To Rudolf E. Kalman: A Personal Goodbye

TRYPHON T. GEORGIOU

I visited Prof. Rudolf Kalman on Sunday, June 12, 2016, three weeks before he passed away peacefully at his home in Gainesville, Florida, on July 2 (Figure 1). I had just learned of his deteriorating health, and I flew into Gainesville to see him for, as it turned out, one last time. He was undergoing chemotherapy at the time, and the signs were not encouraging. However, he was well cognizant that the end was near; he told me so and suggested that I would be writing his obituary very soon. Naturally, my reaction was to provide encouragement about the state of medicine and the abilities of our health-care professionals, to which he expressed doubts and joked. He brought up the fact that President Nixon declared "war on cancer" many years ago and then laughingly noted that although cancer had neither army nor generals, cancer is still around whereas Nixon is not.

We were joined by his wife Dina and sat in the family area at his house, in front of the glass porch with the swimming pool just outside. I lived in that house with my wife Efi for two summers, in 1981 and 1982, when I was in Gainesville as one of his doctoral students. At that time, Kalman would spend most of the summer in Switzerland, except for short periods when he would be back to oversee the Center for Mathematical System Theory and the progress of his students. So I knew that house well, and many memories flashed back. For more than two hours, Kalman rekindled some of those memories and reminisced about the "Center" and the people that came through. He talked about the early times when he, as a young scientist, was at the Massachusetts Institute of Technology, Columbia University, and the Research Institute for Advanced Studies, and then about science and academia, and then later on, about colleagues and friends. He asked me to convey greetings to Larry Marcus and Roberto Triggiani, with whom I told him I had lunch just the previous week. He inquired how recently I had been in touch with Bülent, Eduardo, Yutaka, and talked about my dear friend Pramod who, I explained, was about to join the University of California, Irvine (UCI), by coincidence at the same time as I was, with Pramod as vice chancellor for research and me as chancellor's professor. He expressed happiness about fate and how things turned out and offered a piece of information that was completely new to me, that at some point in the early 1970s he had seriously considered the possibility of moving to the young UCI campus before he decided to go to the University of Florida.

He spoke about the early days of the Kalman filter and how it was received by his contemporaries with a tinge of regret that, what came to be such an ubiquitous and enabling

FIGURE 1 Prof. Kalman (left) and Tryphon Georgiou at Kalman's home in Gainesville, Florida, June 12, 2016. (Photo courtesy of Dina Kalman.)

idea in science and engineering, encountered some resistance at the start. The path through science, mathematics, and engineering was very rewarding, and he spoke about his vision about the simplicity of design and laws. In particular, he noted that a proper definition of a canonical circuit is still absent, one that captures the simplicity of the essential structure, and suggested that this may eventually be possible following his insights on using invariant theory and the efforts to this end by my colleague and dear friend Malcolm Smith. He spoke about the structure of the physical laws, quantum mechanics, and the system-theoretic viewpoint.

Technical discussions were punctuated by his interest in details about my professional path over the past 20 or so years and about my family. He specifically asked about robust control and the gap metric, a topic that I had not had the chance to discuss with him before. He insisted on trying to understand the essence of the new geometric view of stability and robustness, and at that point, a piece of paper materialized, where I started scribbling down lines and boxes! His intellectual vitality and curiosity did not appear to have changed at all since the time I worked under his guidance between 1979 and 1983. I would be remiss if I do not recall his energy and excitement during similar moments back then as, for instance, when he came to my office one morning in 1981 with an idea as to what I should work on for my Ph.D. thesis, and the many exchanges after that, some inspiring and some contentious due to differing viewpoints on the nature of the problem.

Minnesota, where I spent almost 30 years of my life and where I built a significant portion of my academic career, was yet another place that Kalman considered briefly at some point. He joked about Minnesota winters and the rumor that Kolmogorov kept his number of doctoral students low by insisting they try swimming in similarly frigid

winter waters. He talked about science and ideas, then and now, and expressed a slight disappointment about the direction of academia where too much attention is now being paid to funding and fast output.

In closing, one thing that was very dear to his heart was the Center, and he specifically asked me to note the impact that it had on the people who passed through: students, post-doctoral fellows, and visitors. Indeed, this was a unique place where academic osmosis took place that shaped the lives and careers of many of his students and disciples.

The two hours went by very fast. I promised to visit again soon but was unable to do so since the end came quicker than expected. We were looking at each other all the way to the door and waved goodbye. I want to close by expressing my gratitude for the impact he has had in shaping my scientific self and strengthening my resolve to live a life in science striving to attain the academic standards that he aspired.

AUTHOR INFORMATION

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Kalman's Last Decade: Passive Network Synthesis

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The Art Nouveau splendor of Budapest's Hotel Gellért was the scene for a fascinating day of scientific discourse between an 80-year-old Rudolf Kalman and me on a warm Sunday in July 2010. The focal point of the discussions was the classical theory of passive network synthesis—a beautiful subject that reached its zenith around 1960, only to decline steadily thereafter as an active research interest, and yet a subject that still raises many deep and intriguing questions. Widening conversations and a special session at the Mathematical Theory of Networks and Systems conference in the following days led the late Uwe Helmke to organize and host a workshop on network synthesis in September of that year in Würzburg (see Figures 1 and 2), which initiated an inspirational series of meetings that has alternated with Cambridge. What was the origin of Kalman's intense interest in this topic?

It was in 2004, while browsing his reprint collection, that Kalman was taken back to this subject that had fascinated him in his graduate student days at the Massachusetts Institute of Technology. The paper that caught his eye [1]—by the great pioneer of network synthesis R.M. Foster—contained intriguing claims that appeared to rest on the elaborate calculations of an unpublished master's thesis by Foster's last student E.L. Ladenheim [2]. Acquisition of the manuscript did not solve the mystery. The thesis is essentially a catalog of the 108 "generic" RLC networks with at most two reactive elements and at most three resistors. Formulas are given for the impedance parameters in terms of network parameters (straightforward) and vice versa (not at all straightforward). Crucially, no proofs are provided.

This chance encounter with Foster's paper turned into the major scientific interest of Kalman's last decade—one that would break the sequence of the previous three decades of research. This began in the mid 1970s with work on the partial realization problem of covariance sequences, moving on to econometrics and the Reiersol problem in the 1980s, and then to random sequences, volatility, and risk in financial markets in the 1990s. It was the apparently moribund subject of passive network synthesis that took Kalman still further back to one of his great contributions in the first decade of his research and to a fascination with algebraic invariant theory that arose in the second.

The surprising fact that led to our meeting in the Hotel Gellért in 2010 was that we both had, unknown to each other, spent several years studying the very same unpublished Ladenheim thesis, which until then had only one citation, the above-mentioned reference in [1]. An analysis of the Ladenheim catalog was a central part of the Ph.D. dissertation of my student Jason Zheng Jiang, which was published later in [3]. Our motivation—arising from the problem of efficient realization of passive mechanical impedances—was quite distinct from Kalman's. It is worthwhile to elucidate his motivation in more detail.

The first pillar of Kalman's interest in the Ladenheim catalog is explained in his own words, "The baby born from