Preface

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1. Symmetry and Geometry in Neural Representations

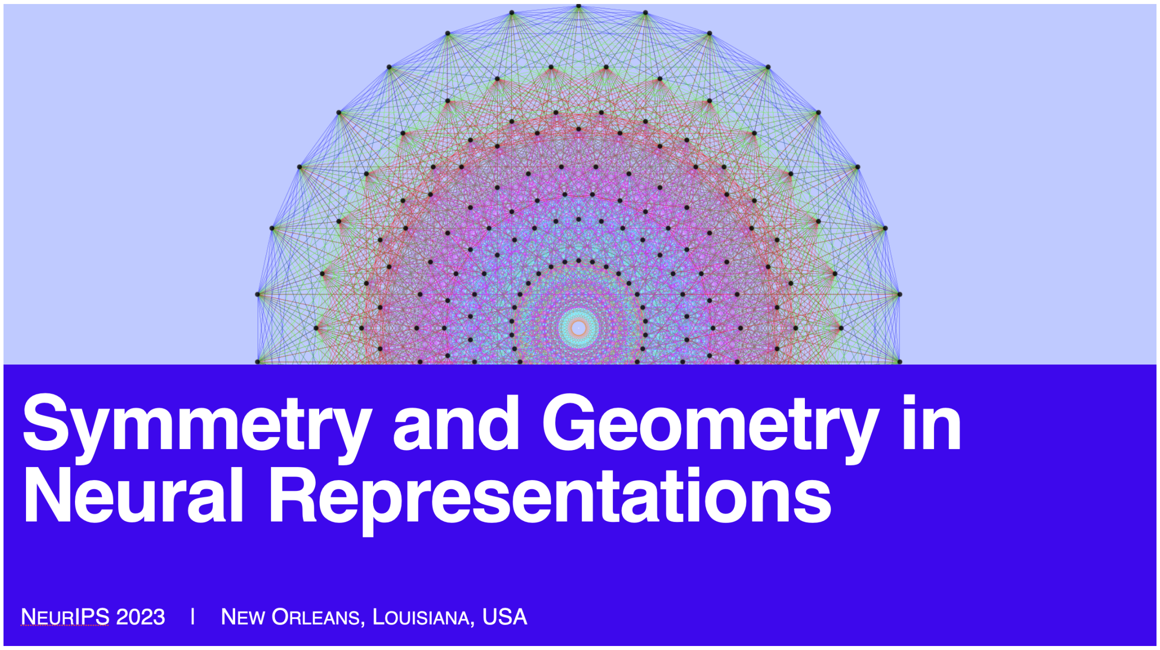
An emerging set of findings in sensory and motor neuroscience is beginning to illuminate a new paradigm for understanding the neural code. Across sensory and motor regions of the brain, neural circuits are found to mirror the geometric and topological structure of the systems they represent—either in their synaptic structure, or in the implicit manifold generated by their activity. This phenomenon can be observed in the circuit of neurons representing head direction in the fly Kim et al. (2017); Wolff et al. (2015), in the activities of grid cells Chaudhuri et al. (2019); Gardner et al. (2022), and in the low-dimensional manifold structure observed in motor cortex Gallego et al. (2017). This suggests a general computational strategy that is employed throughout the brain to preserve the geometric structure of data throughout stages of information processing.

Independently but convergently, this very same computational strategy has emerged in the field of deep learning. The nascent sub-field of Geometric Deep Learning Bronstein et al. (2021) incorporates geometric priors into artificial neural networks to preserve the geometry of signals as they are passed through layers of the network. This approach provably demonstrates gains in the computational efficiency, robustness, and generalization performance of these models.

The convergence of these findings suggests deep, substrate-agnostic principles for information processing. Symmetry and geometry were instrumental in unifying models of fundamental forces and elementary particles in 20th-century physics. Likewise, they have the potential to illuminate unifying principles for how neural systems form useful representations of the world.

2. The Workshop

The second annual NeurIPS Workshop on Symmetry and Geometry in Neural Representations (NeurReps) was conceived to bring together researchers at the nexus of applied geometry, deep learning, and neuroscience, with the goal of advancing this understanding and illuminating geometric principles for neural information processing. Ultimately, we hope that this venue and associated community will support the development of the



geometric approach to understanding neural representations, while strengthening ties to the mathematics community. The Neural Information Processing Systems (NeurIPS) conference historically emerged from the field of theoretical neuroscience or "connectionism." This venue thus further serves the workshop's goal of reinforcing the bond between deep learning and neuroscience.

2.1. Call for Papers

Our call for papers invited submissions for publication in this volume and presentation at the conference. The call requested submissions contributing novel research at the intersection of geometric deep learning, computational neuroscience, geometric statistics, and topological data analysis, which incorporate symmetry, geometry, or topology into the *design of artificial neural networks*, the *analysis of neural data*, or *theories of neural computation*. Both theoretical contributions and applied results were encouraged, as well as the use of diverse mathematical objects such as quotient spaces, fiber bundles, Lie groups, Riemannian manifolds, graphs, and group representations. Two tracks were established:

1. **Proceedings Track**: NeurReps Proceedings papers are up to 10 pages long, excluding references and appendices. This track is intended for self-contained research papers with a high degree of development. Accepted papers are published in this volume.

2. **Extended Abstract Track**: Extended abstracts are up to 5 pages long, excluding references and appendices. This track is a space for contributions such as early-stage results, insightful negative findings, opinion pieces, or novel datasets. Extended abstracts are not included in this volume.

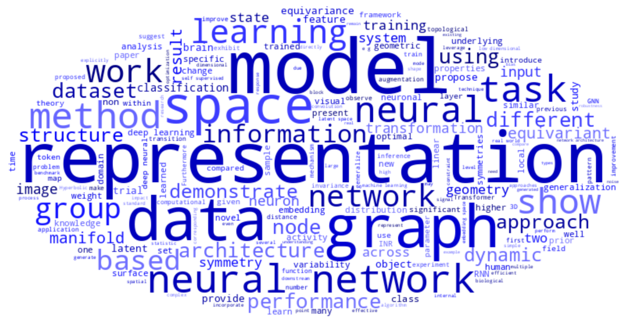


Figure 1: A word cloud constructed from the abstracts of all submissions.

The call for papers yielded 75 submissions, which were reviewed double-blind. Submitted work spanned from questions in statistical learning theory for geometric models, to novel geometric deep learning architectures, to methods for neural data analysis. Each submission received a minimum of three reviews, which were aggregated and assessed by the editors for final inclusion. This resulted in 65 accepted works: 23 full-length papers, and 42 extended abstracts. All of the 23 full-length papers are published in this volume, by choice of the authors. Reviews of the accepted works can be found on the NeurReps OpenReview Portal.

2.2. The Schedule

The workshop was held on December 16th, 2023 in New Orleans, Lousiana, USA, and attracted between 300 and 400 in-person attendees. The workshop featured five invited keynote speakers with talks spanning topics in neuroscience, machine learning, topology and their intersection. In addition, one discussion panel was held. All accepted works were presented as posters during the workshop, with the top eleven submissions selected for ten-minute oral presentation. Awards were given to the best contribution for each area: *Neuroscience & Interpretability*, *Topology & Graphs* and *Algebra & Geometry*. All talks and the panel were live-streamed and recorded and can be found online on SlidesLive.

Keynotes

Pre-structured low-dimensional manifolds for rapid and efficient learning, memory, and inference in the brain
Ila Fiete

Topological deep learning: going beyond graph data
Mustafa Hajij

From local diffeomorphism detection to symbolic representation
Doris Tsao

Physics priors in machine learning
Max Welling

Rotation-equivariant predictive modeling reveals the functional organization of primary visual cortex
Alexander Ecker

Discussion Panel

The Role of world models in intelligence
Panelists: Ila Fiete, Mustafa Hajij, Doris Tsao, Max Welling, Alexander Ecker
Moderator: Sophia Sanborn

Contributed Talks

Neuroscience & Intepretability

Expressive dynamics models with nonlinear injective readouts enable reliable recovery of latent features from neural activity ⋆
Versteeg[†], Sedler, McCart, Pandarinath

On Complex Network Dynamics of an In-Vitro Neuronal System during Rest and Gameplay
Khajehnejad[†*], Habibollahi[*], Loeffler, Kagan, Razi

Topology & Graphs

Spectral Maps for Learning on Subgraphs ⋆
Marco Pegoraro[†], Riccardo Marin, Arianna Rampini, Simone Melzi, Luca Cosmo, Emanuele Rodolà

Algebra & Geometry

Towards Information Theory-Based Discovery of Equivariances ⋆
Hippolyte Charvin[†], Nicola Catenacci Volpi, Daniel Polani

Internal Representations of Vision Models Through the Lens of Frames on Data Manifolds
Henry Kvinge, Grayson Jorgenson, Davis Brown[†], Charles Godfrey, Tegan Emerson

Data Augmentations in Deep Weight Spaces
Aviv Shamsian[†], David Zhang, Aviv Navon, Yan Zhang, Miltiadis Kofinas, Idan Achituve, Riccardo Valperga, Gertjan Burghouts, Efstratios Gavves, Cees Snoek, Ethan Fetaya, Gal Chechik, Haggai Maron

Joint Group Invariant Functions on Data-Parameter Domain Induce Universal Neural Networks
Sho Sonoda[†], Hideyuki Ishi, Isao Ishikawa, Masahiro Ikeda

Euclidean, Projective, Conformal: Choosing a Geometric Algebra for Equivariant Transformers
Pim De Haan[†], Taco Cohen, Johann Brehmer

Symmetry Breaking and Equivariant Neural Networks
Sékou-Oumar Kaba†, Siamak Ravanbakhsh

From Bricks to Bridges: Product of Invariances to Enhance Latent Space Communication
Irene Cannistraci†, Luca Moschella, Marco Fumero, Valentino Maiorca, Emanuele Rodolà

Geometry of abstract learned knowledge in deep RL agents
James Mochizuki-Freeman†, Md Rysul Kabir, Mitesh Gulecha, Zoran Tiganj

⋆ Denotes best area contribution. † Denotes presenting author. * Denotes shared first-authorship

3. The Community

To support the growth of this nascent research area outside of the annual workshop, we have established a digital community for NeurReps, which at the time of writing has over 1200 members. Instructions for joining and contributing to the community can be found on the community page of our website.

4. Program Committee

We extend our immense gratitude to our area chairs, who have diligently supervised the reviewing process and led the selection of contributed talks. Our heartfelt thanks also go out to the 165 reviewers, whose collective efforts resulted in 230 high-quality reviews for the workshop's 75 submissions. Their dedication and expertise have been integral to the success of this workshop. Thank you :

Area Chairs

Neuroscience & Interpretability	Topology & Graphs	Algebra & Geometry
James Whittington	Michael Schaub	Henry Kvinge

Reviewers

Abiy Tasissa	Anton Tsitsulin	Bongjin Koo
Adrian Bertagnoli	Antonio Briola	Brian Wesley Bell
Adrish Dey	Arjun Karuvally	Charles Godfrey
Ahmed Imtiaz Humayun	Artem Moskalev	Clinton Wang
Alex Gabel	Augustine N. Mavor-Parker	Daniel McNeela
Alex H Williams	Behrooz Tahmasebi	Daniel Ordonez-Apraez
Alpha Renner	Bilal Alsallakh	Daniel Platt
Andreea Danielescu	Binxu Wang	Danil Akhtiamov
Ankita Shukla	Bo Zhao	David A. Klindt

David A. R. Robin
David Klee
David Robert Reich
David Sheard
David W. Romero
Davis Brown
Dehong Xu
Dennis George Wilson
Derek Lim
Dimitris Kalatzis
Domas Buracas
Dongmian Zou
Edward Paxon Frady
Ekdeep Singh Lubana
Eloy Geenjaar
Emanuele Rodolà
Eric Qu
Erik J Bekkers
Federico Barbero
Filip Cornell
Filippo Maggioli
Francisco Acosta
Frank Yuchen Qiu
Gergely Berczi
Giovanni Luca Marchetti
Grégoire Sergeant-Perthuis
Guillaume Huguet
Hooman Shayani
Ilyes Batatia
Irene Cannistraci (
Jacob A Zavatone-Veth
Javier Gonzalvo
Jeffrey Seely
Jens Agerberg
Jianke Yang
Joey Bose
Johan Mathe
John Vastola
Jonathan Raymond Huml
Joshua Robinson
Joshua Southern
Julian Suk
Kartik Sharma
Katharina Limbeck
Kijung Yoon
Konstantinos Barmpas
Kristopher T Jensen
Lazar Supic
Leander Girrbach
Liu Ziyin
Lorenzo Giusti
Luca Baroni
Luca Moschella
Maghesree Chakraborty
Maksim Zhdanov
Manos Theodosis
Marco Pegoraro
Mathilde Papillon
Matt Thomson
Matthew Farrell
Matthew James Sargent
Michael G. Rawson
Mikail Khona
Nello Blaser
Nima Dehmamy
Noah Lewis
Ondrej Biza
Peiran Jiang
Pim De Haan
Qingsong Wang
Ramakrishnan Iyer
Randall Balestriero
Rishabh Anand National
Rishi Sonthalia
Robin Walters
Santiago Velasco-Forero
Sarthak Chandra
Sékou-Oumar Kaba
Semih Cantürk
Sepideh Maleki
Seunghyuk Cho
Shahira Abousamra
Sharvaree Vadgama
Siba Smarak Panigrahi
Sigurd Gaukstad
Sjoerd van Steenkiste
Sohir Maskey
Sourabh Palande
Sree Harsha Tanneru
Stefan Mihalas
Stephan Chalup
Sungjun Cho
Takashi Matsubara
Tananun Songdechakraiwut
Tara Akhound-Sadegh
Tegan Emerson
Thomas Gebhart
Tom Needham
Tycho F. A. van der Ouderaa
Uri Cohen
Valentino Maiorca
Vasco Portilheiro
Vinayak Abrol
Vincent Peter Grande
Wenhao Zhang
Wu Lin
Xinyue Cui
Xue-Xin Wei
Yan HU
Ying Nian Wu
Yivan Zhang
Yonatan Gideoni

Figure 2: The NeurReps 2023 poster session.

5. Moving Forward

We believe it is both timely and important to create a research venue and supportive community for the exchange of knowledge at the intersection of differential geometry, topology, machine learning and neuroscience. Moving forward, we will continue to create opportunities for dialogue and discussion on these themes at NeurIPS and other meetings. Furthering our broader aim of community-building, we have also established an active community of students and researchers which we believe will act as a gathering place to organize related events, such as seminars and hackathons.

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