In this issue of IEEE Control Systems Magazine, we interview three prominent researchers in the field of control systems: Alexandre Bayen, the winner of the 2013 Antonio Ruberti Young Researcher Prize; Aaron Ames, the winner of the 2015 Donald P. Eckman Award; and Tom Edgar, the winner of the 2015 American Automatic Control Council (AACC) Richard E. Bellman Control Heritage Award.

Alexandre Bayen is the Liao-Cho Professor of Engineering in the Electrical Engineering and Computer Science Department and the Civil and Environmental Engineering Department at the University of California (UC), Berkeley. He is also the director of the Institute of Transportation Studies at UC Berkeley. He received the B.S. degree from Ecole Polytechnique in 1998 and the M.S. and Ph.D. degrees from Stanford University in 1999 and 2003, respectively. He was a visiting researcher at NASA Ames Research Center from 2000 to 2003. In 2004, he worked as the research director of the Autonomous Navigation Laboratory at the Laboratoire de Recherches Balistiques et Aerodynamiques (Ministere de la Defense, Vernon, France), where he holds the rank of major. He has authored two books and over 150 articles in peer-reviewed journals and conferences. He is the recipient of the Ballhaus Award from Stanford University in 2004 and the CAREER award from the National Science Foundation in 2009, and he was a NASA Top 10 Innovators on Water Sustainability (2010). His projects Mobile Century and Mobile Millennium received the 2008 Best of ITS Award for "Best Innovative Practice" at the Intelligent Transportation Systems World Congress and a TRANNY Award from the California Transportation Foundation in 2009. His project Mobile Millennium was featured more than 200 times in the media, including TV channels and radio stations (CBS, NBC, ABC, CNET, NPR, KGO, and the BBC), and in the popular press (*The Wall Street Journal*, *The Washington Post*, and *Los Angeles Times*). He is the recipient of the Presidential Early Career Award for Scientists and Engineers from the White House in 2010. He is also the recipient of the Okawa Research Grant Award, the Antonio Ruberti Young Researcher Prize from the IEEE, and the Huber Prize from the ASCE.

Aaron D. Ames is an associate professor in the George W. Woodruff School of Mechanical Engineering and the School of Electrical and Computer Engineering at the Georgia Institute of Technology. Prior to joining Georgia Tech, he was an associate professor and Morris E. Foster Faculty Fellow II in Mechanical Engineering, with joint appointments in electrical and computer engineering and computer science and engineering in the Dwight Look College of Engineering at Texas A&M University. He received the B.S. degree in mechanical engineering and the B.A. degree in mathematics from the University of St. Thomas in 2001, and he received the M.A. degree in mathematics and the Ph.D. degree in electrical engineering and computer sciences from UC Berkeley in 2006. He served as a postdoctoral scholar in control and dynamical systems at the California Institute of Technology from 2006 to 2008. At UC Berkeley, he was the recipient of the 2005 Leon O. Chua Award for achievement in nonlinear science and the 2006 Bernard Friedman Memorial Prize in Applied Mathematics. He received the National Science Foundation CAREER award in 2010 for his research on bipedal robotic walking and its applications to prosthetic devices and is the recipient of the 2015 Donald P. Eckman Award recognizing an outstanding young engineer in the field of automatic control. His lab designs, builds, and tests novel bipedal robots and prostheses with the goal of achieving human-like bipedal robotic walking and translating these capabilities to robotic assistive devices.

Tom Edgar is the George T. and Gladys H. Abell Endowed Chair in Engineering at The University of Texas (UT), Austin and director of the UT Energy Institute. He received the B.S. degree from the University of Kansas in 1967 and the M.S. and Ph.D. degrees from Princeton University in 1968 and 1971. For over 40 years, he has concentrated his academic work in process modeling, control, and optimization and has published over 450 articles and book chapters applied to separations, chemical reactors, energy systems, and semiconductor manufacturing. His research has focused on control theory and computation for nonlinear and large-scale systems, where he has supervised more than 80 Ph.D. students. He is a Fellow of the International Federation of Automatic Control, a member of the U.S. National Academy of Engineering, and has received numerous major research, education, and service awards, including the AACC John R. Ragazzini Education Award in 1992 and the AACC Richard E. Bellman Control Heritage Award in 2015. He served as the 1997 president of American Institute of Chemical Engineers (AIChE) and was president of the AACC between

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1989 and 1991. He codirects the Texas–Wisconsin–California Control Consortium (TWCCC, http://twccc.che.wisc.edu/index.html), which is supported by 12 companies and involves six faculty members from UT, the University of Wisconsin, and the University of Southern California. TWCCC has been very effective in bridging control theory and industrial practice and has been responsible for many advances in multivariable control, performance monitoring, fault detection, identification, and real-time optimization that have been applied by chemical, semiconductor, and energy companies during the past 20 years. Recently, he has helped lead the national effort on smart manufacturing and is cofounder of the Smart Manufacturing Leadership Coalition (https://smartmanufacturingcoalition.org/), which has over 40 members from university, industry, government, and nongovernment organizations.

**Jonathan P. How**

## ALEXANDRE BAYEN

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

*Alexandre:* I was trained at the Ecole Polytechnique in France, a very mathematical school, so when I started my Ph.D. work at Stanford and there was an opportunity to work on control of networks in the context of air-traffic management, I jumped right in. The mathematical frameworks we used for this work with my Ph.D. adviser, Prof. Claire Tomlin, were very exciting, and I started working in the field of control and optimization. While doing my Ph.D. with Claire, she introduced me to one of my other great mentors, Jean-Pierre Aubin, which led to a ten-year collaboration and ultimately to my first book with him and Patrick Saint-Pierre on viability theory, a field that I happily link today with Hamilton–Jacobi equations and traffic-flow modeling. This experience ultimately defined the area I am working in, at the intersection of control theory, optimization, mathematical modeling, partial differential equations, and numerical analysis.

**Q. What are some of your research interests?**

*Alexandre:* I am very interested in control of networks, in particular flow networks, that is, networks controlled by equations derived from physical constitutive laws, for example, partial differential equations. I am interested in the mathematical framework required to study them, which is quite exciting and sometimes really challenging for engineers to work on without the help of mathematicians. Within this field, I am particularly interested in the problem of data assimilation, a broad term used by various scientific communities for estimation and system identification, and specifically on the problem of integration of Lagrangian data into distributed-parameter system models. The specific application of this theory I am interested in is mobile sensing. In 2008, my group launched the first mobile app running on Rim and Symbian OSs to collect traffic data from GPS-enabled smartphones; of course, this was before the iPhone had a GPS or the Android existed.

Alex Bayen throws one of the passive floating sensors in the Sacramento River in Walnut Grove, California.

Today, this technology has become part of everyday life. Later, we launched other fun projects, for example the floating sensor network, a set of 100 floating units, equipped with propellers, smartphones, and sensors, which we routinely used in the Sacramento–San Joaquin delta and the San Francisco Bay in California. We also launched the iShake program, one of the first smartphone-based earthquake catchers, now used by seismologists. More recently, we started working with the Memory and Aging Center at UC San Francisco on the use of wearables to help Alzheimer's patients in their homes.

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

*Alexandre:* I teach a graduate course on control of distributed-parameters systems, which touches on my research interests, and gives students their first engineering approach to these distribute-parameter system problems. My favorite course, however, is an advanced undergraduate control course. It has a lab in which the students learn how to stabilize an inverted pendulum using simple control algorithms like proportional-integral-derivative control and Kalman filtering. My style of teaching is fairly European and has worked well with this material: derive every equation on the board to walk the students through all the steps one by one. I also like to illustrate the results with concrete

Alexandre on top of one of the Mobile Century test vehicles a few minutes before launching the Mobile Century experiment in Union City, California.

Alex, center, with the field experimental team of the Floating Sensor Network project in Walnut Grove, California.

examples; for example, this year I asked two students on their skateboards to try to move their combined center of gravity by pushing and pulling each other, in front of the class. First before explaining the controllability matrix $[B\ AB\ A^2B \ldots A^{n-1}\ B]$ and then once again afterwards, so they could understand why they could not do it.

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

***Alexandre:*** On the control-theory side, I think that there are a lot of opportunities in formalizing network control problems, in particular for flow networks (in discrete and continuous form). I believe that the theory to support control algorithms currently used in practice is pretty much in its infancy and does not scale well for practical problems. A lot of phenomena observed in these systems are nonlinear and pose very challenging problems. It is, in essence, the core of cyber-physical systems (CPS): making the C work with the P is the hard part because the C often only works on linear or simplified metaphors of the true P. It is always a difficult tradeoff to figure out the right balance between use of "generic" algorithms that apply to large classes of problems (and because of this might not offer guarantees of optimality or convergence, for instance), and "customized" algorithms that might work much better (but only apply to one specific system at a time). Also, the algorithms that work the best in practice and make a true difference to the world of practitioners are often at the intersection of multiple fields and hence do not necessarily fit in a specific subfield of control theory for which metrics of contributions are well established.

The 2013 graduation ceremony in the Greek Theater at UC Berkeley, with Alexandre hooding doctoral student Aude Hofleitner (EECS Ph.D., 2013).

**Q. You are the author of a book in the control field. What topics are covered in this book?**

***Alexandre:*** I am the coauthor of *Viability Theory, New Directions* with Jean-Pierre Aubin and Patrick Saint-Pierre. Among many things, the book sets up the framework for approaching optimal control problems, viability problems, and capturability problems based on set-valued analysis and differential inclusions. On the theoretical front, I think it is very exciting because it contains a lot of foundations to define capturability, viability, survivability problems, and numerous other concepts in a quite unique manner. It also builds the foundations to compute a new set of solutions for the Hamilton–Jacobi equations, in particular the viability solution. This has a lot of applications, especially in traffic engineering, that require generalizations of the famous viscosity solution. It is also the first book on viability theory to cover applications in robotics, population economics, finance, chaos theory, and many other domains. Working with Jean-Pierre Aubin on this book for many years was a quite unique experience and honor, so I also want to use this interview to acknowledge his scientific generosity and astounding vision for the field.

## Profile of Alexandre M. Bayen

- *Current position:* Liao-Cho Professor of Engineering (EECS and CEE), director of the Institute of Transportation Studies at the University of California, Berkeley.
- *Visiting and research positions:* Nanyang Technological University (NTU), Singapore; NASA Ames Research Center; Autonomous Navigation Laboratory at the Laboratoire de Recherches Balistiques et Aerodynamiques, France.
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- *IEEE Control Systems Society experience highlights:* general cochair, International Conference on Cyber Physical Systems (ICCPS), 2015; program cochair, ICCPS, 2014; member, Technical Committee on Distributed Parameter Systems, since 2011.
- *Notable awards:* Walter L. Huber Civil Engineering Research Prize, ASCE, 2014; Antonio Ruberti Young Researcher Prize, IEEE, 2013; Okawa Foundation Research Award, 2013; Best Application Paper Award, 9th IEEE CASE Conference, 2013; Presidential Early Career Award for Scientists and Engineers, The White House, 2010; NASA Top 10 Innovators on Water Sustainability, 2010; CAREER Award, National Science Foundation, 2009; TRANNY Award, California Transportation Foundation, 2009; Best of ITS Award, citation for "Best Innovating Practice," ITS World Congress, New York, 2008; Clean Technology Innovation Prize, Berkeley Center for Entrepreneurship and Technology, 2008; William F. Ballhaus Prize for Outstanding Doctoral Dissertation in Aeronautics, Stanford University, 2004.

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

*Alexandre:* I love piano music of the romantic era. I started playing the piano when I was five years old, and while an academic career does not allow much time for concert going, which I used to do a lot when I was in college, I get a lot of joy from teaching my daughter Myriam the piano. When my two other kids, Aaron and Leah, grow up, I have high hopes to play the Franz Liszt arrangement of the Racoczy March for eight hands (two pianos) with the three kids. I also collect memorabilia from the composer Franz Liszt, who was historically one of the first "rockstar-status" artists in the history of music and was the inspiration of a quite interesting and rich iconography. And when time permits, between two runs, I like Russian literature.

**Q. Thank you for your comments.**

*Alexandre:* You're welcome, and thank you for letting me share my research thoughts and interests with your audience.

## AARON D. AMES

**Q. What led to your interest in the control field?**

*Aaron:* It probably started with reading science fiction. I read every book I could get my hands on, most notably the works of Asimov, and these painted a picture of technology—and especially robots—that I found deeply compelling. During my undergraduate work, while studying mechanical engineering and mathematics, I started to see how math must underlie this idea of the future.

The deeper I got into my coursework, the more I wanted to understand and describe things in a fundamental way. I wanted to make robots do things that have never been done before while also completely describing this behavior. When I was doing my first proofs, I was building robots in a "robots lab," which was just a room they let me use in the basement where I set up a two-degree-of-freedom robot controlled by salvaged computers that I "Frankensteined" together. It was the confluence of interests in mathematics and robots that motivated me to pursue a Ph.D. in electrical engineering at the University of California (UC), Berkeley. I wanted to increase my theoretic understanding while, at the same time, making robots do the things dreamed of in science fiction.

> **It was the confluence of interests in mathematics and robots that motivated me to pursue a Ph.D. in electrical engineering.**

When I began graduate school at Berkeley, I realized how little I knew. Taking introductory classes in control and mathematics from the best in the field—Shankar Sastry in electrical engineering and Mariusz Wodzicki in mathematics—opened a window to an entirely new world that I had to know more about. Fast forward five years, much of which was spent taking every mathematics class available and spending much of my time in the mathematics library at Berkeley, I finally felt like I had the depth of

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