees and support vector regression to determine optimal moves, this research leverages heuristic evaluation and Means-End Analysis to manage the complexities introduced by Santorini's god system. By focusing on the dynamic and strategic capabilities of AI, this paper extends the scope of traditional board game AI research, presenting a novel methodological approach aimed at enhancing AI adaptability and decision-making prowess in games with variable player powers and complex rule sets.

In the paper on the AI implementation for the 7 Wonders board game [3], "variable player powers" refer to the unique strategic benefits derived from the wonder each player controls, which dictate distinct advantages in resource production, military strength, or scientific advancement. This asymmetric gameplay element necessitates AI algorithms capable of adapting to diverse game states and strategies, reflecting the need to both utilize and counter these powers effectively. Similarly, our research on Santorini involves designing AI that can leverage the unique god powers assigned to players, integrating advanced game theory and strategy optimization to handle the dynamic and complex scenarios presented by these powers.

The study on "Terraforming Mars" [4] offers valuable insights into AI applications in board games with variable player powers. In "Terraforming Mars," players assume the roles of corporation CEOs, each with unique abilities that impact their strategies for terraforming the planet. This setup presents a complex strategic environment similar to "Santorini," where gods grant players distinctive powers. Utilizing the Tabletop Games Framework, the researchers demonstrate how AI can adapt to and strategically navigate games with such variable powers, employing techniques like Monte Carlo Tree Search to handle the dynamic decision-making landscapes. This research aligns closely with the focus of this thesis on understanding AI's performance in games where player powers can significantly influence game dynamics.

The "Pandemic" board game AI [5] and our research on "Santorini" board game. The Pandemic board game AI employs a Rolling Horizon Evolutionary Algorithm to adeptly manage unique player roles and stochastic game conditions in "Pandemic", showcasing the AI's capacity to adapt strategies based on player-specific abilities. Similarly, our study applies Means-End Analysis in "Santorini" to enhance decision-making, reflecting how AI can effectively navigate games with variable player powers, thus optimizing gameplay strategies and decision-making processes. Together, these studies highlight significant advancements in AI applications within games that feature complex, role-dependent dynamics.

The research “Mastering Terra Mystica: Applying Self-Play to Multi-agent Cooperative Board”[6] dives into Terra Mystica, a game known for its variable player powers through different factions that influence players' strategies and interactions significantly. The study applies advanced AI techniques such as self-play and deep reinforcement learning to handle the game's complexities and achieve super-human performance. The challenges faced in Terra Mystica include managing the asymmetry of game rules and the non-uniform game board, both of which are directly influenced by the variable player powers each faction possesses. The research aims to adapt these powers into AI strategies, enhancing its adaptability and strategic decision-making across different gameplay scenarios.

The paper "Turing Completeness and Sid Meier's Civilization"[7] explores the computational complexity of three Civilization games, demonstrating that they are Turing-complete under conditions of infinite turns and map size. This proof shows that these games can simulate a universal Turing machine, highlighting their potential to execute any computable function, akin to a computer. The use of variable player powers, such as unique civilizations with distinct abilities and units, is central to this complexity. In the paper, game elements like units and buildings are used to model the components of a Turing machine, showing how the game's rules and mechanics can embody complex computational processes. This approach underscores how variable player powers enrich the strategic depth and unpredictability of the game, making its outcome and optimal strategies theoretically undecidable and as complex as problems that challenge current computing capabilities.

The paper "Magic: The Gathering is Turing Complete"[8] reveals the complex computational nature of Magic: The Gathering (MTG), illustrating how the game can simulate a universal Turing machine. This complexity arises from MTG’s variable player powers, where players customize decks with over 20,000 unique cards, introducing a high degree of strategic variability. The study demonstrates that MTG’s gameplay, where the outcome can be as complex as the Halting Problem, challenges traditional AI approaches in games. The variable player powers in MTG, much like those in other strategy games with diverse player roles and strategies, significantly elevate the computational demands on AI, pushing the boundaries of what is computationally decidable and modeling in game theory.

In the paper by "A comparative study of the A* heuristic search algorithm used to solve efficiently a puzzle game"[9], the heuristic function is crucial for the A* algorithm to solve a complex puzzle game efficiently. The study compares Manhattan and Hamming heuristics, highlighting that the Manhattan heuristic significantly enhances the algorithm's performance. It reduces space complexity by effectively estimating the minimal movement path, leading to fewer generated and expanded nodes in the search process. This makes the Manhattan heuristic more effective and efficient for navigating large search spaces in puzzle-solving applications.

In the study "Heuristic Evaluation of 'PaPaYa PokPok': A Case Study of a Mobile Game,"[10] heuristic evaluation is used to assess usability issues in the mobile game "PaPaYa PokPok." This method involves experts applying predefined usability principles, known as heuristics, to identify interface problems. The study applied 44 specific heuristics across six objectives to systematically evaluate the game, revealing various usability improvements. This approach highlights the effectiveness of heuristic evaluation in pinpointing design flaws and guiding developers to enhance user engagement and satisfaction in mobile games.

In the study "Benchmark Tests on Heuristic Methods in the Darts Game,"[11] heuristic algorithms are used to optimize throwing strategies in a simulated darts game. The research applies methods such as Particle Swarm Optimization, Ant Colony Optimization, and others to determine optimal throwing angles and speeds, aiming to achieve precise hits on a dartboard. These algorithms adjust model variables to minimize deviation from the target, demonstrating the potential of heuristics to enhance accuracy in sports simulations effectively.

The paper "Game State Evaluation Heuristics in General Video Game Playing"[12] explores how heuristic functions can enhance AI performance in the General Video Game AI (GVGAI) competition. They propose heuristic strategies focusing on avatar information, spatial exploration, and dynamic evaluation based on gameplay data. These techniques significantly improve AI adaptability and decision-making in diverse game environments without prior detailed knowledge of rules. The study demonstrates that integrating these heuristics boosts AI competitiveness, highlighting their potential in developing versatile AI systems for general video game playing.

The paper “Saboteur Game Modelling Using Means-Ends Analysis”[13] outlines the creation of a model for the Saboteur board game using means-ends analysis. The game, where players are divided into gold-miners and saboteurs, involves strategizing paths to a goal using various types of cards. The model proposed incorporates a heuristic value system for the cards and player actions, adjusting based on the player's role and game context. These heuristic values are numerical assessments assigned to each game element to evaluate the effectiveness of various moves. For example, pathway cards might be valued higher for gold-miners, who need to build paths, than for saboteurs, who aim to disrupt them. This dynamic valuation aids the AI in making strategic decisions and predicting the roles of other players, thereby facilitating the development of an AI-driven computer program for playing Saboteur.

The paper “Fast Heuristic Search for RTS Game Combat Scenarios”[14] discusses a heuristic search approach tailored for real-time strategy (RTS) games, specifically through an Alpha-Beta search method adapted for durative moves in game combat scenarios. This method effectively handles the large state and move spaces typical in RTS games by utilizing search enhancements like transposition tables and iterative deepening. It also incorporates combat AI scripts for efficiently sorting moves and evaluating game states through playouts. By conducting searches within strict real-time constraints the method demonstrates significant improvement over common AI scripts, providing a robust strategy for dynamically adapting to game changes and identifying optimal moves.

This sub chapter summarizes research on AI in board games, focusing on how AI handles games with unique player powers and complex rules, such as Santorini, Pylos, and Terra Mystica. Traditionally, AI research centered on simpler, deterministic games like chess, but recent studies explore AI's effectiveness in managing the unique challenges of games with variable player powers, employing techniques like heuristic evaluation and Monte Carlo Tree Search. This work advances AI's strategic capabilities in dynamic game scenarios, paving the way for further innovations in AI game theory and strategy optimization.

1.3 Problem Identification

The core problem identified in this research revolves around the limited exploration of the god system within the strategic board game Santorini by current artificial intelligence (AI) strategies. Despite Santorini's recognition for its blend of simplicity and profound strategic depth, existing AI applications in board games have predominantly focused on basic game mechanics, largely neglecting the nuanced strategic layers introduced by the god system. This oversight represents a significant gap in the field of AI-driven game strategy development, as it fails to capitalize on the complexity and variability that the god system adds to gameplay. Consequently, there is a pressing need for an innovative AI approach that not only acknowledges but also adeptly navigates and leverages the dynamic strategic possibilities offered by Santorini's god system, thereby enhancing AI's adaptability and performance in board games featuring variable player powers.

1.4 Problem Limitation

A notable limitation of this research is its focused analysis on only two of the gods from Santorini's diverse god system: Apollo and Atlas. While these gods were selected for their straightforward impact on gameplay, allowing for a more manageable exploration of AI strategies within the game's complex god system, this choice inherently restricts the scope of the study. Santorini features over 40 unique gods, each introducing different strategic variations and challenges. By concentrating solely on Apollo and Atlas, the research does not account for the broader strategic dynamics and interactions that other gods could introduce. This limitation narrows the understanding of AI's potential adaptability and strategic depth within the full context of Santorini's gameplay. Consequently, the findings and conclusions drawn from this study may not fully represent the complexities and variabilities introduced by the entire god system, suggesting a need for future research to explore AI strategies incorporating a wider range of gods.

The decision to focus exclusively on Apollo and Atlas as representative gods from Santorini's extensive god system introduces a limitation, particularly in terms of the strategic dimensions explored. Apollo and Atlas were selected due to their distinct influences on specific phases of the game, Apollo primarily affects the movement phase, allowing for worker position swaps with opponent worker, while Atlas's influence is most pronounced during the building phase, permitting the construction of domes at any level. This selection was intended to streamline the investigation into the AI's strategic adaptability within these key gameplay aspects. However, it inherently limits the study's exploration to only two facets of the game's strategy: movement and construction. Santorini features a wide array of gods, each with unique powers that impact various phases of gameplay and introduce different strategic considerations. By narrowing the focus to just Apollo and Atlas, the research omits the potential strategic complexity and variability that other gods could introduce, particularly in how they might affect other aspects of gameplay such as planning, foresight, and counter-strategy. This restriction highlights a gap in the current study, underscoring the importance of extending future research to encompass a broader selection of gods for a more comprehensive understanding of AI's performance and strategic depth in Santorini.

1.5 Problem Defintion

To build a model for Santorini board game explained above the following problems belows need to be solved accordingly:

a. How to represent Santorini board game as a game state and game engine?
b. How the heuristic function and value is defined?
c. How the heuristic value impact decision making?

1.6 Research Purpose

The goal of this research is to develop an AI model capable of leveraging Santorini's god powers, aiming to fill the gap in AI's strategic use of these unique game elements. This model focuses on understanding and exploiting the strategic advantages of god powers to improve decision-making in gameplay, specifically through the powers of Apollo and Atlas. By enhancing AI adaptability and strategy with these powers, the study seeks to demonstrate the potential for more sophisticated AI applications in board games.

1.7 Thesis Outline

Chapter I: Introduction sets the stage by introducing the significance of artificial intelligence (AI) in board games, with a specific focus on the Santorini game and its unique god system. The chapter outlines the research gap, noting that current AI applications primarily handle basic game mechanics, thereby overlooking the strategic complexities introduced by god powers. Objectives are clearly defined, aiming to develop an AI model capable of effectively using the god system for enhanced decision-making in gameplay. Limitations are discussed, particularly the focus on selected god powers and their impact on gameplay, alongside the methodological approach involving Mean End Analysis and heuristic functions to optimize AI performance.

Chapter II: Literature Review and Theoretical Framework reviews existing literature on game theory and AI applications in strategic games, detailing the mechanics of Santorini and the critical role of god powers. This chapter sets the theoretical foundation, discussing deficiencies in current AI strategies and hypothesizing how integrating advanced AI techniques with god powers might influence game outcomes.

Chapter III: Methodology describes the AI model's structure, detailing the implementation phases, from the design and development of algorithms to their testing. Simulation tools and game scenarios used for AI strategy testing are specified, along with metrics defined for evaluating AI performance in terms of strategic effectiveness and adaptability.

Chapter IV: Results and Discussion presents the outcomes of AI simulations, analyzing the AI model's performance against various strategic scenarios and comparing it with traditional AI strategies. The effectiveness of heuristic values and the strategic impact of god powers are evaluated, discussing how these findings support or challenge existing theories and their implications for AI gaming.

Chapter V: Conclusion and Recommendations concludes the thesis by summarizing the findings, reflecting on the research objectives and contributions to AI in board games. The chapter acknowledges the study's limitations and suggests future research directions.