

## HAIZHAO YANG

Department of Mathematics  
Department of Computer Science (Affiliated)  
University of Maryland, College Park, MD, USA

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### CURRENT POSITION

Associate Professor	2023 - now
Assistant Professor	2022 - 2023
Department of Mathematics	
Department of Computer Science (affiliated)	
The University of Maryland Institute for Advanced Computer Studies (UMIACS)	
Center of Machine Learning	
University of Maryland College Park, US	

### PREVIOUS POSITION

Assistant Professor (tenure approved in 2022)	2019 - 2022
Department of Mathematics	
Purdue University, US	
Assistant Professor	2017 - 2019
Department of Mathematics	
Affiliate, Institute of Data Science	2019
National University of Singapore, Singapore	
Visiting Assistant Professor, Duke University, US	2015 - 2017
Mentors: Ingrid Daubechies and Jianfeng Lu	

### EDUCATION

<b>Ph.D. in Mathematics</b> , Stanford University, US	2015
Advisor: Lexing Ying	
<b>M.S. in Mathematics</b> , University of Texas at Austin, US	2012
<b>B.S. in Mathematics</b> , Shanghai Jiao Tong University, China	2010

### HONORS

Maryland Research Excellence	2023
ONR Young Investigator Award	2022
Teaching for Tomorrow Award, Purdue University	2021
NSF CAREER Award	2020
AMS-Simons Travel Award	2015-2017
SIAM Early Career Travel Award	2015
SIAM Student Travel Award	2013-15
Shanghai Outstanding Graduate, Shanghai Government	2010
First prize of the senior thesis, Department of Mathematics, Shanghai Jiao Tong University	2010
National scholarship, Chinese Ministry of Education	2009

## PUBLICATIONS

<sup>+</sup> equal contribution; \* corresponding author; <sup>†</sup> student or postdoc mentored.

## Preprints

- S14 Yahong Yang, Yue Wu, **Haizhao Yang**<sup>\*</sup>, Yang Xiang<sup>\*</sup>. Nearly Optimal Approximation Rates for Deep Super ReLU Networks on Sobolev Spaces. Submitted to Journal of Machine Learning Research. <http://arxiv.org/abs/2310.10766>
- S13 Yihui Tu, Zhenli Xu, Haizhao Yang. Hierarchical Interpolative Factorization for Self Green's Function in 3D Modified Poisson-Boltzmann Equations. Submitted. <https://arxiv.org/abs/2307.01060>
- S12 Zezheng Song<sup>†</sup>, Maria K. Cameron, **Haizhao Yang**<sup>\*</sup>. A Finite Expression Method for Solving High-Dimensional Committor Problems. Submitted to SIAM Journal of Scientific Computing. <https://arxiv.org/abs/2306.12268>
- S11 Qiyan Pang<sup>†</sup>, **Haizhao Yang**<sup>\*</sup>. Spectral Clustering via Orthogonalization-Free Methods. Submitted. <http://arxiv.org/abs/2305.10356>
- S10 Wenrui Hao<sup>+</sup>, Chunmei Wang<sup>++</sup>, Xingjian Xu<sup>+</sup>, **Haizhao Yang**<sup>+</sup>. Deep Learning via Neural Energy Descent. Submitted. <https://arxiv.org/abs/2302.10424>
- S9 Zhongyi Jiang<sup>†</sup>, Chunmei Wang, **Haizhao Yang**<sup>\*</sup>. Finite Expression Methods for Discovering Physical Laws from Data. Submitted. <https://arxiv.org/abs/2305.08342>
- S8 Shixin Zheng, **Haizhao Yang**, Xiangxiong Zhang<sup>\*</sup>. On the convergence of orthogonalization-free conjugate gradient method for extreme eigenvalues of Hermitian matrices: a Riemannian optimization interpretation. Submitted to Journal of Computational and Applied Mathematics. <https://arxiv.org/abs/2302.04974>
- S7 Qiyan Pang<sup>†</sup>, **Haizhao Yang**<sup>\*</sup>, A Distributed Block Chebyshev-Davidson Algorithm for Parallel Spectral Clustering. Submitted to Journal of Scientific Computing. [arXiv:2212.04443](https://arxiv.org/abs/2212.04443)
- S6 Senwei Liang<sup>†</sup>, **Haizhao Yang**<sup>\*</sup>. Finite Expression Method for Solving High-Dimensional Partial Differential Equations. Submitted to Forum of Mathematics, Sigma. <https://arxiv.org/abs/2206.10121>
- S5 Hanyang Jiang<sup>++</sup>, Yuehaw Khoo<sup>+</sup>, **Haizhao Yang**<sup>+</sup>. Reinforced Inverse Scattering. Minor revision, SIAM Journal on Scientific Computing. <https://arxiv.org/abs/2206.04186>
- S4 Hao Liu, **Haizhao Yang**<sup>\*</sup>, Minshuo Chen, Tuo Zhao, Wenjing Liao<sup>\*</sup>. Deep Nonparametric Estimation of Operators between Infinite Dimensional Spaces. Submitted to Journal of Machine Learning Research. <https://arxiv.org/abs/2201.00217>
- S3 Senwei Liang<sup>†\*</sup>, Shixiao W. Jiang, John Harlim, **Haizhao Yang**. Solving PDEs on Unknown Manifolds with Machine Learning. Submitted to Applied and Computational Harmonic Analysis. <https://arxiv.org/abs/2106.06682>
- S2 Efficient Attention Network: Accelerate Attention by Searching Where to Plug. Zhongshan Huang, Senwei Liang<sup>†</sup>, Mingfu Liang, Wei He, **Haizhao Yang**<sup>\*</sup>. Submitted to IEEE Transactions on Neural Networks and Learning Systems. <https://arxiv.org/abs/2011.14058>
- S1 Tao Luo<sup>+</sup>, **Haizhao Yang**<sup>++</sup>. Two-Layer Neural Networks for Partial Differential Equations: Optimization and Generalization Theory. <https://arxiv.org/abs/2006.15733>

## Journal Publications

- J61 Zhongzhan Huang, Senwei Liang<sup>†</sup>, Hong Zhang, **Haizhao Yang**, Liang Lin\*, On Fast Simulation of Dynamical System with Neural Vector Enhanced Numerical Solver. To appear, Scientific Report. <https://arxiv.org/abs/2208.03680>
- J60 Ke Chen<sup>+†</sup>, Chunmei Wang<sup>+</sup>, **Haizhao Yang**<sup>++</sup>. Deep Operator Learning Lessens the Curse of Dimensionality for PDEs. To appear, Transactions on Machine Learning Research. <https://arxiv.org/abs/2301.12227>
- J59 Senwei Liang<sup>+†</sup>, Liyao Lyu<sup>+</sup>, Chunmei Wang<sup>+</sup>, **Haizhao Yang**<sup>++</sup>. Reproducing Activation Function for Deep Learning. To appear, Communication in Mathematical Sciences. <https://arxiv.org/abs/2101.04844>
- J58 Jieren Xu, Yitong Li, **Haizhao Yang**<sup>\*</sup>, David Dunson, Ingrid Daubechies. PiPs: a Kernel-based Optimization Scheme for Analyzing Non-Stationary 1D Signals. To appear, Applied and Computational Harmonic Analysis. <https://arxiv.org/abs/1805.08102>
- J57 Fan Chen<sup>+</sup>, Jianguo Huang<sup>+</sup>, Chunmei Wang<sup>+</sup>, **Haizhao Yang**<sup>++</sup>. Friedrichs Learning: Weak Solutions of Partial Differential Equations via Deep Learning. SIAM Journal on Scientific Computing, Vol. 45, Iss. 3, 2023.
- J56 Yiqi Gu<sup>+†</sup>, John Harlim<sup>+</sup>, Senwei Liang<sup>+†\*</sup>, **Haizhao Yang**<sup>+</sup>. Stationary Density Estimation of Itô Diffusions Using Deep Learning. SIAM Journal on Numerical Analysis, Volume 61, Number 1, Pages 45-82, 2023.
- J55 Fusheng Liu, **Haizhao Yang**, Soufiane Hayou, Qianxiao Li\*. From Optimization Dynamics to Generalization Bounds via Łojasiewicz Gradient Inequality. Transactions on Machine Learning Research, 2022. <https://openreview.net/pdf?id=mW6nD3567x>
- J54 Yong Zheng Ong<sup>+†</sup>, Zuowei Shen<sup>+</sup>, **Haizhao Yang**<sup>++</sup>. IAE-Net: Integral Autoencoders for Discretization-Invariant Learning. Journal of Machine Learning Research, 23(286):1-45, 2022.
- J53 Zuowei Shen<sup>+</sup>, **Haizhao Yang**<sup>+</sup>, Shijun Zhang<sup>+†</sup>. Deep Network Approximation: Achieving Arbitrary Accuracy with Fixed Number of Neurons. Journal of Machine Learning Research, 23(276):1-60, 2022.
- J52 Sean Hon<sup>++</sup>, **Haizhao Yang**<sup>+</sup>. Simultaneous Neural Network Approximations for Smooth Functions. Neural Networks, Volume 154, October 2022, Pages 152-164
- J51 Qiang Du<sup>+</sup>, Yiqi Gu<sup>+†</sup>, **Haizhao Yang**<sup>++</sup>, Chao Zhou<sup>+</sup>. The Discovery of Dynamics via Linear Multistep Methods and Deep Learning: Error Estimation. SIAM Journal on Numerical Analysis, Vol. 60, Iss. 4, 2022
- J50 Jingwei Hu<sup>++</sup>, Xiaodong Huang<sup>+</sup>, Jie Shen<sup>+</sup>, **Haizhao Yang**<sup>+</sup>. A fast Petrov-Galerkin spectral method for the multi-dimensional Boltzmann equation using mapped Chebyshev functions. SIAM Journal on Scientific Computing, volume 44, number 3, pages A1497-A1524, 2022.
- J49 Yihui Tu<sup>†</sup>, Zhenli Xu, Qiyuan Pang<sup>†</sup>, Kenneth L. Ho, **Haizhao Yang**. Linear-Scaling Selected Inversion based on Hierarchical Interpolative Factorization for Self Green's Function for Modified Poisson-Boltzmann Equation in Two Dimensions. Journal of Computational Physics, Volume 461, 15 July 2022, 110893
- J48 Zuowei Shen<sup>++</sup>, **Haizhao Yang**<sup>+</sup>, Shijun Zhang<sup>+†</sup>. Optimal Approximation Rate of ReLU Networks in terms of Width and Depth. Journal de Mathématiques Pures et Appliquées, Volume 157, January 2022, Pages 101-135
- J47 Yong-Zheng Ong<sup>†</sup>, **Haizhao Yang**<sup>\*</sup>, Generative Imaging and Image Processing via Generative Encoder. Inverse Problems & Imaging, 16(3): 525-545, 2022.
- J46 Ling Li, Carl Goodrich, **Haizhao Yang**, Katherine R Phillips, Zian Jia, Hongshun Chen, Lifeng Wang, Jinjin Zhong, Anhua Liu, Jianfeng Lu, Jianwei Shuai, Michael P Brenner, Frans Spaepen, Joanna Aizenberg. Microscopic Origins of the Crystallographically Preferred Growth in Evaporation-Induced Colloidal Crystals. Proceedings of the National Academy of Sciences (PNAS), 118(32), 2021.

- J45 Jianfeng Lu<sup>+</sup>, Zuowei Shen<sup>+</sup>, **Haizhao Yang**<sup>+</sup>, Shijun Zhang<sup>†</sup>. Deep Network Approximation for Smooth Functions. *SIAM Journal of Mathematical Analysis*, 53(5), 5465-5506, 2021.
- J44 Yiqi Gu<sup>†</sup>, **Haizhao Yang**<sup>\*</sup>, Chao Zhou. SelectNet: Self-Paced Learning for High-Dimensional Partial Differential Equations. *Journal of Computational Physics*, Volume 441, 15 September 2021, 110444.
- J43 James Bremer<sup>+</sup>, Ze Chen<sup>†</sup>, **Haizhao Yang**<sup>+</sup>, Rapid Application of the Spherical Harmonic Transform via Interpolative Decomposition Butterfly Factorization. *SIAM Journal on Scientific Computing*, 43(6), A3789-A3808, 2021
- J42 Hadrien Montanelli, **Haizhao Yang**<sup>\*</sup>, Qiang Du, Deep ReLU Networks Overcome the Curse of Dimensionality for Bandlimited Functions. *Journal of Computational Mathematics*, 39 (2021), pp. 801-815.
- J41 Yingzhou Li<sup>+</sup>, **Haizhao Yang**<sup>+</sup>, Interior Eigensolver for Sparse Hermitian Definite Matrices Based on Zolotarev Functions. *Communications of Mathematical Sciences*, Volume 19, Number 4, Pages 1113-1135, 2021.
- J40 Zuowei Shen<sup>+</sup>, **Haizhao Yang**<sup>+</sup>, Shijun Zhang<sup>†</sup>. Neural Network Approximation: Three Hidden Layers Are Enough. *Neural Networks*, Volume 141, September 2021, Pages 160-173.
- J39 Yiqi Gu<sup>†</sup>, Chunmei Wang<sup>+</sup>, **Haizhao Yang**<sup>+</sup>. Structure Probing Neural Network Deflation. *Journal of Computational Physics*, Volume 434, 1 June 2021, 110231.
- J38 Zuowei Shen<sup>+</sup>, **Haizhao Yang**<sup>+</sup>, Shijun Zhang<sup>†</sup>. Deep Network Approximation with Discrepancy Being Reciprocal of Breadth to Power of Depth. *Neural Computation* (2021) 33 (4): 1005-1036.
- J37 John Harlim<sup>+</sup>, Shixiao Jiang<sup>+</sup>, Senwei Liang<sup>†</sup>, **Haizhao Yang**<sup>+</sup>. Machine Learning for Prediction with Missing Dynamics. *Journal of Computational Physics*, Volume 428, 1 March 2021, 109922.
- J36 James Bremer<sup>+</sup>, Qiyuan Pang<sup>†</sup>, **Haizhao Yang**<sup>+</sup>. Fast Algorithms for Multi-Dimensional Jacobi Polynomial Transformations. *Applied and Computational Harmonic Analysis*, Volume 52, May 2021, Pages 231-250, 2021.
- J35 **Haizhao Yang**<sup>\*</sup>. Multiresolution Mode Decomposition for Adaptive Time Series Analysis. *Applied and Computational Harmonic Analysis*, Volume 52, May 2021, Pages 25-62, 2021.
- J34 Senwei Liang<sup>†</sup>, Yuehaw Kwo, **Haizhao Yang**<sup>\*</sup>. Drop-Activation: Implicit Parameter Reduction and Harmonic Regularization. *Communications on Applied Mathematics and Computation*, 3, Pages 293-311 (2021).
- J33 Zuowei Shen<sup>+</sup>, **Haizhao Yang**<sup>+</sup>, Shijun Zhang<sup>†</sup>. Deep Network Approximation Characterized by Number of Neurons. *Communications in Computational Physics*, 28 (2020), pp. 1768-1811.
- J32 Hadrien Montanelli<sup>+</sup>, **Haizhao Yang**<sup>+</sup>, Error Bounds for Deep ReLU Networks using the Kolmogorov-Arnold Superposition Theorem. *Neural Networks*, Volume 129, September 2020, Pages 1-6.
- J31 Jianguo Huang<sup>+</sup>, Haoqin Wang<sup>+</sup>, **Haizhao Yang**<sup>+</sup>, Int-Deep: A Deep Learning Initialized Iterative Method For Nonlinear Problems. *Journal of Computational Physics*, Volume 419, 15 October 2020, 109675.
- J30 Xiangxiang Zhu<sup>†</sup>, **Haizhao Yang**, Zhuosheng Zhang<sup>\*</sup>, Jinghui Gao, Naihao Liu. Frequency-Chirp Rate Reassignment. *Digital Signal Processing*, Volume 104, September 2020, 102783.
- J29 Ze Chen<sup>†</sup>, Juan Zhang, Kenneth L. Ho, **Haizhao Yang**<sup>\*</sup>, Multidimensional Phase Recovery and IDBF for Fast Oscillatory Integral Transforms. *Journal of Computational Physics*, Volume 412, 1 July 2020, 109427.
- J28 Gao Tang<sup>†</sup>, **Haizhao Yang**<sup>\*</sup>, A Fast Algorithm for Multiresolution Mode Decomposition. *Multiscale Modeling and Simulation*, 18(2), 707-736, 2020.
- J27 Qiyuan Pang<sup>†</sup>, Kenneth L. Ho, **Haizhao Yang**<sup>\*</sup>. Interpolative Decomposition Butterfly Factorization. *SIAM Journal on Scientific Computing*, Vol. 42, No. 2, pp. A1097-A1115, 2020.
- J26 Yang Liu<sup>+</sup>, **Haizhao Yang**<sup>+</sup>. A Hierarchical Butterfly LU Preconditioner for Two-Dimensional Electromagnetic Scattering Problems Involving Open Surfaces. *Journal of Computational Physics*, al of Computational Physics, Volume 401, 15 January 2020, Pages 109-014.

- J25 Katherine R. Phillips, Cathy T. Zhang, Ting Yang, Theresa Kay, Chao Gao, Soren Brandt, Lei Liu, **Haizhao Yang**, Yaning Li, Joanna Aizenberg, Ling Li\*. Fabrication of Photonic Microbricks via Crack Engineering of Colloidal Crystals. *Advanced Functional Materials*, Volume 30, Issue 26, June 25, 2020, 1908242. **Frontispiece article.**
- J24 Tao Zhang<sup>†</sup>, Ling Li, **Haizhao Yang**\*. 3D Atomic Crystal Analysis via Fast Synchrosqueezed Transform. *Communications of Mathematical Sciences*, Vol. 17, No. 8 (2019), pp. 2113-2140.
- J23 James Bremer<sup>++</sup>, **Haizhao Yang**<sup>+</sup>, Fast algorithms for Jacobi expansions via nonoscillatory phase functions. *IMA Journal of Numerical Analysis*, 04, 2019. ISSN 0272-4979.
- J22 **Haizhao Yang**\*, A Unified Framework for Oscillatory Integral Transforms: When to Use NUFFT or Butterfly factorization? *Journal of Computational Physics*, Volume 388, 1 July 2019, Pages 103-122.
- J21 Zuwei Shen<sup>+</sup>, **Haizhao Yang**<sup>++</sup>, Shijun Zhang<sup>††</sup>. Nonlinear Approximation via Compositions. *Neural Networks*, Volume 119, November 2019, Pages 74-84.
- J20 Jianfeng Lu<sup>+</sup>, **Haizhao Yang**<sup>++</sup>. Phase Space Sketching for Crystal Image Analysis Based on Synchrosqueezed Transforms. *SIAM Journal on Imaging Science*, 11(3), 1954-1978, 2018.
- J19 Victor Wen-zhe Yu, Fabiano Corsetti, Alberto García, William P. Huhn, Mathias Jacquelin, Weile Jia, Björn Lange, Lin Lin, Jianfeng Lu, Wenhui Mi, Ali Seifitokaldani, Álvaro Vázquez-Mayagoitia, Chao Yang, **Haizhao Yang**, Volker Blum\*, ELSI: A Unified Software Interface for Kohn-Sham Electronic Structure Solvers. *Computer Physics Communications*, Volume 222, January 2018, Pages 267-285.
- J18 Jieren Xu, **Haizhao Yang**\*, and Ingrid Daubechies, Recursive Diffeomorphism-Based Regression for Shape Functions. *SIAM Journal of Mathematical Analysis*, 50(1), 5-32, 2018.
- J17 **Haizhao Yang**\*. Statistical Analysis of Synchrosqueezed Transforms. *Applied and Computational Harmonic Analysis*, Volume 45, Issue 3, November 2018, Pages 526-550.
- J16 Yingzhou Li<sup>+</sup>, **Haizhao Yang**<sup>++</sup> and Lexing Ying. Multidimensional Butterfly Factorization. *Applied and Computational Harmonic Analysis*, Volume 44, Issue 3, May 2018, Pages 737-758.
- J15 Yingzhou Li<sup>+</sup>, and **Haizhao Yang**<sup>++</sup>. Interpolative Butterfly Factorization. *SIAM Journal on Scientific Computing*, 39(2), A503-A531, 2017.
- J14 John Harlim<sup>++</sup>, **Haizhao Yang**<sup>+</sup>. Diffusion Forecasting Model with Basis Functions from QR Decomposition. *Journal of Nonlinear Science*, 28, Pages 847-872 (2018).
- J13 Jianfeng Lu<sup>+</sup> and **Haizhao Yang**<sup>++</sup>. A Cubic Scaling Algorithm for Excited States Calculations in Particle-Particle Random Phase Approximation. *Journal of Computational Physics*, Volume 340, 1 July 2017, Pages 297-308.
- J12 Jianfeng Lu<sup>+</sup> and **Haizhao Yang**<sup>++</sup>. Preconditioning Orbital Minimization Method for Planewave Discretization. *Multiscale Modeling and Simulation*, 15(1), 254-273, 2017.
- J11 Bruno Cornelis, **Haizhao Yang**\*, Alex Goodfriend, Noelle Ocon, Jianfeng Lu, and Ingrid Daubechies, Removal of Canvas Patterns in Digital Acquisitions of Painting. *IEEE Transactions on Image Processing*, 26(1):160-171, 2017.
- J10 Jianfeng Lu<sup>+</sup>, Benedikt Wirth<sup>+</sup> and **Haizhao Yang**<sup>++</sup>. Combining 2D Synchrosqueezed Wave Packet Transform with Optimization for Crystal Image Analysis. *Journal of the Mechanics and Physics of Solids*, 89:194-210, 2016.
- J9 **Haizhao Yang**\*, Jianfeng Lu and Lexing Ying. Crystal Image Analysis Using 2D Synchrosqueezed Transforms. *Multiscale Modeling and Simulation*, 13(4), 1542-1572, 2015.
- J8 Yingzhou Li, **Haizhao Yang**, Eileen Martin, Kenneth L. Ho, and Lexing Ying\*. Butterfly factorization. *Multiscale Modeling and Simulation*, 13(2), 714-732, 2015.
- J7 Yingzhou Li<sup>+</sup>, **Haizhao Yang**<sup>++</sup> and Lexing Ying<sup>+</sup>. A Multiscale Butterfly Algorithm for Multidimensional Fourier Integral Operators. *Multiscale Modeling and Simulation*, 13(2), 614-631, 2015.
- J6 **Haizhao Yang**, Jianfeng Lu\*, William P. Brown, Ingrid Daubechies, and Lexing Ying, Quantitative Canvas Weave Analysis Using 2D Synchrosqueezed Transforms: Application of Time-Frequency Analysis to Art Investigation. *Signal Processing Magazine, IEEE*, 32(4):55-63, July 2015.

- J5 **Haizhao Yang**<sup>\*</sup>. Synchrosqueezed Wave Packet Transforms and Diffeomorphism Based Spectral Analysis for 1D General Mode Decompositions, *Applied and Computational Harmonic Analysis*, 39(1):33-66, 2015.
- J4 **Haizhao Yang**<sup>++</sup> and Lexing Ying<sup>+</sup>. Synchrosqueezed Curvelet Transform for Two-Dimensional Mode Decomposition, *SIAM Journal of Mathematical Analysis*, 46(3):2052-2083, 2014.
- J3 **Haizhao Yang**<sup>++</sup> and Lexing Ying<sup>+</sup>. Synchrosqueezed Wave Packet Transform for 2D Mode Decomposition, *SIAM Journal on Imaging Science*, 6(4):1979-2009, 2013.
- J2 **Haizhao Yang**<sup>+</sup> and Lexing Ying<sup>++</sup>. A Fast Algorithm for Multilinear Operators, *Applied and Computational Harmonic Analysis*, 33(1):148-158, 2012.
- J1 Zhenli Xu<sup>\*</sup>, Xiaolin Cheng and **Haizhao Yang**. Treecode-Based Generalized Born Method, *Journal of Chemical Physics*, 134(6):064-107, 2011.

## Conference Proceedings

- C9 Yahong Yang, **Haizhao Yang**<sup>\*</sup>, Yang Xiang. Nearly Optimal VC-Dimension and Pseudo-Dimension Bounds for Deep Neural Network Derivatives. 37th Conference on Neural Information Processing Systems (NeurIPS 2023).
- C8 Songyang Han, Sanbao Su, Sihong He, Shuo Han, **Haizhao Yang**, and Fei Miao<sup>\*</sup>. What is the Solution for State-Adversarial Multi-Agent Reinforcement Learning? ICML Workshop on New Frontiers in Learning, Control, and Dynamical Systems, 2023
- C7 Zuowei Shen<sup>+</sup>, **Haizhao Yang**<sup>+</sup>, Shijun Zhang<sup>++†</sup>. Neural Network Architecture Beyond Width and Depth. 36th Conference on Neural Information Processing Systems (NeurIPS 2022).
- C6 Zuowei Shen<sup>+</sup>, **Haizhao Yang**<sup>+</sup>, Shijun Zhang<sup>++†</sup>. Deep Network Approximation in Terms of Intrinsic Parameters. The 39th International Conference on Machine Learning (ICML 2022), Spotlight.
- C5 Wei He<sup>+</sup>, Zhongzhan Huang<sup>+</sup>, Mingfu Liang, Senwei Liang<sup>†</sup>, **Haizhao Yang**<sup>\*</sup>. Blending Pruning Criteria for Efficient Convolutional Neural Networks. 30th International Conference on Artificial Neural Networks, ICANN, 2021.
- C4 Yong Zheng Ong<sup>†\*</sup>, Nan You, Yunyue Elita Li, **Haizhao Yang**. Digital Rock Image Inpainting using GANs. In 90-th Annual International Meeting, SEG, 2020.
- C3 Yunru Liu<sup>†</sup>, Tingran Gao, **Haizhao Yang**<sup>\*</sup>, SelectNet: Learning to Sample from the Wild for Imbalanced Data Training. Proceedings of Mathematical and Scientific Machine Learning Conference 2020.
- C2 Senwei Liang<sup>++†</sup>, Zhongzhan Huang<sup>+</sup>, Mingfu Liang, **Haizhao Yang**<sup>\*</sup>, Instance Enhancement Batch Normalization: an Adaptive Regulator of Batch Noise. Proceedings of the AAAI Conference on Artificial Intelligence, 2020.
- C1 Zhongzhan Huang<sup>+</sup>, Senwei Liang<sup>++†</sup>, Mingfu Liang, **Haizhao Yang**<sup>\*</sup>, DIANet: Dense-and-Implicit Attention Network. Proceedings of the AAAI Conference on Artificial Intelligence, 2020.

## Book Chapters

- B1 Yuling Jiao<sup>+</sup>, Yanming Lai<sup>+</sup>, Yang Wang<sup>+</sup>, **Haizhao Yang**<sup>++</sup>, Yunfei Yang<sup>+</sup>. Convergence Analysis of the Deep Galerkin Method for Weak Solutions. In Patricia Alonso Ruiz, Michael Hinz, Kasso A. Okoudjou, Luke G. Rogers, Alexander Teplyaev, From Classical Analysis to Analysis on Fractals, A Tribute to Robert Strichartz, Volume 1. <https://arxiv.org/abs/2302.02405>

## TEACHING EXPERIENCE

- University of Maryland College Park Spring 2023  
Instructor in **MATH 401 Applications of Linear Algebra**: This is a second course in linear algebra with a focus on applications. Various applications of linear algebra: matrix factorization, solving linear systems, least squares, principle component analysis, graphs, finite Markov chains, spectral clustering, Linear Programming.
- Purdue University Spring 2022  
Instructor in **MA 36600 Introduction to Ordinary Differential Equations**: This is a method course for juniors in any branch of engineering and science. An introduction to ordinary differential equations with emphasis on problem solving and applications. The one-hour computer lab will give students an opportunity for hands-on experience with both the theory and applications of the subject.
- Purdue University Fall 2021  
Instructor in **Mathematical Theory and Applications of Deep Reinforcement Learning (graduate level)**: This course provides a basic introduction to deep reinforcement learning, applications of deep reinforcement learning in mathematical science and scientific computing, and theoretical analysis of deep reinforcement learning.
- Purdue University Spring 2021  
Instructor in **MA 265 Introduction to linear algebra (undergraduate level)**: Systems of linear equations, matrix algebra, vector spaces, determinants, eigenvalues and eigenvectors, diagonalization of matrices, applications.
- Purdue University Fall 2020  
Instructor in **Mathematical Theory and Applications of Deep Learning (graduate level)**: Part I: machine learning basics; deep feedforward networks; convolutional networks; advanced network design; Part II: approximation theory of deep neural networks; stochastic optimization methods; regularization for deep learning; generalization error of deep neural networks; Part III: sparse and structured computation; sequence modeling: recurrent and recursive nets; deep reinforcement learning; deep generative models; distributed and decentralized learning.
- Purdue University Spring 2020  
Instructor in **MA 30300**: This is a method course for juniors in any branch of engineering and science. Basic techniques for solving systems of linear ordinary differential equations. Series solutions for second-order equations, including Bessel functions, Laplace transform, Fourier series, numerical methods, separation of variables for partial differential equations, and Sturm-Liouville theory.
- National University of Singapore Term II 2017-2019  
Instructor in **Mathematical Theory and Applications of Deep Learning (graduate level)**: Part I: machine learning basics; deep feedforward networks; convolutional networks; advanced network design; Part II: approximation theory of deep neural networks; stochastic optimization methods; regularization for deep learning; generalization error of deep neural networks; Part III: sparse and structured computation; sequence modeling: recurrent and recursive nets; deep reinforcement learning; deep generative models; distributed and decentralized learning.
- National University of Singapore Term II 2018-2019  
Instructor in **Modeling and Numerical Simulation (graduate level)**: This module is designed for graduate students in mathematics. It focuses on modeling problems in real life and other disciplines into mathematical problems and simulating their solutions by scientific computing methods. Major topics covered include modeling and numerical simulations in selected areas of physical and engineering sciences, biology, finance, imaging, and optimization.
- National University of Singapore Term I 2018-2019  
Instructor in **Convex Optimization (undergraduate level)**: modeling examples and basic concepts of optimization; convex functions and properties; gradients and subgradients; gradient methods; sub-gradient methods; Newton-type algorithms and the Barzilai-Borwein method; constrained optimization; accelerated proximal gradient methods; stochastic block coordinate descent methods; convex

conjugacy and duality; splitting algorithms and implementations; CVX Matlab software for convex programming.

- National University of Singapore Term I 2017-2018  
Instructor in **Matrix Computation (undergraduate level)**: QR factorization, singular value decomposition, condition numbers, stability, perturbation analysis, least-squares problems, eigenvalue problems.
- Duke University Spring 2017  
Instructor in **Math 532: Basic analysis II (undergraduate level)**: Fourier and wavelet analysis, differential and integral calculus in  $R^n$ , low-dimensional manifolds, inverse, and implicit function theorems.
- Duke University Fall 2016  
Instructor in **Math 561: Scientific computing I (graduate level)**: direct and iterative solvers for dense and sparse linear systems, QR factorization, eigendecomposition, sparse matrix factorizations, basic parallel computation.
- Duke University Autumn 2015 and Spring 2016  
Instructor in **Math 353 Ordinary differential equations and partial differential equations**.

## CONTRIBUTED PACKAGES

Familiar with high-performance computing with C/C++, Fortran, Matlab, and Python in distributed and parallel computing environments.

- **ButterflyLab** 2014-now
  - Optimal complexity for evaluating multidimensional Fourier integral operators, special function transforms, and Green's functions in 1D to 3D integral equations for high-frequency wave propagation.
  - Optimal complexity preconditioners for high-frequency wave equations.
  - The latest version of ButterflyLab for solving large-scale dense linear systems is organized and coded by Haizhao Yang and is available at <https://github.com/ButterflyLab/ButterflyLab>.
- **ButterflyPACK** 2018-now
  - A mathematical software for rapidly solving large-scale dense linear systems that exhibit off-diagonal rank-deficiency. These systems arise frequently from boundary element methods or factorization phases in finite-difference/finite-element methods.
  - Relies on low-rank or butterfly formats under Hierarchical matrix, HODLR, or other hierarchically nested frameworks to compress, factor, and solve the linear system in quasi-linear time.
  - The butterfly format, originally inspired by the butterfly data flow in fast Fourier Transform, is a linear algebra tool well-suited for compressing matrices arising from high-frequency wave equations or highly oscillatory integral operators.
  - The distributed and parallel version is available at <https://github.com/liuyangzhuan/ButterflyPACK> by Yang Liu. The sequential MATLAB version is referred to ButterflyLab right above by Haizhao Yang.
- **ELSI** 2015-now
  - ELSI provides and enhances scalable, open-source software library solutions for electronic structure calculations in materials science, condensed matter physics, chemistry, molecular biochemistry, and many other fields. ELSI focuses on methods that solve or circumvent the Kohn-Sham eigenvalue problem in density-functional theory. The ELSI infrastructure should also be useful for other challenging eigenvalue problems.



- One of the key design pillars of ELSI is portability and support for various computing environments, from laptop-type computers all the way to the most efficient massively parallel supercomputers and new architectures (GPU and many core processors).
  - Available at <https://wordpress.elsi-interchange.org/>.
- **ZoloEig** 2016-now
    - Interior eigenvalue solver based on fast direct solver and the best high order rational function approximation to step functions.
    - Can be implemented in spectrum slicing libraries for full diagonalization.
    - Can also be used to compute leading eigenpairs.
    - Available at <http://www.math.nus.edu.sg/~matyh/codes/ZoloEig.tar.gz>.
  - **PSP** 2015-now
    - The PSP is an extensible distributed-memory parallel library offering a basic set of linear algebra primitives.
    - It achieves scalability and load balance via its 2D block cyclic distribution.
    - Routines for sparse data types includes (sparse) matrix (sparse) vector multiplication, (sparse) matrix (sparse) matrix multiplication, etc.
    - Supports several sparse formats, e.g. COO, CSC, and CSR.
    - Similar user habits with Scalapack.
    - Available at <https://github.com/HaizhaoYang/PSP>.
  - **DeCom** 2014-2016
    - 1D to 3D Synchrosqueezed wave packet transforms for analyzing instantaneous/local properties of non-linear oscillatory signals in a superposition.
    - 2D synchrosqueezed curvelet transforms for analyzing local properties of banded textures in a superposition.
    - Application examples in atomic materials science, wave propagation in geophysics, biological and medical signals, and canvas painting art investigation.
    - Available at <https://github.com/HaizhaoYang/DeCom>.
  - **SynCrystal** 2015-now
    - A MATLAB toolbox for atomic crystal analysis based on synchrosqueezed transforms and variational optimization.
    - Automatic tool for classifying crystal lattices, identifying grain boundaries, isolated defects, estimating grain orientation and elastic deformation.
    - Fast analysis for 2D and 3D atomic scale crystal data.
    - Available <https://github.com/SynCrystal/SynCrystal>.

## RECOGNITION FOR MENTORING

The EASIAM (East Asia section of SIAM) Student Paper Prize for Shijun Zhang, first prize. 2020

## STUDENTS AND POSTDOCS

## Postdocs

Current:

1. Ling Liang at University of Maryland College Park, 2023-now
2. Ke Chen at University of Maryland College Park, 2022-now
3. Michelle Michelle at Purdue University, 2022-now
4. Ayan Maiti at Purdue University, 2022-now

Previous:

1. Yiqi Gu, August 2019 to May 2021. First position afterward: Postdoc fellow in the Department of Mathematics at Hong Kong University
2. Ricardo A. Delgadillo, August 2019 to April 2020. First position afterward: Research fellow in the Department of Environmental and Civil Engineering, National University of Singapore
3. Simon Etter, August 2019 to July 2021. First position afterward: Research scientist at synchronous.ai
4. Sean Hon, March 2019 to May 2020. First position afterward: Assistant professor in the Department of Mathematics at Hong Kong Baptist University

## PhD Students

Current:

1. Zezheng Song, 2022-now
2. Junaid Aftab, 2023-now.
3. Chugang Yi, 2022-now.
4. Gareth C Hardwick, 2022-now.

Previous:

1. Qiyuan Pang (2023)  
Ph.D. in the Department of Mathematics, Purdue University.  
Thesis title: Distributed Dimensionality Reduction in Large-Scale Spectral Clustering  
Position afterward: Microsoft
2. Yong Zheng Ong (2023)  
Ph.D. in the Department of Mathematics, National University of Singapore.  
Thesis title: Adaptive Neural Network for Discretization Invariant Operator Learning.  
Position afterward: Instructor, School of Information Systems, Singapore Management University
3. Senwei Liang (2022)  
Ph.D. in the Department of Mathematics, Purdue University.  
Thesis title: Learning and Solving Partial Differential Equations with Deep Learning  
Position afterward: Postdoc at Lawrence Berkeley National Laboratory
4. Ze Chen (2020)  
Ph.D. in the Department of Mathematics, National University of Singapore.  
Thesis title: Fast Matrix Vector Multiplication via Interpolative Decomposition Butterfly Factorization.  
Position after graduation: Research Scientist, Shopee, Singapore.
5. Shijun Zhang (2020)  
Ph.D. in the Department of Mathematics, National University of Singapore.  
Co-supervised with Zuowei Shen  
Thesis title: Deep Neural Network Approximation via Function Compositions.

Position afterward: Postdoc at National University of Singapore and Phillip Griffiths Assistant Research Professor at Duke University

Thesis defense committee member:

1. Lizuo Liu (2023)  
Ph.D. in the Department of Mathematics, Southern Methodist University.  
Thesis title: Neural Network Learning for PDEs with Oscillatory Solutions and Causal Operators
2. Lucas Bouck (2023)  
Ph.D. in applied mathematics in the AMSC program, University of Maryland College Park.  
Thesis title: Liquid Crystal Variational Problems: Modeling, Numerical Analysis, and Computation
3. Shixin Zheng (2021)  
Ph.D. in the Department of Mathematics, Purdue University.
4. Xiaodong Huang (2022)  
Ph.D. in the Department of Mathematics, Purdue University.  
Thesis title: Structure Preserving and Fast Spectral Methods for Kinetic Equations
5. Yubo Wang (2022)  
Ph.D. in the Department of Mathematics, Purdue University.  
Thesis title: Efficient Numerical Methods for Kinetic Equations with High Dimensions and Uncertainties
6. Chenyang Cao (2020)  
Ph.D. in the Department of Mathematics, Purdue University.
7. Dr. Tongyao Pang (2019)  
Ph.D. in the Department of Mathematics, National University of Singapore.  
Thesis title: Image and Signal Restoration by Prior Knowledge.
8. Dr. Guodong Xu (2018)  
Ph.D. in the Department of Mathematics, National University of Singapore.  
Thesis title: Sparsity based regularization for signal recovery and clustering.
9. Dr. Guan Yu (2018)  
Ph.D. in the Department of Mathematics, National University of Singapore.  
Thesis title: Convergence Analysis on SVD-Based Algorithms for Tensor Low-Rank Approximations.

## Master Students

Previous:

1. Lin Chen (2019)  
M.Sc. in the Department of Mathematics, National University of Singapore.  
Thesis title: Adversarial Encoder-Decoder for Compressed Sensing.  
Position after graduation: Ph.D. in Management at INSEAD.
2. Yunrui Liu (2019)  
M.Sc. in the Department of Mathematics, National University of Singapore.  
Thesis title: Semi-supervised Learning in Imbalanced Dataset.  
Position after graduation: Machine learning scientist in Facebook, UK
3. Linpo Guo (2019)  
M.Sc. in the Department of Mathematics, National University of Singapore.  
Thesis title: Width and Depth Based Graph Neural Network for Semi-Supervised Classification.  
Position after graduation: Data scientists in Shopee, Singapore
4. Fan Yang (2018)  
M.Sc. in the Department of Mathematics, National University of Singapore.

Thesis title: Single Channel Audio Classification and Source Separation Using Convolutional Neural Networks.

5. Yurui Chen (2018)  
M.Sc. in the Department of Mathematics, National University of Singapore.  
Thesis title: Time-Frequency Analysis in Fetal ECG Extraction.  
Position after graduation: Ph.D. in mathematics at National University of Singapore.
6. Tao Zhang (2018)  
M.Sc. in the Department of Mathematics, National University of Singapore.  
Thesis title: 3D Atomic Crystal Analysis via Fast Synchrosqueezed Transform.  
Position after graduation: Data Scientist in Vivo then Ph.D. in mathematics at the University of Florida.
7. Han Wang (2018)  
M.Sc. in the Department of Mathematics, National University of Singapore.  
Thesis title: Interpolation and Approximation of Computationally Expensive Posterior Density.  
Position after graduation: M.Sc. in statistics at University of Pennsylvania.

Thesis defense committee member:

1. Renbo Zhao (2018)  
M.Sc. in the Department of Mathematics, National University of Singapore.  
Thesis title: Stochastic and Randomized Algorithms for Large-Scale Optimization in Machine Learning.  
Position after graduation: Ph.D. in operation research at MIT.

## Undergraduate Students

Current:

1. Longtian Tang (2023)  
B.S. at Tsinghua University

Previous:

1. John Timothy Quinn (2022)  
B.S. at University of Colorado Boulder  
Position after graduation: M.S. in Applied Mathematics at the University of Colorado Boulder
2. Gengzhi Yang (2022)  
B.S. at Fudan University  
Position after graduation: Ph.D. in the AMSC program at the University of Maryland College Park
3. Zhongyi Jiang (2022)  
B.S. at University of Delaware  
Position after graduation: Ph.D. admission with financial support in the AMSC program at the University of Maryland College Park
4. Jiaheng Chen (2021)  
B.S. in the Zhiyuan College of Mathematics, Shanghai Jiao Tong University  
Position after graduation: Ph.D. in the Department of Statistics at University of Chicago
5. Wenhan Gao (2021)  
B.S. in the Department of Applied Mathematics and Statistics at The State University of New York at Stony Brook  
Position after graduation: Ph.D. in the Department of Mathematics, The State University of New York at Stony Brook, US
6. Jasen Lai (2021)  
B.S. in Mathematics and Computer & Information Sciences at the Ohio State University  
Position after graduation: Ph.D. in the Department of Statistics at Purdue University

7. Shiqin Dai (2020)  
B.S. in the Department of Mathematics and Computer Science, Purdue University  
Position after graduation: M.Sc. in ECE, Duke University.
8. Liyao Lyu (2020 spring and summer)  
B.S. in the Department of Mathematics, Soochow University.  
Position after graduation: Ph.D. in the Department of Computational Mathematics, Science and Engineering, Michigan State University.
9. Nail Sachin Palkar (2019 summer)  
B.S. in the Department of Mathematics and Computer Science, University of North Carolina, Chapel Hill.  
UROPS project: Fourier Analysis in Deep Learning.
10. Ong Yong Zheng (2019)  
B.S. in the Department of Mathematics, National University of Singapore.  
Thesis title: Generative Adversarial Networks for Source Separation.  
Position after graduation: Ph.D. in mathematics with Shopee Fellowship at National University of Singapore.
11. Yong Teck Xuan Ivan (2019)  
B.S. in the Department of Mathematics, National University of Singapore.  
Thesis title: Semi-Supervised Learning for Imbalanced Classification Problems.
12. Lee Zhi Qiang Leonard (2019)  
B.S. in the Department of Mathematics, National University of Singapore.  
Thesis title: Approximation Theory for Deep Learning.  
Position after graduation: Ph.D. in School of Computing with Shopee Fellowship at National University of Singapore.
13. Seow Yaxin Claudia (2019)  
B.S. in the Department of Mathematics, National University of Singapore.  
Thesis title: Decentralised Deep Learning Optimisation.  
Position after graduation: co-founder of NodeFlair.
14. Xueying Guo (2019)  
B.S. in the Department of Mathematics, National University of Singapore.  
Thesis title: Deep Reinforcement Learning for Solving Linear Equations.
15. Mo Zhou (2018)  
B.S. in the Department of Mathematics, Tsinghua University.  
Thesis title: Advanced Mode Decomposition Algorithms in Signal Processing.  
Position after graduation: Ph.D. in mathematics at Duke University, US.
16. Shengtong Zhang (2018)  
B.S. in the Department of Mathematics, Tsinghua University.  
Thesis title: Approximation Theory of Deep Learning.  
Position after graduation: Ph.D. in industrial engineering & management sciences at Northwestern University, US.
17. Qiyuan Pang (2018)  
B.S. in the Department of Mathematics, Sun Yat-Sen University.  
Thesis title: Fast Algorithms for Non-Uniform Fourier Transformation.  
Position after graduation: Ph.D. in mathematics at Purdue University, US.
18. Haoxuan Wang (2018)  
B.S. in the Department of Mathematics, Zhejiang University  
Thesis title: Fast Algorithms for Deep Learning.  
Position after graduation: Ph.D. in mathematics at National University of Singapore.

## High School Students

Current:

1. Amy Xu (2023)  
Walt Whitman High School

## ACADEMIC SERVICE

### University and Departmental Services

- Member, Graduate Admission Committee, the Applied Mathematics & Statistics, and Scientific Computation (AMSC) graduate program, University of Maryland College Park, 2022-2024
- Co-organizer, PSU-Purdue-UMD Joint Seminar on Mathematical Data Science, Department of Mathematics, University of Maryland College Park, 2022-2024
- Member, PDE/Applied Math Field Committee, Department of Mathematics, University of Maryland College Park, 2022-2024
- Member, Numerical Analysis Field Committee, Department of Mathematics, University of Maryland College Park, 2022-2024
- Member, Analysis Field Committee, Department of Mathematics, University of Maryland College Park, 2022-2024
- Member, Computer Committee, Department of Mathematics, Purdue University, 2019-2022
- Member, Search Committee for Data Science, Department of Mathematics, Purdue University, 2019-2021
- Organizer, Mathematical Data Science Seminar, Department of Mathematics, Purdue University, 2019-2022

### Editorial Duties

- Guest Editor, Frontiers in Applied Mathematics and Statistics, a special issue on Machine Learning for Mathematical Modeling and Computation, 2021
- Guest Editor, Computational and Mathematical Biophysics, a special issue on Optimization and Machine Learning Algorithms for Biological Data Analysis, 2020

### Research Grant Refereeing

- 6 US Department of Energy (DOE), Advanced Scientific Computing Research (ASCR), 2023
- 5 US National Science Foundation (NSF), Division of Information and Intelligent Systems, 2023
- 4 US National Science Foundation (NSF), DMS Computational Mathematics, 2022, 2023
- 3 Engineering and Physical Sciences Research Council (EPSRC), 2021
- 2 Centre Européen de Calcul Atomique et Moléculaire (CECAM), 2021
- 1 French National Research Agency (ANR), 2019

## Journal, Conference, and Book Refereeing

Advances in Continuous and Discrete Models: Theory and Applications;  
AIMS Mathematics;  
Annals of Statistics;  
Applied and Computational Harmonic Analysis;  
Applied Mathematics and Computation;  
Applied Numerical Mathematics;  
Applied Sciences;  
Communications in Computational Physics;  
Communications in Mathematical Sciences;  
Communications in Mathematics and Statistics;  
Communications on Applied Mathematics and Computation;  
Computers and Mathematics with Applications;  
Constructive Approximation;  
CSIAM Transaction on Applied Mathematics;  
East Asian Journal on Applied Mathematics;  
Engineering Applications of Artificial Intelligence;  
Geophysics;  
IEEE Signal Processing Magazine;  
IEEE Transactions on Antennas and Propagation;  
IEEE Transactions on Computational Imaging;  
IEEE Transactions on Signal Processing Letters;  
IEEE Transactions on Signal Processing;  
IEEE Transactions on Image Processing;  
IEEE Transactions on Geoscience and Remote Sensing;  
Inverse Problems and Imaging;  
Journal of Computational Physics;  
Journal of Computational Mathematics;  
Journal of Computational and Applied Mathematics;  
Journal of Fourier Analysis and Applications;  
Journal of Machine Learning Research;  
Journal of Neuroscience Methods;  
Journal of Scientific Computing; Mathematics of Computation;  
Nature Computational Science;  
Neural Networks;  
PLOS ONE;  
Philosophical Transactions of the Royal Society A;  
Physica D: Nonlinear Phenomena  
Research in Mathematical Sciences;  
(SIAM) Multiscale Modeling and Simulation;  
SIAM Journal on Imaging Science;  
SIAM Journal on Mathematical Analysis;  
SIAM Journal on Numerical Analysis;  
SIAM Journal on Scientific Computing;  
Terrestrial, Atmospheric and Oceanic Sciences

AAAI; ICANN; International Conference on Domain Decomposition Methods; Mathematical and Scientific Machine Learning Conference (MSML)