In this issue of *IEEE Control Systems*, we speak with Jared Miller and Xin Chen.

Jared Miller recently completed his dissertation, "Safety Quantification for Nonlinear and Time-Delay Systems Using Occupation Measures," at Northeastern University, Boston, MA, USA. His Ph.D. supervisor is Mario Sznaier. He is currently a postdoctoral researcher at the Automatic Control Lab, ETH Zurich, in the research group of Roy Smith (under NCCR Automation). He received his B.S. and M.S. degrees in electrical engineering from Northeastern University in 2018 and his Ph.D. degree in electrical engineering from Northeastern University in 2023. His interests include large-scale convex optimization, nonlinear dynamics, measure theory, and power systems.

Xin Chen recently completed his dissertation, "Distributed and Data-Driven Decision Making for Sustainable Power Systems," at Harvard University. His Ph.D. supervisor is Na Li. He received his master's degree in electrical engineering and two bachelor's degrees in engineering and economics from Tsinghua University. He is now an assistant professor in the Department of Electrical and Computer Engineering at Texas A&M University. His research lies at the intersection of control, learning, and optimization for human–cyberphysical systems, with applications to sustainable power and energy systems.

Rodolphe Sepulchre

Digital Object Identifier 10.1109/MCS.2024.3358692
Date of current version: 26 March 2024

JARED MILLER

Q. How would you pitch your Ph.D. dissertation in one paragraph?

Jared: Imagine that you are in a car going 100 km/h, and near the path of the car, there is a tree. Now compare the following two statements: 1) the current driving plan is safe, or 2) the current plan is safe, but the car will pass within 10 cm of a tree when traveling at high speed. The physical situations in statements 1 and 2 are the same, but statement 2 adds the safety-quantifying information of a 10-cm distance of closest approach. After knowing the 10-cm quantifier, the driver might choose to increase their distance of closest approach so as to insulate against disturbances in track conditions and moments of inattention. My thesis focuses on generating safety quantifiers (for example, the distance of the closest approach, peak current on a power line, and number of infected people in a pandemic) for dynamical systems using the theory of occupation measures. A sequence of upper bounds to the true peak value (or the appropriate lower bounds to distance) may be computed by solving a sequence of convex programs in increasing complexity. Each of these bounds offers certifiable guarantees about system behavior and the performance of all possible trajectories starting from the selected initial conditions. In contrast, barrier function methods offer binary certificates of safety (statement 1), which would appear the same in the case of a 10-cm and a 10-km distance of the closest approach.

Jared Miller.

Digital Object Identifier 10.1109/MCS.2024.3358708
Date of current version: 26 March 2024

Q. How would you describe the significance and relevance of your results?

Jared: Peak estimation and safety quantification inform control designers and policymakers in the evaluation and design of intervention strategies. The finite-dimensional peak estimation problem is generically nonconvex in its optimization variables of the initial condition and stopping time. I used existing work in optimal control synthesis to lift the nonconvex peak estimation problem into an infinite-dimensional linear program in occupation measures, given that peak estimation is an instance of an optimal control problem with a zero-stage cost and a free terminal time. These infinite-dimensional linear programs must be discretized to admit solutions on our finite-dimensional computers, and we chose to employ polynomial optimization methods to admit global guarantees. I extended the peak estimation problem and bounding approach toward systems with possible hybrid and/or time-delay dynamics based on prior work in reachable set estimation and Lyapunov analysis. Peak estimation can be modified for systems with stochastic uncertainty, such as in the sense of finding the maximal conditional value at risk of the objective function along trajectories.

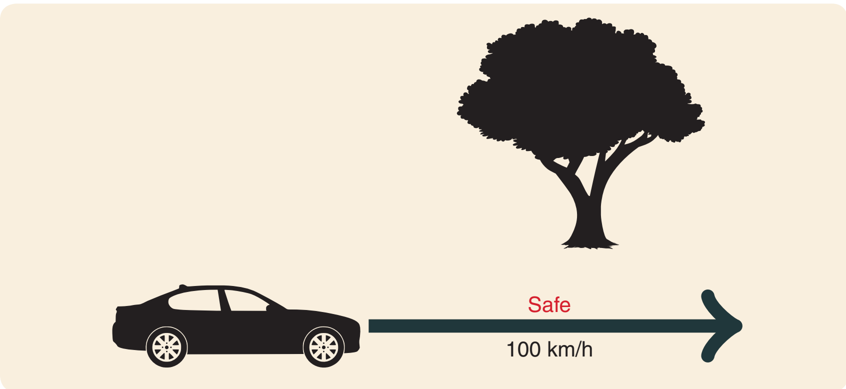
Another application is data-driven safety analysis. In the data-driven set-membership setting, the unknown system parameters can be treated as a robust uncertainty that is adversely trying to maximize the objective function. In addition to quantifying safety based on peak or distance estimates, safety can be quantified by the minimum possible data corruption needed for a consistent model to crash into an unsafe set (crash safety).

Q. How did you get started in control?

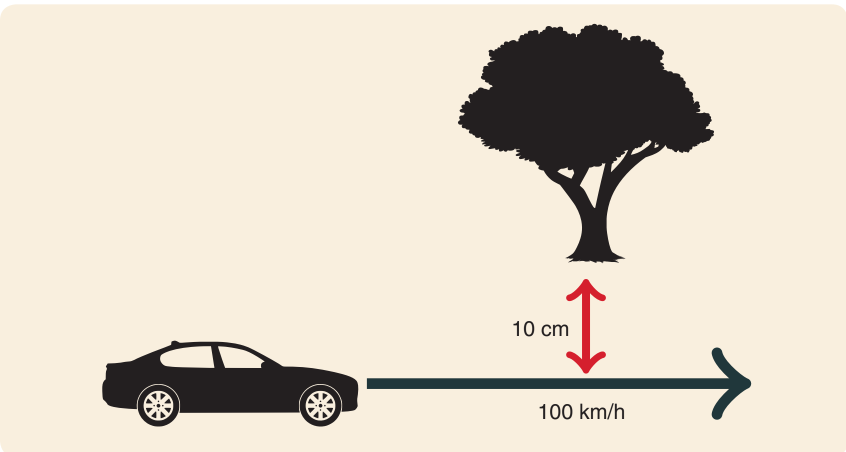
Jared: I became interested in applied mathematics [for example, partial differential equations (PDEs) and complex analysis] in high school when I read *Advanced Engineering Mathematics* by Peter O'Neil. I was first exposed to control during my internship at ASML (Veldhoven, The Netherlands) in 2016, during which I began learning about linear system theory from "Control Tutorials for MATLAB and Simulink" by Profs. Dawn Tilbury and Bill Messner. My background in control and convex optimization kicked off in the spring of 2017, when I attended Prof. Mario Sznaier's course on big data, sparsity, and control at Northeastern University (for which I later assisted in teaching). Mario Sznaier and Octavia Camps welcomed me into the Robust Systems Laboratory as a B.S./M.S. student, and they helped give me an intuition for robust control, nonlinear systems, polynomial optimization, and computer vision. My first applied control project was during my capstone (advised by Prof. Bahram Shafai), in which I modeled the up-and-down dynamics of a bagged air-cushioned vehicle under different air pressure conditions (hovercraft/hyperloop). I attended Eduardo Sontag's course on systems biology, chemical reaction networks, and contraction theory in the spring of 2018, and I officially joined Mario and Octavia's lab as a Ph.D. student in the fall of 2018.

Q. How would you summarize the experience of your Ph.D.?

Jared: Enlightening and exhausting. There's nothing quite like the rush of having code work for the first time, proving a theorem in a pleasant way, or finally understanding and integrating a concept after the *n*th reading. At the same time, the research process involves the frustration of multiple false starts and tracing programming bugs, culminating in the writing of a thesis. Some of the best parts of my Ph.D. involved discussions in the lab, visiting other groups, giving seminars, and chasing possibilities for new control designs and applications.



The car is safe with respect to the tree when traveling at 100 km/h.



The car's motion is safe, but it will pass within 10 cm of the tree.

Some of the best parts of my Ph.D. involved discussions in the lab, visiting other groups, giving seminars, and chasing possibilities for new control designs and applications.

Q. Can you highlight a moment of light or a particularly good memory during the course of your Ph.D.?

Jared: Some of my favorite moments during my Ph.D. occurred during the IEEE Conference on Decision and Control (CDC). CDC 2019 in Nice was my first time presenting my research to the control community. I enjoyed being exposed to many fields of research by attending sessions, discussing results, interacting at poster sessions, and exploring the city with fellow conference-goers. My next time presenting my work in person occurred toward the end of my Ph.D. at CDC 2022 in Cancun due to the intervening COVID-19 epidemic causing event cancellations and remote presentations. These CDC conferences bookended my Ph.D. research career and helped launch me into my current postdoctoral status.

Q. Can you describe a moment of frustration or discouragement during the course of your Ph.D. and how you overcame the challenge?

Jared: My research on peak estimation was motivated by the COVID-19 pandemic. The original problem I was aiming for was peak-minimizing control (flattening the curve): designing an intervention strategy to minimize the maximum number of infected people at any particular time. My goal was to find a single convex program (without bisection) to solve this peak-minimizing control with rigid theoretical guarantees, and I consistently failed at this task during most of my Ph.D. Over the course of this failure, my collaborators (including Mario Sznaier, Didier Henrion, Milan Korda, and Victor Magron) and I identified and solved interesting peak estimation analysis problems over a wide range of other system dynamics. Toward the end of my visit at LAAS-CNRS (Toulouse, France) on 4 July 2022, I attended a seminar by Alain Rapaport, where he discussed numerical solutions to peak-minimizing control problems by objective reformulation. This approach was the missing link toward solving the motivating peak-minimizing control question that sparked my thesis, and I adapted their work when forming crash-safety bounds for data-driven safety analysis.

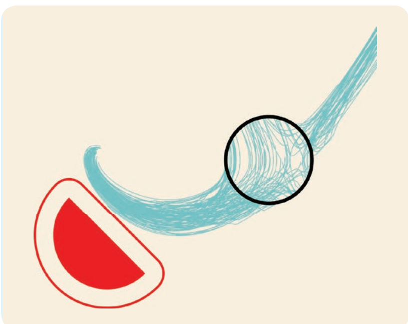
Q. Can you highlight some key reference(s) or article(s) that inspired your research?

Jared: The research that initially inspired me about peak-minimizing control of epidemics includes the following:

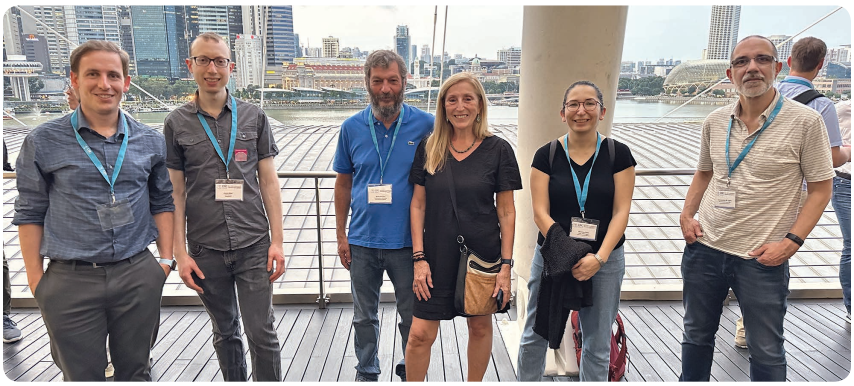
- G. Stewart, K. Van Heusden, and Guy A. Dumont, "How control theory can help us control COVID-19," *IEEE Spectrum*, vol. 57, no. 6, pp. 22–29, June 2020. doi: 1109/MSPEC.2020.9099929.
- M. Sadeghi, J. M. Greene, and E. D. Sontag, "Universal features of epidemic models under social distancing guidelines," *Annu. Rev. Control*, vol. 51, pp 426–444, 2021. doi: 10.1016/j.arcontrol.2021.04.004.

Other references on peak-minimizing control include the following:

- *Reentry heating:* P. Lu and N. X. Vinh, "Minimax optimal control for atmospheric fly-through trajectories," *J. Optim. Theory Appl.*, vol. 57, pp. 41–58, 1988. doi: 10.1007/BF00939328.
- *Necessary optimality conditions:* R. B. Vinter, "Minimax optimal control," *SIAM J. Control Optim.*, vol. 44, no. 3, 2005. doi: 0.1137/S036301290241524.



A robust certified distance contour away from the unsafe set (red half-circle) for all trajectories (cyan) starting in the initial set (black circle).



Enrique Mallada, Jared Miller, Mario Sznaier, Octavia Camps, Necmiye Ozay, and Constantino Lagoa at the CDC Farewell Reception.

- *Objective reformulations:* E. Molina, A. Rapaport, and H. Ramírez, "Equivalent formulations of optimal control problems with maximum cost and applications," *J. Optim. Theory Appl.*, vol. 195, pp. 953–975, 2022. doi: 10.1007/s10957-022-02094-z.

Work on peak estimation in the linear programming framework includes the following:

- *Optimal control:* R. M. Lewis and R. B. Vinter, "Relaxation of optimal control problems to equivalent convex programs," *J. Math. Anal. Appl.*, vol. 74, no. 2, pp. 475–493, 1980. doi: 10.1016/0022-247X(80)90143-2.
- *Peak and stochastics:* M. J. Cho and R. H. Stockbridge, "Linear programming formulation for optimal stopping problems," *SIAM J. Control. Optim.*, vol. 40, no. 6, 2002. doi: 10.1137/S0363012900377663.
- *Peak estimation using polynomial optimization:* G. Fantuzzi and D. Goluskin, "Bounding extreme events in nonlinear dynamics using convex optimization," *SIAM J. Appl. Dyn. Syst.*, vol. 19, no. 3, 2020. doi: 10.1137/19M1277953.

Books I constantly reference are the following:

- Ben-Tal, L. El Ghaoui, and A. Nemirovski, *Robust Optimization*. Princeton University Press, Aug. 30, 2009.
- J.-P. Aubin and H. Frankowska, *Set-Valued Analysis*. Springer, 2009.

For learning about polynomial optimization methods with applications to dynamical systems, I recommend the following:

- J. B. Lasserre, *Moments, Positive Polynomials and Their Applications* in Series on Optimization and Its Applications: vol. 1, World Scientific, Oct. 2009. doi: 10.1142/p665.
- D. Henrion, M. Korda, and J. B. Lasserre, *The Moment-SOS Hierarchy: Lectures in Probability, Statistics, Computational Geometry, Control and Nonlinear PDEs* in Series on Optimization and Its Applications, vol. 4, World Scientific, Nov. 2020. doi: 10.1142/q0252.
- Jasour, "Risk aware and robust nonlinear planning," Course Notes for MIT 16.S498, 2019. [Online]. Available: https://rarnop.mit.edu/Lectures-Codes.

Q. What would you do differently if you were to start your Ph.D. again?

Jared: Much of the work in my Ph.D. involved mathematics, numerical simulation, and system validation. If I were to start my Ph.D. again, I would be more involved with applying control algorithms on real systems. I am currently learning about the dynamic behavior of power systems and power electronics, and I wish that I had entered these fields earlier.

Q. Can you highlight a most promising topic or area of research for a new Ph.D. student in control?

Jared: The climate crisis/energy transition is not a single problem but is instead an entire host of mutually

Jared Miller at the Conservatory of Flowers in San Francisco, CA, USA.

For Further Information About Jared's Dissertation

Link to the Dissertation PDF: https://repository.library.northeastern.edu/files/neu:4f196v79r

KEY PUBLICATIONS:

- J. Miller, D. Henrion, and M. Sznaier, "Peak estimation recovery and safety analysis," *IEEE Contr. Syst. Lett.*, vol. 5, no. 6, pp. 1987–2020, Dec. 1982, doi: 10.1109/LCSYS.2020.3047591.
- J. Miller and M. Sznaier, "Bounding the distance to unsafe sets with convex optimization," *IEEE Trans. Autom. Control*, vol. 68, no. 12, pp. 7575–7590, Dec. 2023, doi: 10.1109/TAC.2023.3285862.
- J. Miller, T. Dai, and M. Sznaier, "Data-driven superstabilizing control of error-in-variables discrete-time linear systems," in *Proc. IEEE 61st Conf. Decis. Control (CDC)*, Piscataway, NJ, USA: IEEE Press, 2022, pp. 4924–4929, doi: 10.1109/CDC51059.2022.9992363.
- J. Miller and M. Sznaier, "Analysis and control of input-affine dynamical systems using infinite-dimensional robust counterparts," 2021. [Online]. Available: https://arxiv.org/abs/2112.14838
- J. Miller and M. Sznaier, "Quantifying the safety of trajectories using peak-minimizing control," 2023. [Online]. Available: https://arxiv.org/abs/2303.11896

AWARDS AND RECOGNITIONS:

- Finalist for Young Author Award, IFAC World Congress 2023
- Outstanding Student Paper Award, IEEE CDC 2021 and 2022
- ASME DSCD Rising Star, 2022
- IFAC Young Author Award, ROCOND 2022
- Chateaubriand Fellowship, 2020

coupled issues. A new Ph.D. student could focus on a few aspects to make a difference while keeping aware of and staying in communication about work being done on other parts of the problem. Such aspects could include control strategies to increase the efficiency and stability of renewable generation (inverter-based resources), sensor selection and event-based architectures, decentralized control of power and communication networks, resilient and adaptable control policies under line outages, the identification and predictive control of enhanced geothermal systems, improved battery coordination, efficient and economical carbon fixation, and energy modeling/policy design to ensure that a just transition occurs.

Q. What would be your main advice to a prospective Ph.D. student in control?

Jared: The Ph.D. process can be roughly divided into two parts. The first part mostly involves literature reviews and trying to find a project/research direction. All of a sudden, there is a phase transition, and you then have plenty of ideas on specific areas for which you can contribute. That chain of inquiry can be later tied together into a story to form your thesis. The timing of the moment of inspiration isn't predictable, but you'll know when it hits, and you should try to be prepared.

Q. Thank you for your comments.

Jared: Thanks again.

XIN CHEN

Q. How would you pitch your Ph.D. dissertation in one paragraph?

Xin: My dissertation aims to address the pressing challenge in today's electric energy systems: the significant uncertainty and volatility introduced by rapidly growing renewable generation, especially solar and wind. My work focuses on autonomously coordinating large-scale distributed energy resources in the grid, such as energy storage, electric vehicles, and flexible loads, to harness their collective power flexibility for reliable system operation. I developed data-driven distributed control algorithms to deal with the two fundamental issues of uncertainty and scalability in the coordination of massive heterogeneous distributed energy devices.

Dr. Xin Chen next to The Little Mermaid in Copenhagen during the 2018 IEEE Conference on Control Technology and Applications.

Dr. Xin Chen and his Ph.D. advisor, Prof. Na Li, at the Harvard graduate commencement.

Digital Object Identifier 10.1109/MCS.2024.3358698
Date of current version: 26 March 2024