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Matthew D. Kvalheim

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

10 **Flux in tilted potential systems: negative resistance and persistence**.
Yuliy Baryshnikov and Matthew D. Kvalheim
Communications in Mathematical Physics, Accepted (2022). (arXiv)

9 **Obstructions to asymptotic stabilization**.
Matthew D. Kvalheim
SIAM J. Control and Optimization, Accepted (2022). (arXiv)

8 **A generalization of the Hopf degree theorem**.
Matthew D. Kvalheim
Proceedings of the American Mathematical Society, 151.1 (2023), pp. 453–454. (article, 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

6 **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)

5 **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)

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)

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)

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)

Mentoring and Outreach

2022– **Volunteer, Females Excelling More in Math, Engineering, and Science (F.E.M.M.E.S.)**, *University of Michigan*, Ann Arbor, MI.

2019–2022 **Mentor of graduate students**, *University of Pennsylvania*, Philadelphia, PA.
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 particpant**, *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

Academic Service

Reviewer for

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

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.

References

Yuliy Baryshnikov
Professor of Mathematics and Electrical & Computer Engineering
University of Illinois Urbana-Champaign
1409 W. Green St
Urbana, IL 61801
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Anthony M. Bloch
Alexander Ziwet Collegiate Professor of Mathematics and Chair
University of Michigan
530 Church St
Ann Arbor, MI 48109
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Daniel E. Koditschek
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