My research interest lies at the intersection of efficient deep learning (DL), quantum machine learning (QML), uncertainty quantification (UQ), and trustworthy AI. I aim to pioneer methodologies to solve complex problems by either hybridizing different techniques or adopting ideas from seemingly unrelated fields to create novel, interdisciplinary solutions. My background in Industrial and Production Engineering and extensive research experience in comparative genomics help me approach challenging issues in machine learning (ML) from a uniquely interdisciplinary perspective. This distinctive lens allows me to conceptualize and implement efficient, unorthodox strategies that go beyond conventional ML frameworks. I am driven by several key questions: How can we design AI systems with fewer parameters that still operate effectively in resource-constrained environments? How can we utilize quantum principles like superposition and entanglement to achieve exponential speedups with minimal qubit usage? How do we quantify prediction variability and evaluate model confidence? And how can we make AI more reliable, energy-efficient, and sustainable? Through hands-on research and interdisciplinary undergraduate projects, I have explored how these areas contribute to building robust AI systems. I am applying to the USC Viterbi CS PhD to deepen my expertise, engage in collaborative research, and pursue answers to these critical questions alongside leading experts in the field.

Interdisciplinary Research Background. My research journey began in my freshman year with a solution to a divisor function problem that required analyzing sums of divisors for numbers with specific multiplicative conditions in the International Youth Math Challenge, which earned me a gold honor (top 5%). The growing interest in ML and gradual self-learning led to a major achievement in 2021 when I led my team to victory in the "Smart Roads Hackathon," which earned me an ML internship at UiT in Norway. At UiT, I introduced a novel safety metric and utilized sophisticated regression methods to predict winter road safety [1], reinforcing my fascination with the practical uses of AI. Later that year, I joined Prof. Jonathan Miller's *(PhD Biology, Cambridge; PhD Physics, Caltech)* lab at the Okinawa Institute of Science and Technology (OIST) as a fully funded research intern (acceptance rate: 14%), focusing on **comparative genomics**, analyzing linear (non-primates) and exponential (primates) power-laws in perfectly conserved sequences (PCS) distributions across UCSC's 44 pairwise genome sequences. My discovery of a unique "knee" in the heavy-tailed PCS distribution sparked a new understanding of sequence conservation. As a visiting research student in 2023, our continued work led to two conference posters at *BBCC'22* [2] and *SMBE'23* [3] on PCS enrichment in small proteins. I developed scripts for PCS generation, sliding window of chromosomes, genomic regulatory blocks, and contiguously mismatched sequence identification with Dr. Lucia Zifcakova, achieving computational efficiency improvements on HPC clusters and generated ≈ 12494 lines of codes and ≈ 5.64 GB plots. I resolved out-of-bound PCS coordinates issues in the 'R Bioconductor' package and generated plots for up to 6th moments and relative entropy distribution of PCS lengths. Since graduation, I have continued as a visiting researcher, collaborating on inter-gap segments and ancestral repeats across species, improving the neutral indel model. What excites me is my work has inspired ongoing collaboration among 4 postdoctoral researchers (Dr. Zdenek Lajbner, Dr. Reuven Pnini, Dr. Priscila Biller, and Dr. Zifcakova).

Research in QML, Explainable AI (XAI), and UQ. Joining the Advanced Machine Intelligence Research Lab (AMIRL) allowed me to work with esteemed AI researchers from across the globe. My undergraduate thesis, **QAmplifyNet** [4], laid the foundation for my work in QML under the supervision of Prof. Md. Saiful Islam, which was funded by Prof. Jungpil Shin at the University of Aizu. My goal was to develop an ML/DL model to address the black-box nature of existing models in supply chain backorder prediction, particularly with scarce, limited, and imbalanced data. Unfortunately, classical models were not able to fulfill the desired objective. During my junior year, I had the opportunity to take a private course on "Quantum Mechanics & Quantum Computing" from Prof. Mahdy Rahman Chowdhury *(ICO Galileo Galilei Awardee)*. This transferrable knowledge led me to design an interpretable hybrid quantum-classical neural network using **Pennylane-Qiskit** that incorporated a 2-qubit variational quantum classifier (VQC) with an amplitude encoder followed by a strongly entangling layer, outperforming classical, quantum, hybrid ML, and DQN-based RL models. QAmplifyNet was published in *Nature Scientific Reports*. When I presented it at the AGI Leap Summit 2024, I discovered research on UQ by R1 university scholars. This inspired me to self-learn and pursue UQ in my next project.

My fascination with the beauty of the aurora has driven my interest in geomagnetic storms, which pose significant risks to satellite and GPS systems, urgently requiring accurate predictions of the disturbance storm-time (Dst) index. I led a project at the NASA Space Apps Challenge 2023, which got a Global Nomination, competing with 57,900 participants, where we developed a hybrid DL model that achieved a root mean squared error (RMSE) of 9.42. After the competition, I was still stuck with this project, trying to solve this problem with improved RMSE and integrate UQ and XAI. Inspired by the dressed VQC architecture of QAmplifyNet, I proposed **TriQXNet** [5], a pioneering framework combining conformal prediction and XAI (ShapTime and permutation feature importance) within a classical-quantum neural network structure. It processes real-time solar wind data from NASA's satellites through 3 parallel channels, including three 4-qubit VQCs, which outperformed 13 state-of-the-art DL models and CIRES/NOAA NCEI geomagnetism team's benchmarks with an RMSE of 9.27 nanoteslas. Inspired by the success of TriQXNet, I was enthusiastic about addressing high parameter requirements in MLP-based classical heart failure detection models. I integrated Kolmogorov-Arnold Networks (KAN) alongside 3 parallel VQCs similar to TriQXNet, replacing MLP layers for univariate, learnable, low-parameter activation functions at edges into a classical-quantum dual-channel neural network **KACQ-DCNN** [6]. KACQ-DCNN outperformed 37 benchmark models, with SHAP and LIME interpretations, and showed model uncertainty with conformal predictive systems via *crepes* and *MAPIE* frameworks followed by estimating CO_2 emissions in our experiments. These projects were conducted at AMIRL under the guidance of Prof. M. F. Mridha, with critical reviews from Prof. R. Simon Sherratt *(IEEE Fellow)* and Prof. Nilanjan Dey, and were funded by Prof. Zeyar Aung at Khalifa University. TriQXNet and KACQ-DCNN are under review at *npj Artificial Intelligence* and *Computers in Biology and Medicine*.

My next two projects resulted from my recent inspiration to tackle the challenges of massive data volume, high dimensionality, and rare signal detection underlying high-energy physics (HEP) data with QML under Prof. Nilanjan Dey's and Prof. Mridha's co-supervision. Working with data from the Large Hadron Collider, I encountered major computational challenges in analyzing complex particle interactions. QML seemed like a promising solution because it uses a large Hilbert space of quantum hardware. However, I realized that current quantum graph neural networks (GNNs) struggle with noise and are restricted by fixed symmetry groups. In response, I developed the Lie-algebra adaptive Lorentz-Equivariant Quantum GNN (**Lorentz-EQGNN**) [7] by replacing classical modules with a 4-qubit VQC. This approach introduced a dimension reducer, enabling a 5.5-fold parameter reduction while outperforming classical and quantum GNNs in jet discrimination and event classification with just 800 training samples.

My next project addressed inefficiencies in existing representation learning for jet tagging, where random augmentations often obscure critical features, limiting their utility in HEP, where interpretability and data efficiency are crucial. Prior studies in graph contrastive learning (GCL) approached this issue with classical rationale generators, but they lacked supervision signals guiding salient feature extraction and suffered from high parameter counts. Recognizing this gap, I developed the Quantum Rationale-aware GCL (**QRGCL**) [8] with **TorchQuantum**, incorporating a quantum rationale generator (QRG) using Hadamard gates and angle embedding to autonomously identify and prioritize critical features within particle jets, ensuring that augmentations retain essential discriminative properties. QRGCL outperformed existing GCL models with a much smaller architecture of only 45 parameters. My role included designing the QRG, integrating it into a GNN encoder and projection head, and conducting performance evaluations. I plan to implement a physics-informed VQC for HEP in the future. Lorentz-EQGNN and QRGCL are under review at *IEEE Transactions on Artificial Intelligence* and *IEEE Transactions on Neural Networks and Learning Systems*, respectively.

In my latest and most impactful project under the supervision of Prof. Nilanjan Dey, I faced challenges as I worked to address the limitations of existing feature selection methods in RL, improving on the AAAI'19 article [9]. Most approaches relied on static feature subsets and manual intervention, which had less adaptability and inefficiency in cost and time. After numerous failures, I could develop dynamic, per-instance **human-in-the-loop feature selection** [10] in DDQN, integrating a combined loss function with feedback loss. By carefully selecting CNN and pooling layers, I ensured feature shapes matched simulated feedback, allowing for its loss computation. I implemented simulated feedback using Gaussian heatmaps and stochastic sampling to refine feature subsets dynamically. By integrating KAN into the Q-network and target network, **KAN-DDQN** achieved significantly better performance than traditional MLP-based DDQN, using 4 times fewer hidden layer neurons than MLP while maintaining model-specific interpretability. The work is under review in *IEEE Transactions on Systems, Man, and Cybernetics*. I'm excited by how my work creates measurable real-world impact and fuels my passion for solving open-ended problems. These projects deepened my appreciation for innovative, user-focused solutions, and I look forward to refining these skills through *formal doctoral training*.

AI in Practical Life. Under Prof. Mridha's supervision, I developed **TRABSA** [11], an explainable sentiment analysis framework combining transformers, BiLSTM, and attention mechanisms, funded by Prof. Yutaka Watanobe at the University of Aizu. To address the challenge of manual labeling, I evaluated diverse unsupervised lexicon-based methods and word-embedding approaches. TRABSA outperformed 15 benchmarks and showed robust performance across 6 multi-class datasets. Inspired by its success, I presented this architecture at *MIT Solve 2024*, proposing its use for disease profiling and personalized treatments based on patient comments. I plan to implement **Gaussian-projected quantum self-attention transformer** to evaluate the potential of quantum Hilbert space in this area. Collaborating on interdisciplinary research being focused on my passion for solving practical problems, I also contributed to the methodology, formal analysis, statistical validation, and original drafting of 4 students' undergraduate theses under Prof. Islam and Prof. Md. Rafiquzzaman on multi-criteria decision-making methods for assessing IoT adoption barriers [12, 13], hybrid genetic algorithm for optimizing port container operations and reducing dockyard rehandles [14], and identifying mismatches in furniture dimensions and proposing ergonomic designs to reduce musculoskeletal risks [15]. Under Emeritus Prof. Md. Kutub Uddin, I contributed to formal analysis and writing in two papers [16, 17] on optimizing cellular manufacturing systems using integer programming. Under Prof. Mridha and Prof. Dey, I co-developed a **unified XAI evaluation framework** [18] and interpretable dynamic GNN-based YOLO11 for small object detection and tracking [19]. I plan to evaluate the effectiveness of **dynamic spiking quantum GNN** in this research.

Beyond collaborative research, I have also initiated and led independent studies. In [20], I explored male domestic violence using ML to uncover hidden patterns and at-risk demographics, where CatBoost outperformed 16 other models. In **MCDFN** [21], I introduced an explainable CNN-LSTM-GRU model with multi-channel data fusion for demand forecasting, outperforming 7 benchmarks with 4% error reduction. Under Prof. Subrata Talapatra, I developed an unsupervised NLP model based on distance metrics and sentence transformers [22] to classify musculoskeletal disorder risk factors, where we found "working posture" to be a critical risk factor. As the first author, I led **3 systematic review** projects in AI for supply chain risk assessment [23], big data analytics for supply chain management (BDA-SCM) forecasting and optimization framework [24], and ultrasound-based AI for COVID-19 detection under Dr. Mohammad Arafat Hussain *(Harvard Medical School)* [25]. I have encountered challenges throughout my academic career, including several submissions of BDA-SCM [24] over 1 to 1.5 years. Despite initial setbacks, I worked diligently to revise and improve my submissions, learning valuable lessons in perseverance and refining my research approach. Notably, I single-handedly revised all my articles, receiving at least one review, with sincere guidance from my supervisors, and wrote point-to-point responses to the journal editor and reviewers.

Future Work. At USC Viterbi CS, I am excited to collaborate with Prof. Craig Knoblock on developing knowledge graphs [7, 8] to address real-world problems, especially in supply chains [4, 14, 21]. I also look forward to working with Prof. Satish Kumar Thittamaranahalli and Prof. Bill Swartout on knowledge representation, efficient ML & DL, and XAI, where I can leverage my expertise in graph representation learning, QML [4–8], XAI, and UQ. Furthermore, I am impressed by Prof. Ning Wang's research in XAI and human-computer interaction (HCI) aimed at enhancing the learning experience for students, which aligns perfectly with my academic and research background in these areas. I am also eager to engage with Prof. Jay Pujara, whose focus on scalable ML [7], UQ [5, 6], probabilistic modeling, NLP [11, 22], and knowledge graph construction closely resonate with my prior research experience. Additionally, I am keen to collaborate with Prof. Jose-Luis Ambite, whose work in knowledge representation, biomedical informatics, and genomics parallels my extensive research experience in comparative genomics.

Where I See Myself. Through my research and academic experiences, I've gained a deeper understanding of the real-world challenges people face across various sectors. These experiences have not only shaped my research interests but also inspired me to pursue solutions that can address some of these challenges. After graduate school, I aspire to work in academia and pursue a professorship, where I can develop new methods and tools to tackle complex problems. By furthering my education at USC Viterbi, I believe I will be able to take the next step towards advancing data-driven decision-making across diverse fields, from healthcare, societal well-being, and particle physics to supply chain optimization. I am excited about the opportunity to develop innovative, interdisciplinary solutions that bridge classical and quantum ML, creating interpretable and uncertainty-aware AI systems that can make a meaningful impact on real-world challenges.

References

[1] **M. A. Jahin** and A. Krutsylo, "DIT4BEARs Smart Roads Internship," July 2021, arXiv:2107.06755

[2] L. Žifčáková, **M. A. Jahin**, and J. Miller, "Perfectly conserved sequences (PCS) between human and mouse are significantly enriched for exonic small proteins," in *Bioinformatics and Computational Biology Conference (BBCC 2022)*, Dec. 13-15, 2022.

[3] L. Žifčáková and **M. A. Jahin**, "Perfectly Conserved Sequences (PCS) Between Human and Mouse Are Significantly Enriched for Small-protein Coding Sequence," in *Society for Molecular Biology and Evolution (SMBE 2023)*, Ferrara, Emilia-Romagna, Italy, July 23-27, 2023.

[4] **M. A. Jahin**, M. S. H. Shovon, M. S. Islam, J. Shin, M. F. Mridha, and Y. Okuyama, "QAmplifyNet: pushing the boundaries of supply chain backorder prediction using interpretable hybrid quantum-classical neural network," *Scientific Reports*, vol. 13, no. 1, pp. 18246, Oct. 2023, doi: 10.1038/s41598-023-45406-7

[5] **M. A. Jahin**, M. F. Mridha, Z. Aung, N. Dey, and R. S. Sherratt, "TriQXNet: Forecasting Dst Index from Solar Wind Data Using an Interpretable Parallel Classical-Quantum Framework with Uncertainty Quantification," Under review at *npj Artificial Intelligence*, July 2024, arXiv:2407.06658

[6] **M. A. Jahin**, M. A. Masud, M. F. Mridha, Z. Aung, and N. Dey, "KACQ-DCNN: Uncertainty-Aware Interpretable Kolmogorov-Arnold Classical-Quantum Dual-Channel Neural Network for Heart Disease Detection," Under review at *Computers in Biology and Medicine*, Oct. 2024, arXiv:2410.07446

[7] **M. A. Jahin**, M. A. Masud, M. W. Suva, M. F. Mridha, and N. Dey, "Lorentz-Equivariant Quantum Graph Neural Network for High-Energy Physics," Under review at *IEEE Transactions on Artificial Intelligence*, Nov. 2024, arXiv:2411.01641

[8] **M. A. Jahin**, M. A. Masud, M. F. Mridha, and N. Dey, "Quantum Rationale-Aware Graph Contrastive Learning for Jet Discrimination," Under review at *IEEE Transactions on Neural Networks and Learning Systems*, Nov. 2024, arXiv:2411.01642

[9] A. H. C. Correia and F. Lecue, "Human-in-the-Loop Feature Selection," Proceedings of the AAAI Conference on Artificial Intelligence, vol. 33, no. 01, Art. no. 01, Jul. 2019, doi: 10.1609/aaai.v33i01.33012438

[10] **M. A. Jahin**, M. F. Mridha, and N. Dey, "Human-in-the-Loop Feature Selection Using Interpretable Kolmogorov-Arnold Network-based Double Deep Q-Network," Under review at *IEEE Transactions on Systems, Man, and Cybernatics*, Nov. 2024, arXiv:2411.03740.

[11] **M. A. Jahin**, M. S. H. Shovon, M. F. Mridha, M. R. Islam, and Y. Watanobe, "A hybrid transformer and attention based recurrent neural network for robust and interpretable sentiment analysis of tweets," *Scientific Reports*, vol. 14, no. 1, pp. 24882, Oct. 2024, doi: 10.1038/s41598-024-76079-5

[12] H. Shahriar*, M. S. Islam, **M. A. Jahin***, I. A. Ridoy, R. R. Prottoy, A. Abid, and M. F. Mridha, "Exploring Internet of Things adoption challenges in manufacturing firms: A Delphi Fuzzy Analytical Hierarchy Process approach," *PLoS ONE*, vol. 19, no. 11, pp. e0311643, Nov. 2024, doi: 10.1371/journal.pone.0311643

[13] K. Ahmad*, M. S. Islam, **M. A. Jahin***, and M. F. Mridha, "Analysis of Internet of things implementation barriers in the cold supply chain: An integrated ISM-MICMAC and DEMATEL approach," *PLoS ONE*, vol. 19, no. 7, pp. e0304118, July 2024, doi: 10.1371/journal.pone.0304118

[14] M. M. Rahman*, **M. A. Jahin***, M. S. Islam, M. F. Mridha, and J. Shin, "Optimizing Container Loading and Unloading through Dual-Cycling and Dockyard Rehandle Reduction Using a Hybrid Genetic Algorithm," Under review at *European Journal of Operational Research*, Nov. 2024, arXiv:2411.04685

[15] A. K. Saha*, **M. A. Jahin***, M. Rafiquzzaman, and M. F. Mridha, "Ergonomic design of computer laboratory furniture: Mismatch analysis utilizing anthropometric data of university students," *Heliyon*, vol. 10, no. 14, July 2024, doi: 10.1016/j.heliyon.2024.e34063

[16] M. K. Uddin, M. S. Islam, **M. A. Jahin**, M. S. I. Seam, and M. F. Mridha, "Solving Generalized Grouping Problems in Cellular Manufacturing Systems Using a Network Flow Model," Under review at *OPSEARCH*, Nov. 2024, arXiv:2411.04685

[17] M. K. Uddin, M. S. Islam, **M. A. Jahin**, M. T. H. Irfan, M. S. I. Seam, and M. F. Mridha, "Designing Cellular Manufacturing System in Presence of Alternative Process Plans," Under review at *OPSEARCH*, Nov. 2024, arXiv:2411.15361

[18] M. A. Islam, M. F. Mridha, **M. A. Jahin**, and N. Dey, "A Unified Framework for Evaluating the Effectiveness and Enhancing the Transparency of Explainable AI Methods in Real-world Applications," Under review at *Information Fusion*, Dec. 2024, arXiv:2412.03884

[19] S. Soudeep*, M. F. Mridha, **M. A. Jahin***, and N. Dey, "DGNN-YOLO: Interpretable Dynamic Graph Neural Networks with YOLO11 for Small Object Detection and Tracking," Under review at *Pattern Recognition*, Nov. 2024, arXiv:2411.17251

[20] **M. A. Jahin**, S. A. Naife, F. T. J. Lima, M. F. Mridha, and J. Shin, "Analyzing Male Domestic Violence through Exploratory Data Analysis and Explainable Machine Learning Insights," Under review at *Scientific Reports*, Mar. 2024, arXiv:2403.15594

[21] **M. A. Jahin***, A. Shahriar*, and M. A. Amin, "MCDFN: Supply Chain Demand Forecasting via an Explainable Multi-Channel Data Fusion Network Model," Under review at *Evolutionary Intelligence*, June 2024, arXiv:2405.15598

[22] **M. A. Jahin** and S. Talapatra, "A Natural Language Processing-Based Classification and Mode-Based Ranking of Musculoskeletal Disorder Risk Factors," *Decision Analytics Journal*, vol. 11, pp. 100464, June 2024, doi: 10.1016/j.dajour.2024.100464

[23] **M. A. Jahin**, S. A. Naife, A. K. Saha, and M. F. Mridha, "AI in Supply Chain Risk Assessment: A Systematic Literature Review and Bibliometric Analysis," Under review at *Supply Chain Analytics*, Jan. 2024, arXiv:2401.10895

[24] **M. A. Jahin**, M. S. H. Shovon, J. Shin, I. A. Ridoy, and M. F. Mridha, "Big Data—Supply Chain Management Framework for Forecasting: Data Preprocessing and Machine Learning Techniques," *Archives of Computational Methods in Engineering*, vol. 31, no. 6, pp. 3619-3645, Mar. 2024, doi: 10.1007/s11831-024-10092-9

[25] A. Morshed, A. A. Shihab, **M. A. Jahin***, M. J. A. Nahian, M. M. H. Sarker, M. S. I. Wadud*, M. I. Uddin, M. I. Siraji, N. Anjum, S. R. Shristy, T. Rahman, M. Khatun, M. R. Dewan, M. Hossain, R. Sultana, R. Chakma, S. B. Emon, T. Islam, and M. A. Hussain*, "Ultrasound-Based AI for COVID-19 Detection: A Comprehensive Review of Public and Private Lung Ultrasound Datasets and Studies," Under review at *Multimedia Tools and Applications*, Nov. 2024, arXiv:2411.05029

*denotes co-first authorship.