Ph.D. Research Proposal

Title: Integrating Mathematical Optimization and Artificial Intelligence for Complex System Modeling and Decision-Making

The integration of mathematics and computer science has become a cornerstone of innovation in today's technology-driven world. Mathematics provides the analytical foundation to represent complex systems, while computer science through artificial intelligence, machine learning, and computational modeling offers the tools for large-scale data processing and intelligent decision-making. This research aims to combine the strengths of both disciplines to develop mathematically grounded AI models capable of solving complex optimization and decision-making problems with improved accuracy, interpretability, and computational efficiency. Traditional AI models often operate as "black boxes," offering limited interpretability and lacking theoretical guarantees, while purely mathematical methods sometimes struggle to handle high-dimensional, uncertain, or dynamic systems. Therefore, this research proposes a hybrid approach that blends mathematical optimization techniques, such as convex and nonlinear programming, with machine learning and data-driven modeling. The rationale is to create algorithms that are both explainable and scalable, capable of addressing real-world challenges in fields such as smart energy systems, healthcare, finance, and transportation.

The primary objectives of this research are to develop novel mathematical frameworks that integrate optimization theory with machine learning algorithms, design interpretable AI models based on mathematical constraints, and implement scalable computational methods for large datasets. Furthermore, the research seeks to validate the developed models in practical domains such as power grid optimization, medical diagnostics, and transportation planning, thereby

demonstrating the real-world impact of mathematically enhanced AI systems. To achieve these goals, the study will employ a multidisciplinary methodology. Mathematical modeling will form the theoretical backbone, employing tools such as differential equations, stochastic analysis, and variational methods to describe system behavior. Computational implementation will use languages like Python and MATLAB, incorporating deep learning, reinforcement learning, and Bayesian optimization frameworks. Hybrid models will be designed by embedding mathematical constraints directly into AI architectures, ensuring stability, convergence, and interpretability. Validation will be conducted through simulations and real-world datasets, assessing performance using metrics like accuracy, robustness, computational cost, and scalability.

The expected outcomes of this research include the development of a new theoretical framework combining mathematical rigor and AI flexibility, the design of efficient algorithms for high-dimensional optimization, and the creation of prototype systems or software tools that can be applied to real-world problems. The findings are expected to contribute to leading journals such as *SIAM Journal on Optimization* and *IEEE Transactions on Neural Networks*, bridging the gap between theoretical mathematics and practical computing. This research has broad potential applications. In smart energy systems, it can improve load forecasting, fault detection, and predictive maintenance. In healthcare, it can aid in disease modeling and intelligent diagnostics. In finance, it can optimize portfolio management and risk modeling under uncertainty. Similarly, in transportation, hybrid AI-mathematical models can enhance routing, traffic prediction, and autonomous control systems.

The proposed work is planned over four years. The first year will focus on literature review, theoretical foundation, and mathematical model formulation. The second year will involve algorithm development and preliminary testing. The third year will emphasize model

refinement, simulations, and optimization. The final year will focus on application case studies, result validation, and dissertation preparation. The research will require access to high-performance computing facilities, relevant datasets, and software tools such as TensorFlow, MATLAB, and Python for algorithmic development. In conclusion, this Ph.D. research will explore the powerful intersection of mathematics and computer science to design intelligent, explainable, and efficient computational models. By integrating mathematical optimization with artificial intelligence, the study aims to overcome limitations of traditional approaches, offering both theoretical advancements and practical solutions to complex system modeling and decision-making problems. The outcome of this research will significantly contribute to the fields of applied mathematics, computer science, and interdisciplinary engineering, aligning with global efforts toward sustainable, data-driven, and intelligent technological systems.