In this issue of *IEEE Control Systems Magazine* (*CSM*) we speak with Enrique Zuazua, research professor at the Basque Foundation for Science, Ikerbasque, in Bilbao, Spain, and research director of the Basque Center for Applied Mathematics. He is the editor in chief of *ESAIM: Control, Optimization, and Calculus of Variations* and an associate editor of several journals in the systems and control field. His research interests encompass a wide range of problems in applied mathematics, including diffusion, waves and fluid-structure interaction, and flow control.

We also speak with Dragan Nesic, professor in the Department of Electrical and Electronic Engineering at the University of Melbourne, Australia. Dragan is a Fellow of the IEEE, a Fellow of the Institution of Engineers Australia (IEAust), a Humboldt Fellow, and an Australian Professorial Fellow, and he currently holds a Future Fellowship funded by the Australian Research Council. He has a long history of service to the CSS, both as an associate editor and as a member of conference organizing committees. His research interests include topics in nonlinear, sampled-data, and networked control systems.

ENRIQUE ZUAZUA

Q. Can you please describe your educational background, especially how it led you to the systems and control field.

Enrique: I graduated in Bilbao, Basque Country, Spain, in 1984, where I received the best student prize. I then enrolled in the doctoral program of the Université Pierre et Marie Curie in Paris, where I developed my Ph.D. thesis under Prof. Alain Haraux (CNRS). In 1987 I received the Ph.D. from the University of the Basque Country, where I was awarded the prize of the Faculty of Sciences for the best thesis, and in 1988 I received the Ph.D. at Université Pierre et Marie Curie. My research was influenced by close collaboration with Prof. Jacques Louis Lions while writing the lectures notes for one of his classes. My research was supported by a fellowship of the Basque Government and an "Allocation de Recherche" of the Collège de France.

Jacques Louis Lions's guidance and inspiration led me to the field of systems and control. He was one of those mathematical "giants" born in the late 1920s. He was a mathematical analyst who understood the importance that computers would play in future research. He thus developed an enormous amount of deep analytical apparatus to solve partial differential equations (PDEs), first as the main models of mechanics and then as numerical analysis methods.

Prof. Lions was one of the main founders of the modern theory of control of PDEs. He was motivated by industrial and technological applications, and his research was strongly inspired by the most challenging issues of the second half of the 20th century. Because of this, his work has been doubly influential in mathematics and especially in applied mathematics, a discipline he contributed to in a significant manner. He received many honors and awards but, more importantly, he was admired and appreciated by his colleagues, former students, and collaborators. Prof. Lions sadly passed away on May 17, 2001.

Q. What positions have you held since you received your Ph.D.?

(From left) Enrique Zuazua, daughter Oihane, mother-in-law Blanca, daughter Ainara, mother María Pilar (passed away in 2010), wife Magaly, and brother Xabier.

Digital Object Identifier 10.1109/MCS.2011.941965
Date of publication: 16 September 2011

Enrique: From 1987 to 1990 I lectured at the University of the Basque Country and Universidad Autónoma de Madrid, and I was a postdoc at the Courant Institute of New York University. In 1990 I became a professor in applied mathematics at the Universidad Complutense in Madrid. In 2001 I moved to the Universidad Autónoma de Madrid, where I contributed to launching the Instituto de Ciencias Matemáticas (ICMAT). In September 2008 I was hired by the Basque Foundation for Science, Ikerbasque, in Bilbao, where I am a research professor and the research director of the newly launched Basque Center for Applied Mathematics (BCAM), which aims to develop research in applied mathematics, covering fundamental mathematical topics, and addressing R+D+I (research, development, and innovations) applications. Within BCAM I am the research leader of PDEs, numerics, and control.

Q. What are some of the current projects at BCAM?

Enrique: BCAM is an interdisciplinary research center on applied mathematics with a focus on interdisciplinary research in mathematics, training, attraction of talented scientists, and promotion of scientific and technological advances worldwide. BCAM is currently located in the Technology Park of Bizkaia, close to Bilbao.

The center is scientifically organized around research that covers various aspects of modern applied mathematics. The PDE line is devoted to the analysis of PDEs, the development of new numerical methods of approximation, and their control. The NET line is devoted to network design, analysis, and optimization. The MBMS line develops molecular computer simulation methods and research in mathematical biology. The CM research analyzes and develops fundamental methods for computational mathematics. We also carry out research in computational fluid mechanics, kinetics, quantum control, mathematical finance, calculus of variations, and elasticity theory. BCAM has also developed links with industry and leading R&D companies.

My main focus has been the study of controllability properties of PDEs and numerical approximation schemes.

Q. What kinds of research problems have you focused on? What are some of the overarching themes of your work?

Enrique: My fields of expertise cover various aspects of PDEs, systems control, and numerical analysis. These interconnected fields have as their ultimate goal the modeling, analysis, computer simulation, and control and design of natural phenomena and engineering problems, including optimal shape design for aerodynamic applications. My main focus has been the study of controllability properties of PDEs and numerical approximation schemes. I have addressed both wave-like equations, which are reversible in time, and heat processes as a paradigm of strong time irreversibility, together with some mixed models such as those in thermoelasticity and fluid-structure interactions. In the last few years I have also investigated flow control problems, mainly motivated by aeronautics shape design. This work has led to other topics in PDE and numerical analysis, such as asymptotics for PDEs with singular and rapidly varying coefficients and numerical approximation schemes for Schrödinger equations.


Enrique Zuazua in his office at BCAM.

My current research interests focus on understanding the spurious high-frequency numerical solutions generated by the interaction of wave propagation and numerical discretization. There are some fundamental questions, for instance, such as dispersive properties, unique continuation, and control and inverse problems, that are well understood in the context of PDEs through the celebrated Strichartz and Carleman inequalities but which are unsolved and poorly understood for numerical approximation schemes. Of course, this has an immediate impact on systems and control issues. New analytical and numerical tools are required, and they need significant development beyond the frontiers of classical numerical analysis to incorporate ideas and tools from micro-local and harmonic analysis.

Q. What are some of the challenges of optimal aeronautical shape design in particular?

Enrique: Most of our effort in this field, in cooperation with Carlos Castro at the Polytechnic University of Madrid and Francisco Palacios at Stanford, is oriented toward developing efficient numerical algorithms for optimal control and optimal design in fluid mechanics when solutions

present singularities. There is plenty to be done to understand the effectiveness of fluid mechanics numerical solvers for solutions with singularities, the associated adjoint equations arising in control problems, and how all this should be combined to develop efficient optimization algorithms.

Ceremony for the reception of the Euskadi Prize for Science in 2007. (From left) Tontxu Campos (minister of education and research of the Basque Government), Enrique Zuazua, the *Lehendakari* Juan José Ibarretxe (president of the Basque Government), and Juan Rodés (chairman of the prize committee).

Q. What are some of the fundamental open problems relating to control and PDEs?

Enrique: Although there has been important progress made in PDE control, there is still plenty to be done. For instance, techniques that have been developed to deal with controllability issues for wave and heat equations, as paradigms of conservative time-reversible equations and smoothing and strongly irreversible ones, respectively, are of a different nature and hard to combine. Systems combining heat and wave equations as the equations of thermoelasticity are poorly understood. There is also plenty to be done at the numerical analysis level. Most of the existing results on the controllability of numerical approximation schemes have been proved using Fourier analysis techniques and therefore hold only for uniform grids and numerical meshes. The extension of these results to irregular and nonuniform grids that are most often required in real applications is a challenging open problem.

Q. Do you have a teaching philosophy? Any advice for young instructors?

Enrique: Teaching is rapidly changing in Europe, in the frame of the Bolonia systems. Teaching demands more and more dedication, and it is often hard to combine teaching activities with intense research. Definitely, one of the main challenges of young university faculty will be to combine these two activities efficiently and simultaneously. In any case, young fellows should always keep in mind that research needs a constant and continuous attitude and dedication. I believe that daily teaching has to be integrated with the enthusiasm that researchers apply when performing good research.

Q. Outside of work, what are your interests and hobbies?

Enrique: I live in the Basque Country, my home country. I moved here after spending almost 24 years abroad and in Madrid. In my spare time I enjoy hiking and sea sports as well as biking.

Being here is a privilege that allows me to enjoy speaking the Basque language, Euskara, while being part of the generous nature of the Basque people. Euskara is the ancestral language of the Basque people, who inhabit a region spanning an area in northeastern Spain and southwestern France. Euskara is spoken by 25% of Basques, about 600,000 people, in the geographical area. Basque is a minor language and is difficult to learn, which makes its survival and growth difficult in this age of globalization.

Q. Thank you for speaking with *CSM!*

Enrique: You're welcome.

DRAGAN NESIC

Q. Your undergraduate studies were in mechanical engineering at the University of Belgrade, in the former Yugoslavia. How did those studies influence you to specialize in systems and control?

Dragan: The faculty of mechanical engineering at the University of Belgrade was unique in the 1980s as it had a stream specializing in automatic control that I pursued in my undergraduate studies. The five-year degree consisted of coursework for four and a half years followed by a thesis completed in the final semester. The first two years were common to all students covering fundamental subjects such as mathematics, physics, mechanics, machine elements, and strength of materials, with students choosing a specialization in the third year.

I chose automatic control. As well as topics such as linear systems and nonlinear systems, the coursework included more practical aspects of modeling pneumatic and hydraulic components of control systems. I think it was great preparation for research; modeling and mathematical fundamentals of signals and systems were covered very thoroughly. I benefited from great teachers who were enthusiastic about the subject and inspired me to pursue further research in this area.

After I finished my degree, I was offered a position as a teaching assistant with the same group, and I taught and tutored subjects in linear and nonlinear systems, as well as digital control and modeling of hydraulic

Digital Object Identifier 10.1109/MCS.2011.941966
Date of publication: 16 September 2011