

# Matthew D. Kvalheim

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Citizenship: USA

## Research Interests

Nonlinear systems in general, and in particular: dynamics, control theory, stochastic processes, robotics.

## Employment

- 2022– **Postdoctoral Assistant Professor**, *University of Michigan*, Department of Mathematics.  
**Mentor:** Anthony M. Bloch
- 2019–2022 **Postdoctoral Researcher**, *University of Pennsylvania*, Department of Electrical and Systems Engineering.  
**Mentors:** Yuliy Baryshnikov, Daniel E. Koditschek
- 2018–2019 **Postdoctoral Research Fellow**, *University of Michigan*, Department of Electrical Engineering and Computer Science.  
**Mentors:** Anthony M. Bloch, Shai Revzen

## Education

- 2013–2018 **Ph.D.**, *University of Michigan*, Electrical Engineering.
- 2013–2017 **M.S.**, *University of Michigan*, Mathematics.
- 2013–2017 **M.S.**, *University of Michigan*, Electrical Engineering.
- 2009–2013 **B.S.**, *Ohio University*, Electrical Engineering, first in EECS graduating class.

### Doctoral Thesis

Title Aspects of invariant manifold theory and applications  
Adviser Shai Revzen

## Published or Accepted Journal Papers

- 8 **A generalization of the Hopf degree theorem.**  
*Matthew D. Kvalheim*  
Proceedings of the American Mathematical Society, Accepted (2022). ([arXiv](#))
- 7 **Planning of obstacle-aided navigation for multi-legged robots using a sampling-based method over directed graphs.**  
*Kaustav Chakraborty, Haodi Hu, Matthew D. Kvalheim, and Feifei Qian*  
IEEE Robotics and Automation Letters, 7.4 (2022), pp. 8861–8868. ([article](#))
- 6 **Necessary conditions for feedback stabilization and safety.**  
*Matthew D. Kvalheim and Daniel E. Koditschek*  
J. Geometric Mechanics, 14.4 (2022), pp. 659–693. ([article](#), [arXiv](#))
- 5 **Families of periodic orbits: closed 1-forms and global continuability.**  
*Matthew D. Kvalheim and Anthony M. Bloch*  
J. Differential Equations, 285 (2021), pp. 211–257. ([article](#), [arXiv](#))

- 4 **Conley's fundamental theorem for a class of hybrid systems.**  
*Matthew D. Kvalheim, Paul Gustafson, and Daniel E. Koditschek*  
 SIAM J. Applied Dynamical Systems (SIADS), 20.2 (2021), pp. 784–825. ([article](#), [arXiv](#))
- 3 **Existence and uniqueness of global Koopman eigenfunctions for stable fixed points and periodic orbits.**  
*Matthew D. Kvalheim and Shai Revzen*  
 Physica D, 425 (2021), pp. 132959. ([article](#), [arXiv](#))
- 2 **Gait modeling and optimization for the perturbed Stokes regime.**  
*Matthew D. Kvalheim, Brian Bittner, and Shai Revzen*  
 Nonlinear Dynamics, 97.4 (2019), pp. 2249–2270. ([article](#), [arXiv](#))
- 1 **Global linearization and fiber bundle structure of invariant manifolds.**  
*Jaap Eldering, Matthew D. Kvalheim, and Shai Revzen*  
 Nonlinearity, 31.9 (2018), pp. 4202–4245. ([article](#), [arXiv](#))

## Submitted Papers and other Preprints

- 8 **The role of symmetry in constructing geometric flat outputs for free-flying robotic systems.**  
*Jake Welde, Matthew D. Kvalheim, and Vijay Kumar*  
 IEEE International Conference on Robotics and Automation, Under Review (2022). ([arXiv](#))
- 7 **Obstructions to asymptotic stabilization.**  
*Matthew D. Kvalheim*  
 SIAM J. Control and Optimization (SICON), Under Review (2022). ([arXiv](#))
- 6 **Estimating phase from observed trajectories using the temporal 1-form.**  
*Simon Wilshin, Matthew D. Kvalheim, Clayton Scott, and Shai Revzen*  
 Physical Review E, Under Review (2022). ([arXiv](#))
- 5 **Flux in tilted potential systems: negative resistance and persistence.**  
*Yuliy Baryshnikov and Matthew D. Kvalheim*  
 Communications in Mathematical Physics, Under Review (2021). ([arXiv](#))
- 4 **A pasting lemma for Lipschitz functions.**  
*Matthew D. Kvalheim, Paul Gustafson, and Samuel A. Burden*  
 (2021). ([arXiv](#))
- 3 **Phase response curves and the role of coordinates.**  
*Simon Wilshin, Matthew D. Kvalheim, and Shai Revzen*  
 (2021). ([arXiv](#))
- 2 **Poincaré-Hopf theorem for hybrid systems.**  
*Matthew D. Kvalheim*  
 (2021). ([arXiv](#))
- 1 **Reverse-engineering invariant manifolds with asymptotic phase.**  
*Matthew D. Kvalheim and Shai Revzen*  
 (2016). ([arXiv](#))

## Peer-reviewed Conference Papers

- 2 **Generic properties of Koopman eigenfunctions for stable fixed points and periodic orbits.**  
*Matthew D. Kvalheim, David A. Hong, and Shai Revzen*  
 IFAC-PapersOnline, 54.9 (2021), pp. 267–272. ([article](#), [arXiv](#))
- 1 **Data-driven models of legged locomotion.**  
*Shai Revzen and Matthew D. Kvalheim*  
 SPIE Defense + Security. International Society for Optics and Photonics (2015). ([article](#))

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## Book Chapters

- 2 **Bioinspired legged locomotion, chapter 3.2: Templates and anchors.**  
*Matthew D. Kvalheim and Shai Revzen*  
Butterworth-Heinemann, Elsevier, Oxford (2017)
- 1 **Bioinspired legged locomotion, chapter 3.5: Locomotion as an oscillator.**  
*Shai Revzen and Matthew D. Kvalheim*  
Butterworth-Heinemann, Elsevier, Oxford (2017)

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## Teaching Experience

- 2022 **Course Instructor**, *University of Michigan*, Ann Arbor, MI.  
Instructor of record for two course sections of Calculus I (Math 115) in Fall 2022
- 2015–2022 **Private Tutor**, *WyzAnt, Inc.*  
Independent contractor; mathematics, electrical engineering;  
perfect score on student evaluations (out of 19 total); 160+ hours experience
- 2019 **Guest Lecturer**, *University of Pennsylvania*, Philadelphia, PA.  
Graduate course: Dynamical Systems for Engineering and Biological Applications (ESE 512)  
Course instructor: Daniel E. Koditschek
- 2014 **Graduate Student Instructor**, *University of Michigan*, Ann Arbor, MI.  
Senior-level course: Discrete-Time Signal Processing (EECS 451)  
Course instructor: Laura Balzano
- 2011–2012 **Supplemental Instruction Leader**, **Academic Achievement Center**, *Ohio University*, Athens, OH.  
Sophomore-level course: Statics (CE 220)

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## Mentoring and Outreach

- 2019–2022 **Mentor of graduate students**, *University of Pennsylvania*.  
Mentored 2 graduate students in research
- 2019 **Volunteer, demonstrations to visiting K-12 students, Philly Robotics Expo (PRX)**, *University of Pennsylvania*, Philadelphia, PA.  
Representing GRASP Laboratory, University of Pennsylvania; robotics outreach
- 2019 **Volunteer, demonstrations to members of the National Society of Black Engineers, 45th Annual Convention of the National Society of Black Engineers (NSBE)**, Detroit, MI.  
Representing BIRDS Laboratory, University of Michigan; robotics outreach
- 2013–2018 **Mentor of undergraduate and graduate students, BIRDS Laboratory**, *University of Michigan*.  
Mentored 2 undergraduate and 3 graduate students
- 2015 **Volunteer, demonstrations to visiting Chinese dignitaries**, *University of Michigan*, Ann Arbor, MI.  
Representing University of Michigan; robotics outreach
- 2015 **Volunteer, demonstrations to alumni and industry, Engineering Graduate Symposium**, Ann Arbor, MI.  
Representing BIRDS Laboratory, University of Michigan; robotics outreach
- 2015 **Volunteer, panel participant**, *Graduate Student Council*, Ann Arbor, MI.  
Member of panel of University of Michigan graduate students; answering questions from prospective graduate students

- 2014 **Volunteer, demonstrations to elementary schoolers**, *Bryant Elementary School*, Ann Arbor, MI.  
Representing BIRDS Laboratory, University of Michigan; robotics outreach

## Talks

- 2022 **Negative resistance in small-noise dynamics via persistent homology**, *Invited talk*, *Indian Institute of Technology Bombay*, online.  
SysConTalks
- 2022 **Nonlinear systems**, *Invited talk*, *University of Michigan*, Ann Arbor, MI.
- 2022 **Large deviations, persistent homology, and Brownian conductors with negative resistance**, *Invited talk*, *Cornell University*, online.  
Probability Seminar
- 2022 **When can hybrid systems operate safely?**, *Invited talk*, *University of Michigan*, online.  
Control Seminar
- 2022 **Flux in small noise dynamics: persistence and negative resistance**, *Invited talk*, *Brown University, Division of Applied Mathematics*, online.
- 2021 **Flux in small noise dynamics: negative resistance and persistence**, *Invited talk*, *University of Illinois Urbana-Champaign*, online.  
Mathematical Biology Seminar
- 2021 **When and how are hybrid dynamical systems conjugate to their classical quotients?**, *Invited talk*, *SIAM Conference on Control and its Applications*, online.  
*with Samuel A. Burden*  
Minisymposium: Physically grounded semantics for programming hybrid dynamical systems
- 2021 **Toward a physically grounded type theory for robot task composition.**, *Invited talk*, *IEEE International Conference on Robotics and Automation (ICRA)*, online.  
*with Daniel E. Koditschek and Paul Gustafson*  
Workshop: Compositional robotics: mathematics and tools
- 2021 **Toward a physically grounded type theory for robot task composition**, *Invited talk*, *IEEE International Conference on Robotics and Automation (ICRA)*, online.  
*with Daniel E. Koditschek and Paul Gustafson*  
Workshop: Compositional robotics: mathematics and tools
- 2021 **Small noise dynamics, persistence, and negative resistance**, *Invited talk*, *SIAM Conference on Applications of Dynamical Systems*, online.  
*with Yuliy Baryshnikov*  
Minisymposium: Stochastic oscillators
- 2021 **Flux in tilted potential systems: negative resistance and persistence**, *Invited talk*, *Army Research Office SLICE MURI W911NF-18-1-032 Group Meeting*, online.
- 2021 **Towards a Conley theory for hybrid dynamical systems**, *Invited talk*, *Rutgers University*, online.  
TRIPODS/DATA-INSPIRE Workshop: Dynamics, Topology, and Robotic Control
- 2021 **Hierarchical composition via collapse of dimension in dynamical systems**, *Invited talk*, *ETH Zürich*, online.  
Series: Autonomy Talks
- 2021 **Existence and uniqueness of global linearizing coordinates**, *Invited talk*, *Army Research Lab*, online.  
Representing the MURI group funded by Army Research Office MURI 911NF-17-1-0306

- 2021 **Safety and stabilization: necessary conditions**, *Invited talk, Army Research Office SLICE MURI W911NF-18-1-032 Group Meeting*, online.
- 2021 **Necessary conditions for feedback stabilization and safety**, *Invited talk, University of Pennsylvania*, online.  
Kod\*Lab Research Seminar
- 2020 **Proving periodic orbits exist: global continuation and Lyapunov 1-forms**, *Invited Talk, University of Pennsylvania*, online.  
Graduate Research Seminar in Applied Topology (GRST)
- 2020 **Proving periodic orbits exist: Lyapunov 1-forms and global continuation**, *Invited talk, University of Pennsylvania*, online.  
Kod\*Lab Research Seminar
- 2020 **Geometry and dynamics of circulant systems**, *Invited talk, AMS sectional meeting*, online.  
*with Anthony M. Bloch (speaker)*  
Special session: Geometric dynamics
- 2020 **Conley's fundamental theorem for a class of hybrid systems**, *Invited talk, Army Research Office SLICE MURI W911NF-18-1-032 Group Meeting*, online.
- 2020 **Conley's fundamental theorem for a class of hybrid systems**, *Invited talk, University of Pennsylvania*, online.  
Kod\*Lab Research Seminar
- 2020 **Toward a task planning theory for robot hybrid dynamics**, *Invited talk, BIRS-CMO*, online.  
*with Daniel E. Koditschek and Paul Gustafson*  
Workshop: Topological complexity and motion planning
- 2020 **Isochrons from short, noisy data**, *Invited talk, Dynamics Days Europe*, online.  
*with Simon Wilshin, Clayton Scott, and Shai Revzen*  
Minisymposium: Stochastic oscillators
- 2019 **Invariant manifolds, locomotion, and the Koopman operator**, *Invited Talk, University of Pennsylvania, Philadelphia, PA*.  
Chaudhari Research Group Seminar
- 2019 **Templates, anchors, and normally hyperbolic invariant manifolds**, *Invited Talk, University of Pennsylvania, Philadelphia, PA*.  
DAIR Lab Research Seminar
- 2019 **Templates, anchors, and normally hyperbolic invariant manifolds**, *Invited Talk, University of Pennsylvania, Philadelphia, PA*.  
ScalAR Lab Research Seminar
- 2019 **Existence and uniqueness of linearizing semiconjugacies for stable fixed points and periodic orbits**, *Invited talk, California Institute of Technology, Pasadena, CA*.  
Army Research Office MURI 911NF-17-1-0306 Group Meeting
- 2019 **Is legged locomotion almost smooth?**, *Dynamic Walking, Calgary, AB, Canada*.  
*with Shai Revzen (speaker) and George Council*
- 2019 **Dynamics of circulant systems of ODEs**, *Invited talk, SIAM Conference on Applications of Dynamical Systems, Snowbird, UT*.  
*with Anthony M. Bloch (speaker)*

- 2019 **Reduced-order models for locomotion in the perturbed Stokes regime**, *Invited talk*, SIAM Conference on Applications of Dynamical Systems, Snowbird, UT.  
with Shai Revzen
- 2019 **Hybrid oscillators: phase and amplitude in a class of non-smooth systems**, *Invited talk*, SIAM Conference on Applications of Dynamical Systems, Snowbird, UT.  
with Shai Revzen
- 2018 **Aspects of invariant manifold theory and applications**, *Invited talk*, University of California Santa Barbara, Santa Barbara, CA.  
Army Research Office MURI 911NF-17-1-0306 Group Meeting
- 2018 **Oscillators, asymptotic phase, and reduction of dynamical systems**, *Invited talk*, University of Michigan, Ann Arbor, MI.  
Applied and Interdisciplinary Mathematics Student Seminar
- 2018 **Testing an extended 'Posture Principle'**, *Annual meeting of the Society for Integrative and Comparative Biology (SICB)*, San Francisco, CA.  
with Shai Revzen
- 2018 **Invariant manifolds, asymptotic phase, and data-driven algorithms**, *Invited talk*, University of Pennsylvania, Philadelphia, PA.  
Kod\*Lab Research Seminar
- 2016 **A recipe for embedding templates in anchors**, *Invited talk*, University of Michigan, Ann Arbor, MI.  
Legged Robotics Seminar
- 2015 **Introduction to homology: towards topological data analysis, pt. II/II**, *Invited talk*, University of Michigan, Ann Arbor, MI.  
Signal Processing Student Seminar
- 2015 **Introduction to homology: towards topological data analysis, pt. I/II**, *Invited talk*, University of Michigan, Ann Arbor, MI.  
Signal Processing Student Seminar
- 2015 **Phase-based models of rhythmic systems**, *Dynamic Walking*, Columbus, OH.  
with Shai Revzen
- 2015 **Better models of rhythmic systems: predicting locomotion from phase alone**, *Annual meeting of the Society for Integrative and Comparative Biology (SICB)*, West Palm Beach, FL.  
with Shai Revzen
- 2014 **Why the trot?**, *Annual meeting of the Society for Integrative and Comparative Biology (SICB)*, Austin, TX.  
with Shai Revzen and Sam Burden (speakers)

## Posters

- 2020 **A mode map representation to predict steady states and attraction basins for legged locomotion on obstacle terrains**, *International Conference on Intelligent Robotics and Systems (IROS)*, online.  
with Haodi Hu (presenter), Michelle Joyce, Simon Wilshin, Andrew Spence, and Feifei Qian  
Workshop: Robotics-inspired biology

- 2019 **Principal Koopman eigenfunctions for nonlinear and nonsmooth systems**, *University of California, Los Angeles*, Los Angeles, CA.  
with Shai Revzen  
Workshop: Operator theoretic methods in dynamic data analysis and control
- 2019 **Principal Koopman eigenfunctions for nonlinear and nonsmooth systems**, *University of California, Los Angeles*, Los Angeles, CA.  
with Shai Revzen  
Workshop: Operator theoretic methods in dynamic data analysis and control
- 2018 **Global linearization and fiber bundle structure of invariant manifolds**, *AIMS Conference Series on Dynamical Systems and Differential Equations*, Taipei, Taiwan.  
with Jaap Eldering and Shai Revzen
- 2018 **Templates and Anchors: a review of notions of model reduction**, *Dynamic Walking*, Pensicola, FL.  
with Shai Revzen
- 2017 **Asymptotic phase, model reduction, and control of Templates & Anchors**, *Ohio State University, Mathematical Biosciences Institute*, Columbus, OH.  
with Shai Revzen  
Workshop: Sensorimotor control of animals and robots
- 2017 **A dynamical systems perspective on Templates & Anchors: some general methods for anchoring templates**, *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Vancouver, BC.  
with Shai Revzen  
Workshop: Robotics-inspired Biology
- 2014 **Phase-based algorithm for modeling time-rescaling distortion of rhythmic data**, *University of Michigan*, Ann Arbor, MI.  
with Shai Revzen  
Engineering Graduate Symposium
- 2013 **A hybrid system provides a robust alternative to a linear regulator**, *University of Michigan*, Ann Arbor, MI.  
with Shai Revzen  
Engineering Graduate Symposium
- 2013 **An indoor navigation device for use in GPS-denied environments**, *University of Michigan*, Ann Arbor, MI, Award: 1st place, EECS division.  
with Ryan Kollar, Christopher Moore, Jessica Belzer, and Matthew Miltner  
Ohio University Student Expo

## Honors and Awards

- 2013 **Rackham Engineering Award**, *University of Michigan*.  
Graduate fellowship awarded by Rackham Graduate School
- 2013 **Outstanding Senior in Electrical Engineering**, *Ohio University*.  
Awarded by a faculty panel
- 2013 **First place, Undergraduate Student Expo**, *Ohio University*.  
Senior design team awarded first place in the EECS division
- 2012 **Undergraduate Research Award, College of Engineering**, *Ohio University*.  
My proposal was funded for a semester of undergraduate research
- 2012 **Outstanding Junior in Electrical Engineering**, *Ohio University*.  
Awarded by a faculty panel

- 2009–2013 **Gateway Excellence Scholarship**, *Ohio University*.  
Academic merit-based scholarship (full tuition)
- 2011 **Dean's Scholarship**, *Ohio University*.  
Academic merit-based scholarship
- 2011 **Fritz/Dolores Russ Scholarship**, *Ohio University*.  
Academic merit-based scholarship

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## Academic Service

### Reviewer for

**SIAM J. Control and Optimization; Stochastic Models; Biological Cybernetics; Annual Reviews in Control; IEEE Conference on Decision and Control (CDC); ASME J. Biomechanical Engineering; Robotics: Science and Systems (RSS); International Symposium on Nonlinear Theory and Its Applications (NOLTA); Mathematics of Control, Signals, and Systems**, and others.

### Co-organizer

- 2022 **IEEE International Conference on Robotics and Automation (ICRA)**.  
Workshop: Compositional Robotics: Mathematics and Tools
- 2022 **Festschrift in honor of Daniel E. Koditschek**.

### Professional Memberships

**American Mathematical Society (AMS), Institute of Electrical and Electronics Engineers (IEEE), Society for Industrial and Applied Mathematics (SIAM), SIAM Activity Group on Dynamical Systems (SIAG/DS)**, and others.

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## Other work experience

- 2012 **Undergraduate Student Researcher**, *Ohio University*, Athens, OH.  
Funded undergraduate research; sensor fusion and navigation for drones  
**Adviser:** Maarten Uijt de Haag
- 2012 **Co-Op**, *GE Aviation Systems*, Vandalia, OH.
- 2011 **Engineering Intern**, *Lakeshore Cryotronics*, Westerville, OH.



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## References

**Yuliy Baryshnikov**

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**Frederick A. Leve**

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