

Pravin Pratap Varaiya (1940–2022)

Prof. Pravin Pratap Varaiya, the Nortel Networks Distinguished Professor Emeritus at the University of California (UC), Berkeley, USA, and a towering figure in control and communications engineering, passed away due to a freak accident that cut short an active life of research and mentorship right till the end. He was born in Mumbai, India and did his B.E. in electrical engineering from the Victoria Jubilee Technical Institute in Mumbai. He obtained his M.S. in electrical engineering from UC Berkeley in 1962 and after a short stint with Bell Labs during 1962–63, resumed his Ph.D. at UC Berkeley, which he completed in 1966. In an unusual move, his alma mater immediately hired him as a member of its faculty and his subsequent career shows that the faith his teachers had in him was more than justified. He rapidly rose through the ranks to become a full professor in 1970, and barring visiting positions at the Federal University of Rio de Janeiro, Brazil (Fall 1970) and MIT, USA (January 1974–January 1975), remained with UC Berkeley throughout his life. This included a joint appointment with the Department of Economics during 1972–92. His long career spanned a vast spectrum of areas, both in breadth and depth, ranging from abstract theory to industrial practice. His Ph.D. thesis was on ‘Nonlinear programming and optimal control’ under the guidance of Lotfi Zadeh. An interesting spin-off was the pedagogical text *Notes on Optimization* that he wrote in 1972, which effortlessly walks the reader from the basics of optimization to optimal control, giving a unified view of both the static and the dynamic problems. His main research area remained control engineering, which informed his forays into other areas such as communication networks, information theory, transportation, power system, etc. in an essential way.

Varaiya’s work spanned every corner of control engineering. Beginning with classical deterministic control (which included its multi-agent variant, viz. differential games), he quickly moved on to the upcoming stochastic control where, through a decade or so, he made a lasting impact. In particular, jointly with his friend and colleague Eugene Wong and their students, he co-authored a series of works that brought the modern martingale calculus to bear upon control of both continuous and jump processes. By now, it has become the *de facto*

language of the field. He also initiated fresh activity in stochastic adaptive control, both the ‘self-tuning’ and ‘Markov bandit’ varieties, that went beyond the dormant classics and gave a major boost to the fields that have now developed into significant research areas. His book *Stochastic Systems: Estimation, Identification and Adaptive Control* with P. R. Kumar is a classic, and has been re-issued in the ‘Classics’ series of the Society for Industrial and Applied Mathematics (SIAM).



When industrial imperatives dictated the need to go beyond continuous variables to discrete or logical variables, Varaiya was quick to identify the immense importance and potential of the ‘discrete event systems’, and their sequel on the continuous–discrete interface, hybrid control, and went on to make major contributions to both. This also led to his long-standing collaboration with Alexander Kurzhanskii on certain computational issues that resulted in a definitive monograph.

In this respect, it is worthwhile to fall back upon an important aspect of Varaiya’s training. He did his graduate studies at the peak of the ‘system theory’ era. Rooted in circuit theory, the broad idea was to isolate the common principles of stability, control, interconnections, etc., underlying disparate fields in order to develop a common framework to think about diverse problems. Eventually, with its rapid growth, the subject got somewhat fragmented into multiple subdisciplines. Having been a student before that set in, he was trained in a wide range of techniques, from control of differential equations or random processes to finite automata and logic. This made it

easy for him to work in these interface areas, much to their benefit. One important offshoot was his introductory text with Edward Lee, *Structure and Interpretation of Signals and Systems*, which attempts to revive that unified culture and was the basis of a successful introductory course at UC Berkeley.

From stochastic control, he made a smooth transition to communication networks when the network revolution began. Beginning with control problems associated with communication networks, he went on to deal with multiple aspects of the field, such as resource allocation, pricing, and even the abstract end thereof represented by information theory, wherein he has his most cited work, joint with his student Andrea Goldsmith (now the Dean of Engineering and Applied Science at Princeton University). He also wrote a landmark book *High-Performance Communication Networks* with his former student, and, subsequently, colleague and long-standing collaborator and friend Jean Walrand. He led the important INDEX Project for studying consumer behaviour in communication networks and its policy implications.

He concurrently was leading on two other fronts. All these engagements remained with him throughout. One was power systems, where he brought to bear upon power system analysis sophisticated tools from dynamical systems such as stability, bifurcation and chaos, and made major contributions not only to mainstream issues such as swing dynamics, but also to pricing, a theme that has become dominant with the advent of smart grid. One important upshot of this work was the notion of ‘risk-limiting dispatch’.

In terms of scale, the biggest effort he was involved in was perhaps the PATH Project from the California Transportation Department, which he headed during a crucial period. It led to the first successful demonstration of platooning by autonomous vehicles on highways near San Diego in 1994, and the development of the now widely used sensor network for highways, which included the deployment of novel sensor technology as well as data analytics for sensor data.

Varaiya was also involved in urban economics, particularly rents and geographical issues. It also informed his work on pricing in communication networks and power systems.

PERSONAL NEWS

Despite being a modest man who kept a low profile in public, his talent and achievements did not go unnoticed. The major honours that came his way include Member of the National Academy of Engineering (1999) 'For contributions to the theory of systems and control', Fellow of the American Academy of Arts and Sciences (2006), IEEE Fellow (1980) 'For fundamental contributions to the theory and control of large-scale stochastic systems', IEEE Simon Ramo Medal (2022) 'For seminal contributions to the engineering, analysis, and design of complex energy, transportation, and communication systems', IEEE Intelligent Transportation Systems Lifetime Achievement Award (2018), Fellow of the International Federation of Automatic Control (2014), IEEE Intelligent Transportation Systems Outstanding Research Award (2009), Richard E. Bellman Control Heritage Award (2008) 'For pioneering contributions to stochastic control, hybrid systems and the unification of theories of control and computation', IEEE Control Systems Society Henrik W. Bode Lecture Prize (2005), and IEEE Control Systems Award

(2002) 'For outstanding contributions to stochastic and adaptive control and the unification of concepts from control and computer science'. He was a Miller Research Professor (July 1977–June 1978), and a Fellow of the John Simon Guggenheim Memorial Foundation (1971). He received honorary doctorates from three European universities. As the foregoing list indicates, he received every major honour in systems and control, and in transportation science.

He groomed a large number of students, many of whom excelled in their respective fields. These include, in addition to Andrea Goldsmith and Jean Walrand, the late Mark Davis of Imperial College, London, the late Ari Arapostathis of University of Texas at Austin, Rene Boel of University of Ghent, Venkat Anantharam of UC Berkeley, Eyad Abed of University of Maryland at College Park, Steven Low of Caltech, and Rahul Jain of University of Southern California. The present author was also fortunate to be his Ph.D. student.

Going beyond science and engineering, he was an exceptional human being, always gentle and caring towards his students, col-

leagues and friends alike. His benign presence was enough to dispel any ambient tensions. He was interested in diverse topics, was extremely well read in literature, arts, politics and social issues, and had a fund of knowledge well beyond his specialities. He took teaching very seriously and constantly pondered about ways to improve it, his text with Lee being a manifestation thereof. He not only thought about social and political issues, but actively participated in relevant activism, such as for human rights in Central America. He was as valued by his associates in this sphere as by his academic peers.

He is survived by his wife Ruth Kosh, a fellow activist whom he married in 1963.

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