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Bruce Francis: A Personal Tribute [Historical Perspectives]

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of our daughter Aparna. According to the doctors, she was due in October 1982, so when someone bashed up our car in a grocery parking lot in late September, I took the car in for repair. As luck would have it, my wife had to be taken to the hospital that same night. I called Bruce, who drove over and, after dropping him back at his place, I used his car to take my wife to the hospital and drive around for the next few days.

In 1984, Bruce made his final career move, back to his alma mater, the University of Toronto. He retired in 2011, one year ahead of schedule. With his manifold contributions to control theory, he remained a star attraction throughout.

Given that Bruce and I differed in age by just nine days, during the 1990s we began to plan how to celebrate our 50th birthdays together. By this time, my family and I had moved back to India, but e-mail was pervasive, and it was easy to make plans. We had agreed that we would celebrate our 50th birthdays in Bangalore, India, and our 60th birthdays in Toronto. Bruce dutifully came to Bangalore for the 50th birthday workshop in India and had a good time. Figure 1 shows us at the famous Halebeedu Temple near Bangalore. Unfortunately, during the early 2000s the symptoms of his Parkinson's disease began to manifest themselves. Bruce, with characteristic modesty, declined to have a celebration of his 60th birthday in 2007, even though his many friends and admirers were very keen on the celebration.

I was very glad to have had the opportunity to visit Bruce and Jingwen in November 2017, and Jingwen took a photo of us on the occasion. The photo shows that Bruce was very happy to see me (and vice versa, of course). Instead of sharing that photo, I would prefer to share a photo (Figure 2) taken on the banks of the San Antonio river during the 1983 Conference on Decision and Control, when we were both 36 years old. We looked ready to conquer the world, which Bruce most definitely did.

Were it not for Bruce's seminal contributions, I doubt that we would all be using the phrase "H-infinity control."

FIGURE 1 Bruce Francis (left) and Mathukumalli Vidyasagar at the famous Halebeedu temple, Karnataka, India, in January 1998.

FIGURE 2 Bruce Francis (left) and Mathukumalli Vidyasagar on the shores of the San Antonio River, at the 1983 IEEE Conference on Decision and Control.

Bruce was a scholar in the traditional mold and always insisted on absolute clarity and precision in both thought and exposition. He was a role model for many, including myself. From him I learned to aim higher in my research. The controls community will miss him very badly.

Some Personal Reminiscences About Bruce Allen Francis

TRYPHON T. GEORGIU and ALLEN R. TANNENBAUM

The purpose of this article is to pay tribute to a remarkable colleague who left an indelible mark on the birth and development of the modern theory of robust con-

trol and a lasting impact on our own lives and academic careers. We first met Bruce in the early 1980s and have shared wonderful, as well as testing, times together. Thus, we decided to share this space and join in providing personal memories and expressing our deep loss of our dearest friend, Prof. Bruce Allen Francis, of blessed memory.

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REMINISCES FROM ALLEN TANNENBAUM

I first met Bruce at the University of Waterloo in 1983. He was a guest of Sagar (Mathukumalli Vidyasagar). That was when I also met Abie Feintuch from Ben-Gurion University, who was working with Bruce on an H^∞ type theory for general, linear, time-varying systems using the results of William Arveson on nested algebra [1]. I spent a lot of time with Bruce that week, talking about control, mathematics, philosophy, and life. It really was the beginning of a wonderful lifelong friendship. Bruce at that time was very much engrossed with George Zames, working on H^∞ problems. In fact, it was Bruce who first formulated a constructive solution based on the H^∞/L^1 duality to the sensitivity minimization problem [2]. I had already been using Nevanlinna–Pick-type interpolation for the gain margin problem [3], and after a conversation with Bill Helton, Bruce and George Zames realized that this would provide a solution to H^∞ sensitivity minimization as well [4]. Bruce and I discussed the fact that the two problems may in fact be closely related, a result that was formulated and proven in the subsequent work of Pramod Khargonekar and me [5] using conformal mapping theory and non-Euclidean metrics.

I spent the 1985–1986 academic year in Montreal (McGill University) as a guest of George Zames. Bruce came to visit several times, and on occasions, we were joined by Tryphon. Bruce would stay with our family in Westmount. Our children, Manny and Sarah, loved him. Manny at the time was six years old, and it was Bruce who taught him (and actually the entire family) how to snow ski. Bruce was actually an excellent athlete: superb bicyclist, aerobic master, and runner. Bruce, John Doyle, and I (and sometimes Tryphon) would go to various gyms at conferences around the world to test and compare our strength [see Figure 1(a)]. Typically, Bruce and I would be roommates at these conferences. Bruce would always wear earplugs (to muffle my snoring).

In 1991–1992, the Institute for Mathematics and Its Applications (IMA) had a year of workshops dedicated to advances in the field of control. Bruce was a long-term visitor at IMA for that year. He had met Jingwen previously in Japan, and she came to visit him in Minneapolis. The rest is history. Jing and Bruce lived in the same building as my

family for about three months, and the families spent a lot of time together. Among Bruce's many talents was an ability to make spaghetti and a delicious sauce without spilling anything. After cooking, the kitchen was cleaner than before Bruce started preparing the meal! Bruce and Jing married soon after they returned to Toronto (where Bruce was a professor). They have a beautiful daughter Lian, who was Bruce's pride and joy and, in many ways, is a copy of him! During that period at IMA, Bruce and I spent some time completing a book that we were writing with John Doyle on feedback theory [6], as well as doing some joint work on sampled data systems.

We met a number of times over the years. I visited Bruce several times in Toronto (the last time in 2012), and Bruce visited Georgia Tech in 2005, where he gave a great talk on cyclic pursuit problems [8]. He was particularly interested in problems in curve shortening and the geometric heat equation [9] and the profound connections with the pursuit problems. Tryphon and I also spent quite a bit of time with Bruce [see Figure 1(c)] in India in 2007, when we celebrated Sagar's 60th birthday in Hyderabad, India.

In the fall of 2015, Bruce came to visit us in New York City. It was clear that his disease had progressed. At times, the body tremors were quite severe, and Bruce just had to lie down. Nevertheless, at other times, Bruce seemed almost normal. In fact, we enjoyed several long walks by the East River. Bruce was quite stoic about his situation and understood that only drastic action could hope to ameliorate his debilitating condition. This was the deep-brain stimulation procedure that he underwent several months later that apparently did not work as we had hoped. Bruce, as usual, was extremely strong, brave, and accepting of his situation. One of my fondest memories was seeing him play with our granddaughter Maya during the visit. She immediately took to Bruce. Toddlers have an instinctive feel for who is a good person, and Bruce was a very good person. That was the last time that I saw my friend.

REMINISCES FROM TRYPHON GEORGIU

I first met Bruce at the Fort Lauderdale 24th IEEE Conference on Decision and Control (CDC) in 1985. I introduced myself,

(a)

(b)

(c)

FIGURE 1 Images of Bruce Francis: (a) lifting, (b) laughing, and (c) reading.

but there was not much of a chance to talk, as we were in a large group. The next time, it was at the 25th CDC in Athens, in December 1986. He was chatting with Allen in the lobby of the Athenium Intercontinental Hotel, where the CDC was held. I walked up to them, and Allen introduced me. Bruce was kind and engaging. At the time, I was interested in periodic and sampled data control. The topic resonated with Bruce. We talked on the subject for about 20 minutes and then he invited me to visit him in Toronto, which I gladly accepted.

Earlier that day at the conference, Allen and I made plans to visit the ancient temple of Poseidon at Sounio, so we invited Bruce to join us. Sounio is the tip of a peninsula, a truly majestic place at sunset with Poseidon's temple overlooking the Aegean sea. We took some nice sunset pictures, as well as some silly ones, pretending to be modern Goliaths with the temple pillars. Those moments were the start of a deep friendship that continued to the end.

The following day, I suggested that we take my sister Eleni up on an offer to host a dinner at her house, which was nearby. Bruce and Allen agreed, and on the way, we roped in George Zames and John Doyle, who were happy to join us. It was a truly delightful evening.

I visited Bruce in Toronto shortly afterwards. I gave a seminar, and, on the spur of the moment, Bruce asked me to provide an impromptu "guest lecture" to his class. One cannot help but smile when remembering those early formative experiences and the nervousness I felt in lecturing without preparation in front of a colleague for whom I had such an immense respect. Later on that day, we began working on sampled-data control but ended up focusing on periodic control and gain-margin (before looking at the mix of continuous and discrete) in an H_∞ context, which seemed more difficult at the time. We scribbled a few things on the board and then I returned to Iowa. We spoke regularly on the phone after that, often daily. At some point, Bruce thought that we should begin writing a "draft in troff" (I was still using a typewriter) and volunteered to take a first shot and send it to me "via bitnet" (to which my reaction was "what's that?"). It was 1987. The paper was published a year later [10]. We had plans to write more, but for one reason or another, we never did.

Bruce visited me in Ames twice. Whenever Bruce was there, my wife Efi, Bruce, and I would go running in the morning. After work, we would go to the movies or a theater play, the only one in Ames at the time. Besides bitnet, troff, and his superb expository style, I learned a great deal from Bruce about life.

Bruce always had a quick retort and dry sense of humor [see Figure 1(b)]. Years later, when the announcement came about the new "Pope Francis," and I congratulated him, he

duly sent me his blessings. Bruce was keenly interested in understanding every detail in a paper and working everything out himself. In later years, I sent him a joint paper by Malcolm and myself on the "arrow of time" in feedback theory. We exchanged e-mails daily for a week while he dissected the various points, at one point e-mailing me, "I'm still stuck. You're going to regret giving me that paper..."

I saw Bruce at the 53rd CDC in Los Angeles. After his plenary lecture, we sat outside the hotel and talked about the past. His disease had progressed but was still under control. We spoke a few more times over the phone but did not see each other again. December 2014 was the last time I saw my friend.

CONCLUDING THOUGHTS

Bruce Francis had a profound impact in control theory and control engineering. He will always be remembered as one of the fathers of modern robust control. Besides his foundational work throughout the 1980s, his creativity continued on unabated until almost the end. From his early student days until the sunset of his life, Bruce produced a wealth of scholarly works that will inspire and educate future generations of control engineers and scientists. On a personal level, Bruce had a profound impact on our lives and careers, and for that we will be eternally grateful. Bruce was a scholar and a gentleman and, most importantly, a deeply caring and compassionate person. We deeply miss our dearest friend Bruce.

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