Honors Research Reflection Essay

The research project we did this semester was to delve deep into the intuitive picture of *parton distribution functions* (PDFs), as they are some of the most important mathematical objects used in making predictions in theoretical physics. They are also the current bottleneck in terms of accuracy, and it is of utmost importance to do our best to improve this accuracy and efficiency of the programs that calculate them.

To give a brief description, high-energy physics is concerned with the behavior of the universe on the smallest possible energy scales. One way we answer these questions is accelerating protons to nearly the speed of light, and colliding them together. At such high speeds/energies, the protons' structure breaks down, leading to thousands of smaller particles in the final state. These fly into detectors and our analysis tools help us figure out what happened in the interaction. One of our main goals is to try and uncover signatures of new interactions. These are indicated/predicted by theoretical physicists.

As mentioned, the proton's structure begins to break down at high energies. Inside the protons are partons, things like quarks, and they become the main factor that plays into the interations, rather than the structure of the proton itself. PDFs encode information relative to how these quarks are interspersed throughout the proton. Specifically, they give a probability that one will find a given parton with a certain fraction of the proton's momentum.

One way we can analyze these PDFs is via the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi equations, denoted DGLAP equations, where the name comes from the physicists who came up with them. These tell how the PDFs change at different energy scales, meaning they tell us how the probabilities of finding quarks within the proton with a given momentum fraction change with different energies/speeds of the protons.

The DGLAP equations are highly complex integro-differential equations that are impossible to solve by hand; their solutions must be numerically calculated. The main guts of our research this semester was in determining how to numerically compute the solutions. In particular, we make an approximation of the *form* of the solutions which contain some unknown coefficients, then determine, from initial conditions, what the coefficients must be. From there, we can calculate the coefficients then plug them into our approximation to determine the full answer.

It is not so easy to just generate some generic solution and solve for the coefficients, however, because the mathematical structure of the equations must be preserved because it inherently encodes some of the physics of the system as well. Further, with the number of moving pieces at this level, the code takes already a very long time to run, so smart choices must be made.

Another one of our goals is to start incorporating corrections to physical quantities used in the calculation that are being calculated for in recent years. The original code from my professors group was made around 20 years ago, and only in the past few years have substantial corrections to quantities been made, so now it is time to incorporate those, as well, to generate even more accurate solutions.

Unlike the previous reflections I have done, this time we have done more than just some more directed learning, and have gotten our hands on with genuine advancements in the research (I am not saying that previous reflections were not research: the knowledge we gained there was more than any class, even graduate ones, would offer). Currently, the code that calculates the solutions has been heavily upgraded from C to C++, with many efficiency improvements made, and also other libraries that can do some complex numerical calculations are now used, and the code runs much faster and looks much nicer.

Our goals were originally to have fully implemented a new solution assumption, called an ansatz, and have it tested before the end of the semester. However, with everyone’s busy schedules and some unforeseen complications with the ansatz, this was much harder than we expected, and we were unable to achieve that. However, we are very close, and this summer a paper will almost certainly be able to be published with novel results.

I absolutely grew during this experience, as well as the previous ones. The knowledge that I have gained will be absolutely indispensable for my future as a high-energy theoretical particle physicist, and getting hands on with such complex and novel problems this early in my career has already boosted my resume and overall experience very much.

In terms of how this can be applied to other coursework, largely due to the highly advanced things that are being done that are simply not even considered for any of the undergraduate classes I'm taking. The only thing I can think of is that the programming experience I have gained may make next semester's Computational Physics II class a bit easier, but my programming experience is already quite high, because I have a Computer Science minor and I've been programming for many years already.

Critical thinking was without a doubt the main Honors foundation we focused on. This time, there are no textbook answers to compare to or anything like that; we have to think hard and come up with solutions ourselves. We can see how others in the literature do similar things, but again, this is completely novel research that we have to think about ourselves. Critical thinking is a must to get anywhere in this field.

In general, this was a fantastic experience. I received the Birla Carbon award to continue this research over the summer, and hopefully, unless the research funding cuts hit here, we will continue to get some money from the National Science Foundation (NSF) to continue in the fall and next spring.