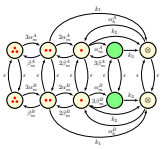
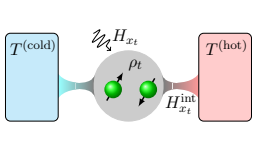

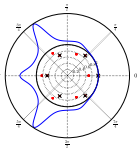

Paul M. Riechers

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Research Interests

Theoretical physicist with expertise in the physics of information—especially the generation and prediction of stochastic processes, quantum information, machine learning, and spectral theory.

Affiliations

Co-founder and *Chief Scientist* 2024 – present
Simplex AI Safety

Co-founder and *Senior Scientist* 2023 – present
Beyond Institute for Theoretical Science (BITS)

Research Scholar Winter 2024
Machine-learning Alignment and Theory Scholars (MATS)

Research Fellow 2018 – 2023
The Quantum and Complexity Science Initiative
Nanyang Quantum Hub, School of Physical and Mathematical Sciences
Nanyang Technological University, Singapore

Postdoctoral Scholar 2018
Complexity Sciences Center and Department of Physics
University of California at Davis

Sabbatical 2017
Self-funded world travel while investigating nonequilibrium thermodynamic limits of computation.

Education

Ph. D., Physics, University of California, Davis, 2016
"Exact Results Regarding the Physics of Complex Systems via Linear Algebra, Hidden Markov Models, and Information Theory"

- The state of a complex system is revealed only over time. This dissertation considers the generation, prediction, and physical implication of stochastic time-series with hidden structure. It extends the bedrock of linear algebra and the frontier of nonequilibrium thermodynamics.

M. S., Electrical and Computer Engineering, University of California, Davis, 2012
"Influencing Nanoscale Dynamical and Complex Systems for Advanced Computation and Materials"

- This thesis introduced the concept of *attractor logic* and gave examples of implementation via gated interactions among non-linear oscillators.

B. S., Applied Physics, with Honors, University of California, Davis, 2009
Minor in Philosophy
Minor in Technology Management

Service and Honors

- Co-organizer of Agents, AI, and Alignment (AAA) workshop, Oxford (2024)
- Satellite Co-Chair for the International Conference on Complex Systems CCS2019
- Reviewer for *PRX*, *PRL*, *Nature Communications*, *Quantum*, *Journal of Statistical Physics*, *Proceedings of the Royal Society A*, *Entropy*, *Foundations of Physics*, *Chaos*, & others

- Member of ΣΠΣ, physics honor society
- Research grant from IBM for Excellent Contributed Talk at QC40: Physics of Computation Conference 40th Anniversary (2021)

Publications

· *Book Chapter* ·

P. M. Riechers. "Transforming metastable memories: the nonequilibrium thermodynamics of computation." In D. Wolpert, C. Kempes, P. Stadler, and J. Grochow, editors, *The Energetics of Computing in Life and Machines. SFI Press*, (2019).

· *Scientific Journal Papers* ·

S. E. Marzen, **P. M. Riechers**, J. P. Crutchfield. "Complexity-calibrated benchmarks for machine learning reveal when prediction algorithms succeed and mislead." *Scientific Reports*, accepted (2024).

(**P. M. Riechers**, R. C. Huang)*, M. Gu, and V. Narasimhachar. "Engines for predictive work extraction from memoryfull quantum stochastic processes." *Quantum* 7, 1203, (2023). *Co-first authors.

P. M. Riechers and M. Gu. "Impossibility of achieving Landauer's bound for almost every quantum state." *Physical Review A*, 104 (1),012214, (2021).

P. M. Riechers and M. Gu. "Initial-state dependence of thermodynamic dissipation for any quantum process." *Physical Review E*, 103 (4), 042145, (2021).

G. W. Wimsatt, A. B. Boyd, **P. M. Riechers**, and J. P. Crutchfield. "Refining Landauer's Stack: Balancing Error and Dissipation When Erasing Information." *Journal of Statistical Physics*, 183 (1), 1-23, (2021).

P. M. Riechers and J. P. Crutchfield. "Fraudulent white noise: Flat power spectra belie arbitrarily complex processes." *Physical Review Research*, 3 (1), 013170, (2021).

P. M. Riechers, A. B. Boyd, G. W. Wimsatt, and J. P. Crutchfield. "Balancing error and dissipation in computing." *Physical Review Research* 2 (3), 033524, (2020).

P. M. Riechers and J. P. Crutchfield. "Beyond the spectral theorem: spectrally decomposing arbitrary functions of nondiagonalizable operators." *AIP Advances*, 8, 065305, (2018).

P. M. Riechers and J. P. Crutchfield. "Spectral simplicity of apparent complexity, Part I: the nondiagonalizable metadynamics of prediction." *Chaos*, 28, 033115, (2018). (**Featured** by *Chaos*)

P. M. Riechers and J. P. Crutchfield. "Spectral simplicity of apparent complexity, Part II: exact complexities and complexity spectra." *Chaos*, 28, 033116, (2018).

P. M. Riechers and J. P. Crutchfield. "Fluctuations when driving between nonequilibrium steady states." *Journal of Statistical Physics*, 168(4), 873–918, (2017).

A. B. Boyd, D. Mandal, **P. M. Riechers**, and J. P. Crutchfield. "Transient dissipation and structural costs of physical information transduction." *Physical Review Letters*, 118, 220602, (2017).

P. M. Riechers, J. R. Mahoney, C. Aghamohammadi, and J. P. Crutchfield. "Minimized state complexity of quantum-encoded cryptic processes." *Physical Review A*, 93, 052317, (2016).

J. P. Crutchfield, C. J. Ellison, and **P. M. Riechers**. "Exact complexity: the spectral decomposition of intrinsic computation." *Physics Letters A*, 380(9-10): 998–1002, (2016).

P. M. Riechers, D. P. Varn, and J. P. Crutchfield. "Pairwise correlations in layered close-packed structures." *Acta Crystallographica Section A: Foundations and Advances*, 71(4): 423–43, (2015).

D. Wittman, **P. M. Riechers**, and V. E. Margoniner. "Photometric redshifts and photometry errors." *The Astrophysical Journal Letters*, 671(2): L109, (2007).

· *Scientific Preprints* ·

D. Wolpert et al. "Is stochastic thermodynamics the key to understanding the energy costs of computation?" arXiv:2311.17166 (2023).

P. M. Riechers. "Ultimate limit on learning non-Markovian behavior: Fisher information rate and excess information." arXiv:2310.03968 (2023).

P. M. Riechers, Chaitanya Gupta, Artemy Kolchinsky, and M. Gu. "Thermodynamically ideal quantum-state inputs to any device." arXiv:2305.00616 (2023).

A. B. Boyd, **P. M. Riechers**, G. W. Wimsatt, J. P. Crutchfield, and M. Gu. "Time symmetries of memory determine thermodynamic efficiency." arXiv:2104.12072.

P. M. Riechers, D. P. Varn, and J. P. Crutchfield. "Diffraction patterns of layered close-packed structures from hidden Markov models." arXiv:1410.5028.

· *Refereed Conference Proceedings* ·

P. M. Riechers and R. A. Kiehl, "A scheme for computation in nanoscale dynamical systems: Gated discrete phase-shift interactions." *2011 IEEE/ACM Intl. Symposium on Nanoscale Architectures*, June 8-9, San Diego, Calif, 2011.

P. M. Riechers and R. A. Kiehl, "CNN Implemented by Nonlinear Phase Dynamics in Nanoscale Processes." *12th IEEE Intl. Workshop on Cellular Nanoscale Networks and Applications*, Feb. 3-5, Berkeley, Calif, 2010.

· *Other Publications* ·

P. M. Riechers. "Collaborative disappearing act trumps levitation as useful trick for future electronics." *Prized Writing 2008-2009*. Ed. Pamela Demory. University Writing Program of the University of California at Davis, 2009. 144-50.

Invited Talks

Ultimate limit on learning non-Markovian behavior: Fisher information rate and excess information. Nanyang Quantum Hub NTU, Singapore, April 3$^{\text{rd}}$, 2024.

Computational mechanics predicts behavior and internal representations of transformers. MATS Symposium, Berkeley, March 14$^{\text{th}}$, 2024.

Computational mechanics: Fundamental limits of prediction, learning, and agency. Agency, AI, & Alignment (AAA) Workshop, Oxford, UK, March 4$^{\text{th}}$ 2024.

What sayeth the Second Law of Thermodynamics? Modern physics revises its sacred script. Spitzer seminar, Cal State East Bay, February 9, 2024.

Thermodynamically ideal quantum-state inputs to any device. Information Engines at the Frontiers of Nanoscale Thermodynamics, Telluride Science Research Center, Colorado, July 23, 2023.

Quantum fluctuation relations, with and without interventions. Quantum Intelligence Workshop, Birr, Ireland, September, 6, 2022.

Quantum-information engines. Information Engines at the Frontiers of Nanoscale Thermodynamics, Telluride Science Research Center, Colorado, July 23, 2022.

Adventures in entropy production. Complexity Sciences Center, UC Davis, California, May 18, 2022.

The impossibility of Landauer's bound for almost every quantum state. Information Engines at the

Frontiers of Nanoscale Thermodynamics, Telluride Science Research Center, Colorado (Virtual), July 22, 2021.

The Error–Dissipation Tradeoff when Computing with Time-Symmetric Protocols. Stochastic Thermodynamics of Complex Systems, Vienna, Austria, (Virtual, due to Covid), May 28$^{\text{th}}$ 2020.

Thermodynamic cost of misaligned expectations. Agency at the Interface of Quantum and Complexity Science, Singapore, January 14$^{\text{th}}$ 2020.

The Error–Dissipation Tradeoff when Agents Compute. Nonequilibrium Thermodynamics of Complex Agents: Information Processing from Nanophysics to Life, CCS2019, Singapore, October 2$^{\text{nd}}$ 2019.

Detecting Information Processing? The Case of Structured White Noise. Information Processing in Complex Systems, CCS2018, Thessaloniki, Greece, September 26$^{\text{th}}$ 2018.

The Error–Dissipation Tradeoff when Computing with Time-Symmetric Protocols. Information Engines at the Frontiers of Nanoscale Thermodynamics, Telluride, Colorado, July 21$^{\text{st}}$ 2018.

Physics of very simple observers—some very simple observations. FQXi Workshop on The Physics of Very Simple Observers, Scotts Valley, California, July 1$^{\text{st}}$ 2018.

Strongly Coupled Systems, Exact Excess, and Renormalized Housekeeping. Information Engines at the Frontiers of Nanoscale Thermodynamics, Telluride, Colorado, July 1$^{\text{st}}$ 2016.

Drazin Inverse per Spectral perSpective, with applications to complex systems. Learning, Information Theory, and Non-Equilibrium Thermodynamics seminar series, Berkeley, California, October 23$^{\text{rd}}$ 2015.

Broken Reversibility, Structured Environments: New Theory, Exact Results. Santa Fe Institute, Santa Fe, New Mexico, June 24$^{\text{th}}$ 2015.

The Computational Burden of Reward-Harvesting Bayes-Optimal Agents in an Environment with Hidden Structure. 2015 Computational Neuroscience seminar series, Center for Neuroscience, Davis, California, April 14$^{\text{th}}$ 2015.

Thermodynamics of Agency. Information Engines meeting, Berkeley, California, January 8$^{\text{th}}$ 2015.

Dynamics and Exact Complexity from Hidden Markov Models in Neuroscience. 2014 Computational Neuroscience seminar series, Center for Neuroscience, Davis, California, May 6$^{\text{th}}$ 2014.

Complexity per Spectral perSpective. Complexity Sciences Center, Davis, California, May 22$^{\text{nd}}$ 2013.

Information Processing through the Interactions of Phase Locked Neurons: the Attractive Logic of Interacting Attractors. 2012 Computational Neuroscience seminar series, Center for Neuroscience, Davis, California, February 21$^{\text{st}}$ 2012.

A Scheme for Computation Beyond the Digital Hegemony: Gated Discrete Phase Shift Interactions. Complexity Sciences Center, Davis, California, May 11$^{\text{th}}$ 2011.

Contributed Talks

Thermodynamically ideal quantum-state inputs to any device. Asian Quantum Information Science (AQIS 2023), Seoul, South Korea, August 30, 2023. (Among only 15% of talks accepted.)

The impossibility of Landauer's bound for almost every quantum state. AQIS 2021, Japan (virtual), September 3, 2021.

The impossibility of Landauer's bound for almost every quantum state. Thermodynamics and Information in the Quantum Regime, Online conference, July 7$^{\text{th}}$, 2021.

The impossibility of Landauer's bound for almost every quantum state. QC40: Physics of Compu-

tation Conference 40th Anniversary, Hosted jointly by IBM and MIT, May 6th 2021. (One of 18 talks selected out of 120+ submissions. Won grant award as an Excellent Contributed Talk.)

Fe_3O_4/GaAs Hybrid Ferromagnet/Semiconductor Nanostructures. 53rd Electronic Materials Conference, Santa Barbara, California, June 23rd 2011.

Interviews and Outreach

Exploring Quantum Spacetime and Spirituality with Dr. Paul Riechers. The Infinite Podcast. March 1, 2022.

Quantum Science Visit, "Quantum To Go" outreach event via APS. Carmen Noble's high school senior class, Puerto Rico, April 11, 2023.

Predoctoral Research Experience

Graduate Student Researcher 2012 - 2016
in Physics and Complex Systems with James P. Crutchfield

- Developed meromorphic functional calculus to treat functions of hidden Markov model transition dynamics via spectral analysis.
- Contributed theoretical advances in chaotic crystallography, analysis of complexity measures, quantum memory compression, and nonequilibrium thermodynamics.

Graduate Student Researcher 2009 - 2012
in Electrical and Computer Engineering with Richard A. Kiehl

- Introduced novel computational strategies of *attractor logic* and *programmable analog spin glass*, both realizable in nanoscale dynamical systems.
- Worked in a Class 100 cleanroom to fabricate magnetic nanostructures (magnetic nanocrystals coupled to 2-D electron gas in semiconductor heterostructure); used EBL, AFM, SEM.

Research Assistant 2007
in Cosmology with David Wittman

- Explored and mitigated the effect of non-Gaussian noise in photometric redshift estimation by incorporating alternative noise models in Bayesian inference algorithms—these improved estimates can then be used to infer the history and fate of large-scale cosmological evolution.

Programming

Python
Regularly implement sophisticated simulations and numerical validations of new theoretical results.

LaTeX, HTML, C, Matlab etc.

Teaching Experience

Guest Lecturer August 2019
for PH3404: The Physics of Classical and Quantum Information NTU, Singapore

Guest Lecturer Spring 2014 and Spring 2015
for PHY 256: The Physics of Information Processing in Complex Systems UC Davis

- Wrote and presented lectures to Professor J. P. Crutchfield's graduate physics class on natural computation and self organization. This course won the 2013 SIAM Teaching Dynamical Systems award.

Teaching Assistant Spring 2014
for NPB 100L: Experimental Neuroscience UC Davis

Teaching Assistant Spring 2012
for EEC 142B: Engineering Electromagnetics UC Davis

Lab Instructor — Spring 2012
for PHY 9C: Electromagnetics — UC Davis

Teaching Assistant — Fall 2011
for NPB/NSC 167/267: Computational Neuroscience — UC Davis

Advising

Co-advised undergraduate Final Year Project for Chaitanya Gupta, who won Best Presentation in Physics for the project in the Odyssey Symposium (2021-2022)

Co-advised undergraduate Final Year Project for Ruo Cheng Huang, who is now continuing this research as a PhD student at NTU (2020-2021)

Co-advised undergraduate Final Year Project for Hon Lin Too, who received a 'Highly Commended' recognition for the project from The Global Undergraduate Awards (2019-2020)