Wenxin Liu

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Education

Imperial College London **Sep. 2024 – Sep. 2025**
Master of Science in Applied Mathematics(Scientific computing and Machine Learning)

Xi'an Jiaotong Liverpool University **Sep. 2020 – Jun. 2024**
Bachelor of Science in Applied Mathematics *First class honors*

Relevant Courses

- Discrete Mathematics
- Functional analysis
- Theory of PDEs
- Computational Linear Algebra
- Computational PDEs
- Finite Element
- Scientific Computing
- Data Science
- Optimization

Highly relevant experiences with numerical analysis and optimization

Postgraduate Final Project about Optimal Transport **Jan. 2025–Sep. 2025**

- Conduct symmetric Douglas-Rachford splitting and prime-dual method with proximal operator for solving the dynamic optimal transport problem, compare its performance with the Sinkhorn algorithm.
- Use Schrödinger Bridge to approximate the solution of optimal transport problems in both dynamic way and static way, and implement the algorithm for solving the Schrödinger Bridge problem with Forward and Backward system with proximal recursion.
- Implement the Schrödinger Bridge problem with nonlinear prior drift and reflective boundary conditions, and apply the algorithm to solve the problem with prior drift and boundary conditions like obstacles.

Computational Partial Difference Equation Project **Jan. 2025 – Apr. 2025**

- Solve second order Nonlinear ODE and nonlinear heat equation with explicit method, lagged approach and implicit Newton linearization, analyze numerical result with physical meaning and theoretical perturbation analysis.
- Develop numerical solutions for elliptic PDEs with non-uniform boundary conditions using structured grid mapping and adaptive mesh refinement (AMR) to enhance accuracy in complex geometries. For matrix computation, implement iterative solvers (Gauss-Seidel, SOR, multigrid) for large sparse linear systems, as well as comparing their convergence rates and computational efficiency.
- Develop second-order accurate numerical solvers for the wave equation using the Leapfrog method with Neumann and transparent boundary conditions. Perform discrete Fourier analysis to assess numerical dissipation and dispersion, and designed a position-dependent Perfectly Matched Layer (PML) to reduce boundary reflections by 85%. Validated accuracy and convergence through analytical Fourier analysis and MATLAB-based 3D simulations.
- Design an IMEX finite difference framework for coupled wave-heat systems, combining explicit wave solvers and implicit thermal diffusion. Derived stability criteria via Fourier and Jury analysis, and implement efficient solvers using staggered grids and tridiagonal matrix methods. Demonstrated the effect of thermal diffusivity on energy dissipation and wave behavior with vary of variables through numerical experiments.

Finite Element: theory and implementation Project **Jan. 2025 – Apr. 2025**

- Implement an object-oriented finite element framework in Python to solve elliptic PDEs (Helmholtz/Poisson equations), featuring modular classes for Lagrange elements, function spaces, structured meshes (UnitSquareMesh), and Gauss quadrature rules. Engineer a global node numbering system to map local-to-global degrees of freedom, enabling efficient sparse matrix assembly via cell-wise contributions. Utilized einsum-optimized tensor operations to compute stiffness/mass matrices.
- Engineer a mixed finite element solver for Stokes equations ($\mu\Delta\mathbf{u} = \nabla p + \mathbf{f}, \nabla\cdot\mathbf{u} = 0$) with structured 2D meshes. Design vector-valued Lagrange elements with tensor-product basis functions, extending scalar tabulation to handle 2D velocity fields via Vandermonde matrix-based evaluations. Implemented divergence and gradient coupling terms through block matrix assembly ($A = \begin{bmatrix} A_{\mathrm{u}} & B^T \\ B & 0 \end{bmatrix}$) using SciPy's sparse lil_matrix format, and stabilized the saddle-point system via pressure Poisson stabilization (diagonal perturbation). Optimize strain-rate tensor $\left(\epsilon(\mathbf{u}) = \frac{1}{2}\left(\nabla\mathbf{u} + \nabla\mathbf{u}^T\right)\right)$ integration using einsum -accelerated operations. Then deploy the solver to simulate incompressible viscous flows ($\mu = 1$) with analytic benchmarks derived from stream functions ($\psi(x, y) = (1 - \cos 2\pi x)(1 - \cos 2\pi y)$).

Data Science Project **Jan. 2025 – Apr. 2025**

- Develop multi-class classifiers (Decision Trees, Random Forests) and Huberised SVM models with Numpy for airfield weather condition prediction, leveraging meteorological features (frost days, humidity, wind speed). Designed a weighted Gini index with custom loss matrices to prioritize critical class discrimination (e.g., class 0 vs 1), achieving 18% higher pairwise accuracy for rare weather events. Optimized Random Forests via Gini importance-based feature selection, identifying precipitation and wind speed as dominant predictors. Stabilized SVM training with modified Huber loss and mini-batch SGD, achieving 94.1% test accuracy.

- Design a compound loss MLP for joint runway temperature prediction with physical constraints. Implemented transfer learning by freezing pretrained MLP hidden layers and fine-tuning sigmoid output layers for binary classification, achieving accuracy to 99.8% versus 97% for non-transferred models. Validated via activation histograms and probabilistic calibration, demonstrating reduced overfitting on limited training data.
- Design a U-Net convolutional neural network in PyTorch for joint dimensionality reduction and gene expression regression. Train the model using a multi-task loss ($L_{\text{multi}} = \text{MSE}_{\text{regress}} + \alpha\text{MSE}_{\text{reconstruct}}$) with Adam optimization $\left(\eta = 10^{-3}\right)$, tuning different α via validation-set cross-validation. Achieved $R^2 = 0.69$ on regression with early stopping, demonstrating synergistic learning between feature reconstruction and target prediction. Visualized per-feature reconstruction errors via heatmaps.
- Construct a spectral layout using normalized Laplacian eigenvectors for data analysis and clustering, conducting analysis for degree centrality via bipartite histograms.

Computational Linear Algebra Project **Sep. 2024–Jan. 2025**

- Develope QR-based solvers for least squares problems (over/underdetermined systems), implementing 4 algorithms: Normal Equations, Classical/Modified Gram-Schmidt, and Householder (Python/Numpy). Design regularization method for ill-posed least-square problems using augmented QR factorization, reducing condition number by 5 orders of magnitude with $\lambda = 1e - 6$ penalty.
- Implement and analyze the practical QR algorithm for computing eigenvalues of real symmetric matrices, including enhancements such as Wilkinson shift and deflation. Demonstrate the efficiency of Wilkinson shift in accelerating convergence through comparative experiments across varying matrix sizes, and verify eigenvalue accuracy via inverse iteration.
- Extend the GMRES algorithm by implementing Jacobi and Gauss-Seidel preconditioners to improve convergence on ill-conditioned systems. Conduct a comparative analysis of residual decay and convergence rates for varying ϵ values, showing that preconditioning significantly improves performance, especially with Gauss-Seidel under increasing ill-conditioning.

Scientific computing Project **Sep. 2024 – Jan. 2025**

- Implement and analyze linear search, merge sort with binary search method $(O((m + n) \log n))$ for searching and pattern matching in large datasets. Apply the Rabin-Karp algorithm for pattern matching in amino acid sequences, utilizing optimized hash calculations for fast sequence comparison.
- Develop and analyze numerical solutions for a nonlinear dynamical system of ODEs, focusing on equilibrium solutions, perturbation energy, and system dynamics. Implemented tests comparing perturbation energy calculations with simulations, showing consistency and accuracy. Analyzed periodic, aperiodic, and chaotic behaviors for different system sizes, using Principal Component Analysis (PCA) and correlation dimension analysis to identify chaotic dynamics.
- Implement the extended Kalman filter for Lorenz system, analyze the computational cost of one step of the extended Kalman filter. Focused on identifying the most computationally expensive portions of the method and explored trends in wall time with varying problem sizes.

Undergraduate Final Project about Numerical Optimization **Sep. 2023–Jun. 2024**

- Apply the interior point method by transforming inequality-constrained problems into equality-constrained forms using indicator functions, enabling the use of barrier methods for numerical solution approximation, and implement the algorithm for linear programming solvers.
- Implemented Newton's method as the core iterative approach, deriving iterative equations from the KKT conditions. Extended the framework to a primal-dual approach by reformulating the KKT conditions into residual functions.

Teaching Assistant for School Numerical Analysis course **Feb. 2024–Jun. 2024**

- Assistant for lab course and teach basic skills with Matlab.

Honors/Awards

School Operational Research Festival | *Competition* **May 2023**

- Serve as the captain in a team competition at the School of Operational Research, leading a group in the study of integer programming to solve the Traveling Salesman problem. Dive into the intricacies of integer programming models pertaining to scheduling and activity table arrangements. As a result of our diligent research efforts, we secured first place in the inter-school festival competition.

Honor in Mathematic Competition in Modeling(MCM) **Jan. 2021**

- A multi-day mathematical modeling competition is held annually in the US. Awarded to top 15% teams based on an outstanding competition record and unusual potential for math modeling.

Technical Skills

Computer Languages: Python, Java, Matlab, R, Lingo
Developing Tools: NumPy, Scipy, Pandas, PyTorch