Rudolf Kalman as a Ph.D. Adviser

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My path to Rudolf Kalman (from now on "REK," as he is known to his students) was based on two lucky breaks. Mathematics undergraduates at the University of Buenos Aires are required to write theses on a subject of their choosing. With no clue as to topics, I decided to browse the library bookshelves—a quaint data exploration activity, which a few readers of this publication might once have been familiar with. This is how I found *Topics in Mathematical Systems Theory* (Kalman, Falb, and Arbib, McGraw Hill, New York, 1969). It was amazing to discover that it was possible to combine the mathematical beauty of algebra with applicable mathematics, and a thesis on automata and linear dynamical systems quickly followed.

The second lucky event came in early 1972 when my PDE instructor Héctor Fattorini happened to attend the Sanibel Island Conference on Mathematical Systems Theory, during which he learned that REK was moving from Stanford to Florida and was looking for graduate students. Fattorini told me, I contacted REK, and within a few days of graduating I landed in Gainesville.

REK's role as adviser was not ordinary. For me, his only direct guidance consisted of two items, 1) upon arrival to his Center for Mathematical Systems Theory, I found waiting for me a draft of Michel Fliess' thesis on noncommutative power series and formal languages, which he rightfully recognized as highly relevant to nonlinear realization theory, and 2) he described his ideas of viewing states as elements of the Zariski spectrum, which in turn generalizes Stone's representations of Boolean rings and Gelfand's C^*-algebra representations. This latter dual view of states as functionals ended up being central to my thesis, which also combined elements of Fliess' approach. Other than setting these initial conditions, he expected excellence in research and did not request any specific activities, with the exception of the occasional 15-minute ride to the airport to meet a visitor, which provided a fantastic opportunity to meet them, or to help in organizing and classifying the preprint and reprint collection of the Center, which helped me appreciate the breath and depth of the control theory field.

The main influence of REK as a Ph.D. advisor was as a role model. While giving his students absolute and complete freedom to pursue their interests, he inspired the pursuit of mathematical rigor, the choice of deep and foundational problems, clarity of exposition orally and in writing, and intellectual honesty, including the critical evaluation of one's own and others' work. Unfortunately, this latter practice, when emulated, added questionable value to his students' professional careers.

The field of control theory was being revolutionized in the mid 1970s, and the Center was as intellectually rich an environment as one could imagine. Sabbatical and postdoc long-term visitors included Roger Brockett, "Sammy" Eilenberg, Michel Fliess, Yves Rouchaleau, Malo Hautus, and Michael Heymann, and there were many shorter-term visitors, several of them repeat visitors, such as Steve Morse, Ed Kamen, Alberto Isidori, Sanjoy Mitter, Michael Hazewinkel, Jan Willems, Héctor Sussmann, and David Elliot. Much learning came from their seminar talks, which were always animated, with REK aggressively quizzing speakers and questioning basic assumptions (for his students, another learned trait that turned out to be not always well-appreciated).

No discussion of REK is complete without the obligatory "Kalman story." One evening, or rather early morning (2 a.m. or so) in about mid-1975, I left on REK's desk at the Center a note to the extent that bilinear I/O systems realization theory could be done in a manner analogous to the Fliess/Isidori approach to internally bilinear systems. This is something that REK was seriously interested in accomplishing, and my note was, in retrospect, too short and cryptic. At some uncivilized hour, approximately 6 or 7 a.m., I got an angry call from REK summoning me to the office ASAP to report on the "absolute nonsense" that I had written. (I was deep asleep when the call came, so my recollection is imperfect, but I believe recalling an agitated REK saying how disappointed he was with me, how incredible it was that a promising student could write such stupidity, and so forth. He is not exactly known for tact and diplomacy in his dealings with people, and students were no exemption.) My response was that I was going back to sleep, but I would be

Roger Brockett, Eduardo Sontag, Mike Warren, and Alberto Isidori, closely listening to a speaker at the Center for Mathematical System Theory at the University of Florida in 1974. Roger and Eduardo are sporting the latest fashions.

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glad to come to the Center around noon to discuss my note. By the time that I arrived, REK had calmed down somewhat, but he was still clearly upset with me. However, it took just five minutes at the blackboard for him to be convinced of my argument and to congratulate me on a good job. The point of the story is that just as he can be critical, REK is also even quicker to recognize when he is wrong. I was actually quite happy after this exchange!

My experience as REK's student was incredibly rewarding and useful and provided excellent preparation for my professional activities and my own role as an adviser. I owe him a deep gratitude for this.

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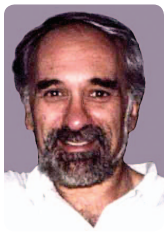

Eduardo D. Sontag is professor of mathematics at Rutgers University. His current research interests lie in systems molecular biology and control theory. He received his licenciado degree from the University of Buenos Aires in 1972, and the Ph.D. at the University of Florida, 1976, both in mathematics. Since 1977, he has been with the Department of Mathematics at Rutgers, The State University of New Jersey, where he is currently professor II of mathematics and a member of the Advisory Committee for the BioMap Institute for Quantitative Biology. He is also a member of the graduate faculties of the Department of Computer Science and of the Department of Electrical and Computer Engineering, the director of the Rutgers Center for Systems and Control, and a member of the Cancer Institute of New Jersey. He has authored over 400 journal and conference papers and book chapters as well as three books, including *Mathematical Control Theory: Deterministic Finite Dimensional Systems* (second edition, New York: Springer, 1998). His awards include the Reid Prize in Mathematics in 2001, the 2002 Hendrik W. Bode Lecture Prize from the IEEE, the 2002 Board of Trustees Award for Excellence in Research from Rutgers, and the 2005 Teacher/Scholar Award from Rutgers. He is a Fellow of the Society for Industrial and Applied Mathematics and of IEEE. He is on the editorial board of several journals. In addition, he is a cofounder and comanaging editor of the Springer journal *Mathematics of Control, Signals, and Systems*.

My Florida Days with Rudolf Kalman

YUTAKA YAMAMOTO

I received my Ph.D. in August 1978, under the supervision of Rudolf E. Kalman. It is inevitably not without some kind of emotion to realize that one is already way over the age of his mentor at the time of his own doctorate. On the occasion of this special issue, I would like to shed some light on his unique character manifested in his research.

My first encounter with Rudolf Kalman's work was his celebrated paper "On the General Theory of Control Systems," published in the proceedings of the first IFAC Congress in Moscow in 1960. I read this paper as part of a seminar course when I was a junior in Kyoto University. It was the second semester in the fall of 1971. The paper literally determined the course of my scientific life.

Until then, I was exposed only to classical control theory. Transfer functions, frequency response, Nyquist and Bode plots. Scattered results, with obvious relevance with practice, but not much of scientific excitement, and often not coherently given. This paper, instead, started with a rigorous definition of systems, introduced such notions as controllability and observability, and proved what can be deduced from them. Very transparent, yet highly suggestive in providing a fundamental view on reality.

I can still recall the surprise I felt on how control theory can be so mathematically elegant, yet simultaneously intrinsically relevant to reality. I was also deeply impressed with the truly fascinating touch with which the author related mathematical concepts to practical problems. Due to this paper, I decided to choose control theory as my major subject. Little did I know then that I was bound to become a student of the author himself.

In the early summer of 1973, my supervisor Prof. Sawaragi received a letter from Rudolf Kalman, soliciting a doctoral student. I immediately expressed my interest. Fortunately, I was admitted. I entered the mathematics department upon Rudolf Kalman's suggestion.

Yutaka Yamamoto, Efi Foufoula-Georgiou, and Tryphon Georgiou in a night out in Gainesville in 1972. (As usual, Yutaka sports a neat color-coordinated outfit.)

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