Ruiwen (Aaron) Zhong

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PROFILE

I am a self-motivated and result-driven graduate prepared to pursue advanced studies focused on applied math and machine learning with an immense interest in optimization theory. I possess exceptional research and writing skills and am adept at data and image analysis with a solid foundation in mathematics. I have studied with well-respected academics while completing my bachelor's degree.

EDUCATION

Feb 2020 — Jan 2023

Bachelor of Science & Bachelor of Science (Honours) in Applied Mathematics, University of New South Wales

Sydney, Australia

- **Relevant Courses**: Applied Real and Functional analysis, Modern Analysis, Modern Algebra, Higher Probability and Stochastic Process, Topology and differential geometry, Optimization, Mathematical computing for finance, Mathematical optimization for data science.
- **Grade** : Bachelor of Science: Mathematics Major (76/100, Distinction Average) | Bachelor of Science (Honors) in Applied Mathematics (Graduated with Second Class Honors, Upper Division) (Completed the total 4-year undergraduate program in 3 years)
- **Honor's Degree Thesis**: The Construction of the Generalized Wasserstein Distance with High Computational Efficiency. Under the Supervision of Professor Gary Froyland (Fellow of SIAM and Australian Academy of Science)

Feb 2019 — Nov 2019

Diploma of Engineering (Information Technology), Monash College

Melbourne, Australia

Graduated with Distinction Average.

EMPLOYMENT HISTORY

Sep 2023 — Present

Junior Research Assistant, The Chinese University of Hong Kong, Department of Mathematics

Hong Kong

- Working as a research assistant at the Department of Mathematics of CUHK under the supervision of Professor Ronald Lok Ming Lui. The research project focuses on pavement shape analysis, which sits at the intersection of differential geometry and image analysis. Specifically, my task is to use Matlab/Python to compute the geometric quantities of the pavement's surface and then apply advanced image processing, machine learning and deep learning techniques to identify all kinds of defective parts and classify them.
- Geometry deep generative model (with focus on medical image analysis)

Aug 2022 — Dec 2022

Research Assistant, University of New South Wales, School of Population Health

Sydney, Australia

Working as a research assistant in the School of Population Health of UNSW Medicine to support Professor James Wood to carry out the project about COVID Modeling for the New South Wales Ministry of Health. My specific task is to use MATLAB to build the pandemic model and to refine the model (discrete time SIR type) assumptions through comparisons to data, stratify this to be spatially explicit, and build in some additional relevant time-varying components (ascertainment, vaccination rate).

PROJECTS

Jan 2022 — Dec 2022

Honor's Degree Research Project

Sydney, Australia

- My Honor Year Project focused on the construction of the generalized Wasserstein Distances between heat-maps of the sea surface temperature anomalies with high computational efficiency.
- I devised a novel approach to construct the new generalized Wasserstein distance to achieve high computational efficiency, enabling its implementation in real-world cases using the Julia programming language.

SKILLS

Machine Learning	Matlab
Python	Julia
Research & Analysis	Data Analysis

LANGUAGES

English	Highly proficient
Chinese	Native speaker

Statement of Purpose

Ruiwen Zhong

My journey in applied mathematics and computer science has been driven by a growing fascination with the power of abstract mathematical theories and algorithmic approaches to solve real-world problems. This fascination has led me to pursue a PhD in Computer Science at Columbia University. My research interests lie in optimization, particularly in linear and nonlinear programming, optimal transport theory, and convex optimization, with applications spanning robotics, computer vision, and machine learning. These interests dovetail perfectly with the interdisciplinary focus of Columbia's program and particularly with the research conducted in Assistant Professor Brian Plancher's Accessible and Accelerated Robotics Lab (A^2R Lab).

My passion for applied mathematics and its widespread applications in computer science was ignited during my undergraduate studies at the University of New South Wales (UNSW), where I majored in Applied Mathematics. Courses such as Modern Analysis, Abstract Algebra, and Optimization revealed the elegance and power of mathematical reasoning and its potential for solving complex computational problems. This realization cemented my resolve to pursue a career at the intersection of applied mathematics and computer science, with a focus on robotics. The rigorous curriculum at Columbia, including advanced courses in robotics (COMS W4733 Computational Aspects for Robots), machine learning (COMS W4772 Advanced Machine learning), and computer vision (COMS 4731 Computer Vision), promises to build on my theoretical foundation and turbocharge my ability to grapple with the world's most complex yet intriguing challenges.

A watershed moment in my academic journey was my honors degree project under the supervision of Professor Gary Froyland at UNSW. This project focused on developing a computationally efficient generalized Wasserstein distance, a challenge rooted in optimal transport theory. We aimed to quantify the similarity between heatmaps depicting sea surface temperature anomalies. This experience was transformative, requiring me to blend rigorous mathematical proofs with practical implementation.

The project presented significant challenges, particularly in extending the standard Wasserstein distance from the space of probability measures $P(X)$ to the space of finite non-negative Radon measures $M^+(X)$, leveraging Kellerer's extension of the Kantorovich-Rubinstein theorem. Drawing inspiration from the Jordan Decomposition theorem and the Radon-Nikodym theorem, we proposed a novel construction of a generalized Wasserstein distance, denoted as $D_1^a(\mu, \nu)$, which combines the standard Wasserstein distance d_{W_1} with the absolute difference between $\mu(X)$ and $\nu(X)$ to account for mass differences. A key innovation in our approach was the introduction of a reference measure $\gamma \in M^+(X)$ and the definition of a space of restricted Radon measures $M_\gamma(X)$, consisting of measures absolutely continuous with respect to γ with bounded Radon-Nikodym derivatives. This allowed us to prove that our proposed generalized Wasserstein distance satisfies metric properties, ensuring its mathematical validity and practical utility. This work not only advanced the theoretical understanding of optimal transport but also opened up new possibilities for its application in various domains, including robotics and computer vision.

Following my graduation from UNSW, I sought to deepen my knowledge and gain practical experience in applied mathematics and its applications in computer science. This realization led me to my current position as a Research Assistant at the Chinese University of Hong Kong, working under Professor Ronald Lok Ming Lui. Our research project focuses on 3D pavement shape analysis, a topic at the intersection of differential geometry and shape analysis. My responsibilities include designing algorithms and utilizing MATLAB/Python to calculate geometric quantities (Beltrami coefficient, Gaussian curvature...) for 3D surfaces of road pavements and using MeshLab to generate synthetic geometry data. I also apply machine learning algorithms to identify potholes and other defects, classifying them accordingly. This experience has broadened my horizons, exposing me to advanced computational geometry and optimization techniques and their wide-ranging applications combined with machine learning techniques. The interdisciplinary nature of Columbia's program, with collaborations across departments such as Industrial Engineering and Operations Research, would allow me to expand on this experience and apply mathematical techniques to an even broader range of computer science problems.

My interest in pursuing a PhD at Columbia University is further driven by the opportunity to work with Professor Brian Plancher and join his A^{2}R Lab. Professor Plancher's work, developing and implementing open-source algorithms for dynamic motion planning and control of robots, resonates strongly with my research interests and past experiences. My background in optimal transport theory, 3D shape analysis, and optimization, combined with Professor Plancher's expertise in robotics and computer architecture, sets the stage for an ideal environment where I can further develop my skills and contribute to groundbreaking research in robotics, fulfilling my dream of applying abstract mathematical theory to the real world.

I am particularly excited about the potential applications of my work in the context of Professor Plancher's research projects, especially in Next Generation (Nonlinear) Optimization Solvers and their applications in robotics. My background in optimal transport theory and exposure to nonlinear optimization problems positions me well to contribute to this research. The insights gained from my work on the generalized Wasserstein distance and my current research in 3D shape analysis offer unique perspectives on robotics optimization problems:

- Parallel Optimization for Real-time Robotics: Drawing from my work in optimization, I'm keen to explore parallel optimization techniques for robotics applications. This could involve developing GPU-accelerated versions of popular optimization algorithms, such as interior point methods or sequential quadratic programming, to enable real-time performance for complex robotic systems.

- Trajectory Optimization using Optimal Transport: The optimal transport framework I've worked with can be applied to generate smooth, efficient trajectories for robots. By treating the robot's start and goal configurations as probability distributions, we can formulate trajectory planning as an optimal transport problem, potentially leading to more natural and efficient motion plans.

- Multi-robot Coordination through Distributed Optimization: Extending my work on the generalized Wasserstein distance, I'm excited about the possibility of developing distributed optimization algorithms for multi-robot systems. This could involve formulating coordination problems as distributed optimal transport problems, enabling efficient and scalable solutions for large teams of robots.

These research directions align closely with Professor Plancher's work on developing robust optimization methods for real-time applications in robotics. By combining my background in mathematical optimization with the A^2R Lab's focus on algorithm-hardware co-design and guidance from Professor Planche, the Computer Science program at Columbia University provides the ideal combination of theoretical depth and real-world application that I am seeking for my doctoral studies. I'm particularly excited about the potential of leveraging insights from optimal transport theory to develop novel optimization techniques that can handle the complex, high-dimensional problems encountered in modern robotics applications. Moreover, I am drawn to the strong faculty in the Computer Science Department at Columbia University. The opportunity to collaborate with other academics, such as working with Professor Changxi Zheng in computer graphics or Professor Shree Nayar in computer vision, would allow me to apply my mathematical and computational skills to an even broader range of problems.

Looking ahead, I am champing at the bit to push the envelope in robotics by leveraging optimization and machine learning techniques. I am confident that through collaboration with Professor Plancher and active engagement with the diverse Columbia community, including with the university's IEOR departments, I will acquire the necessary skills and knowledge to make this aspiration a reality. Upon completing my PhD, I aim to pursue a career as a research scientist, either in academia or at a pioneering robotics company. My aim? To bridge the gap between theoretical computer science and mathematical optimization and apply it to practical robotics, developing innovative solutions to advance the field and its real-world implementations.

My academic background, research experiences, and future aspirations make me well-suited for the Computer Science PhD program at Columbia University. The department's strong emphasis on interdisciplinary research, state-of-the-art facilities, and vibrant academic community provide an ideal environment for my doctoral studies. I am enthusiastic about the opportunity to contribute to the vibrant research environment at Columbia and to work under the guidance of Professor Plancher. I am confident that this program will equip me with the knowledge, skills, and opportunities required to make substantial contributions to computer science and its applications in robotics and beyond.