AISHWARYA H. BALWANI

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RESEARCH INTERESTS

Machine Learning, Theoretical & Computational Neuroscience
- Analysis of Artificial & Biological Neural Networks
  - Sparse, Low-Rank & Low-Dimensional Representations of Data
  - Transferability, Interpretability & Generalizability of Features in Neural Networks
- Predictive Coding, Structure-Function Relationships in Neural Networks
- Information Geometry, Topological Data Analysis, Optimization, Group Theory
- AI Safety: Alignment, Robustness, Misgeneralization

PhD THESIS

Through the Recurrent Neural Network Looking Glass: Structure-Function Relationships in Cortical Circuits for Predictive Coding
- Inductive Biases and Predictive Coding in the Canonical Cortical Microcircuit
  - Used RNN models of the cortical microcircuit to explore the impact of inter-areal laminar connections and a predictive-coding inspired training strategy on hierarchical information processing and the geometry of neuronal representations.
  - Demonstrated in-silico that feedback connections enable differentiation between expected and unexpected inputs in sequential tasks, supported by mathematical analysis.
  - Showed that the addition of a predictive-coding based loss improves the ability to distinguish expected and unexpected inputs in populations receiving inter-areal feedback deeper in the cortical column.
- Constructing Biologically Constrained RNNs and their Application
  - Designed and implemented RNNs that incorporate Dale's law and sparse, anatomically-consistent connectivity motifs in a mathematically-grounded manner, with performance guarantees under specific conditions.
  - Applied the constrained RNNs to reconstruct 2-photon calcium imaging data from visual behaviour in mice, revealing multi-regional functional neuronal interactions consistent with predictive coding theory.

EDUCATION

Georgia Institute of Technology
- PhD, Electrical & Computer Engineering, 2018-2025.
  Minor(s): Mathematics, Computer Science
- MS, Electrical & Computer Engineering, 2016-2018.

University of Mumbai
- BE, Electronics & Telecommunication, 2012-2016. (First Class with Distinction)

SKILLS

Machine Learning & AI
- Deep Learning (FCNs, RNNs, CNNs, Transformers), Neural Network Pruning, Representation Learning, Fine-Tuning, Transfer Learning, Multi-task Learning, Unsupervised Learning

Applied Mathematics
- Linear Algebra, Convex Optimization, Topological Data Analysis, High-dimensional Geometry, Low-Dimensional Approximations, Signal Processing

Computational Neuroscience
- Predictive Coding, Biologically-constrained Neural Networks, Population Dynamics, Synaptic Plasticity, Neural Coding

Programming & Tools
- Python, PyTorch, Scikit-Learn, MATLAB, Git, LaTeX, Data Visualization, Statistical Analysis

PUBLICATIONS, PREPRINTS & PEER REVIEWED ABSTRACTS

Publications
- Ozan Bozdag G., Zamani-Dahaj S.A., Kahn P., Day T., Tong K., **Balwani A.**, Dyer E., Yunker P., & Ratcliff W. "*De Novo* Evolution Macroscopic of Multicellularity." *Nature*, 2023.
- **Balwani A.**, Krzyston J. "Zeroth-order Topological Insights into Magnitude-based Neural Network Pruning." *PMLR Volume on Topology, Algebra, and Geometry in Learning*, 2022.
- **Balwani A.***, Miano J.*, Liu R., Kitchell L., Prasad J., Johnson E., Gray-Roncal W., & Dyer E. "Multi-Scale Modeling of Neural Structure in X-ray Imagery" *IEEE International Conference on Image Processing (ICIP)*, 2021.
- Prasad, J., **Balwani, A.**, Johnson, E., Miano, J., Sampathkumar, V., De Andrade, V., ... & Dyer, E. "A three-dimensional thalamocortical dataset for characterizing brain heterogeneity." *Nature Scientific Data*, 2020.
- Liu, R., Subakan, C., **Balwani, A.**, Whitesell, J., Harris, J., Koyejo, S., & Dyer, E. "A generative modeling approach for interpreting population-level variability in brain structure." *International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI)*, 2020.
- **Balwani, A.**, & Dyer E. "Modeling variability in brain architecture with deep feature learning." *2019 53rd Asilomar Conference on Signals, Systems, and Computers. IEEE*, 2019.
- Milligan K., **Balwani A.**, Dyer E. "Brain Mapping at High Resolutions: Challenges and Opportunities." *Current Opinion in Biomedical Engineering*, 2019.
- Lee T., Kumar A., **Balwani A.**, Brittain D., Kinn S., Tovey C., Dyer E., da Costa N., Reid R., Forest C., & Bumbarger D. "Large-scale neuroanatomy using LASSO: Loop based Automated Serial Sectioning Operation." *PloS one*, 13.10, 2018.

Preprints and In-Submission
- **Balwani A.**, Wang A. Y., Najafi F., Choi H. "Constructing Biologically Constrained RNNs via Dale's Backpropagation and Topologically-Informed Pruning." *bioRxiv*, 2025. (Under review at *Science Advances*)
- **Balwani A.**, Cho S., Choi H. "On the Architectural Biases of the Canonical Cortical Microcircuit." *bioRxiv*, 2024. (Accepted at *Neural Computation*)
- **Balwani A.**, & Dyer E. "A Deep Feature Learning Approach for Mapping the Brain's Microarchitecture and Organization." *bioRxiv*, 2020.

- Amarnath C., **Balwani A.**, Ma K., & Chatterjee A. "TESDA: Transform Enabled Statistical Detection of Attacks in Deep Neural Networks" *arXiv*, 2021.

In Preparation
- **Balwani A.** "A Hole in One: Topologically Motivated Deep Neural Network Pruning and Retraining."

Workshop Papers & Peer Reviewed Abstracts
- **Balwani A.**, Wang A., Najafi F., Choi H., "Constructing Biologically-Constrained RNNs via Dale's Backprop and Topologically-Informed Pruning." (Poster), COSYNE 2025.
- Zhou W., **Balwani A.**, Chung S., Schneider D., "Motor-sensory Experience Reshapes Neural Manifolds in Auditory Cortex to Reflect Acoustic Expectations." Advances and Perspectives in Auditory Neuroscience 2023.
- **Balwani A.**, Choi H. "On the Architectural Biases of the Canonical Cortical Microcircuit." (Talk, Top 3.2% of submissions), COSYNE 2023.
- Cho S., **Balwani A.**, Choi H. "Leveraging Predictive Coding to Improve Artificial Neural Network Performance" (Poster), Collaborative Research in Computational Neuroscience (CRCNS), 2022.
- **Balwani A.**, Krzyston J. "Zeroth-order Topological Insights into Magnitude-based Neural Network Pruning." (Spotlight, Top 9.8% of submissions), *Topology, Algebra, and Geometry in Machine Learning, ICML*, 2022.
    - Also presented as a poster at *Sparsity in Neural Networks*, 2022.
- **Balwani A.**, & Dyer E. "Modeling Brain Microarchitecture with Deep Representation Learning." (Poster), *ML Interpretability for Scientific Discovery, ICML*, 2020.
- **Balwani A.**, Miano J., Prasad J., & Dyer E. "Learning to Segment at Multiple Scales." (Poster), *BioImage Informatics*, 2019.
- Milligan K., **Balwani A.**, Maguire A., Margulies S., & Dyer E. "Deep Learning for Characterization of Neuroinflammation in Traumatic Brain Injury." (Poster), *BioImage Informatics*, 2019.

RESEARCH & WORK EXPERIENCE

- **Forecasting Mentee**, Epoch FRI AI Mentorship Program (Summer 2023)
    - Worked towards quantifying the value that various antecedent questions add to a bigger "ultimate" question using Bayesian probability. (Mentor: Molly Hickman)
    - Proposed modifications to and compared different metrics from the literature on two distinct forecasting datasets to identify questions that are the most predictive of beliefs regarding certain topics, as well as those which drive agreement or disagreement from responders with differing beliefs.

- **Winter Project Intern**, Good Futures Initiative, EA Berkeley (December 2022 – January 2023)
    - Worked towards scoping out and developing a mathematical framework leveraging the geometry of the learnt representations with respect to a task to detect and potentially address AI misalignment.
    - Studied the potential for using predictive coding-based training approaches and local learning rules to avoid misgeneralization in deep learning systems.

- **Summer Research Associate**, Center for Computational Neuroscience, Flatiron Institute, Simons Foundation (Summer 2022)
  - Areas of Research: Bio-plausible learning rules for training deep neural networks; Representational Geometry (Supervisor: Dr. SueYeon Chung)
  - Developed a three-factor Hebbian learning rule that operates on non-negative neural networks with a recurrent structure.
  - Both theoretically and empirically showed that the learning rule largely updates weights in the same direction as the loss gradient. Provided exact conditions under which the updates would always be sign-matched with the loss gradient.
  - Analyzed data from the auditory cortex of mice and generated insightful low-dimensional visualizations of their neuronal trajectories, quantified disentanglement between neuronal trajectories and task-relevant separating hyperplanes, found neuronal coordinates that encoded meaningful directions with respect to the experimental task.

- **Graduate Research Assistant**, Georgia Institute of Technology
  - Summer 2021 – Present: Architectural biases in cortical microcircuits and their effects on sequence learning, Predictive coding, Dimensionality of representations in neural networks across learning and brain areas, RNN training with biological constraints.
  - Summer 2018 – Spring 2021: Representation learning, Transfer/Meta and Multi-task learning, Sparse and low-rank representations of data, Models of brain structure and organization.

- **Graduate Student**, Georgia Institute of Technology
  - Meta-learning biologically plausible update rules for unsupervised and semi-supervised representation learning (Spring 2021)
  - Modeling visual invariance with group-theoretic regularization (Spring 2021)
  - Neural event recovery from noisy data via sparse deconvolution (Spring 2018)
  - Deep learning in autonomous driving (Fall 2017)

- **R&D Intern** (Algorithms Team), Intellifusion, China (Summer 2017)
  - Areas of Research: Image Processing, Data Compression and Encryption.

TEACHING & MENTORING EXPERIENCE

Teaching Assistant
- Linear Algebra, Georgia Tech (Spring 2024)
- AI Safety Fundamentals, Georgia Tech (Facilitator, AI Safety Institute) (2023)
- Professional and Technical Communications for ECE, Georgia Tech (Summer 2021)
- Data Analytics for Engineers, Georgia Tech (Fall 2019, 2018)
- Hands-On Tech Day Camp, Georgia Tech (June 2019)
- Deep Learning for Microscopy Image Analysis, Marine Biological Laboratory (May 2019)
- Mathematical Foundations for Data Science, Georgia Tech (Spring 2018)
- Embedded Systems & IoT, Eduvance (Summer 2016)

HONOURS & AWARDS

Academic Awards & Fellowships
- ECE Coulter MS Fellowship, Georgia Institute of Technology, 2016-2017

Grants
- Open Philanthropy, Career Development and Transition Funding, 2025.

Registration & Travel Awards
- COSYNE Presenters Travel Award, 2023.
- ICML Diversity and Inclusion Fellowship, 2020

Competitions & Hackathons
- Best Poster – Frontiers in Science Conference and Symposium (Intelligence), Georgia Tech, 2025
- Winner (Technical Track) – Hacklytics, Data Science at Georgia Tech, 2019
- Winner (Best Project) – AI/ML for Social Good Hackathon at Georgia Tech, 2018
- Gold Award - IEEE UBTech-Education Robotics Design Challenge, 2017

PROFESSIONAL SERVICE

Reviewing
- Journals: Distill
- Conferences: AISTATS (2023, 2024), MIDL (2022, 2023), CoLLAs (2022, 2023)
- Workshops: Workshop on Geometrical and Topological Representation Learning (ICLR 2021, 2022, 2023), Topological Data Analysis and Beyond (NeurIPS 2020), Lifelong Learning Workshop (ICML 2020), Workshop on Continual Learning in Computer Vision (CVPR 2020, 2021, 2023), Workshop on Continual Semi-Supervised Learning (IJCAI 2021)
- Other: Neuromatch Academy 2020, President's Undergraduate Research Awards – Georgia Tech (Spring 2020 - 2023; Summer 2021, 2023; Fall 2020 - 2023)

Professional & Student Organizations
- Senator (ECE), Graduate Student Association, Georgia Institute of Technology, 2017-2018

WORKSHOPS & SEMINARS

Attendee
- Define, Design, and Align, AI Safety @ UCLA (January 2023)
- AI Safety Workshop, Berkeley (December 2022)
- London Geometry and Machine Learning Summer School (July 2021)
- Banach Center – Oberwolfach Graduate Seminar: Mathematics of Deep Learning, Institute of Mathematics, Polish Academy of Sciences (November 2019)
- Foundation of Data Science Summer School, Georgia Institute of Technology (August 2019)
- Spinning Up in RL Workshop, OpenAI (February 2019)