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Research Interests

Applied information theory powered by machine learning for the purpose of understanding complex systems; data science and visualization; representation learning

Education

University of Chicago, Chicago IL

Ph.D., Physics, *Granular Materials as a Model for How Disordered Systems Adapt*, June 2019

M.S., Physical Sciences, June 2014

University of California, Berkeley, Berkeley CA

B.A. with High Distinction, Physics, Computer Science emphasis, May 2013

Research positions

Postdoctoral Fellow July 2021 - Present
University of Pennsylvania, Department of Bioengineering, Philadelphia PA

Advisor: Dani S. Bassett

- Localization of information with machine learning and the Information Bottleneck, as a route to interpretable machine learning and AI for science
- Practical methods of computing complexity with machine learning
- Information analysis of chaotic dynamical systems
- Machine learning to predict nonaffine motion in simulated glasses under deformation
- Unsupervised disentanglement of learned representations

AI Resident October 2019 - June 2021
Google Research, New York NY

Mentors: Ameesh Makadia, Srikumar Ramalingam

- Representation learning utilizing set supervision
- 3D object pose estimation
- Implicit representation of distributions on $\mathbf{SO}(3)$, and manifolds generally
- Network expressivity of random multilayer perceptrons (MLPs)
- Generative adversarial network (GAN) training dynamics
- Learned color space compression

Research Assistant October 2013 - June 2019
University of Chicago, Department of Physics, Chicago IL

Advisor: Heinrich M. Jaeger

- Amorphous plasticity in granular materials composed of different particle shapes
- Memory and glassy dynamics of a granular material undergoing stress relaxation
- Orientational ordering due to shape interactions, studied through CT scans of granular materials
- Geometrically frustrated self-entangling particles as a novel architectural material
- Membrane-encapsulated swarm robotics
- Drag laws under constant speed impact into granular beds
- Self-organized criticality in a modification to the random field Ising model (RFIM)
- Machine learning methods (evolutionary strategies) to design properties of a granular packing through particle shape

Undergraduate Research Assistant June 2012 - June 2013
Lawrence Berkeley National Laboratory, Berkeley CA

Advisors: Steve Lidia, Jonathan Wurtele

- Construction and benchmarking of NDCX-II, a heavy ion linear accelerator to study nuclear fusion
- Beam emittance degradation along the beamline

Undergraduate Research Assistant May 2011 - August 2011
University of California, Davis, Davis CA

Advisors: Lorenzo Berti, Kit Lam

- Localized heating of gold and iron nanoparticles for potential cancer treatment

Publications (Google Scholar)

Journal publications

11. **Murphy, K.A.**, Bassett, D.S., "Machine-learning optimized measurements of chaotic dynamical systems via the information bottleneck." *Phys. Rev. Lett.* 132, 197201 (2024) [link] ***Editors' Suggestion.***

10. **Murphy, K.A.**, Bassett, D.S., "Information decomposition in complex systems via machine learning." *Proc. Natl. Acad. Sci.* 121 (2024). [link] [project page]

9. Reyes-Martinez, M.A., Chan, E., Soles, C.L., Han, E., **Murphy, K.A.**, Jaeger, H.M., Reid, D.R., de Pablo, J.J, "Tuning the mechanical impedance of disordered networks for impact mitigation." *Soft Matter* 18, 2039-2045 (2022). [link]

8. **Murphy, K.A.**, Kruppe, J., Jaeger, H.M., "Memory in nonmonotonic stress relaxation of a granular system." *Phys. Rev. Lett.* 124, 168002 (2020). [link] ***Editors' Suggestion.***

7. **Murphy, K.A.**, "Granular materials as a model for how disordered systems adapt" Dissertation, University of Chicago, 2019. [link]

6. **Murphy, K.A.**, MacKeith, A., Roth, L.K. Jaeger, H.M., "The intertwined roles of particle shape and surface roughness in controlling the shear strength of a granular material." *Granular Matter* 21, 72 (2019). [link]

5. Lim, M.X., **Murphy, K.A.**, Jaeger, H.M., "Edges control clustering in levitated granular matter." *Granular Matter* 21, 77 (2019). [link]

4. **Murphy, K.A.**, Dahmen, K.A., Jaeger, H.M., "Transforming mesoscale granular plasticity through particle shape." *Phys. Rev. X* 9, 011014 (2019). [link]

3. **Murphy, K.A.**, Roth, L.K., Peterman, D., Jaeger, H.M., "Aleatory architectures based on jamming." *Architectural Design* 187, 74-81 (2017). [link] [pdf]

2. **Murphy, K.A.**, Roth, L.K., Jaeger, H.M., "Adaptive granular matter," in Active Matter, ed. Skylar Tibbits, MIT Press, Cambridge (2017).

1. **Murphy, K.A.**, Reiser, N., Choksy, D., Singer, C.E., Jaeger, H.M., "Freestanding load bearing structures with Z-shaped particles." *Granular Matter* 18, 26:21-29 (2016). [link]

Conference proceedings (peer-reviewed)

4. Patankar, S., Ouellet, M., Cervino, J., Ribeiro, A., **Murphy, K.A.**, Bassett, D.S., "Intrinsically motivated graph exploration using network theories of human curiosity."(*Learning on Graphs Conference* 2023) [OpenReview link] [arxiv link]

3. **Murphy, K.A.**, Bassett, D.S., "Interpretability with full complexity by constraining feature information." (*International Conf. on Learning Representations (ICLR)* 2023) [OpenReview link] [arxiv link] [project page]

2. **Murphy, K.A.**, Jampani, V., Ramalingam, S., Makadia, A., "Learning ABCs: Approximate Bijective Correspondence for isolating factors of variation." (*Conf. on Computer Vision and Pattern Recognition (CVPR)* 2022) [link] [project page] ***Selected for oral presentation.***

1. **Murphy, K.A.***, Esteves, C.*, Jampani, V., Ramalingam, S., Makadia, A., "Implicit representation of probability distributions on the rotation manifold." (*International Conf. on Machine Learning (ICML)* 2021). [link] [project page]

Workshop papers (light peer-review)

3. **Murphy, K.A.**, Yin, Z., Bassett, D.S., "Which bits went where? Past and future transfer entropy decomposition with the information bottleneck." "Machine learning and the physical sciences" NeurIPS 2024 workshop. [link]

2. **Murphy, K.A.**, Bassett, D.S., "Where is the information in data?" IEEE VIS 2024 workshop, "Visualization for AI Explainability" [link to interactive tutorial]

1. **Murphy, K.A.**, Bassett, D.S., "Characterizing information loss in a chaotic double pendulum with the Information Bottleneck." NeurIPS 2022 workshop, "Machine learning and the physical sciences." ***Selected for oral presentation.*** [link]

Submitted/ArXiv

4. **Murphy, K.A.**, Zhang, Y., Bassett, D.S., "Surveying the space of descriptions of a composite system with machine learning." arxiv:2411.18579 (2024). [link]

3. **Murphy, K.A.**, Dillavou, S., Bassett, D.S., "Comparing information content of representation spaces for disentanglement with VAE ensembles." arxiv:2405.21042 (2024). [link] (Under review)

2. Ouellet, M., Bassett, D.S., Bassett, L.C., **Murphy, K.A.**, Patankar, S.P., "Mechanical prions: Self-assembling microstructures." arXiv:2402.10939 (2023). [link]

1. **Murphy, K.A.**, Bassett, D.S., "The Distributed Information Bottleneck reveals the explanatory structure of complex systems." arXiv:2204.07576 (2022) [link]

Fellowships

- *AI x Science Postdoctoral Fellow*, University of Pennsylvania (2024-2025)
- *Data Science Postdoctoral Fellow*, Data Driven Discovery Initiative, University of Pennsylvania (2022-2023, 2023-2024)

  Includes weekly discussion group about topics in data science and leading summer "data hangouts" tutorial sessions for undergraduates.

Press

- Penn Engineering Today, "Measuring Chaos: Using Machine Learning to Satisfy Our Need to Know" [link] (July 22, 2024).
- *Quantum Photonics* on Clubhouse (audio app) "Can deep learning break down what it learns?" (May 13, 2022).

Presentations

Invited

- 'Information theory, machine learning, and network sciences (infoLeNS)' seminar series, University of Pennsylvania, "Searching through distributed compression schemes to answer 'where is the information in data?' " (April 12, 2024).
- Penn ASSET/IBI Symposium on Trustworthy AI for Health Care, University of Pennsylvania, "Optimizing clinical monitoring for delivery room resuscitation using novel interpretable AI" (Oct. 6, 2023, presented with Elizabeth Foglia, Perelman School of Medicine).
- James Franck Institute Special Seminar, University of Chicago, "All information is not created equal: Using machine learning to approximate relationships for interpretability and information theoretic analyses of complex systems." (Feb. 9, 2023).

Oral

- 2024 American Physical Society March Meeting, "Coloring a chaotic attractor with machine learning: Optimized measurements of chaotic dynamical systems via the information bottleneck."
- 2024 Dynamics Days, Davis, California, "Optimized measurements of chaotic systems via the information bottleneck."
- 2023 American Physical Society March Meeting, "The Information Bottleneck and the double pendulum: Using machine learning to study how chaos destroys information."
- 2022 American Physical Society March Meeting, "The information bottleneck powered by deep learning to illuminate micro to macro relationships in complex systems."
- 2019 American Physical Society March Meeting, "How to extract memories from a relaxing granular material."
- Sackler Colloquium series at National Academy of Sciences, "Randomness and Mind Games in Virtual Reality" (2018).
- 2018 American Physical Society March Meeting, "Granular Plasticity in Triaxial Compression Experiments: Nonuniversal Stress Fluctuations and Particle Shape Dependence."
- BASF and Particulate Solid Research, Inc. campus visit, "Granular Plasticity and Particle Shape" (2018).
- Particulate Solid Research, Inc. campus visit, "Plasticity and Particle Shape" (2017).
- 2017 American Physical Society March Meeting, "The Dependence of Granular Plasticity on Particle Shape."
- Corning Inc. campus visit, "Designing Granular Material with Evolutionary Strategies" (2015).

Poster

- "How machine learning and an information theory perspective can enrich research on complex systems" 2023 APS poster session.
- "Characterizing information loss in a chaotic double pendulum with the Information Bottleneck." NeurIPS 2022 workshop, Machine learning and the physical sciences.

- "Where is the information in a complex system?" 2022 DEEPenn STEM outreach event.
- "Time will tell" 2022 APS DSOFT Gallery of Soft Matter.
- "Designed to fail: granular plasticity and particle shape." 2018 IUTAM Symposium on Architectured Materials Mechanics.
- "Transforming granular plasticity through particle shape." 2018 Gordon Research Conference on Granular Matter. *Award for best poster.*
- "Particle shape dependence in granular plasticity and stress fluctuations." Powders and Grains 2017.
- "How does particle shape influence stress fluctuations beyond yielding?" 2016 Gordon Research Conference on Granular Matter.

FUNDED PROPOSALS

- University of Chicago's **Art, Science, and Culture Initiative**, project titled *Randomness and Mind Games* – Partnered with an MFA student from the School of the Art Institute of Chicago on a project that utilized virtual reality (VR) to explore the concept of randomness. We created several VR experiences, and presented our work at both schools (2017).
  Acquired additional funding to present at the National Academy of Sciences in Washington, D.C. (Sackler Collaborative Creativity and Creative Collaborations Student Fellows Symposium, 2018).

PROPOSAL WRITING

- **Optimizing Clinical Monitoring for Delivery Room Resuscitation Using Novel Interpretable AI**, University of Pennsylvania Perelman School of Medicine + School of Engineering and Applied Science – Helped with the conception and writing of this proposal to use the interpretability of the Distributed Information Bottleneck as a novel route toward trustworthy AI in medicine (2022). Funded, $100k/year.
- **Optimal integration of distributed sources of information with machine learning**, Army Research Laboratory – Helped with the conception and writing of this proposal about using the Distributed Information Bottleneck optimize multi-agent systems (2022). Funded, $100k/year.
- **Design Principles for Soft Robots Based on Boundary Constrained Granular Swarms**, National Science Foundation – Helped with the conception and writing of this proposal for a collaboration across two universities and four PIs (2018). Funded.

TEACHING

- **Instructor** – REU workshop on machine learning, University of Pennsylvania (2023, 2024)
- **Instructor** – Data Driven Discovery Initiative Data Hangouts 2022, 2023, 2024 (undergraduates)
  Taught two hour-long lessons on topics "Intro to machine learning" and "Computer vision and pre-trained models"
- **Instructor** – Introduction to machine learning through iPython notebooks: Bassett Lab 2021 (graduate students and postdocs) [Github repository]
  Created eight interactive code notebooks to introduce paradigmatic ideas in machine learning.

- **Instructor** – "Sustainability Training: Recycling and Waste", Google NYC (2021)
  Helped create an hour-long presentation about the state of recycling in the world today, and co-led multiple sessions.

- **Instructor** – "Paradigm shift", University of Chicago (2014)
  Designed and ran eight interactive lessons on various aspects of physics to a group of 5 students at a nearby middle school.

- **Teaching assistant** *Life in the Universe I&II* (University of Chicago Physics department, undergraduate class, 2013-2014)

- **Teaching assistant** *General Physics III: Waves, Optics, and Modern Physics* (University of Chicago Physics department, undergraduate class, 2014)

Outreach and community service

- **Reviewer for journals, conferences**

  - *Neural Information Processing Systems (NeurIPS)*
  - *International Conference on Machine Learning (ICML)*
  - *Conference on Computer Vision and Pattern Recognition (CVPR)*
  - *International Conference on Learning Representations (ICLR)*
  - *Physical Review X (PRX)*
  - *PRX Life*
  - *Entropy*
  - *Physical Review E*
  - *Granular Matter*

  Miscellaneous: Noticed inconsistency that led to the retraction of Phys. Rev. E 102, 011001(R) (2020) [link].

- **Co-creator and Instructor** – "Bicycle Physics" outreach program at Blackstone Bicycle Works, Chicago (2015, 2016, 2017)
  Helped create and then ran multiple years of a summer program of weekly, hands-on lessons and demos to teach kids ages 5-15 about the physics of bicycles. We designed and delivered the full curriculum.

- **Graduate Mentor** – University of Chicago Bridge Program (2016) *Selected to be a mentor for the physics department's first year of a program to provide additional support to underrepresented minority (URM) PhD students.*

- **Co-Organizer** – Tutorial at the APS March meeting for statistical and nonlinear physics (GSNP), called "Adventures with computational modeling and information theory: from grains to bits" (2023) [website]
  Enlisted six speakers on the topic of information theory in physics and machine learning; fund-raised; advertised; handled logistics.

- **Session organizer, chair** – APS March meeting focus session, "Information theory and physics" (2023, 2024)
  Proposed the topic, reviewed abstracts, invited a speaker, ran the session.

- **Onboarding Mentor** – AI Residency, Google NYC (2020 - 2021)
  Selected to help a new AI resident acclimate to Google infrastructure and the residency program. Worked with her through the design and execution of an onboarding project implementing DeepSets.

- **Volunteer** – "Physics with a Bang!", University of Chicago (2013 - 2019)
  Yearly outreach event at the University of Chicago where several hundred kids from around the city visit the physics department for demos and lab tours.
- **Co-organizer** – Monthly journal club for graduate students and postdocs in soft matter physics, University of Chicago (2017 - 2019)
- **Undergraduate Mentor** – Direct oversight, training, and supervision of 12 students on more than 10 unique projects. Jaeger lab, University of Chicago (2014 - 2019)
- **Laboratory Safety Officer** – Jaeger lab, University of Chicago (2015 - 2019)

Outside activities

- **Co-Founder, Tepe Labs LLC** (2023 - Present)
  Created a method for decentralized yet private file storage based on distributed cryptography, with Harang Ju (MIT). Won $2500 in a hackathon hosted by WeaveDB. Website, Documentation
- **Compost Manager** – Teikoku Restaurant, Newtown Square, PA (2020 - 2022)
  Construction and regular maintenance of several cubic yards of compost using organic waste from the restaurant.
- **Camp Counselor** – Camp Kesem, UC Berkeley (2012, 2013)
  Summer camp for children whose parents have or have had cancer, providing an escape for the kids and a break for the parents.