Statement of Purpose

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My research interests lie in uncovering the mathematics that drives Machine Learning and deep learning and their theoretical nature. What are the theoretical foundations explaining the success of deep networks? Are there inherent limits to their expressiveness? What are the potential applications of learned representations in various domains, such as computer vision, natural language processing, and speech recognition? How do we address the challenges of interpretability and explainability in these learned representations? I aim to explore these problems to develop an understanding of the theoretical limits of Machine Learning. I am particularly interested in understanding and applying these algorithms across engineering and natural sciences to build intelligent systems and conduct research in physics and mathematics to solve problems such as approximating numerical computations using neural networks, astronomical simulations, assisted theorem proving, etc. My unwavering passion for engineering and research is evident in my academic achievements during my undergraduate years, reflected in my transcripts and my active involvement in extracurricular activities. My journey has underscored the importance of further specialization and enrichment required for a successful research career. In this regard, I am convinced that Caltech is the ideal place to nurture my potential.

During my bachelor's I was extremely fascinated by astrophysics and its intersection with computer science. In my junior year, I led a team of three and delved into the research on neural network applications in galaxy morphology classification. Identifying galaxy morphologies has important implications in many astronomical tasks, e.g., studying galaxy evolution. The recent data influx in astronomy necessitates a robust and automated system for processing large amounts of images. We aimed to set up a 7-class classification system that classified galaxy images using CNNs, which can surpass existing benchmarks. I was responsible for establishing a robust training pipeline and optimizing various neural network architectures from the ground up. Our collective efforts outperformed the second-best submission on the Kaggle Public Leaderboard. I gained a profound understanding of the intricacies of applying deep learning to various tasks and explored aspects such as hyperparameter tuning and custom model design for converging to global optimum—each underscored by a need for a profound grasp of the underlying theory. Training large-scale models requires enormous compute, but has been made efficient owing to their parallel nature. Dr. Anima Anandkumar's work in the analysis and design of tensor algorithms is extremely relevant to my interests in developing systems for physical sciences which often deal with high-dimensional data. I am particularly interested to explore and design efficient ways to escape local minimums, a problem generally faced during training complex models. I would like to work with her to gain an in-depth understanding of the subject.

The Galaxy Morphology Classification project proved to be a stepping stone in connecting astrophysics to computer science. Soon after that project, I began contributing to EinsteinPy, an open-source Python package designed to address issues in General Relativity and gravitational physics. My work specifically involved incorporating various symbolic computations, such as the Reissner–Nordström metric and calculations for the event horizon and ergosphere of a Kerr-Newmann black hole. While symbolic computations are valuable in controlled environments, real-world problems often necessitate approximate rather than exact solutions. This led me to investigate the processes used for various physical simulations where numerical methods are widely popular. The potential for deep learning in simulating complex system behaviors is vast, e.g., in surrogate modeling where we can use deep learning to approximate behaviors in complex systems allowing for faster evaluations when original simulation using numerical methods is computationally expensive. In simulations, gravitational interactions are currently computed using hierarchical tree algorithms like the Barnes-Hut & Fast Multipole Method. I am interested in leveraging AI and Machine Learning for this task in the long term. One possible approach is to model the gravitational interactions of various particles as nodes of a graph and learn the patterns as they evolve over time by using Graph Neural Networks. My interests in these topics are multi-faceted and at the center of multiple fields like astronomy, gravitational physics & machine learning. Dr. Katherine Bouman's research in computational imaging is extremely inspiring. I believe our research interests overlap greatly and my background in applying machine learning to physics provides me an opportunity to contribute to her ongoing research. Another interesting problem is the simulation of hydrodynamic processes involved in galaxy formation using deep learning. Dr. Oscar Bruno and Dr. Elizabeth Carlson's individual expertise in high-performance numerical PDE solvers and high-performance computing would guide me tremendously while exploring this problem in further detail. I would be honored to have an opportunity to work with them.

For my bachelor's thesis, I worked on utilizing Conditional GANs for astronomical image colorization. Space archives are filled with large amounts of low-quality, greyscale images, many of which go unnoticed. I was interested in utilizing generative models for creating aesthetically pleasing representations of celestial scenes. Generative models are attractive because they enable us to better understand, create, and work with data, having many practical and theoretical implications. In my work, I focused on tasks like image-to-image translation and style transfer, where I realized the need for distributional robustness in my application to maintain quality in my output images, even in varying conditions. GANs often deal with high-dimensional data and are used for various conditional image generation tasks, hence, it is important to study their optimization landscape and convergence guarantees. In my ongoing academic journey, I'm equally interested in gaining a theoretical understanding of how various neural network models generalize, especially in complex, high-dimensional spaces when provided with different conditions or inputs. In this regard, Dr. Yang Song's expertise in generative models makes him interesting to me as an advisor. Dr. Oscar Leong's insights in inverse problems and machine learning complement my interests perfectly, and I would like to work with him on these problems.

For the past two years, I have been working as an ML consultant at Relfor Labs, an AI startup. My professional experience in Machine Learning has further motivated me to pursue graduate studies to kick-start a research career. The scientific landscape has been consistently evolving, but many longstanding problems have eluded complete solutions for many years. Looking into the future, I wish to make a difference in this significant era. My determination to pursue a research career is unwavering, and I aspire to eventually work in an academic setting as a professor. The vibrant community of students and researchers at Caltech is the perfect place for me to nurture myself and further my commitment to help expedite this scientific advancement. Thank you for considering me as a prospective student at your university.