In this issue of *IEEE Control Systems Magazine* (*CSM*), we speak with Francis J. (Frank) Doyle III who is the Mellichamp Professor of Process Control in the Department of Chemical Engineering at the University of California, Santa Barbara (UCSB). Prior to his appointment at UCSB, he held faculty appointments at Purdue University and the University of Delaware and held visiting positions at DuPont, Weyerhaeuser, and the University of Stuttgart. He has coauthored four books and over 400 journal and conference papers and is a Fellow of IEEE, IFAC, AIMBE, and AAAS. He recently completed a two-year term as the vice president for Publication Activities of the IEEE Control Systems Society.

Next, we speak with Alberto Bemporad who is a full professor in control systems at the IMT Institute for Advanced Studies Lucca, where he has recently been appointed director. He was formerly an associate professor at the University of Trento in the Department of Mechanical and Structural Engineering and at the University of Siena in the Department of Information Engineering and postdoctoral fellow at ETH Zurich in the Automatic Control Laboratory. He has coauthored three books, more than 250 papers, and various Matlab toolboxes for model predictive control design, including the Model Predictive Control Toolbox (The Mathworks, Inc.) and the Hybrid Toolbox. He is a Fellow of the IEEE.

We speak with Changyun Wen who is a professor in the School of Electrical and Electronic Engineering at Nanyang Technological University, Singapore. He has coauthored three books and more than 260 journal and conference papers, primarily in robust adaptive control, decentralized adaptive control, and backstepping-based adaptive control for both linear and nonlinear systems. He is a Fellow of IEEE.

We also speak with Erik I. Verriest, who is a professor in the School of Electrical and Computer Engineering at the Georgia Institute of Technology. He has coedited a book and written over 250 journal and conference papers, and is a Fellow of IEEE and a Member of the Royal Flemish Academy of Sciences and Arts of Belgium (elected in 2012).

We conclude with Petros Voulgaris who is a professor in the Coordinated Science Laboratory and the Department of Aerospace Engineering at the University of Illinois at Urbana-Champaign (UIUC), where he is also an affiliate in the Department of Electrical and Computer Engineering. He has written over 100 journal and conference papers and is a Fellow of IEEE.

FRANCIS J. DOYLE III

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

Frank: My early exposure to the control field happened in an undergraduate (elective) course at Princeton in which I was enrolled in my senior year. The text for the class was the (then) new book by George Stephanopoulos, and I remember being fascinated by principles of feedback and the mathematical analysis of dynamic systems. After my senior year, I studied for a year at the University of Cambridge, took courses in the control engineering department, and did a research thesis on a novel sensor for feedback control of a spark ignition engine. Following that year in England, I started my Ph.D. studies with Manfred Morari at the California Institute of Technology (Caltech) on the topic of robust nonlinear control of chemical reactors using differential geometric control techniques. The work was both highly mathematical (nonlinear control design, traveling wave theory for fixed bed reactors) but was also very applied (targeted toward a fixed bed methanation reactor). The control and dynamics research atmosphere at Caltech was exciting in those days, with John Doyle and Manfred leading the programs, along with Richard Murray, who started as a faculty member while I was graduating.

At this point, my career took a very interesting turn. I accepted a visiting scientist position at the DuPont Company (effectively a one-year postdoctoral scholar position) and worked on three different projects: i) advanced control design for a distillation column that was located at a plant in Texas, ii) process model identification and control using Volterra series (which led to a book coauthored with Tunde Ogunnaike and Ron Pearson, published by Springer), and iii) bio-inspired controller design based on

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principles underlying the baroreceptor vagal reflex (beat-to-beat regulation of blood pressure).

That began a career-long fascination with biological control principles, and today all the students in my research group work on either projects in systems biology or biomedical control.

I would characterize my teaching style as "varied" in the sense that I do not rely on one single modality for conveying information.

Q. What are some of your research interests?

Frank: My research group works in the field of systems biology, bringing systems-theoretic approaches to the modeling and analysis of complex biophysical systems. The biophysical networks we study range from gene regulatory networks to protein signaling networks to intercellular coupling. We have a particular interest in periodic phenomena in nature, such as circadian timekeeping, and bring novel analysis and simulation methods to the treatment of stochastic coupled oscillators. In the medical arena, we work closely with medical partners for clinical trials and with biologists for experimental studies. We have a large research effort in the area of diabetes, designing an artificial pancreas for subjects with type 1 diabetes and working to identify novel drug targets for insulin resistance underlying type 2 diabetes. Larger collaborative efforts include modeling tauopathies in Alzheimer's disease and biomarker discovery for post-traumatic stress disorder.

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

Frank: I have taught a number of courses through the years related to control. The course I have taught most often is a required senior-level class on process dynamics and control. I also teach an elective course to the seniors at the University of California, Santa Barbara (UCSB) that includes more advanced topics (e.g., multivariable control) and has an experimental laboratory component. Through the years, at Purdue, Delaware, and UCSB, I have also offered graduate control courses on robust control, nonlinear control, and model predictive control.

At UCSB, I also teach an elective course to graduate students on engineering methods in systems biology. This is a really exciting class because of the dynamic nature of the field. It is nearly impossible to use a single text for the class, so I rely instead on current articles in the literature. I have offered this class via distance education to industrial participants in some years. The students complete a detailed course project at the end of the course, which basically answers the question: what did I learn about this biological system by using systems engineering methods?

I would characterize my teaching style as "varied" in the sense that I do not rely on one single modality for conveying information. I try to mix up traditional verbal lectures, with visuals (PowerPoint, movies, etc.), with equations, with schematics, or with words—and many combinations of these methods for one single topic. I audited a transformative course as a young professor at Purdue, titled "Teaching Engineering" by Phil Wankat and Frank Oreovicz, where I learned about "diversity" in the classroom in terms of learning styles. Since that time, I have strived to convey complex ideas in myriad of different manners, attempting to engage as many of the students as possible. This approach to teaching has proven to be very effective and rewarding.

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

Frank: I see two very interesting directions for our community. One direction is molecular scale phenomena. Whether it is in the field of biology or materials or other areas, there are a myriad of challenging synthesis and analysis problems at the scale of individual molecules. New techniques for measurement, as well as manipulation, allow control at unprecedented scales. There are

Frank Doyle in Ireland with his family (photo courtesy of F. Doyle, Jr.).

Profile of Francis J. Doyle III

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- *Notable awards:* Computing in Chemical Engineering Award (AIChE CAST Division), 2005; IEEE Fellow, 2008; AIMBE Fellow, 2009; IFAC Fellow, 2009; IEEE Control Systems Society Distinguished Member Award, 2009; AAAS Fellow, 2009; Zaborszky Distinguished Lectureship, Washington University, 2010; ASEE Lectureship Award, Chemical Engineering Division, 2010; Harry Nicholson Distinguished Lectureship in Control, Sheffield University, 2010; David Himmelblau Award (AIChE CAST Division), 2011; IFAC Best Survey Paper Award, *Journal of Process Control*, 2008–2011; Richard S.H. Mah Lectureship, Northwestern University, 2012.

challenging problems in modeling these systems, fascinating problems in dynamic behavior, and intriguing opportunities for control design. For example, in biological systems, the challenge of "synthetic biology" remains elusive, namely the design of complex circuits that can exhibit robust performance, using biological building blocks.

At the other end of the spectrum, in some sense, are problems of network systems, which is the second interesting direction for our community. There are a wide spectrum of control and performance analysis issues that arise in the dynamics of networks used in application areas such as communications, computers, transportation, manufacturing, Web ranking and aggregation, social networks, biology, power systems, and economics. In fact, in my capacity as VP Publication Activities, I have worked to successfully develop a new journal from the IEEE Control Systems Society, *IEEE Transactions on Control of Network Systems*, which will be launched in 2014.

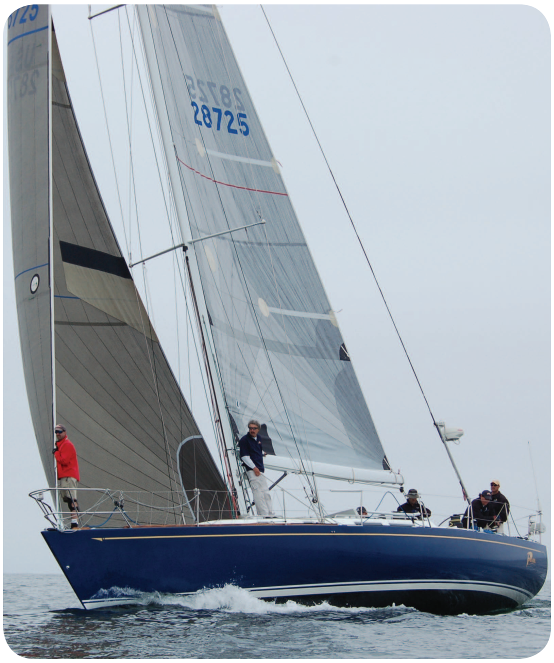
Q. You are the author of four books in the control field. What topics do these books cover?

Frank: The first book is a workbook of process modeling and control exercises, which was meant to accompany a conventional textbook. At Purdue and subsequently at Delaware and UCSB, we developed computer modules in Matlab and Simulink referred to as "Process Control Modules" (PCM) that emulated real-time control systems. These modules were the basis of a computer laboratory to enhance the conventional lecture experience and included modules for a heated furnace and a binary distillation column. The second book was titled *The Identification and Control of Process Systems Using Volterra Models* and arose from my work at DuPont on nonlinear modeling and control. The third book was the product of an international study with contributions from a team of colleagues on the topic of systems biology. We traveled around the world benchmarking the research activities on this topic, and published a comprehensive review of our findings. The most recent textbook, *Process Dynamics and Control*, arose when the three authors of the original edition (Dale Seborg, Tom Edgar, and Duncan Mellichamp) invited me to join in a major revision for a new edition that included, among other things, new chapters on biosystems analysis and control. We also included an updated version of the PCMs, with new modules for a fermentor and a medical control problem (artificial pancreas). That was a very exciting book-writing project and continues to be a very fruitful collaborative endeavor with the coauthors.

Q. What are some of the administrative roles you have held at your university?

Frank: Presently, I am the director of the Institute for Collaborative Biotechnologies (ICB), which is an Army-funded research center that is comprised of 60 faculty from UCSB, Caltech, and Massachusetts Institute of Technology (MIT). We have been operational for ten years and were recently awarded a renewal for an additional five years with an annual budget of approximately US$14 million. The ICB focuses on biologically inspired routes to material synthesis, control strategies, and sensor design. The ICB investigates the functioning of high-performance biological networks and uses these insights to design powerful new technologies for scalable and robust mobile ad hoc networking, reliable robotic flight, and locomotion and control of autonomous vehicle networks. We investigate opinion dynamics and models of persuasion in social networks to better understand and predict their evolution.

In addition, I have been serving as the associate dean for research in the College of Engineering at UCSB since 2008. In that role I am responsible for leading a number of initiatives in the field of bioengineering, including the development of a new academic program for bioengineering. As part of that initiative, and supported by the ICB research activities, I have been designing a new bioengineering building at UCSB. Finally, I have helped to establish a new Translational Medical Research Laboratory at UCSB, to bridge world-class medical doctors at hospitals and clinics in Santa Barbara with the top-ranked research programs in science and engineering at UCSB.



Frank Doyle racing on the sailboat *Prevail* (Frank is in the red jacket).

My favorite sport for competition is sailboat racing.

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

Frank: Outside of my professional career, I enjoy spending time with my wife, Diana, and our three kids, Sara (17), Brianna (15), and Frankie (13). We enjoy a variety of outdoor activities, including hiking, downhill skiing, soccer, and sailing. I am an avid soccer referee and have officiated approximately 300 matches. I recently completed my national referee certification and had the chance to officiate at the California State Championships in 2012. My favorite sport for competition is sailboat racing, and I have been a sailing enthusiast since I was about five years old. I raced on the varsity team in college and continued to race in California, first as a graduate student in the 1980s and then as a professor since 2002. I presently crew on a 52-ft sailboat based in Santa Barbara, and our team has competed in regattas from Los Angeles to Cabo Mexico and from San Francisco to Santa Barbara, and we recently completed the 2012 Transpac Regatta (2250 mi from Los Angeles to Honolulu), finishing second in our division.

Q. Thank you for your comments.

Frank: It has been my pleasure—thanks for inviting me to participate in this interview.

ALBERTO BEMPORAD

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

Alberto: I was perhaps an atypical child in that I enjoyed building my own toys rather than playing with them, considering math and numbers playthings in their own right. This inclination then led to a passion for repairing bikes (something I still enjoy today) and soldering simple electrical circuits for my own amusing applications. I was certainly atypical in that I always got great pleasure in doing my math homework as well! By the time I was a teen, this tradition was well consolidated, as I was happier programming my own video games in BASIC on my home computer than actually playing them. This aptitude undoubtedly paved the way to my decision to enroll in electrical engineering (EE) at college. Despite also being very drawn to math and physics, I was particularly attracted by a fourth year course in nonlinear control and robotics in the EE program, which helped to secure my decision. As I quickly progressed with my courses and exams, receiving very high marks allowed me to win helpful grants every year that I studied, and I discovered that my favorite subject was linear algebra, being fascinated by its mathematical beauty and rigor. To this day, the final exam for this course is my favorite of all time. As I later went on to take courses in electrotechnics, mechanics, and hydraulics, solid mechanics and theory of structures, and electromagnetic fields, what struck me the most was the multiple analogies all of these fields had in common, like the fact you can model complex mechanical or hydraulic systems as equivalent electrical circuits and that theorems

Alberto Bemporad, director and professor of control systems at IMT Institute for Advanced Studies Lucca, Italy.

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