Academic Statement of Purpose

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Long Term Degree Objectives

My professional and undergraduate research experiences have motivated me to pursue graduate studies to kick-start a research career. Many longstanding problems in computer science and machine learning have eluded complete solutions for many years, e.g. the theory explaining the success of deep neural networks. 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 work in an academic setting and eventually pursue a Ph.D. The vibrant community of students and researchers at Purdue University is the perfect place for me to nurture myself and further my commitment to help expedite this scientific advancement.

Research

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, debugging, troubleshooting, and custom model design. (Kalvankar et al., 2020)

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. Exploring GANs was a natural progression to enhance my skills after working extensively with CNN architectures. GANs introduce a new layer of complexity with their unique architecture and loss functions, providing an ideal opportunity to deepen my understanding of developing intricate deep learning systems. (Kalvankar et al., 2022)

In addition to helping hone my research skills and nurture my critical thinking abilities, my role as the project lead in these projects was a significant learning experience that taught me various aspects of management, communication, and project planning.

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. I learned crucial concepts in physics and general relativity and the experience highlighted potential applications of deep learning within this domain. (Bapat et al., 2020)

Future Research Interests

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 and 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 find Prof. Rajiv Khanna's work in interpretability and generalization guarantees fascinating in this regard and would like to work with him to explore these problems.

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. Prof. Yexiang Xue's interests in AI for scientific discovery align extremely well with mine, and I wish to work with him in this domain. A particularly interesting problem that I wish to explore is applying deep learning to gravitational simulations. In simulations, gravitational interactions are currently computed using hierarchical tree algorithms like the Barnes-Hut & Fast Multipole Method. 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. I believe Prof. Bruno Ribeiro's expertise in Graph Neural Networks can help me immensely in my future research pursuits.

Other Comments

Because of my interest in simulations, I look forward to courses in "Numerical Computing" as they promise a comprehensive exploration of various mathematical concepts that extend beyond my previous academic coursework.

My research experiences in deep learning have underscored a need for a profound grasp of the underlying theory. Consequently, I eagerly anticipate the advanced topics in coursework such as "Foundations Of Deep Learning" (CS 58700), offering a more in-depth exploration of the core principles of deep learning and rigorous mathematics compared to my prior senior-year coursework.

In my ongoing academic journey, I'm equally interested in gaining a theoretical understanding of how various neural network models, like GANs, generalize, especially in complex, high-dimensional spaces when provided with different conditions or inputs. Undergraduate studies seldom comprehensively cover advanced machine learning theory. In this regard, I see Prof. Steve Hanneke's coursework in "Machine Learning Theory" as an exhilarating opportunity to immerse myself in these concepts more formally than ever. It promises a more profound understanding and a pathway to engaging with these fundamental theories at a higher level.

I believe my research interests, background, and career goals align extremely well the offerings of Purdue university. Having set ambitious goals in the intersection of deep learning and astrophysics, my background in physics, coupled with a robust understanding of crucial concepts such as general relativity, positions me at the nexus of theoretical and applied research. The institution's emphasis on pushing the boundaries of knowledge and providing a supportive academic environment resonates with my commitment to contributing meaningfully to the scientific community. Thank you for considering me as a prospective student at your university.

Publications

S. Bapat, R. Saha, B. Bhatt, S. Jain, A. Jain, S. O. Vela, P. Khandelwal, J. Shivottam, J. Ma, G. S. Ng, P. Kerhalkar, H. S. Sarode, R. Sharma, M. Gupta, D. Gupta, T. Tyagi, T. Rustagi, V. Singh, S. Bansal, N. Tayal, A. Manhas, R. Reyna, G. Kumar, G. Dixit, R. Kumar, S. Mishra, A. Jamgade, R. Singh, R. Sanjay, K. Shaikh, B. Vidyarthi, S. R. N. K, V. Gandham, N. Vashistha, A. Das, Saurabh, S. Kalvankar, G. Tarone, A. Mangat, S. Garg, B. Gautam, S. Srinivasan, A. Gautam, S. K. Singh, S. Salampuria, Z. Yauney, N. Gupte, G. Shenoy, and M. Y. Chan. Einsteinpy: A community python package for general relativity, 2020.

S. Kalvankar, H. Pandit, and P. Parwate. Galaxy morphology classification using efficientnet architectures, 2020.

S. Kalvankar, H. Pandit, P. Parwate, A. Patil, and S. Kamalapur. Astronomical image colorization and up-scaling with conditional generative adversarial networks. *INFORMATIK 2022*, 2022.