Research Statement

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1 Introduction

I'm largely interested in Computational Mathematics, specificially regarding the algorithms and analysis of them. Therefore, some fields that I find interesting are numerical linear algebra, computational group theory, fast PDE/ODE solvers, etc. In addition, I have a substantial interest in the methods used to accomplish such tasks, such as compilers and high performance computing. Most have my study has gone to the pursuit of such topics, and most of my projects are directly related.

Ideally, I would like to work on projects or libraries similar to FLINT [1], LinBox [2], or FEniCS [3], as they do exactly what I'm interested in. However, I am trained in the relevant pure fields, and perhaps can add value to a project here by taking a computational approach.

2 Projects

To give you a better idea of what I've done so far, here's a few applications.

2.1 FFPoly

This is a new project I've begun, and have taken into my high performance computing course as a term project. In my graduate algebra course I was exposed to some algebraic number theory, and upon request, my professor showed me a few papers regarding the computational aspects of it. Intrigued, I decided to write a module in C++ implementing a element of the field $\mathbb{F}_p[x]$, for small $p \in \mathbb{Z}$.

This polynomial field is interesting, since the splitting behavior of minimal polynomials of number fields gives information of the splitting behavior of the corresponding primes in the algebraic number field. Furthermore, using Minkowski's bound, we could said information to verify the class groups of certain small quadratic number fields, which is interesting. SageMath has such a capability, but I had a couple of special ideas that I wanted to try; specifically I wanted to investigate the performance of parallelization on these problems. Regarding this, there is lots of potential for optimization in the field operations and factoring

[1] Fast Library for Number Theory: http://www.flintlib.org/
[2] Exact computational linear algebra: http://www.linalg.org/
[3] Finite Element Computational Software: https://fenicsproject.org/

steps, and some interesting active research going on in the field [4]. The goal here is to research a few ways to turn some computational algebra algorithms into parallel friendly methods, and use them to maybe try and beat out a few similar serial libraries in speed.

2.2 Algebraic Point Set Surfaces

During the Spring 2018 semester, my sophomore year, I took this course called Geometric Modeling. This was a masters/PhD level course, intended for those interested in computer graphics research or cutting edge level industry work, and I attended on reccomendation from a professor who thought the coursework was wild. While the whole class was a beautiful exercise in Numerical Optimization and Linear Algebra, my term project is currently a main motivation for me to pursue research in this field.

My final project was to implement the paper *Algebraic Point Set Surfaces* by Gunnebaud and Gross. Roughly speaking, in geometric modeling we have the pipeline: Physical object $\rightarrow$ spatial point cloud representing external surface $\rightarrow$ triangularized mesh representing object. The paper focused on a fast method to take the point cloud to a triangularized mesh. A prevailing method was to consider an open neighborhood of a point in the cloud, and fit a plane to it that minimized the distance to the points in that neighborhood. Such a plane would become part of the later mesh. The paper suggested fitting a sphere to these points instead, which was hugely advantageous in regions of high curvature. Such a fit would result in a non-linear optimization problem, but the key idea of using the algebraic definition of a sphere, results in a nicer computation. Specifically, given normals we can have a linear system solve, and the also proposed a method to estimate said normals with a generalized eigenproblem.

The truly difficult parts of this project to me wasn't the actual graphics theory, that was laid out nicely in the paper. What really plagued me was the implementation; I ran into serious runtime issues in the actual construction of the matrices involved in the eigenproblem, and later the system solve. I spent most of my time making various vectorization arguments to speed up the construction, and then later making sparsity arguments in the actual system solve.

Despite the difficulty of my first research level project, I truly enjoyed the construction process, nothing to say of the relief when I finally managed to triangularize a bunny [5]. In addition, it verified to me that I not only enjoyed the study of numerical methods, but liked and was capable of research and development in them.

[4] See the paper *Parallel Integer Polynomail Multiplication* by Chen, Covanov, Mansourim Maza, Xie and Xie

[5] A classic point cloud to construct is the Stanford Bunny model.