

A Game Theory Simulation on the Battle of Gettysburg using Agent-Based-Modeling

Rubén Hernández O'Kelly

^aInstitute for Computing in Research, Santa Fe, NM, 2023,

Abstract

This paper intends to find the difference between the Battle of Gettysburg, an important battle of the American Civil War, and an agent-based simulation of the battle using the principles of Game Theory as basis for the agents' decisions. In this simulation, the Union will be the main focus. As the simulation ends, the two results will be compared and will show the best actions that the Union could have made.

Keywords: Game Theory, Agent-based modeling, Simulation, Gettysburg

1. Introduction

“Let your plans be dark and impenetrable as night, and when you move, fall like a thunderbolt.” — Sun Tzu, *The Art of War*. Sun Tzu's quote epitomizes the significance of secrecy and surprise in warfare. In the context of the Battle of Gettysburg and the project's exploration of game theory and agent-based modeling, it emphasizes the importance of uncertainty and adaptive decision-making by the generals. Employing this strategic philosophy, simulated agents in agent-based modeling can replicate the challenges faced by real generals, allowing for a deeper understanding of the battle's complex dynamics.

2. Scenario and Methodology

The Battle of Gettysburg, fought from July 1 to July 3, 1863, during the American Civil War, was a pivotal and bloody conflict between the Union Army of the Potomac, commanded by General George G. Meade, and the Confederate Army of Northern Virginia, led by General Robert E. Lee. It took place in the small town of Gettysburg, Pennsylvania, and is often considered the turning point of the Civil War. The battle was a result of Lee's second invasion of the North and his attempt to gain a strategic advantage by taking the war to Union territory. The three-day battle saw intense fighting and heavy casualties on both sides, with approximately 51,000 soldiers killed, wounded, or missing. The Union emerged victorious, and Lee's Confederate forces were forced to retreat back to Virginia, effectively ending the South's hopes for a successful invasion of the North.

The Battle of Gettysburg is renowned for its significance in the Civil War's outcome and its impact on American history. The Union victory boosted Northern morale and solidified President Abraham Lincoln's resolve to issue the Emancipation Proclamation later that year, declaring the freedom of all slaves in Confederate-held territories. Furthermore, the battle prompted Lee to abandon future offensives in the North, shifting the focus of the war to Virginia and eventually leading to the Union's triumph.

Game theory is a branch of mathematics and economics that deals with strategic interactions among multiple decision-makers (players) who aim to maximize their utility or payoff (rewards). It provides a formal framework to analyze and predict how individuals or organizations make decisions in competitive situations. Developed in the mid-20th century, game theory has found applications in various fields, including economics, political science, biology, and computer science. The central concept in game theory is the “game,” which consists of players, strategies, and payoffs. Different games, such as Prisoner's Dilemma, Battle of the Sexes, and Chicken, present various scenarios of conflict, cooperation, and decision-making, offering valuable insights into real-world situations.

Agent-Based Modeling (ABM) is a computational modeling technique used to simulate the behavior and interactions of individual agents to understand complex systems' emergent properties. In ABM, agents are autonomous entities that follow predefined rules and adapt their behavior based on their local environment and interactions with other agents. The model's dynamics emerge from the collective behavior of these agents, allowing researchers to observe and analyze the system's macro-level patterns and outcomes. ABM has gained popularity across various domains, including sociology, ecology, economics, and epidemiology, as it provides a powerful tool to study systems that involve numerous autonomous agents and complex interactions. ABM allows researchers to explore “what-if” scenarios, test hypotheses, and gain insights into the system's behavior that may not be apparent through traditional analytical methods.

3. Methods and Results

The simulation results will be compared to the historical outcome of the Battle of Gettysburg to identify effective strategies that the Union could have employed. By applying game theory principles and agent-based modeling, we hope to gain valuable insights into the decision-making dynamics of this critical historical event.

To conduct the agent-based simulation, we developed a Python program that models the Battle of Gettysburg using game theory principles. The simulation involves two teams, the Union and the Confederacy, each represented by agents with unique characteristics such as health, attack range, and attack strength. The agents follow predefined rules and adapt their actions based on their local environment and interactions with other agents. In the simulation, the number of agents per team has been calculated to be historically accurate while also keeping within program limitations.

The simulation progresses through a series of steps, with each step representing a moment in the battle. At each step, the agents make decisions on whether to attack enemy agents within their attack range or to retreat to a common point for regrouping. The agents' strategies are based on the principles of game theory, seeking to maximize their utility (in this case, winning the battle) while anticipating the opponents' actions.

The program is conducted in such a way that the agents are arranged by formations which resemble those used in the actual battle:

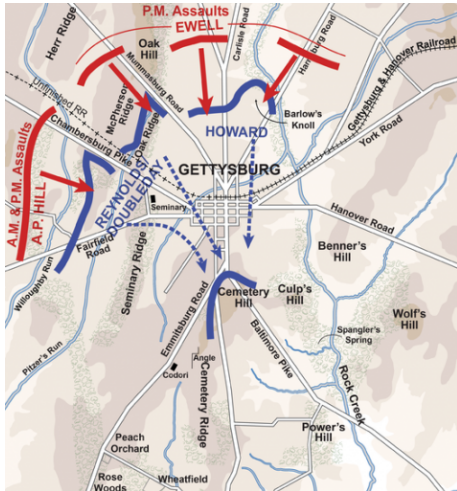


Figure 1: The map of the Battle of Gettysburg

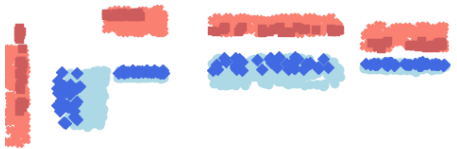


Figure 2: A simulated map of the Battle of Gettysburg

Upon completion of the simulation, we compare the results with the historical outcome of the Battle of Gettysburg. We evaluate the effectiveness of different strategies employed by the Union agents and identify potential improvements in their decision-making. The findings shed light on the significance

of adaptive decision-making and the impact of uncertainty on battle outcomes.

The agent-based simulation of the Battle of Gettysburg is conducted using principles derived from Game Theory, where simulated agents representing Union and Confederate forces make strategic decisions based on interactions with other agents and the battlefield environment. By employing Game Theory as the foundation, the simulation aims to recreate the challenges faced by the real generals during the historic battle and uncover the best possible actions that the Union could have taken.

During the simulation, each agent represents a unit in the army, with distinct attributes such as position, health, attack range, and attack strength. The agents utilize the principles of Game Theory to determine their actions, choosing between attacking an enemy agent or retreating to a common point with fellow teammates. The simulation progresses through a series of time steps, and at each step, agents interact with their surroundings and adapt their strategies based on the observed outcomes.

To enhance the realism of the simulation, the agent-based model also introduces stochastic fictitious play, a variant of the fictitious play algorithm in game theory. Stochastic fictitious play adds an element of randomness to the agents' decisions, making their strategies more robust in the face of uncertainty. As the simulation unfolds, the agents update their beliefs about their opponents' strategies and adjust their own actions accordingly, converging towards optimal responses to the mixed strategies of their adversaries. This allows the simulation to capture the dynamic and evolving nature of the battlefield, where unexpected outcomes and changing circumstances influence decision-making.

4. Summary and conclusions

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetur id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetur adipiscing elit. In hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

Acknowledgements

Thanks to ...

Appendix A. Appendix title 1

Appendix B. Appendix title 2