

# Rahul Parhi

*curriculum vitae*

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## Research Summary

I am interested in the interplay between **functional and harmonic analysis** and **data science**—broadly defined—and their applications to **signal processing**, **machine learning**, **statistics**, and **optimization**. In particular, my research focuses on the following areas:

- **foundations of neural networks and deep learning**
  - mathematical characterizations of functions and representations learned from data
  - approximation properties of neural networks
  - nonparametric function estimation with neural networks
  - function spaces and representation costs of neural networks
- **mathematics of data science**
  - sparsity and compressed sensing
  - optimal recovery, information-based complexity, and minimax estimation
  - wavelet-based signal processing and inverse problems more generally
  - mathematical statistics and information theory
- **pure and applied aspects of functional and harmonic analysis**
  - Radon transforms and their generalizations
  - wavelets, their generalizations, and other kinds of space-scale or time-frequency analysis
  - optimization and convex analysis on Banach spaces and more general topological vector spaces
  - geometry of (quasi-)Banach spaces

Almost all of my research is fundamentally motivated by problems data science and, in particular, our (lack of) understanding of neural networks. Improving our understanding there is a principal outstanding problem. What is particularly fascinating is that, in many instances, once a research question is stripped of the “applied language”, one is left with a fundamental question in pure mathematics. As a result, my research touches on and also contributes to various areas of pure mathematics. From this perspective, data science is an extremely exciting area to be working in as it is the best of two worlds: Beautiful mathematics that leads to meaningful real-world impact.

## Employment

- 2024– **Assistant Professor**, *University of California, San Diego*, La Jolla, California, USA  
Department of Electrical and Computer Engineering
- 2022–2024 **Collaborateur Scientifique**, *École Polytechnique Fédérale de Lausanne*, Lausanne, Switzerland
- Summer 2018 **Software Development Engineer Intern**, *Amazon.com, Inc.*, Seattle, Washington, USA
- Summer 2017 **Software Development Engineer Intern**, *Amazon.com, Inc.*, Seattle, Washington, USA

## Education

- 2018–2022 **Ph.D., Electrical Engineering**, *University of Wisconsin–Madison*, Madison, Wisconsin, USA  
**Minor in Mathematics**  
Supervisor: Robert D. Nowak  
Committee: Ronald DeVore, Nicolás García Trillos, Dimitris Papailiopoulos, Betsy Stovall, Michael Unser  
Thesis: *Splines, Neural Networks, and Radon-Domain BV Spaces*  
*Harold Peterson Outstanding Dissertation Award*

2018–2019 **M.S., Electrical Engineering**, *University of Wisconsin–Madison*, Madison, Wisconsin, USA  
 2015–2018 **B.S., Mathematics**, *University of Minnesota, Twin Cities*, Minneapolis, Minnesota, USA  
**B.S., Computer Science**, *University of Minnesota, Twin Cities*, Minneapolis, Minnesota, USA  
**Minor in Physics**, Graduated *magna cum laude*

## Selected Honors and Awards

- 2026 SIAM Review SIGEST Paper Award
- 2024 Conference on Parsimony and Learning (CPAL) Rising Stars Award
- 2023 Harold Peterson Outstanding Dissertation Award from the University of Wisconsin–Madison
- 2020 NSF Graduate Research Fellowship (3 year award, only used 2)  
 Awarded for the project titled *Bringing Approximation Theory to Data Science*
- 2017 Astronaut Scholarship
- 2017 Barry M. Goldwater Scholarship

## Papers

### Manuscripts Under Review

- 2025 Tongtong Liang, Dan Qiao, Yu-Xiang Wang, and **Rahul Parhi**. “Stable Minima of ReLU Neural Networks Suffer from the Curse of Dimensionality: The Neural Shattering Phenomenon”. June 2025. arXiv: 2506.20779 [stat.ML].
- 2025 Luke McDermott, Robert W. Heath Jr., and **Rahul Parhi**. “LoLA: Low-Rank Linear Attention With Sparse Caching”. May 2025. arXiv: 2505.23666 [cs.CL].
- 2025 Ronald DeVore, Robert D. Nowak, **Rahul Parhi**, Guergana Petrova, and Jonathan W. Siegel. “Optimal Recovery Meets Minimax Estimation”. Feb. 2025. arXiv: 2502.17671 [math.ST].

### Journal and Journal-Equivalent ML/AI Conference Publications

- 2025 Ronald DeVore, Robert D. Nowak, **Rahul Parhi**, and Jonathan W. Siegel. “Weighted Variation Spaces and Approximation by Shallow ReLU Networks”. In: *Applied and Computational Harmonic Analysis* 74.101713 (2025), pp. 1–22. DOI: 10.1016/j.acha.2024.101713.
- 2025 Akash Kumar, **Rahul Parhi**, and Mikhail Belkin. “A Gap Between the Gaussian RKHS and Neural Networks: An Infinite-Center Asymptotic Analysis”. In: *Conference on Learning Theory (COLT)*. Vol. 291. 2025, pp. 3463–3485. URL: <https://proceedings.mlr.press/v291/kumar25b.html>.
- 2025 **Rahul Parhi**, Pakshal Bohra, Ayoub El Biari, Mehrsa Pourya, and Michael Unser. “Random ReLU Neural Networks as Non-Gaussian Processes”. In: *Journal of Machine Learning Research* 26.19 (2025), pp. 1–31. URL: <https://jmlr.org/papers/v26/24-0737.html>.
- 2025 **Rahul Parhi** and Michael Unser. “Function-Space Optimality of Neural Architectures with Multivariate Nonlinearities”. In: *SIAM Journal on Mathematics of Data Science* 7.1 (2025), pp. 110–135. DOI: 10.1137/23M1620971.
- 2024 **Rahul Parhi** and Michael Unser. “Distributional Extension and Invertibility of the  $k$ -Plane Transform and Its Dual”. In: *SIAM Journal on Mathematical Analysis* 56.4 (2024), pp. 4662–4686. DOI: 10.1137/23M1556721.
- 2024 Joseph Shenouda, **Rahul Parhi**, Kangwook Lee, and Robert D. Nowak. “Variation Spaces for Multi-Output Neural Networks: Insights on Multi-Task Learning and Network Compression”. In: *Journal of Machine Learning Research* 25.231 (2024), pp. 1–40. URL: <https://www.jmlr.org/papers/v25/23-0677.html>.

- 2023 **Rahul Parhi** and Robert D. Nowak. “Near-Minimax Optimal Estimation With Shallow ReLU Neural Networks”. In: *IEEE Transactions on Information Theory* 69.2 (2023), pp. 1125–1140. DOI: 10.1109/TIT.2022.3208653.
- 2023 **Rahul Parhi** and Robert D. Nowak. “Deep Learning Meets Sparse Regularization: A signal processing perspective”. In: *IEEE Signal Processing Magazine* 40.6 (2023), pp. 63–74. DOI: 10.1109/MSP.2023.3286988.
- 2023 **Rahul Parhi** and Michael Unser. “The Sparsity of Cycle Spinning for Wavelet-Based Solutions of Linear Inverse Problems”. In: *IEEE Signal Processing Letters* 30 (2023), pp. 568–572. DOI: 10.1109/LSP.2023.3275916.
- 2022 **Rahul Parhi** and Robert D. Nowak. “What Kinds of Functions Do Deep Neural Networks Learn? Insights from Variational Spline Theory”. In: *SIAM Journal on Mathematics of Data Science* 4.2 (2022), pp. 464–489. DOI: 10.1137/21M1418642.
- 2021 **Rahul Parhi** and Robert D. Nowak. “Banach Space Representer Theorems for Neural Networks and Ridge Splines”. In: *Journal of Machine Learning Research* 22.43 (2021), pp. 1–40. URL: <https://jmlr.org/papers/v22/20-583.html>.
- 2020 **Rahul Parhi** and Robert D. Nowak. “The Role of Neural Network Activation Functions”. In: *IEEE Signal Processing Letters* 27 (2020), pp. 1779–1783. DOI: 10.1109/LSP.2020.3027517.

#### Other Conference Publications

- 2025 **Rahul Parhi** and Ben Adcock. “Upper Bounds on Averaged Sampling Numbers for General Model Classes”. In: *International Conference on Sampling Theory and Applications (SampTA)*. 2025, pp. 1–5.
- 2023 **Rahul Parhi** and Michael Unser. “Modulation Spaces and the Curse of Dimensionality”. In: *International Conference on Sampling Theory and Applications (SampTA)*. 2023, pp. 1–5. DOI: 10.1109/SampTA59647.2023.10301395.
- 2023 Joseph Shenouda, **Rahul Parhi**, and Robert D. Nowak. “A Continuous Transform for Localized Ridgelets”. In: *International Conference on Sampling Theory and Applications (SampTA)*. 2023, pp. 1–5. DOI: 10.1109/SampTA59647.2023.10301398.
- 2022 **Rahul Parhi** and Robert D. Nowak. “On Continuous-Domain Inverse Problems with Sparse Superpositions of Decaying Sinusoids as Solutions”. In: *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*. 2022, pp. 5603–5607. DOI: 10.1109/ICASSP43922.2022.9746165.
- 2018 **Rahul Parhi**, Michael Schliep, and Nicholas Hopper. “MP3: A More Efficient Private Presence Protocol”. In: *International Conference on Financial Cryptography and Data Security*. 2018, pp. 38–57. DOI: 10.1007/978-3-662-58387-6\_3.
- 2015 **Rahul Parhi**, Chris H. Kim, and Keshab K. Parhi. “Fault-Tolerant Ripple-Carry Binary Adder Using Partial Triple Modular Redundancy (PTMR)”. In: *IEEE International Symposium on Circuits and Systems (ISCAS)*. 2015, pp. 41–44. DOI: 10.1109/ISCAS.2015.7168565.

#### Lightly-Refereed Workshop Papers

- 2025 Luke McDermott and **Rahul Parhi**. “Finding Stable Subnetworks at Initialization with Dataset Distillation”. In: *ICLR Workshop on Neural Network Weights as a New Data Modality*. 2025. URL: <https://weight-space-learning.github.io/papers>.

- 2021 **Rahul Parhi**, Jack Wolf, and Robert D. Nowak. “On the Sparsity of Deep Neural Networks in the Overparameterized Regime: An Empirical Study”. In: *ICML Workshop on Overparameterization: Pitfalls & Opportunities (OPPO)*. 2021. URL: <https://sites.google.com/view/icml2021oppo/accepted-papers>.

## Talks and Presentations

### Tutorials

- 2025 “*A Function-Space Tour of Data Science*”. Conference on Parsimony and Learning (CPAL), Stanford, California, USA. Mar. 2025. URL: <https://function-space-tour.github.io/cpal/>.

### Invited Talks at University Seminars and Colloquia

- 2025 “*Do Neural Networks Generalize Well? Low-Norm vs. Flat Minima*”. Machine Learning Seminar, Georgia Institute of Technology. Sept. 2025.
- 2025 “*Function-Space Models for Deep Learning*”. Applied Math/PDE/Data Science Seminar, Department of Mathematics, University of California, Santa Barbara. May 2025.
- 2025 “*Function-Space Models for Deep Learning*”. Colloquium on Signal Processing and Machine Learning, Department of Information Technology and Electrical Engineering, ETH Zürich. Apr. 2025.
- 2025 “*Characteristic Functionals and the Innovations Approach to Stochastic Processes With Applications to Random Neural Networks*”. Probability Seminar, Department of Mathematics, University of California, San Diego. Feb. 2025.
- 2025 “*Function-Space Models for Deep Learning*”. Joint Seminar on Mathematical Data Science, PSU + Purdue + UMD. Feb. 2025.
- 2025 “*Function-Space Models for Deep Learning*”. Frontiers in Electrical Engineering, Caltech. Feb. 2025.
- 2025 “*Function-Space Models for Deep Learning*”. Mathematics of Data Science Seminar, Department of Mathematics, University of California, San Diego. Jan. 2025.
- 2024 “*Deep Learning Meets Sparse Regularization*”. Seminar, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology. Mar. 2024.
- 2024 “*Deep Learning Meets Sparse Regularization*”. Seminar, Department of Electrical and Computer Engineering, University of California, San Diego. Feb. 2024.
- 2024 “*Deep Learning Meets Sparse Regularization*”. Seminar, Department of Applied Mathematics, University of Colorado, Boulder. Feb. 2024.
- 2024 “*Deep Learning Meets Sparse Regularization*”. Seminar, Department of Computing Science, University of Alberta. Feb. 2024.
- 2024 “*Deep Learning Meets Sparse Regularization*”. Seminar, Department of Mathematics, Rutgers University. Jan. 2024.
- 2024 “*Deep Learning Meets Sparse Regularization*”. School of Science and Engineering Seminar, Chinese University of Hong Kong, Shenzhen. Jan. 2024.
- 2023 “*Deep Learning Meets Sparse Regularization*”. Seminar, Departments of Electrical and Systems Engineering + Statistics and Data Science, Washington University in St. Louis. Dec. 2023.
- 2023 “*Deep Learning Meets Sparse Regularization*”. Chair for Mathematical Information Science Seminar, ETH Zürich. Dec. 2023.

- 2023 “*Deep Learning Meets Sparse Regularization*”. Statistics Seminar, Université Catholique de Louvain. Nov. 2023.
- 2023 “*Deep Learning Meets Sparse Regularization*”. Math Machine Learning Seminar, Max Planck Institute for Mathematics in the Sciences + University of California, Los Angeles. Sept. 2023.
- 2022 “*Regularizing Neural Networks via Radon-Domain Total Variation*”. Mathematical Institute for Data Science (MINDS) Seminar, Johns Hopkins University. Nov. 2022.
- 2021 “*On BV Spaces, Splines, and Neural Networks*”. Analysis Seminar, Department of Mathematics, University of Wisconsin–Madison. Nov. 2021.
- 2021 “*What Kinds of Functions Do Neural Networks Learn?*” Working Group on Mean Field Neural Networks, Simons Institute for the Theory of Computing. Nov. 2021.
- 2020 “*A Representer Theorem for Single-Hidden Layer Neural Networks*”. Institute for Foundations of Data Science (IFDS) Seminar, University of Wisconsin–Madison. July 2020.
- 2019 “*Neural Networks Learn Splines*”. Human, Animal, and Machine Learning: Experiment and Theory (HAMLET) Seminar, University of Wisconsin–Madison. Oct. 2019.
- 2019 “*Minimum ‘Norm’ Neural Networks and Splines*”. Institute for Foundations of Data Science (IFDS) Seminar, University of Wisconsin–Madison. Sept. 2019.

#### Invited Talks at Conferences and Workshops

- 2025 “*Are Global and Local Minima of Shallow Neural Networks Fundamentally Different?*” IFDS Workshop on Theoretical Foundations of Applied AI, University of Washington, Seattle, Washington, USA. Aug. 2025.
- 2025 “*A Dual-Certificate Analysis for Neural Network Optimization Problems*”. International Conference on Continuous Optimization (ICCOPT), Los Angeles, California, USA. July 2025.
- 2024 “*Deep Learning Meets Sparse Regularization*”. Mathematics of Machine Learning Session, Canadian Mathematical Society (CMS) Winter Meeting, Richmond, British Columbia, Canada. Nov. 2024.
- 2024 “*The Role of Sparsity in Learning With Overparameterized Deep Neural Networks*”. Learning Functions with Low-Dimensional Structure Using Neural Networks Minisymposium, SIAM Conference on Mathematics of Data Science (MDS), Atlanta, Georgia, USA. Oct. 2024.
- 2024 “*A Banach-Space View of Neural Network Training*”. Nonsmooth and Hierarchical Optimization in Machine Learning Session, International Symposium on Mathematical Programming (ISMP), Montréal, Québec, Canada. July 2024.
- 2024 “*On the Sparsity-Promoting Effect of Weight Decay in Deep Learning*”. Rising Stars Session, Conference on Parsimony and Learning (CPAL), Pok Fu Lam, Hong Kong. Jan. 2024.
- 2020 “*A Banach Space Representer Theorem for Single-Hidden Layer Neural Networks*”. Young Researchers Spotlight Session, SLOWDNN Workshop, Online. Oct. 2020.

#### Conference Paper Oral Presentations

- 2025 “*Upper Bounds on Averaged Sampling Numbers for General Model Classes*”. International Conference on Sampling Theory and Applications (SampTA), Vienna, Austria. July 2025.
- 2023 “*Modulation Spaces and the Curse of Dimensionality*”. International Conference on Sampling Theory and Applications (SampTA), New Haven, Connecticut, USA. July 2023.

- 2022 “On Continuous-Domain Inverse Problems with Sparse Superpositions of Decaying Sinusoids as Solutions”. IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), Singapore. May 2022.

## Teaching

### University of California, San Diego

Spring 2026	ECE 161C: Applications of Digital Signal Processing (a.k.a. Image Processing)	<i>Instructor</i>
Fall 2025	ECE 251C: Filter Banks and Wavelets	<i>Instructor</i>
Winter 2025	ECE 172A: Introduction to Intelligent Systems (a.k.a. Image Processing)	<i>Instructor</i>
Fall 2024	ECE 251C: Filter Banks and Wavelets	<i>Instructor</i>

### École Polytechnique Fédérale de Lausanne

Spring 2024	MICRO 512: Image Processing II	<i>Teaching Assistant</i>
Fall 2023	MICRO 511: Image Processing I	<i>Teaching Assistant</i>
Spring 2023	MICRO 512: Image Processing II	<i>Teaching Assistant</i>
Fall 2022	MICRO 511: Image Processing I	<i>Teaching Assistant</i>

### University of Wisconsin–Madison

Spring 2022	ECE/CS 761: Mathematical Foundations of Machine Learning	<i>Teaching Assistant</i>
Fall 2021	ECE/CS/ME 532: Matrix Methods in Machine Learning	<i>Teaching Assistant</i>
Spring 2021	ECE 901: Nonparametric Methods in Data Science	<i>Co-Instructor and Teaching Assistant</i>
Fall 2020	ECE/CS/ME 532: Matrix Methods in Machine Learning	<i>Teaching Assistant</i>
Spring 2020	ECE/CS 761: Mathematical Foundations of Machine Learning	<i>Teaching Assistant</i>

### University of Minnesota, Twin Cities

Spring 2018	MATH 5651: Basic Theory of Probability and Statistics	<i>Teaching Assistant</i>
Fall 2017	CSCI 1933: Introduction to Algorithms and Data Structures	<i>Teaching Assistant</i>
Spring 2017	CSCI 1933H: Honors Introduction to Algorithms and Data Structures	<i>Teaching Assistant</i>
Fall 2016	CSCI 1933: Introduction to Algorithms and Data Structures	<i>Teaching Assistant</i>
Spring 2016	CSCI 1933: Introduction to Algorithms and Data Structures	<i>Teaching Assistant</i>

## Research Advising and Mentoring

### University of California, San Diego

Spring 2025–	<b>Henry Pritchard</b> , <i>B.S./M.S. Student</i> , Electrical and Computer Engineering
Winter 2025–	<b>Anil Kamber</b> , <i>Ph.D. Student</i> , Electrical and Computer Engineering
Fall 2024–	<b>Luke McDermott</b> , <i>Ph.D. Student</i> , Electrical and Computer Engineering

### École Polytechnique Fédérale de Lausanne

- 2023 **Ayoub El Biari**, *Master’s Thesis*  
 Ayoub’s thesis led to the publication: **Rahul Parhi**, Pakshal Bohra, Ayoub El Biari, Mehra Pourya, and Michael Unser. “Random ReLU Neural Networks as Non-Gaussian Processes”. In: *Journal of Machine Learning Research* 26.19 (2025), pp. 1–31. URL: <https://jmlr.org/papers/v26/24-0737.html>
- 2023 **Bassam El Rawas**, *Master’s Project*  
 Bassam’s project focused “Approximation Theory With Exponential Splines” and is currently being prepared for publication.

## Professional Service



## University Service at UCSD

2024– Teaching Innovations and Undergraduate Affairs Committee, Electrical and Computer Engineering

### Meetings Organized and Chaired

July 2025 Organizer and chair (with Thibaut Horel) for the session on “relaxations of optimization problems and extreme point results in infinite dimensions”, International Conference on Continuous Optimization (ICCOPT), Los Angeles, California, 2025

July 2024 Chair for the session on “nonsmooth and hierarchical optimization in machine learning”, International Symposium on Mathematical Programming (ISMP), Montréal, Québec, Canada, 2024

### Reviewer for the Following Journals

Annals of Statistics, Applied and Computational Harmonic Analysis, Biometrika, IEEE Open Journal of Signal Processing, IEEE Signal Processing Magazine, IEEE Transactions on Information Theory, IMA Journal of Applied Mathematics, Integral Transforms And Special Functions, Journal of Computational and Applied Mathematics, Journal of Machine Learning Research, Neural Networks, Neurocomputing, SIAM Journal on Imaging Sciences, SIAM Journal on Mathematical Analysis, SIAM Journal on Mathematics of Data Science, SIAM Journal on Scientific Computing

### Reviewer for the Following Conferences and Workshops

Conference on Machine Learning and Systems (MLSys), IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), International Conference on Artificial Intelligence and Statistics (AISTATS), Learning for Dynamics & Control Conference (L4DC), ICLR Workshop on Weight Space Learning

### Other Reviewing

2024– Regular contributor of Mathematical Reviews® for MathSciNet®

### Professional Societies

2015, 2022– IEEE Member

2024– SIAM Member

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## Miscellaneous

### Other Honors and Awards

2022 IEEE Signal Processing Society Travel Grant

2022 University of Wisconsin–Madison ECE Dissertator Travel Award

2018 LUCID NSF Research Traineeship (NRT) from NSF grant 1545481 (2 years)

2018 NSF Graduate Research Fellowship Program Honorable Mention

2015 IEEE Circuits and Systems Society Travel Grant

2013–2015 Post-Secondary Enrollment Options (PSEO) Student at the University of Minnesota, Twin Cities  
Enrolled full-time at the University of Minnesota–Twin Cities during 11th and 12th grades through PSEO.

2008–2013 University of Minnesota Talented Youth Math Program (UMTYMP)

Completed differential and integral calculus, linear algebra, differential equations, set theory, methods of proof, and multivariable calculus at the University of Minnesota–Twin Cities at the end of 10th grade through UMTYMP.

Erdős Number: **3** via many different paths, including

- Paul Erdős and Ambikeshwar Sharma. “On Tchebycheff Quadrature”. In: *Canadian Journal of Mathematics* 17 (1965), pp. 652–658. DOI: 10.4153/CJM-1965-064-X
- Ronald DeVore, Amram Meir, and Ambikeshwar Sharma. “Strongly and Weakly Non-Poised HB Interpolation Problems”. In: *Canadian Journal of Mathematics* 25.5 (1973), pp. 1040–1050. DOI: 10.4153/CJM-1973-111-8
- Ronald DeVore, Robert D. Nowak, **Rahul Parhi**, and Jonathan W. Siegel. “Weighted Variation Spaces and Approximation by Shallow ReLU Networks”. In: *Applied and Computational Harmonic Analysis* 74.101713 (2025), pp. 1–22. DOI: 10.1016/j.acha.2024.101713

### Personal Information

Date of Birth: 10 January 1998

Citizenship: USA

Last Updated: August 22, 2025