Application of Game Theory to Analysis of Machine versus Human Strategies

Helena and Kalliope Luna Welch

December 2025

Abstract

The goal of this project is to analyze whether machine learning algorithms and individual humans are able to make decisions according to game theoretical logic. We accomplish this by querying existing machine learning algorithms with hypothetical scenarios and comparing the corresponding decisions of characters from operas. We then find the optimal sequence of decisions with game theory. Potential future steps include training our own model as a multi-agent system based on what we learn from preexisting models' decision-making capabilities.

Background

As machine learning becomes increasingly prevalent in our current society, it is assuming a more and more influential role upon individuals' decisions. The interplay of such decisions made by different players affect many aspects of life, from finance and politics to biological systems. [1] Machine learning algorithms have the potential to aid in these decisions, but only when examined first to ensure that their own choices are rational.

This study aims to assess the validity of different machine learning algorithm's decisions by comparing them to optimal decisions determined by game theoretical concepts. This project will also compare optimal and large-language model-generated decisions to those that humans might make in these situations.

Our input data consists of the decision trees of opera plots. Opera scenarios are suitable for our task because they provide a large and immediately accessible corpus of data without creating too much complexity within each plot. In addition, operas distinguish themselves from other art forms in that they are multifaceted works of art (*Gesamtkunst*), combining both storyline and music.[2] We use the musical element to quantify the emotions that drive the human decisions of each character. We (a) test how optimal each character's decisions are using game theory and (b) illustrate why these "human" decisions may differ from the optimal strategy using this musical component.

Procedure

First, we map the sequence of decisions made by each character in the opera, along with the preceding and consequential events. We select Charles Gounoud's *Faust* [3] as a first source of data. We record the number of times each character makes an offer to another character, whether or not this offer is accepted, and whether each character ends up in a positive or negative situation. Having organized each character's decisions and outcomes in a data file, we apply a decision tree algorithm [4] to discover the optimal sequence of decisions, based on which sequences of decisions in the opera resulted in the highest number of positive outcomes for that character. In the event that an alternative solution is more optimal than any decision made in the opera dataset, we also incorporate counterfactual paths into the decision tree. [5] Ultimately, we plan to add a 15 to 20 more operas to our dataset.

We next prompt different machine learning algorithms with the opera's problem scenario and ask them to determine the sequence of decisions that will lead to the optimal outcome. Comparing the machine's logic with that of each character in the opera and the laws of game theory will inform how accurate a machine versus a character is in making decisions with maximum positive results for every player.

Knowing that opera characters often portray typical human mistakes, we expect that most characters' decisions will not produce the most positive outcomes possible. To better understand why each character did not choose the most positive course of action, we analyze the vocal and instrumental elements of the opera. We quantify music through pitch relative to the base note, duration, dynamics, and combination of notes by different parts (chords). We will examine whether patterns in the music convey the emotion

felt by characters who make irrational choices. This serves to supplement our overall understanding of human versus mathematically correct decisions.

Next Steps

Our ultimate goal is to build a machine learning model that simulates opera plots using a multi-agent network. If we train the model using reinforcement learning, [6] [7] will its decisions have the maximum positive effects as determined by such mathematical laws as the Nash Equilibrium? This would follow from previous studies' analyses using typical hypothetical scenarios such as the Prisoner's Dilemma. [1] [8]

References

[1] Agrawal, Anurag and Jaiswal, Deepak. "When Machine Learning Meets AI and Game Theory." 2012. Accessed 12 December 2025. https://cs229.stanford.edu/proj2012/AgrawalJaiswal-WhenMachineLearningMeetsAIandGameTheory.pdf.

[2] Wolfman, Ursula Rehn. 2013. "Richard Wagner's Concept of the 'Gesamtkunstwerk.'" Interlude. March 11, 2013. https://interlude.hk/richard-wagners-concept-of-the-gesamtkunstwerk/.

[3] Barbier, Jules and Carre Michel. "Faust." *The Book of 101 Opera Librettos*. Edited by Jessica M. MacMurray, Deluxe ed., Tess Press, 1996, pp. 330-344.

[4] scikit-learn. "1.10. Decision Trees — Scikit-Learn 0.22 Documentation." Scikit-Learn.org, 2025, scikit-learn.org/stable/modules/tree.html.

[5] Daskalakis, Constantinos, and Gemp, Ian and Jiang, Yanchen and Paes Leme, Renato and Papadimitriou, Christos and Piliouras, Georgios et al. "Charting the Shapes of Stories with Game Theory." 2024. Neural Information Processing Systems. 10.48550/arXiv.2412.05747.

[6] "Introduction to Deep Reinforcement Learning - Hugging Face Deep RL Course." Huggingface.co, huggingface.co/learn/deep-rl-course/unit1/introduction.

[7] Sutton, Richard S. and Barto, Andrew G. "Reinforcement Learning: An Introduction." MIT Press, 1998.

[8] Malinovskiy, Pavel. "Advanced Game-Theoretic Frameworks for Multi-Agent AI Challenges: A 2025 Outlook." 2024 4th International Research Journal of Modernization in Engineering Technology and Science, Ghaziabad, India, 2024, pp. 255-260, http://dx.doi.org/10.56726/IRJMETS69135.