BIOGRAPHICAL SKETCH

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NAME: Kuske, Rachel

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POSITION TITLE: Chair/Professor, School of Mathematics

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE (if applicable)	END DATE MM/YYYY	FIELD OF STUDY
University of Wisconsin, Green Bay, WI	BS	05/1987	Mathematics
Northwestern University, Evanston, IL	PHD	1992	Engineering Sciences/Applied Mathematics
University of Utrecht, Utrecht, Utrecht	Postdoctoral Fellow	06/1994	NSF-NATO PD Fellowship, Applied Mathematics
Stanford University, Stanford, CA	Postdoctoral Fellow	07/1996	NSF Fellowship, Applied Mathematics

A. Personal Statement

My role in this project is the application of spatio-temporal models to capture the underlying mechanisms behind patterns in microbial dynamics, and to improve these models through data-driven model selection. My expertise is focused on applications in nonlinear dynamics in complex settings that include noise, heterogeneity, and complex transitions. I develop novel computational and analytical methods for models that explain physical and biological phenomena. These approaches reveal the applicability of the models to observed phenomena, as well as the mechanisms described by them. The innovation and power from these approaches follows from knowledge transfer across areas of application through a dynamical perspective, allowing new perspectives from one field to explain novel and unexpected behavior in another. Over my career I have regularly collaborated with theoretical biologists, (bio-)physicists, mechanical engineers, and atmospheric scientists. Such collaborations have provided the opportunity both to focus on application-relevant results while also facilitating the cross-fertilization across domain science boundaries. Some examples of this knowledge transfer relevant to this proposal are reflected in the publications below. They include expanding ideas from stochastic resonance, commonly studied in neuroscience, to explain phenomenon in epidemiology and control in pattern forming systems; pioneering analysis of tipping points – rapid transitions between states – applied in climate and neuronal spiking patterns, and dynamical perspectives from control switches applied to novel PDE-constrained optimization approaches for model identification.

1. Daskalakis E, Kuske R, Herrmann F. Accelerating Sparse Recovery by reducing chatter. SIAM Journal on Imaging Sciences. SIAM J. Imaging Sci., 13(3), 1211-1239, 2020.

2. Kuske R, Lee C, Rottschafer V. Patterns and coherence resonance in the stochastic Swift- Hohenberg equation with Pyragas control: the Turing bifurcation case. Physica D. Nonlinear phenomena. 2018; 365(5):57.

3. Zhu J, Kuske R, Erneux T. Tipping points near a delayed saddle node bifurcation with periodic forcing. SIAM Journal on Applied Dynamical Systems. 2015; 14:2030.

4. Yu N, Li YX, Kuske R. A computational study of spike time reliability in two types of threshold dynamics. J Math Neurosci. 2013 Aug 14;3(1):11. PubMed PMID: 23945258; PubMed Central PMCID: PMC3849148.

B. Positions and Honors

Positions and Employment

1996 - 1997	Asst. Professor, Tufts University
1997 - 2002	Asst./Assoc. Professor, University of Minnesota
2002 - 2012	Canada Research Chair, Applied Mathematics, University of British Columbia
2006 - 2016	Assoc./Full Professor, Department of Math, University of British Columbia
2007 - 2011	Head, Mathematics, University of British Columbia
2011 - 2015	Provost's Sr. Adv. on Women Faculty, University of British Columbia
2017 -	Chair/Professor, School of Mathematics, Georgia Tech

Other Experience and Professional Memberships

2005 - 2017	Editorial Board, SIAM J. Applied Mathematics
2006 - 2007	Associate Director, Program Diversity, American Institute of Mathematics
2006 - 2008	Chair, NSERC Grant Selection Committee, Pure/Applied Math B
2008 -	Editorial Board, European J. Applied Math
2012 - 2017	Editorial Board, Discrete and Continuous Dynamical Systems-B
2015 -	Editorial Board, Transactions of Mathematics and its Applications
2016 - 2016	Simons Fellow, Isaac Newton Institute, Cambridge University
2017 - 2020	Scientific Advisory Board, Institute for Computational and Experimental Research in Mathematics
2019 -	Board Member, National Academies' Board on Mathematical Sciences and Analytics
2019 -	Editorial Board, SIAM Multiscale Modeling and Simulation

Honors

1998	McKnight Land Grant Professorship, University of Minnesota
2002	Canadian Research Chair II, Applied Math, UBC
2011	Krieger-Nelson Prize, CMS
2013	Service Award, Association for Women in Mathematics
2015	SIAM Fellow, SIAM
2016	Simons Fellowship, Simons Foundation

C. Contribution to Science

1. Heterogeneity in Pattern forming systems, including localized patterns:

   By developing a number of new computational and analytical approaches, we have been able to identify mechanisms that drive heterogeneous patterns in both biological systems and more general nonlinear and complex environments. These occur via different mechanisms including asymmetric initial conditions or environmental conditions (b,c), different noise sources (b), variations in coupling, transmission, and component connections (b,c), and snaking bifurcations for complex hybrid patterns formed of fronts and Turing patterns, driven by energy minimization and environmental constraints (a,d). We also identify conditions for the onset of these patterns, predicting system biases that favor their appearance for all of (a)-(d).

   a. Budd C, Chakhchoukh A, Dodwell T, Kuske R. Chevron folding patterns and heteroclinic orbits. Physica D: Nonlinear Phenomena. 2016; 330(1):32-46.
   b. Thompson W, Kuske R, Li Y. , Stochastic phase dynamics of noise driven synchronization of two conditional coherent oscillators. Discrete and Continuous Dynamical Systems A. 2012;
   c. Rotstein H, Kuske R. Localized and asynchronous patterns via canards in coupled calcium oscillators. Physica D: Nonlinear Phenomena. 2006;

d. Budd C, Hunt G, Kuske R. Asymptotics of cellular buckling close to the Maxwell load. Proceedings of the Royal Society A. 2001; 457.

2. Use of data for model identification and selection:

Stochastic dynamical perspectives are adapted for applications in biology, imaging, and machine dynamics, motivating new modes of model identification. These incorporate previously unexplored measures of stochastic resonance to characterize stochastically-driven bifurcations for state transitions (c), and use experimentally-observed state transitions (b,d), which are then combined with model choices and/or parameters for completing model identification. In the context of inverse problems where a model is inferred from data, a PDE model is treated as a constraint, appended as a penalty function to an objective function optimized for data fit. Exploiting the resulting nearly-convex structure, we develop an innovative Bayesian approach to drastically improve computational efficiency to parametrize the PDE model (a).

a. Dombovari Z, Iglesias A, Molnar TG, Habib G, Munoa J, Kuske R, Stepan G. Experimental observations on unsafe zones in milling processes. Philos Trans A Math Phys Eng Sci. 2019 Sep 9;377(2153):20180125. PubMed PMID: 31329062; PubMed Central PMCID: PMC6661331.
b. Fang Z, Da Silva C, Kuske R, Hermann F. Uncertainty quantification for inverse problems with weak PDE-constraints. Geophysics. 2018; 83:R629.
c. Borowski P, Kuske R, Li YX, Cabrera JL. Characterizing mixed mode oscillations shaped by noise and bifurcation structure. Chaos. 2010 Dec;20(4):043117. PubMed PMID: 21198087.
d. Cao Y, Kuske R, Li H. Direct observation of markovian behavior of the mechanical unfolding of individual proteins. Biophys J. 2008 Jul;95(2):782-8. PubMed PMID: 18375518; PubMed Central PMCID: PMC2440450.

3. Noise-sustained patterns in neuroscience and epidemiology:

We greatly expand the applicability of the coherence resonance concept, to explain how noise can sustain regular behavior that is expected to be merely transient. Examples include noise-enhanced activity-based coupling, driving emergent regular activity bursts in networks of neurons (c), with both inhibitory and excitatory modes. Both linear and nonlinear mechanisms, which drive regular recurrence of diseases in large populations, are, surprisingly, sustained purely by random fluctuations. Our analysis explains why seasonality and other regular variations are not necessary (a)-(b). We also expose new unexpected nonlinear routes to instabilities in human balance, based on physiologically-based intermittent control models(d). These instabilities appear as susceptibility to both noise-sustained leaning and wobbling, with potential for falling.

a. Simpson D, Kuske R, Li Y. Dynamics of Simple Balancing Models with Time-Delayed Switching Feedback Control. Journal of Nonlinear Science. 2012;
b. Chaffee J, Kuske R. The effect of loss of immunity on noise-induced sustained oscillations in epidemics. Bull Math Biol. 2011 Nov;73(11):2552-74. PubMed PMID: 21347814.
c. Kuske R, Gordillo LF, Greenwood P. Sustained oscillations via coherence resonance in SIR. J Theor Biol. 2007 Apr 7;245(3):459-69. PubMed PMID: 17173935.
d. Reinker S, Li YX, Kuske R. Noise-induced coherence and network oscillations in a reduced bursting model. Bull Math Biol. 2006 Aug;68(6):1401-27. PubMed PMID: 17149822.

4. Dynamic bifurcations, transitions, and tipping points :

We develop innovative uses of multiple scale analyses, combined with computational and analytical approximations to capture the primary mechanisms for noise-sensitive transitions or tipping points. These are rapid state transitions due to proximity to critical thresholds which are then crossed dynamically. We demonstrate how slowly varying conductance in a model of neuronal bursting in a dendritic spine head leads to noise-sensitive activity, with dramatic transitions from regularly on-off bursting patterns to intermittency with increased frequency of spiking, even with very small noise (d). Similarly, in neural networks with synaptic coupling in subthreshold regimes, asymmetric spiking states can appear in the same regime as symmetric states, with noise and perturbations driving transitions between the two (b). We

also apply multiple scale stochastic analyses to illustrate how a form of coherence resonance amplifies very small noise near certain types of bifurcation thresholds, which leads to large regular oscillations known as chatter in mechanical systems(d). Furthermore, internal noise sources result in correlations on rapid time scales, which then accumulate as large fluctuations on longer time scales. These large variations appear with surprising frequency (a), thus driving large and unexpected variations. This result is demonstrated for general models of climate dynamics, and are applicable for many other systems with multiple levels of temporal or spatial scales.

a. Thompson WF, Kuske RA, Monahan AH. Reduced α-stable dynamics for multiple time scale systems forced with correlated additive and multiplicative Gaussian white noise. Chaos. 2017 Nov;27(11):113105. PubMed PMID: 29195322.
b. Yu N, Kuske R, Li YX. Stochastic phase dynamics and noise-induced mixed-mode oscillations in coupled oscillators. Chaos. 2008 Mar;18(1):015112. PubMed PMID: 18377093.
c. Buckwar E, Kuske R, L"Esperance B, Soo T. NOISE-SENSITIVITY IN MACHINE TOOL VIBRATIONS. International Journal of Bifurcation and Chaos. 2006; 16(8):2407-2416.
d. Kuske R, Baer SM. Asymptotic analysis of noise sensitivity in a neuronal burster. Bull Math Biol. 2002 May;64(3):447-81. PubMed PMID: 12094405.

5. New directions for applied analysis of stochastic non-smooth systems (switches and impacts)

We have developed a completely new suite of analytical and computational approaches for applied modeling of non-smooth systems, that is, with on-off control, abrupt parameter changes (switches), and impacts. These techniques expose mechanisms for a range of phenomena, indicating where the dynamics is either robust or sensitive to perturbations. Stochastic non-smooth systems have received limited attention historically due to technical complications of combined randomness and switching/non-smooth dynamics. We provide quantitative comparisons of external noise vs. surface randomness on an impacting surface, explaining why and how the latter drives unpredictable behavior in mechanical systems with impacts (c). We capture regular modes in a new design of energy harvesting, transferring mechanical impacts to output voltage, and we quantitatively predict how noise can either increase or decrease transitions to irregular or inefficient impacts (a). In systems with control switches, we show how hidden slow and fast scales play a critical role in system efficiency, as noise influences the variability of the activity-dependent switch (d). For on-off control in systems where the control has delayed feedback, we show how the interaction of the delay and noise can severely limit the robustness of the controlled behavior (b).

a. Serdukova L, Kuske R, Yurchenko D. Stability and bifurcation analysis of the period-T motion of a vibroimpact energy harvester. Nonlinear Dynamics. 2019 November; 98(3):1807.
b. Wang J, Kuske R. The influence of parametric and external noise in act-and-wait control with delayed feedback. Chaos. 2017 Nov;27(11):114319. PubMed PMID: 29195303.
c. Simpson D, Kuske R. The influence of localized randomness on regular grazing bifurcation with applications to impacting dynamics. Journal of Vibration and Vontrol : JVC. 2016; 24:407.
d. Simpson D, Kuske R. Stochastic Perturbations of Periodic Orbits with Sliding. Journal of Nonlinear Science. 2015; 25:967.