Personal, Background, and Future Goals Statement

Introduction

"Integrity first; service before self; excellence in all we do" – a phrase that stuck with me at every turn. To me, I view integrity as a discipline to work towards a goal, taking time to achieve it. I see service as an act toward something bigger than myself, leading efforts towards a greater good. When I observe excellence, I view it as a passion to provide my best efforts in the areas I am committed to. With these values in mind, they lay the foundation for my love for research and mentorship.

I first began building my enthusiasm by participating in various research opportunities. I encountered theories that I did not initially understand, but I took the time to read and comprehend these concepts. This experience made me want to intellectually challenge myself and work on topics that intrigued me. Later, I sought a greater cause to devote myself to, joining the Air Force Reserve Officer Training Corps (AFROTC) at Arizona State University (ASU) with the goal of commissioning into the Air Force. My time there solidified my discipline and commitment to lead those around me. However, fate had other plans, as I was medically disqualified. Nevertheless, that did not stop me from pursuing my ambitions. Combining my experiences in AFROTC with the knowledge I gained over the years, I was able to study and collaborate on meaningful research that remained intellectually challenging and fascinating. I found this new path, which fate had led me, to be an exciting one. This inspired me to strive to be a mentor who guides students, while also working with them to achieve impactful results in the machine learning (ML) field for space applications. In my vision, **I aspire to engage in research that demands intellectual rigor and to work on areas that further not only the field but also the development of my future mentees.**

Intellectual Merit

Part 1, *"Integrity First"*: My first research experience was an internship before my freshman year, where I was tasked with estimating rice production in regions of the Philippines. I wanted to use machine learning (ML) for the project but had no background in the field, so I taught myself the basics of neural networks. Learning from prior works and recognizing that El Niño sea surface temperatures played a key role in estimations, I combined statistics from the El Niño 3.4 region with other data to create a dataset. By applying different configurations of recurrent neural networks and multi-layer perceptrons, I developed a rough model that forecasted the next quarter's production. Reflecting on this, I realized that although I knew little about ML at first, I had built the discipline to teach myself. Driven by curiosity, I wanted to learn more.

During my freshman year at ASU, I emailed Dr. Yezhou Yang for research opportunities, and he invited me to his vision and language lab, Active Perception Group (APG). I attended the lab's meetings, but the discussions were beyond my understanding. However, that did not deter me from pursuing my goals. Instead, I spent time trying to learn from the graduate students, leading me to multiple surveys and papers talking about machine translation, latent spaces, and much more. Armed with the knowledge provided by peers around me, I became interested in doing my own research work. I applied for the ASU Fulton Undergraduate Research Initiative (FURI), and I was later accepted.

Confident with the support that I had, I wanted to explore the use of large language models (LLMs) to generate orchestral pieces from lyrics (text-2-music generation). This niche was quite sparse and I had little knowledge about it, but I pressed forward. Utilizing what the graduate students had taught me, I had to first embark on data collection. Realizing that there were online repositories that had musical files and lyrics associated with them, I utilized multithreading and parsing libraries to scrape these websites and store the scraped samples. Once the data was collected, I implemented a prior work to represent the features of the music with their Music Byte Pair Encoding algorithm. The next step was developing a model to learn this data. Pulling inspiration from works in latent-space translations, I designed a model that encoded the musical data into embeddings and then conditioned these embeddings on lyrical information in an auto-regressive manner. The challenges faced in this research work were magnitudes greater than the rice production estimation work. This was because the needed work to translate one modality to another required numerous techniques and state-of-the-art ideas. However, the obstacles in this adventure were learning experiences that solidified my understanding of transformer models, shaping my competencies in the ML field. In the end, **this work led to two poster presentations at the ASU FURI symposium and a highlight of my work as a freshman.** Furthermore, this work was later carried into another semester by another undergraduate whom I mentored, leading to a third poster presentation of this work. However, I didn't just want to build a knack for research. I wanted to find a bigger purpose to contribute to while finding a way to develop my character.

Part 2, *"Service Before Self"*: During my sophomore year, I joined the AFROTC program at ASU. AFROTC is a training environment that is meant to turn college students into commissioned officers of the U.S. Air Force. I saw this opportunity as a means to become a second lieutenant and to learn important leadership skills. Under the command of Lieutenant Colonel D. Shane Richardson, I trained and learned from my superiors about the details of team building, types of leadership styles, and effective communication. **My efforts and guidance of my peers merited recognition from my chain of command, ranking me top third in my class.**

Through my excellence in the AFROTC program, I became a research intern during the summer before my junior year. There I met with my mentor Evan Kain from the Air Force Research Laboratory (AFRL). His work focused on the issues of solar radiation damaging memory components, causing misrepresentation of ML models or programs for space vehicles. To test hardware reliability, researchers radiated the hardware of the ML models and observed their performance over time. This method was very inefficient as it permanently damaged the hardware being tested. To efficiently test reliability, I utilized prior works to expand benchmarks that simulated these effects by perturbing bits within a model prior to inference (fault injection). During our experimentation, we noticed that certain models had more reliable performance over several runs due to their architecture. Because of the success of my work and the potential of this research, I returned to this opportunity the next summer to find even more surprising behaviors. I formulated a new fault injection platform that not only simulates radiation effects in memory, but also in the instruction level as well. **This accumulated to two poster presentations and a second-place crowd favorite achievement across my time with AFRL.**

Part 3, *"Excellence in All We Do"*: However, during the second half of my junior year, the Air Force had medically disqualified me. I could no longer be a commissioned officer. Although my time in the program may have seemed to be a waste, I utilized what I had experienced to be even more effective in my work. These skills allowed me to take leadership in other exciting research, and augment them to make meaningful impact, specifically in ML for space and natural language processing (NLP).

Around the same time, I collaborated with Maitreya Patel, a Ph.D. student under Dr. Yang, to address a gap in current NLP models and benchmarks, the inability to handle hierarchical text structures. For example, existing benchmarks don't account for the nesting of bullet points under paragraphs or references embedded within multiple documents. This is an important consideration as documents like technical manuals and academic papers rely on hierarchical and dependent information. Recognizing that context free grammar rules (CFG) can generate outputs that represent these structures, we leveraged this system to synthetically make sentence templates. These sentence templates are then used to generate tasks that require varying parts of the prompt to produce outputs, testing their ability to process hierarchical information. Boolean logic is an example of this as it requires the model to deduct parts of a sentence at a time to make a true or false prediction. The usage of CFGs even provides the benefit of creating in-context learning samples via the derivation process during generation. This is key to our work as it provides a means to test reasoning abilities of models if they are provided with few-shot examples of solving complex and nested prompts. Our ongoing work provides a framework for researchers to assess models' abilities to learn and inference on nested context.

After working on my second AFRL internship, I gained a passion for fault injection, and I took the initiative to bring my work from AFRL to ASU to expand its scope beyond the Air Force's priorities. Transformer-based models, despite their success in various domains, have not been extensively studied for fault tolerability due to their inability to be deployed on spacecraft. This is because the components in these vehicles have to sacrifice computation capabilities to maximize radiation hardening and minimize package size. Recognizing this gap, I met Dr. Hannah Kerner and her Ph.D. students who agreed to advise me on this work. The reason for this collaboration was because of their lab's focus on Earth observation data (EOD) and machine learning theory. Together, we are working to expand the benchmark I developed at AFRL to evaluate transformer-based models on vision tasks, particularly on EOD tasks. Furthermore, we aim to test compression techniques to determine which methods best preserve model performance and fault tolerance. Our motivation is to enable online inference of models on satellites, reducing the need for extensive data transmission by providing reliable onboard inferencing. By addressing these challenges, this work has the potential to significantly advance knowledge in space-based ML by overcoming fault tolerance issues and expands the ability of using larger models on smaller resources aboard satellites.

Broader Impacts

Witnessing the growth of others is deeply rewarding to me, reflecting my own journey of development throughout my undergraduate years. This has driven me to mentor individuals in their path to success, even so to participate in AFROTC to learn how to be a better leader and mentor. This passion has driven me to mentor high school students, undergraduates, and cadets. During my first AFRL internship, I was working with a high school intern who was interested in ML but was struggling with the fundamentals. Seeing this, I spent time with them, using my experiences to share my knowledge with them. Slowly, they began to understand, and they were able to carry out their work. They grew, similar to how I did during my first research experience. This high school intern later became part of the Turing Scholars Program at UT-Austin, a prestigious honors program for undergraduates. Moved by their success, I sought to learn how to be a better mentor to those around me.

In AFROTC, I was given the position of executive officer for the cadet wing (detachment). My job was to send correspondence and announcements from cadet leadership across the detachment. Noticing the freedom I had in this role, I took it a step further to test my leadership. I initiated a project called WingSuite, a web application that bridged multiple communication platforms into one program. I led multiple teams for this project, mentoring cadets under me and executing the needs of AFROTC cadre. Furthermore, I helped create a new position within the wing called the knowledge management officer, responsible for managing the wing's repository of resources and announcements. I learned many skills from this opportunity, applying leadership theory to action that made value. Combining many various efforts from other cadets and mine, **our cadet wing achieved the "Best Largest Detachment in the Nation" Award for the year of 2023 for our excellence and initiative to those around us.**

Looking forward, I am committed to combining my enthusiasm for research and mentorship to become a professor, establishing a laboratory focused on fault-tolerable ML models for space applications. Through this work, there are several critical areas that require further exploration, such as developing novel compression techniques or model architectures that are fault tolerable. Exploring these areas for this topic requires vast amounts of time and assistance from others. Using my passion for this subfield and the leadership skills that I have gained over time, I strive to build mentorship programs that provide research opportunities to future students. Through these efforts, I aim to make significant contributions to the field of space-related ML applications while developing future researchers.

Future Goals

I am currently a senior undergraduate who will move into an accelerated master's program next year, focusing on building and using the fault injection framework on transformer-based models with Dr. Kerner and others. This work will provide the steppingstone that can be later used to test compression techniques and find methods to increase fault tolerability. Doing a master's program will give me a broad and deep understanding of topics related to ML theory, allowing me to accelerate my future Ph.D. studies. Receiving the NSF GRFP will empower me to pursue this innovative research with greater creative freedom, allowing me to lead projects, collaborate with other researchers, guide future students, and provide major contributions for space-based ML.