In this issue of IEEE Control Systems, we speak with Andreas A. Malikopoulos, who is a professor at Cornell University. He received a diploma from the National Technical University of Athens, Greece, and his M.S. and Ph.D. degrees from the University of Michigan, Ann Arbor in 2004 and 2008, respectively, all in mechanical engineering. Before he joined Cornell, he was the Terri Connor Kelly and John Kelly Career Development Professor in the Department of Mechanical Engineering (2017–2023) and the founding director of the Sociotechnical Systems Center (2019–2023) at the University of Delaware (UD). Prior to these appointments, he was the Alvin M. Weinberg Fellow (2010–2017) in the Energy and Transportation Science Division at Oak Ridge National Laboratory (ORNL), the deputy director of the Urban Dynamics Institute (2014–2017) at ORNL, and a senior researcher in General Motors Global Research and Development (2008–2010).

Andreas is the recipient of several prizes and awards, including the 2007 Dare to Dream Opportunity Grant from the University of Michigan Ross School of Business, the 2007 University of Michigan Teaching Fellow, the 2010 Alvin M. Weinberg Fellowship, the 2019 IEEE Intelligent Transportation Systems Young Researcher Award, and the 2020 UD's College of Engineering Outstanding Junior Faculty Award. He was selected by the National Academy of Engineering to participate in the 2010 German–American Frontiers of Engineering (FOE) Symposium and organize a session on transportation at the 2016 European–American FOE Symposium. He was also selected as a 2012 Kavli Frontiers of Science Scholar by the National Academy of Sciences. He is currently an associate editor of *Automatica* and *IEEE Transactions on Automatic Control* as well as a senior editor of *IEEE Transactions on Intelligent Transportation Systems*. He is a Senior Member of IEEE, a fellow of the American Society of Mechanical Engineers, and a member of the Board of Governors of the IEEE Intelligent Transportation Systems Society.

Rodolphe Sepulchre

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ANDREAS A. MALIKOPOULOS

Q. How did your education and early career lead to your initial and continuing interest in the control field?

***Andreas*:** Since I was in high school, I had a natural inclination in math courses. Math would typically consume most of my time as a student, as I challenged myself to solve problems beyond the boundaries of my school's textbook. When I joined the National Technical University of Athens (NTUA), thankfully, we had to take two or three math courses every semester in the first three years, including algebra, advanced calculus, real analysis, complex analysis, and analytical geometry, which eventually helped me build a strong foundation for engineering. In the fourth and fifth years of my studies—NTUA, as most polytechnic schools in Europe, provides a five-year engineering program—I took courses on classical and modern control theory, which essentially put my math background in an engineering context and, eventually, designated my career trajectory.

Q. What are some of your research interests?

***Andreas*:** My research interests span several fields, including analysis, optimization, and control of cyber-physical systems (CPSs); decentralized stochastic systems; stochastic scheduling and resource allocation; and learning in complex systems. My research aims to develop rigorous theories and data-driven system approaches at the intersection of learning and control for making CPSs able to realize their optimal operation while interacting with their environment. The emphasis is on improving energy efficiency and reducing greenhouse gas emissions in applications related to emerging mobility systems (for example, connected and automated vehicles [CAVs], electric vehicles, and shared mobility) and smart cities, thus contributing to the planet's health.

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Math would typically consume most of my time as a student, as I challenged myself to solve problems beyond the boundaries of my school's textbook.

My interest in this area started early on, while I was still at graduate school, when I read an article about the discrepancy between the true fuel economy of a vehicle and the one posted on the window sticker. The article discussed the implications of the driver's driving style on engine operation and stated that the state-of-the-art control methods, by that time, consisted of static controllers that could not optimize engine operation for different driving styles but only for predetermined ones. This article provided inspiration that eventually led to forming the topic of my dissertation. In my dissertation, I developed the theoretical framework and control algorithms that can turn the engine of a vehicle into an autonomous intelligent system capable of learning its optimal operation in real time while the driver is driving the vehicle. I modeled the evolution of the state of the engine as a control Markov chain and proved that it eventually converges to a stationary probability distribution deemed characteristic of the driver's driving style. Through this approach, the engine progressively perceives the driver's driving style and eventually learns to operate in a manner that optimizes specified performance criteria (such as fuel economy and emissions) with respect to the driver's driving style. The framework also allows the engine to identify the driver, and, thus, it can adjust its operation to be optimal for any driver based on what it has learned in the past regarding their driving style. The outcome of my dissertation research eventually led to a U.S. patent.

Moving to General Motors Research and Development as a senior researcher, I had the chance to continue working on self-learning control for advanced powertrain systems. I led several projects on autonomous intelligent propulsion systems and developed computational mathematical models and control algorithms toward making highly energy-efficient and eco-friendly vehicles. I was a member of the team that successfully demonstrated the implementation of learning control algorithms in two demo vehicles: the Saturn Aura and Opel Vectra.

When I joined Oak Ridge National Laboratory (ORNL) as an Alvin M. Weinberg Fellow, although the focus of my fundamental research interests remained the same, the emphasis of the applications shifted from powertrain systems to vehicles and then to CAVs. At ORNL, I had the chance to work across different technical areas including stochastic optimal control, optimal power management control, routing of hybrid electric vehicles (HEVs) and plug-in HEVs, and driver feedback systems. The last of these eventually led to a technology that was licensed at SanTed Project Management LLC. I also made contributions to the solution of problems that included smart buildings aimed at optimizing energy system parameters to 1) improve sustainability, 2) facilitate cost-effective energy generation, and 3) allocate demand optimally to different energy sources (for example, solar, wind, etc.). On the fundamental research front, I established a theoretical framework for the analysis and stochastic control of complex systems consisting of interactive subsystems. Later on, in my role as the deputy director of the Urban Dynamics Institute at ORNL, I developed several research initiatives with the goal of investigating how we can use efficient computational methods on scalable data and informatics to enhance understanding of the environmental implications of CAVs and improve transportation sustainability and accessibility.

When I joined the University of Delaware, I established the Information and Decision Science Laboratory, which facilitates the first-ever scaled (1:25) robotic city with more than 50 robotic cars, with the vision to advance the state of the art in emerging mobility systems (for example, CAVs and shared mobility). A mobility system

Andreas Malikopoulos by the Information and Decision Science Lab's Scaled Smart City (IDS^{3}C) at Cornell University.

encompasses the interactions of three heterogeneous dimensions:

- *technological*: transportation systems and modes (such as CAVs, shared mobility, and public transit) integrated with advanced control algorithms
- *social*: the behavior of drivers, operators (for autonomous vehicles), and travelers (or pedestrians) interacting with these systems
- *institutional*: the behavior of organized units, such as administrators, that govern the transportation systems through policies.

The constellation of these three dimensions constitutes a sociotechnical system, which, in my group, we analyze and study holistically.

Q. What courses do you teach relating to control? Do you have a favorite course? How would you describe your teaching style?

***Andreas*:** I have taught fundamental control courses as well as advanced courses in the areas of stochastic optimal control, game theory, mechanism design, convex optimization, and nonlinear programming. At Cornell, I teach some of my favorite topics on optimal decision-making and team theory, along with courses on emerging mobility systems for smart cities.

Many of my activities as a teacher and mentor are governed by my conviction that the key to effective teaching is enthusiasm, both for your subject and for conveying knowledge to your students. In my professional career in industry, national labs, and academia, I have realized that the only way to learn a subject is through hard work and applying theoretical knowledge to real projects. Students work hard when they are motivated, encouraged when they face adversity, and rewarded for their accomplishments. As a teacher, I show my students my own excitement about the topics of my research related to the learning and control of CPSs. The key to motivating students to sincerely master these subjects is to implement a creative and interactive teaching–learning process. The creative process requires examples and applications of the topics stimulating students' interest. For instance, demonstrating how effectively a theory has been used to solve a challenging engineering problem or utilized in a well-known application can affect students' motivation and willingness to put in the required effort to master this theory. The interactive process rests on an open and informal class atmosphere that encourages students to ask, answer, or discuss questions. My students are continuously involved in precisely such discussions of topics covered by the class agenda.

Utilizing active learning methods has been shown to be efficient in engineering classes and has proven to be beneficial, especially to undergraduate students or to graduate students

Andreas Malikopoulos with his wife, Voula, and daughter, Georgina, in Santorini, Greece.

Andreas Malikopoulos delivers opening remarks at the National Academy of Engineering's 2016 European–American Frontiers of Engineering Symposium.

who have not yet crystallized their research interests. Such methods include practical and creative exercises during class or term projects that help students visualize abstract concepts or newly introduced theories. Without compromising the teaching of fundamentals, I have introduced an approach to further my students' education through the incorporation and coordinated use of a series of computer simulation tools, selected movies, and real-life case studies presented within and in parallel with my lectures. When teaching an advanced "Game Theory–Mechanism Design" class, I assign term projects in which students learn to apply the theory and design mechanisms in problems either directly related to their research or newly defined problems. The projects emphasize the concepts and understanding of the importance of the assumptions related to theory.

Encouraging my students when they face adversity and rewarding them for their intellectual accomplishments is an important aspect of my teaching philosophy. In my classes, I include a diversity of assignments that help me evaluate students' performance and learning progress. Such a diversity of assignments allows me to monitor each individual's progress and effort and encourage or reward students accordingly. It also gives me the opportunity to set up individual meetings with students whose performance is below expectations. Such meetings help me realize whether my teaching is not efficient for them, and individual adjustments are necessary, or if there are other reasons for their low performance.

Andreas Malikopoulos windsurfing in Greece.

Profile of Andreas A. Malikopoulos

- *Current position*: professor, Cornell University.
- *Visiting and research positions:* senior researcher, General Motors R&D (2008–2010); Alvin M. Weinberg Fellow, Oak Ridge National Laboratory (ORNL) (2010–2017); deputy director, Urban Dynamics Institute, ORNL (2014—2017); senior fellow, National Science Foundation Institute of Pure and Applied Mathematics (2015 and 2020); resident scholar, Center for Information and Systems Engineering, Boston University (2020); Terri Connor Kelly and John Kelly Career Development Associate Professor, University of Delaware (2017–2023).
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- *IEEE Control Systems Society (CSS) experience highlights:* CSS Editorial Board (2018–present); chair, Technical Committee on Smart Cities (2020–2022); associate editor, *IEEE Transactions on Automatic Control* (2020–present); publicity chair, IEEE Conference on Decision and Control (CDC) (2022); workshop cochair, CDC (2023).
- *Notable awards:* University of Michigan Teaching Fellow (2007); Alvin M. Weinberg Fellow (2010); National Academy of Sciences Kavli Frontiers of Science Scholar; IEEE Senior Member (2017–present); fellow of the American Society of Mechanical Engineers (2017); IEEE Intelligent Transportation Systems Young Researcher Award (2019); UD's College of Engineering Outstanding Junior Faculty Award, 2020.

Q. What are some of the most promising opportunities you see in the control field?

***Andreas*:** CPSs, in most instances, represent systems of systems with an informationally decentralized structure, such as emerging mobility systems, networked control systems, manufacturing, smart power grids, power systems, mobility markets, social media platforms, the cooperation of robots, and the Internet of Things. To optimize the operation of such systems, we typically assume an ideal model. Such model-based control approaches cannot effectively facilitate optimal solutions with performance guarantees due to the discrepancy between the model and the actual CPS. On the other hand, in most CPSs, there is a large volume of data with a dynamic nature, which is added to the system gradually in real time and not altogether in advance. Thus, traditional supervised learning approaches cannot always facilitate robust solutions using data derived offline. In contrast, applying reinforcement learning approaches directly to the actual CPS might impose significant implications on the safety and robust operation of the system.

I think one promising opportunity in the control field is to investigate how to circumvent these challenges in CPSs, where the human is in the loop, with data-driven system approaches by "separating" the learning and control tasks. One potential approach in this area is to institute an information state for the system that does not depend on the control strategy. An important consequence of this independence is that, for any given choice of a control strategy and a realization of the system's variables until time t, the information states at future times do not depend on the choice of the control strategy at time t (but only on the realization of the decision at time t). In other words, the future information states are separated from the choice of the current control strategy. Such control strategies are called *separated control strategies*. Using separated control strategies, we can derive offline the optimal strategy of the system parameterized with respect to all realizations of the information state and then use standard learning approaches to learn the information state online while data are added gradually to the system in real time. This approach could effectively facilitate optimal solutions with performance guarantees in a wide range of CPS applications.

Q. You are the author of two books in the control field. What topics do these books cover?

***Andreas*: My monograph** *Real-Time, Self-Learning Identification and Stochastic Optimal Control of Advanced Powertrain Systems* provides the theory and algorithms that aim at making the powertrain of a vehicle an autonomous intelligent system capable of learning its optimal operation in real time while the driver drives the vehicle. Powertrain operation is modeled as a control Markov chain, and it is shown that it eventually converges to a stationary probability distribution deemed characteristic of the driver's driving style. Through this approach, the controller progressively perceives the driver's driving style and eventually learns to operate the powertrain of the vehicle in a manner that optimizes specified performance criteria (such as fuel economy and emissions) with respect to the driver's driving style.

The other book, coedited with Petros Ioannou, *Transportation Mobility in Smart Cities*, provides a road map on what innovations are needed for emerging mobility systems, how to address the challenges, and how to holistically explore a research path moving forward.

Q. What are some of your interests and activities outside of your professional career?

Andreas: I love water sports. More recently, I started windsurfing, which has become my ultimate passion. Standing on the board, holding the sail, and getting the power of the wind is a unique feeling. You can hear the board crossing the waves, which is relaxing. Like other water sports, windsurfing offers an original manner to exercise and enjoy the sea. It's a fun way to stay active physically given that learning any new sport is quite motivating and challenging. Since I can do windsurfing mainly in the summer, I started learning how to sail in Cayuga Lake in Ithaca, so I keep my connection with the water throughout the year. I also love cooking and experiencing different cuisines, but mainly Greek cuisine. The problem is that, when I am done cooking, the kitchen is a disaster, so getting authorization from my wife to cook is not trivial. Many Saturdays, we organize Greek nights at home with friends, where I cook a traditional dish while watching a classic black-and-white Greek movie.

Q. Thank you for your comments.

Andreas: I appreciate the opportunity to have this discussion.