Thomas F. **Varley**

Complex Systems & Networks · Computational & Clinical Neurosciences

University of Vermont, Burlington, VT

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Education & Academic Experience

University of Vermont — *Burlington, VT, USA*

Postdoctoral Research Scientist — *Sept. 2023 - Present*

- Supervisor: Dr. Joshua Bongard
- Areas of Research: Computation in biological & artificial systems, xenomics.

Indiana University Bloomington — *Bloomington, IN, USA*

PhD Complex Networks & Systems

PhD Computational Neurosciences — *Aug. 2018 - June 2023*

- Thesis: *Uncovering Higher-Order Structures in Complex Systems with Multivariate Information Theory*
- Supervisors: Dr. Olaf Sporns, Dr. John Beggs

University of Cambridge — *Cambridge, UK*

MPhil Clinical Medicine (Clinical Neurosciences) — *Sept. 2017 - Aug. 2018*

- Thesis: *Consciousness & Complexity in Clinical Neurosciences*
- Supervisors: Dr. Emmanuel Stamatakis, Dr. David Menon

Hampshire College — *Amherst, MA*

BA Systems Neuroscience — *Sept. 2012 - May 2016*

- Thesis: *The Role of the 5-HT$_{2A}$ Receptor in Anxiety & BDNF Expression in Zebrafish*
- Supervisors: Dr. Cynthia Gill, Dr. Ethan Meyers, Dr. John Castorino

Research

Higher-order interactions in the brain.

One of the most common approaches to analyzing neuroimaging data is with network models: a graphical representation of pairwise connections or dependencies between elements (neurons, cortical regions, etc). While powerful, networks are limited in that they can only directly represent interactions between pairs of elements; polyadic dependencies must be constructed out of pairwise links. This research program explores how multivariate information theory can be used as a foundation on which to build generalized statistics that account for higher-order redundancies and synergies directly. Relevant papers: Varley et al. (2023); Varley (2023); Varley et al. (2024)

Biological basis of neural computation

The question of how the brain integrates information at the level of neuronal networks is a fundamental question in neuroscience. Understanding these abstract computational processes, however, requires understanding how computations are implemented in the "wetware" of neural tissue. This arm of research combines theoretical and computational approaches with wet-lab bench science to understand how changes in the "computational structure" of neuronal activity is regulated by biological perturbations. I am particularly interested in the serotonergic system and the role of the 5-HT$_{2A}$ receptor in regulating information dynamics. Relevant papers: Varley et al. (2024); Varley (2023); Newman et al. (2022)

The role of the central nervous system in post-viral illness.

Post-viral illnesses like long COVID are massive, morally urgent unsolved problems in medicine and public health. They are also opportunities for science to deepen our understanding how the brain, the immune system, and the environment interact in complex ways. I have recently become interested in how neuroscience can help us understand the origins, pathophysiology, and ultimately treatment of these conditions. In work with the patient-led Renegade Research nonprofit, I am exploring the role of the brainstem in particular in regulating central, peripheral, and immune system dysfunction, and how that is represented in patient biometric data.

Grants & Awards

Grants

2020	**Source Research Foundation Graduate Student Research Grant**, $2,000	*Bloomington, IN*
2020	**Young Researchers of the Complex Systems Society Bridge Grant**, $1,090.50	*Bloomington, IN*
2018-20	**NSF Student Traineeship**, $34,000 / year	*Bloomington, IN*
2015-16	**Culture, Brain, & Development Fund Student Project Grant**, $1304.00	*Amherst, MA*
2015	**Ray & Lorna Coppinger Endowment Grant**, $804.00	*Amherst, MA*

Awards

2024	**Irving J. Saltzman Award for Outstanding Graduate Achievement**, Department of Psychological & Brain Sciences, IU Bloomington	*Bloomington, IN*
2024	**Editor's Choice Award at MDPI Entropy**, Revealing the Dynamics of Neural Information Processing with Multivariate Information Decomposition	
2023	**J.R. Kantor Graduate Award**, Department of Psychological & Brain Sciences, IU Bloomington	*Bloomington, IN*

Service

Ad Hoc Reviews

Neuroscience of Consciousness, Neuroimage, Human Brain Mapping, Network Neuroscience, Journal of Healthcare, PLoS ONE, Cerebral Cortex, Journal of Psychopharmacology, BMC Anaesthesia, Artificial Life, Nature Communications,

Graduate Workers Coalition (IGWC-UE)

Union Representative, Department of Psychological & Brain Sciences *2021-2023*

Presentations & Posters

NYU Infant Consciousness Conference *New York University*

Emergence of a synergistic scaffold in the brains of human infants (Presentation) *New York City, New York*

February, 2025

Binghamton CoCo Seminar Series *SUNY Binghampton*

Stability, Integration, and Higher-Order Interactions in Complex Systems (Invited presentation) *Binghamton, NY*

April, 2024

Neuroscience 2023 *Society for Neuroscience*

The emergence of a synergistic scaffold in the infant human brain. (Poster) *Washington, DC, USA*

November, 2023

IOP Complexity, Computers, and Consciousness Workshop *Imperial College London*

The serotonergic psychedelic N,N-dipropyltryptamine alters information-processing dynamics in cortical circuits. (Presentation) *London, UK*

November, 2023

International Conference on Systems Biology (ICSB 2023) *University of Connecticut*

Extracting calcium dynamics from *xenopus* tissue (co-presenter) *Hartford, CT*

October, 2023

UVM-KIAS Workshop on Group Interactions *Vermont Complex Systems Center*

Exploring higher-order group interactions in complex systems with multivariate information theory (Invited presentation) *Burlington, VT*

September, 2023

NetSci-X 2022 *The Network Science Society*

Uncovering higher-order interactions using multivariate entropy decomposition (Presentation) *Porto, Portugal*

Februrary, 2022

IUNI 2022 Workshop Series *Indiana University Network Sciences Institute*

Inferring Effective Networks from Time Series Using Information Theory (Workshop) *Bloomington, IN*

January, 2022

University of Glasgow Methods & Meta-Science Seminar *University of Glasgow*

Intersectional Synergies (Invited Presentation) *Glasgow, UK*

December, 2021

CNS*2021 *Organization for Computational Neuroscience*

Neural Information Dynamic and Topological Correlates of Complex Behaviors in Macaques (Presentation) *Online*

June, 2021

Indiana University Cognitive Science Colloquium *Indiana University Bloomington*

Emergence and Attractor Dynamics During LSD-Induced Psychedlia in Humans (Presentation) *Bloomington, IN*

February 2020

The Science of Consciousness *University of Arizona*

Topological and Information-Theoretic Analysis of Propofol and Ketamine Anesthesia (Presentation) *Tucson, AZ*

September 14-18, 2020

Publications

* Indicates co-first author

Varley, T. F., Foti, T., Brosius, E., Yada M., Ramirez-Burnett, I., Falor, F. (*In prep*). Identifiying transient remission events in ME/CFS and Long COVID."

Wood, J., **Varley, T.F.**, Hartman, J., Melier, N., Fallor, T. (*In prep*). The role of the brainstem in myalgic encephalomyletis and long covid.

Varley, T.F.*, Pai, V.*, Grasso, C., Lunshof, J., Levin, M., & Bongard, J. (2024). Identification of brain-like functional information architectures in embryonic tissue of Xenopus laevis. (p. 2024.12.05.627037). bioRxiv. *(Under review at Nature Communications)*
https://doi.org/10.1101/2024.12.05.627037

Pope, M., **Varley, T. F.**, Grazia Puxeddu, M., Faskowitz, J., & Sporns, O. (2025). Time-varying synergy/redundancy dominance in the human cerebral cortex. Journal of Physics: Complexity, 6(1), 015015.
https://doi.org/10.1088/2632-072X/adbaa9

Varley, T. F. (2024). A Synergistic Perspective on Multivariate Computation and Causality in Complex Systems. Entropy, 26(10), Article 10.
https://doi.org/10.3390/e26100883

Varley, T. F., Havert, D., Fosque, L., Alipour, A., Weerawongphrom, N., Naganobori, H., O'Shea, L., Pope, M., & Beggs, J. (2024). The serotonergic psychedelic N,N-dipropyltryptamine alters information-processing dynamics in in vitro cortical neural circuits. Network Neuroscience, 1–35.
https://doi.org/10.1162/netn_a_00408

Puxeddu, M. G., Pope, M., **Varley, T. F.**, Faskowitz, J., & Sporns, O. (2024). Leveraging multivariate information for community detection in functional brain networks (p. 2024.07.22.604675). bioRxiv. *Under review at PNAS*
https://doi.org/10.1101/2024.07.22.604675

Madan Mohan, V., **Varley, T. F.**, Cash, R., Seguin, C., & Zalesky, A. (2024). Event-marked Windowed Communication: Inferring activity propagation from neural time series. *Under review at PNAS*
https://doi.org/10.1101/2024.07.30.605466

Varley, T. F. (2024). A scalable synergy-first backbone decomposition of higher-order structures in complex systems. Npj Complexity, 1(1), 1–11.
https://doi.org/10.1038/s44260-024-00011-1

Varley, T. F., & Bongard, J. (2024). Evolving higher-order synergies reveals a trade-off between stability and information-integration capacity in complex systems. Chaos: An Interdisciplinary Journal of Nonlinear Science, 34(6), 063127.
https://doi.org/10.1063/5.0200425

Blackiston, D., Dromiack, H., Grasso, C., **Varley, T. F.**, Moore, D. G., Srinivasan, K., Sporns, O., Bongard, J., Levin, M., & Walker, S. I. (2024). Revealing non-trivial information structures in aneural biological tissues via functional connectivity (p. 2024.05.09.593467). bioRxiv. *Under review at PLoS Computational Biology*
https://doi.org/10.1101/2024.05.09.593467

Varley, T. F., Sporns, O., Stevenson, N. J., Welch, M. G., Myers, M. M., Vanhatalo, S., & Tokariev, A. (2024). Emergence of a synergistic scaffold in the brains of human infants (p. 2024.02.23.581375). bioRxiv. *Under review at Nature Communications Biology*
https://doi.org/10.1101/2024.02.23.581375

Varley, T. F. (2024). Generalized decomposition of multivariate information. PLOS ONE, 19(2), e0297128.
https://doi.org/10.1371/journal.pone.0297128

Varley, T. F., Pope, M., Maria Grazia, P., Joshua, F., & Sporns, O. (2023). Partial entropy decomposition reveals higher-order information structures in human brain activity. Proceedings of the National Academy of Sciences, 120(30), e2300888120.
https://doi.org/10.1073/pnas.2300888120

Pope, M., Seguin, C., **Varley, T. F.**, Faskowitz, J., & Sporns, O. (2023). Co-evolving dynamics and topology in a coupled oscillator model of resting brain function. NeuroImage, 277, 120266.
https://doi.org/10.1016/j.neuroimage.2023.120266

Varley, T. F. (2023). Information Theory for Complex Systems Scientists (arXiv:2304.12482). arXiv. https://doi.org/10.48550/arXiv.2304.12482

Varley, T. F.*, Pope, M.*, Faskowitz, J., & Sporns, O. (2023). Multivariate information theory uncovers synergistic subsystems of the human cerebral cortex. Communications Biology, 6(1), Article 1. https://doi.org/10.1038/s42003-023-04843-w

Varley, T. F. (2023). Decomposing past and future: Integrated information decomposition based on shared probability mass exclusions. PLOS ONE, 18(3), e0282950. https://doi.org/10.1371/journal.pone.0282950

Varley, T. F., Sporns, O., Schaffelhofer, S., Scherberger, H., & Dann, B. (2023). Information-processing dynamics in neural networks of macaque cerebral cortex reflect cognitive state and behavior. Proceedings of the National Academy of Sciences, 120(2), e2207677120. https://doi.org/10.1073/pnas.2207677120

Varley, T. F. (2023). Flickering Emergences: The Question of Locality in Information-Theoretic Approaches to Emergence. Entropy, 25(1), Article 1. https://doi.org/10.3390/e25010054

Varley, T. F., & Kaminski, P. (2022). Untangling Synergistic Effects of Intersecting Social Identities with Partial Information Decomposition. Entropy, 24(10), Article 10. https://doi.org/10.3390/e24101387

Newman, E. L., **Varley, T. F.**, Parakkattu, V. K., Sherrill, S. P., & Beggs, J. M. (2022). Revealing the Dynamics of Neural Information Processing with Multivariate Information Decomposition. Entropy, 24(7), 930. https://doi.org/10.3390/e24070930

Varley, T. F., & Hoel, E. (2022). Emergence as the conversion of information: A unifying theory. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 380(2227), 20210150. https://doi.org/10.1098/rsta.2021.0150

Rosas, F. E., Mediano, P. A. M., Luppi, A. I., **Varley, T. F.**, Lizier, J. T., Stramaglia, S., Jensen, H. J., & Marinazzo, D. (2022). Disentangling high-order mechanisms and high-order behaviours in complex systems. Nature Physics, 1–2. https://doi.org/10.1038/s41567-022-01548-5

Varley, T. F., & Sporns, O. (2022). Network Analysis of Time Series: Novel Approaches to Network Neuroscience. Frontiers in Neuroscience, 15. https://www.frontiersin.org/article/10.3389/fnins.2021.787068

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Mediano, P. A. M., Ikkala, A., Kievit, R. A., Jagannathan, S. R., **Varley, T. F.,** Stamatakis, E. A., Bekinschtein, T. A., & Bor, D. (2021). Fluctuations in Neural Complexity During Wakefulness Relate To Conscious Level and Cognition (p. 2021.09.23.461002). https://doi.org/10.1101/2021.09.23.461002

Varley, T. F., Denny, V., Sporns, O., & Patania, A. (2021). Topological analysis of differential effects of ketamine and propofol anaesthesia on brain dynamics. Royal Society Open Science, 8(6), 201971. https://doi.org/10.1098/rsos.201971

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sciousness. PLOS ONE, 15(2), e0223812.
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Varley, T. F.*, Luppi, A. I.*, Pappas, I., Naci, L., Adapa, R., Owen, A. M., Menon, D. K., & Stamatakis, E. A. (2020). Consciousness & Brain Functional Complexity in Propofol Anaesthesia. Scientific Reports, 10(1), 1–13
https://doi.org/10.1038/s41598-020-57695-3

Varley, T. F., Carhart-Harris, R., Roseman, L., Menon, D. K., & Stamatakis, E. A. (2020). Serotonergic psychedelics LSD & psilocybin increase the fractal dimension of cortical brain activity in spatial and temporal domains. NeuroImage, 220, 117049.
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References available upon request.

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