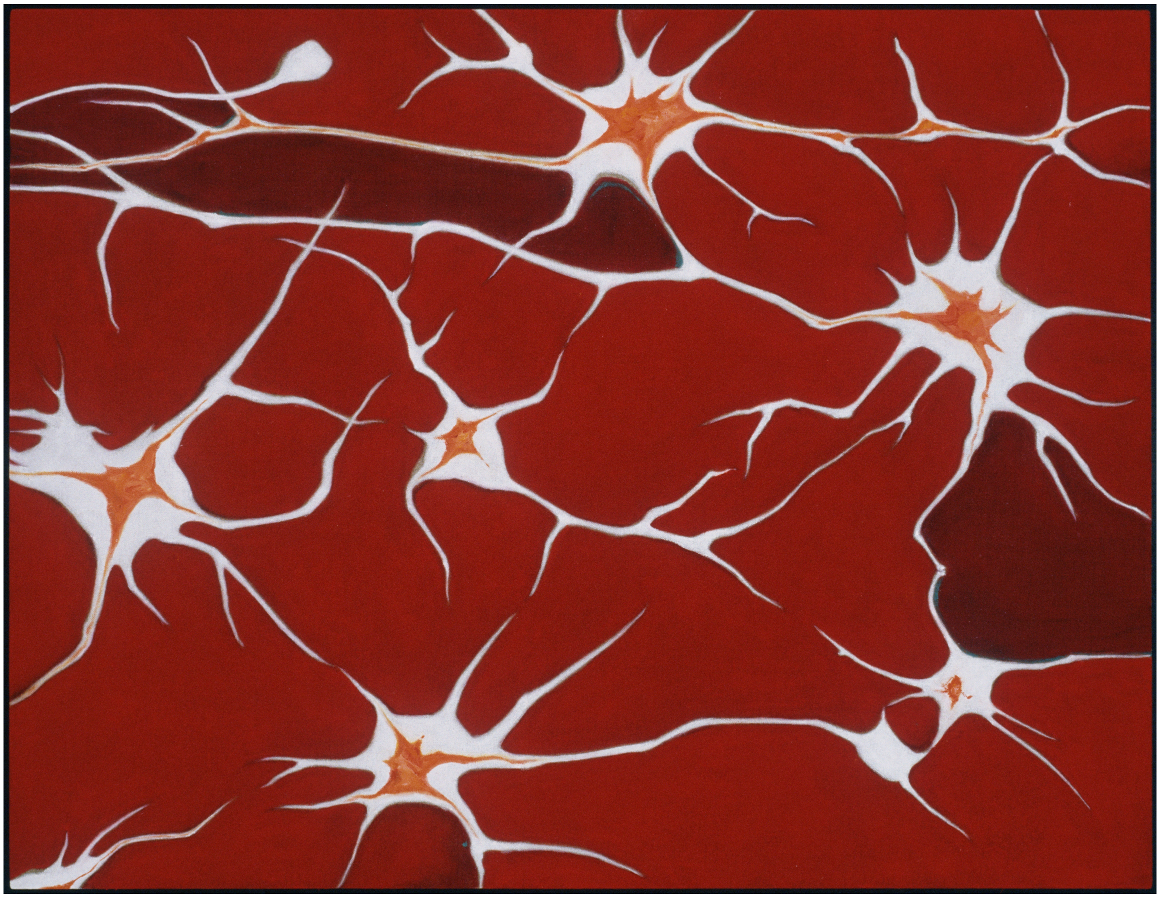


2015 Kailath Lecture & Colloquium
September 17 & 18
Clark Center, Stanford University

XXCth Birthday of Professor Thomas Kailath
(variously TK/Tom/Prof-Kailath to his students, collaborators and colleagues)
Why XXC?

Most of us are a stickler for accuracy in what we say and do; one of my very best students, for example, always adjusts his tips so that the digits of the final bill at restaurants add up to an odd number; allowing him to do a quick parity check of his monthly credit card statements :). With age and wisdom, however, we have learned that a precise statement is but only part of the story, and more often that not, it needs to be modulated.

Assuming that TK was born at a certain hour on June 7, 1935, we would quickly peg TK down as completing his 80th year sometime on June 7 2015; for those of us who are in the business of counting the exact hours, let us for now leave this uncertainty as an AWGN, and you can use your favorite models about human birth-hour distributions to estimate the mean and variance. But, I digress, as we will have plenty of opportunities at the Kailath Lecture and Colloquium to hash out whether AWGN is in fact a good prior.

Coming back to the issue at hand, I cannot help but dislike the number 80, and other than it being even, it is especially inadequate when it comes to qualifying anything about TK -- TK wouldn't be caught dead with a total count of 80, no matter what the context is. The man thinks in terms of (C)enturies and millions and billions, whether it is the number of theorems in his papers or awards or citations or ….. add your favorite measure ….. TK is not turning 80 by any means; he is just getting started! So how does one say 80 without saying it? Unfortunately, no one at our VP Joe Biden's office would return my call.

I decided to resort to the Internet instead, and found that one way out is to reverse what were considered "plain text" and "cipher text" in medieval Europe. The infallible Wikipedia tells us that on its introduction, the decimal system, along with the accompanying algorithms for division/multiplication etc., was treated as black magic of sorts, and as a means for secret communication. But the tables have turned and just like Super Bowl numbering, why not use by-now-cipher-like Roman Numerals instead of the same-old 80. A Google search quickly confirmed my suspicion that "LXXX" is the commonly used encoding for 80. But as TK is involved in all this, we want at least a "C"(entury) in it, and fortunately, the non-uniqueness of the roman number system (is it really Roman in origin? something makes me think that as with everything else, they borrowed it from another culture), came to my rescue leading to "XXC" instead.

Sincerely,

Vwani Roychowdhury

2015 Kailath Lecture & Colloquium
September 17 & 18
Clark Center, Stanford University

Thursday, September 17 2015

9:00am Introduction
Roychowdhury and Prof. Kailath

9:30am-11am Session 1 (Chair: Roychowdhury)
Bruckstein, Sayed, and Verghese

11am-11:30am Break

11:30am -12:30pm Session 2 (Chair: Varvarigou)
Jagadish and Kung

12:30pm – 1:30pm Lunch at Clark Cafeteria

1:30pm- 3:30pm Session 3 (Chair: Orlitsky)
Roychowdhury, Varvarigou, Ljung, and Bolsckei

3:30pm-4pm Break

4pm-5:30pm The Kailath Lecture
Introduction by: Prof. Eli Yablonovitch
Lecture by: Prof. Stanley Osher

Friday, September 17 2015

9:00-11am Session 4 (Chair KVS Hari)
Wax, Swindlehurst, Tong, Rao, Jover

11am-11:30am Break

11:30am -12:30pm Session 5 (Chair: Bolsckei)
Lev Ari and Dewilde

12:30pm – 1:30pm Lunch at Clark Cafeteria

1:30pm- 3:30pm Session 6 (Chair: Sayed)
Orlitsky, Hassibi, Bistritz and Vikalo

3:30pm-4pm Break

4pm-5:30pm Session 7 (Chair: Hari)
Levy, Verriest, and Entrepreneurship Panel

The Kailath Endowment

To mark the occasion of Professor Thomas Kailath's 70th birthday in June 2005, a group of his former students and associates joined to honor his influence by endowing a fund that will support an annual lecture, as well as, colloquia, workshops, and other research-enhancing activities.

Following the example of his remarkably wide ranging career the aim is to foster greater awareness of the power of mathematics-based disciplines of information theory, communication, computation, control and signal processing to address challenging problems in engineering, and increasingly, the physical, biological, and social sciences.

Founding Donors:

Jim Omura and the Gordon and Betty Moore Foundation
Debojoyti and Rupa Pal, Sailesh and Jaine Rao,
George Verghese and Ann Kailath, John and Assia Cioffi
Fang-Cheng Chang, Atul Sharan and Clearshape Technologies Inc.
Juan and Ken Ahonen-Jover, Vwani and Mary Roychowdhury
Yao-Ting Wang and Ying-Chih ChangGuanghan and Mei Xu
John and Elizabeth Kailath, Paul, Priya, and Ryan Kailath

Abbas and Suzanne El Gamal, Boaz and Aliza Porat,
Arogyaswami and Nirmala Paulraj, Joice DeBolt,
Joohwan and Eunmi Chun, Sun Yuan and Suwei Kung.

The Kailath Lecturers

2005	Prof. Robert Gallager, MIT
2006	Prof. Jacob Ziv, The Technion, Haifa
2007	Prof. David Forney, MIT
2008	Prof. Rudolf Kalman, ETH, Zurich
2009	Dr. Andrew Viterbi, The Viterbi Group
2010	Prof. Leonard Kleinrock, UCLA
2011	Dr. Irwin Jacobs, Qualcomm
2013	Prof. Elwyn Berlekamp , UC Berkeley
2014	Prof. Donald Knuth, Stanford
2015	Prof. Stanley Osher, UCLA

website: http://kailathlecture.stanford.edu

The 2015 Kailath Lecture and Colloquium

September 17 – 18, 2015 James H. Clark Center

318 Campus Drive West, Stanford University, CA 94305

Program details are posted on http://kailathlecture.stanford.edu/

Professor Stanley Osher
Professor of Mathematics, Computer Science,
Electrical Engineering and
Chemical and Biomolecular Engineering,
University of California, Los Angeles
Director of Special Projects,
Institute for Pure and Applied Mathematics (IPAM)

Title: What Mathematical Algorithms Can Do for the Real (and Even Fake) World

Abstract: When I entered the Courant Institute at NYU in 1962, applied mathematicians used techniques such as asymptotic analysis, special functions, and separation of variables. The language was partial differential equations, functional analysis and perhaps complex analysis. Numerical analysis was just emerging from the shadows and many regarded it as the last refuge of scoundrels. The notion that I could have a research career based on devising algorithms that would be widely used in computer programs with applications ranging from supersonic flow to image processing to computer graphics to sparse recovery to chip design would have been as surprising to me as hearing that people using my algorithms would win academy awards.

In this talk I will try to give a personal overview of the role of mathematics in designing algorithms that domain scientists find useful, and how new applications emerge serendipitously.

Very Brief Bio:

Stanley Osher is a Professor of Mathematics, Computer Science, Electrical Engineering and Chemical and Biomolecular Engineering at UCLA. He is also Director of Special Projects at UCLA's NSF-funded Institute for Pure and Applied Mathematics. He received his MS and Ph.D. degrees from the Courant Institute at NYU. His orbit was: Brookhaven National Laboratory, U.C. Berkeley, SUNY Stony Brook, then UCLA in 1977.

Among the Honors:

In 2014 he received the Carl Friedrich Gauss Prize from the International Mathematics Union. This is regarded as the highest prize in Applied Mathematics. He gave the John von Neumann lecture at the SIAM 2013 annual meeting and a one hour plenary address at the 2010 International Congress of Mathematicians. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences, a Thompson-Reuters top 1% cited researcher in Mathematics and Computer Science with an h index of 100 and an average of more than one new citation per hour in recent years. He is also an inaugural SIAM and AMS fellow, has received two honorary degrees, several SIAM, ICIAM and other prizes, and co-founded three fairly successful companies.

From Ants to A(ge)nts

Alfred M Bruckstein
Ollendorff Professor of Science
Technion, IIT, Haifa Israel

It was said long ago:

"Go to the ant, thou sluggard; consider her ways, and be wise:
which having no guide, overseer, or ruler,
Provideth her meat in the summer, and gathereth her food in the harvest."
(King James Version of The Bible, Proverbs 6:6-8)

...and we do go to the ants to borrow ideas on how to design systems composed of many simple, autonomous ant-like agents (or a(ge)nts), which must carry out their tasks by interacting in clever ways. Such systems are distributed and decentralized, like the ants "having no guide, overseer or ruler", and, to accomplish their missions, the agents' interactions should lead to various types of desired collective behaviors.

The "local rules of interaction" for swarms of identical, anonymous, oblivious agents that lack means of direct communication but can detect the current presence, and maybe even past traces of their fellows in their neighborhood due to pheromones, must be simple motion commands, telling the agents where to go, given what they sense at their location in the environment. These rules may implement "attraction" to neighbors residing at the far limit of the sensing range, but "repulsion" by neighbors to close for comfort, or tendencies to move to areas where the pheromone, or some other chemical material's levels are higher, or lower than felt agents at their current location.

Many systems with swarms of identical and autonomous mobile agents were studied and proved to efficiently solve various tasks, such as cleaning
The environment, and foraging for food, patrolling a region and detecting invaders, and cooperatively searching for evading targets, or mapping an uncharted territory. The environments where swarms, or flocks, or hoards of autonomous "a(ge)nts" or "(ro)bots" are assumed to be acting vary, from physical outdoor terrains to
3-dimensional air-space, from built environments, to complex networks of chambers, connected in various ways by corridors forming grids and other types of interconnected, graph-modeled structures, from local area networks of interconnected computers to the entire Internet or some specific on-line social network.

The mathematics of analyzing multi-agent systems based on an amazing array of techniques borrowed from control theory, graph theory, linear algebra, geometry and linear and nonlinear dynamic systems theory, and the challenges in proving stability, resilience to faults and agent losses, and attacks by malicious agents, as well as in proving that the desired goal is indeed achieved are often formidable. Performance analysis, as well as bounds of the time of task completion and their dependence on the number of agents and their sensing range and capabilities, is available in relatively few cases, and people often resort to extensive simulations to test their proposed rules of local interactions and see the emerging global behavior and subsequently evaluate the performance of their proposals.

Several systems we analyzed using various mathematical tools will be presented in my talk, and the challenges encountered in their analysis will be discussed.
This area of research remains very active, there are many interesting open questions the mathematical challenges often being quite formidable.

Professor Alfred M. Bruckstein

Alfred M. Bruckstein, born in Transylvania, Romania, in 1954, received his BSc and MSc degrees at the Technion, Haifa, in 1976 and 1980, respectively and then earned a Ph.D. degree in Electrical Engineering in Stanford University, California in 1984, his advisor being Professor Thomas Kailath.

From October 1984 he has been with the Technion, where he now holds of the Ollendorff Chair in Science, in the Computer Science Department. His research interests are in Ants and Swarm Robotics, Signal and Image Processing, Image Analysis and Synthesis, Pattern Recognition, and various aspects of Applied Geometry. Professor Bruckstein authored and co-authored over one hundred and fifty journal papers in the fields of interest mentioned.

Professor Bruckstein held visiting positions at MIT, Groningen University in Holland, Stanford University, and TsingHua University in Beijing, China, Evry University and at CEREMADE, Dauphine University in Paris, France, and was a visiting Member of Technical Staff at Bell Laboratories at Murray Hill, from 1987 to 2000, working with Dr. Arun Netravali and several colleagues there on Image Processing and Computer Vision topics. Since 2009 he is also a Visiting Professor at the Nanyang Technological University in Singapore, at the School of Mathematical and Physical Sciences.

From 2002 till 2005 he served as the Dean of Technion's Graduate School, and from 2006-2011 as the Head of Technion's Excellence Program for Undergraduate Studies.

Professor Bruckstein is a member of the AMS, and MAA, and a SIAM Fellow for contributions to Signal Processing, Image Analysis, and Ant Robotics, and received SIAM's 2014 SIAG-Imaging Science Prize (with David Donoho and Michael Elad, for the paper "From Sparse Solutions of Systems of Equations to Sparse Modeling of Signals and Images")

Professor Bruckstein is happily married to Rita and they have one son, Ariel, with whom they wrote and illustrated a bestiary of imaginary animals of Ariel's invention called "The Knocktopus and His Friends", published by Panopticum Press in 2013. He also illustrated several books published by his late father Ludovic Bruckstein, in Romanian, Hebrew and French, and a collection of comical verse in Hebrew, by Professor Irad Yavne, entitled "Comical Relief", describing Academic Life in general, and at the Technion, in particular.

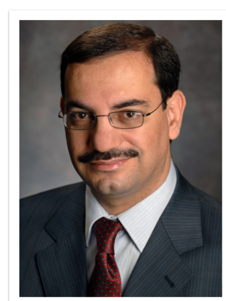
How Well Do We Learn Over Networks?

Ali H. Sayed, *UCLA*

Network science deals with issues related to the aggregation, processing, and diffusion of information over graphs. While interactions among agents can be studied from the perspective of cluster formations, degrees of connectivity, and small-world effects, it is the possibility of having agents interact dynamically with each other, and influence each other's behavior, that opens up a plethora of notable possibilities [1,2]. For example, examination of how local interactions influence global behavior can lead to a broader understanding of how localized interactions in the social sciences, life sciences, and system sciences influence the evolution of the respective networks. For long, system theory has focused on studying stand-alone dynamic systems with great success. Nowadays, rapid advances in the biological sciences, animal behavior studies, and in the neuroscience of the brain, are revealing the striking power of coordination among networked units. These discoveries are motivating deeper studies of information processing over graphs in various disciplines including signal processing, machine learning, optimization, and control.

In this presentation, we examine the learning behavior of adaptive networked agents over both strongly-connected and weakly-connected graphs and describe some interesting patterns of behavior on how information flows over graphs. In the strongly-connected case, all agents are able to learn the desired true state within the same accuracy level even when different agents are subjected to different noise conditions and to different levels of information. In contrast, in the weakly-connected case, a leader-follower relationship develops with some agents dictating the behavior of other agents regardless of the local information clues that are sensed by these other agents. The findings clarify how asymmetries in the exchange of data over graphs can make some agents totally dependent on other agents. This scenario arises, for example, from intruder attacks by malicious agents or from failures by critical links. The results help explain why strong-connectivity of the network topology, adaptation of the consultation policy, and clustering strategies are critical to equalize the learning abilities of all agents. The results also clarify how weak-connectivity reduces the effect of outliers on learning performance.

[1] A. H. Sayed, "Adaptive networks," *Proceedings of the IEEE*, vol. 102, no. 4, pp. 460–497, April 2014.
[2] A. H. Sayed, *Adaptation, Learning, and Optimization over Networks*, Foundations and Trends in Machine Learning, vol. 7, issue 4–5, pp. 311–801, NOW Publishers, Boston-Delft, 2014.



Bio: Ali H. Sayed is Distinguished Professor and former Chairman of Electrical Engineering at UCLA, where he directs the *UCLA Adaptive Systems Laboratory* (www.ee.ucla.edu/asl). An author of 460+ scholarly publications and six books, his research involves several areas including adaptation and learning, network science, information processing theories, and biologically-inspired designs. His work has been recognized with several awards including the 2014 Papoulis Award from the European Association for Signal Processing, the 2013 Meritorious Service Award, the 2012 Technical Achievement Award, and the 2005 Distinguished Lecturer from the IEEE Signal Processing Society, the 2005 Terman Award from the American Society for Engineering Education, the 2003 Kuwait Prize, and the 1996 IEEE Donald G. Fink Prize. He was awarded several Best Paper Awards from the IEEE (2002, 2005, 2012, 2014) and is a Fellow of both the IEEE and the American Association for the Advancement of Science; the publisher of the journal *Science.* He is recognized as a Highly-Cited Researcher by Thomson Reuters. He served before as Editor-in-Chief of the *IEEE Transactions on Signal Processing* (2003-2005). He has been elected to serve as President-Elect (2016,2017) and President (2018,2019) of the IEEE Signal Processing Society.

Physiological modeling and estimation for bedside informatics

George Verghese
EECS, MIT

Large volumes of high-resolution monitoring data are collected at the patient bedside in critical care units, and more modest amounts are obtained on the general wards and in ambulatory settings. These are augmented by nurse-verified measurements, lab results, imaging studies, and clinician notes. It is generally the case, however, that only intermittent and surface use is made of all this data.

At the time-scale of seconds to minutes to hours, mechanistic physiological models of the involved organ systems can be very helpful in summarizing, integrating, and making deeper sense of the data, to better guide diagnosis and therapy. (At longer time scales, the number of confounding factors can increase, complicating the picture.) A computer at the bedside, with some "knowledge" of physiology, could run computational models that draw on the measured multivariate data streams, and turn the data into patient-specific estimates of clinically relevant parameters. A key challenge is to develop meaningful but simple models that can run robustly and in real time at the bedside. I will describe some of our explorations of the challenges and possibilities of this "bedside informatics" paradigm, in the context of noninvasive cerebrovascular and cardiorespiratory monitoring.

These investigations have also led us to more general (and sometimes unkind) thoughts and speculations, for example on model reduction, Big Data, machine learning, evidence-based medicine, electronic medical records, and the future of physiology textbooks. I will share some of these.

Biography

George Verghese was born in Addis Ababa, Ethiopia in 1953, and studied through high school there. He received his BTech from the Indian Institute of Technology, Madras in 1974 and his MS from the State University of New York, Stony Brook in 1975, before driving cross-country to Stanford University for his doctoral work under Prof. Thomas Kailath. His formidable office mates during his Stanford years included Benjamin Friedlander, Sun-Yuan Kung, Bernard Levy and Augusto Cesar Gadelha Vieira, from and with whom he did much of his learning. He also had the opportunity to tag along when Prof. Kailath went on sabbatical to the Indian Institute of Science in Bangalore and (with Augusto as well) to the Katholieke Universiteit Leuven. This stay in Leuven brought George in contact with Prof. Patrick Dewilde and his student at the time, Paul Van Dooren (and also enabled wonderful weekend excursions in Augusto's car to a spectacular array of towns and cities, rich in history and museum collections). The various strands of learning during his graduate studies came together (the moment of inspiration was actually fifteen minutes into a seminar by Prof. Howard Rosenbrock!) in time for him to submit his PhD thesis at the end of 1978, and he has been at the Massachusetts Institute of Technology ever since.

At MIT, George is now the Henry Ellis Warren (1894) Professor of Electrical and Biomedical Engineering, in the Department of Electrical Engineering and Computer Science. He served as EECS Education Officer for five years, overseeing the staffing (100 professors, 120 TAs) and administration of 80–90 subjects at all levels, and helping to design and implement a major revision of the department's undergraduate curriculum. He was named a MacVicar Faculty Fellow at MIT for the period 2011-2021, for outstanding contributions to undergraduate education. George is also a Principal Investigator with MIT's Research Laboratory of Electronics (RLE). His research interests and publications are in the areas of dynamic systems, modeling, estimation, signal processing and control in various applications, initially in power systems and power electronics. For this work he was elected IEEE Fellow in 1998. Over the past dozen years, his research focus has shifted entirely to applications in biomedicine. He now co-directs the Computational Physiology and Clinical Inference Group in RLE, http://www.rle.mit.edu/cpci/

George has coauthored two advanced undergraduate textbooks: *Principles of Power Electronics* (with John Kassakian and Martin Schlecht, Addison Wesley 1991) and more recently *Signals, Systems and Inference* (with Alan Oppenheim, Pearson 2016). He has dedicated the latter book to his parents and to Prof. Kailath. In the Acknowledgements he writes (referring to Prof. Kailath): "He undoubtedly thought forty years ago that he was only signing on to be my doctoral thesis advisor, but fifteen years later found himself a part of my family." This alludes to George's wedding in 1989 to Ann Kailath, in Memorial Church at Stanford; they are the proud parents of Prof. Kailath's two grandchildren, Deia (Stanford Class of 2013) and Amaya. George's other close Stanford connection – and a valued sounding board for his biomedical research – is his physician-author brother Abraham, who is Professor for the Theory and Practice of Medicine at the medical school.

The Ethics of Big Data

H V Jagadish
Bernard A Galler Collegiate Professor of Electrical Engineering and Computer Science
University of Michigan

We live in the era of Big Data. Every aspect of our selves, our things, our environment, and our actions is now being recorded, quantified, linked, and analyzed. The potential benefits are great, from better healthcare to better government, not to mention better utilization of resources and hence economic benefit. Yet, there are growing privacy concerns, and we are seeing thoughtful warnings from people in the know about the brave new world without privacy. As these well-founded worries become more widespread, there will be a backlash, which can prevent us from realizing these benefits because of the fear of potential costs.

In light of these major trends, it is no longer acceptable for us, as technologists to claim merely to the creators of instruments that can be used both to provide benefits and to do harm depending on their manner of use, which we take no responsibility for. This is akin to the arms manufacturer who happily sells arms to any buyer and takes no responsibility for the use of these arms for good or for evil. We have a moral responsibility, and that is to be ethical.

Ethics are the fundamental ideas of right and wrong upon which our society is constructed. These shared notions are the foundation of civilization, and are often the basis for laws. But ethics go beyond laws. I don't snatch something I covet from someone weaker than me because I fear the law. But I wouldn't snatch even if I were in a situation where I could be assured I would not be caught: I would not do it because it is wrong, even if there were no fear of punishment. That is ethical action. If I orally promise you something, that may not be an enforceable legal contract, but ethics requires me to keep my word.

If we are to behave in an ethical way, a basic requirement is that we must know what ethics requires. We need some simple, fundamental axioms beginning from which we can reason our way through any specific situation. In the case of data, particularly personal data, these fundamental axioms are not clearly enunciated. This talk lays out my attempt and developing these ethical foundations for Big Data.

Additional information can be found at http://www.bigdatadiscuss.com

Biography

H. V. Jagadish is Bernard A Galler Collegiate Professor of Electrical Engineering and Computer Science, and Chief Scientist of the Michigan Institute for Data Science, at the University of Michigan in Ann Arbor. After earning his PhD from Stanford in 1985, he spent over a decade at AT&T Bell Laboratories in Murray Hill, N.J., eventually becoming head of AT&T Labs database research department at the Shannon Laboratory in Florham Park, N.J. He has also served as a Professor at the University of Illinois in Urbana-Champaign.

Professor Jagadish is well known for his broad-ranging research on information management, and has approximately 200 major papers and 37 patents. He is a fellow of the ACM ("The First Society in Computing") and serves on the board of the Computing Research Association. He has been an Associate Editor for the ACM Transactions on Database Systems (1992-1995), Program Chair of the ACM SIGMOD annual conference (1996), Program Chair of the ISMB conference (2005), a trustee of the VLDB (Very Large DataBase) foundation (2004-2009), Founding Editor-in-Chief of the Proceedings of the VLDB Endowment (since 2008), and Program Chair of the VLDB Conference (2014).

More information about him can be found at http://www.eecs.umich.edu/~jag

Thesis supervision

George Verghese has supervised 70 Masters theses at MIT, and the following 25 PhD theses:

1. Ignacio J. Perez-Arriaga, "Selective Modal Analysis, with Applications to Electric Power Systems," May 1981 (co-supervised with Prof. F.C. Schweppe). (Professor at the Universidad Pontificia Comillas, Madrid; Member of the Royal Spanish Academy of Engineers; IEEE Fellow; Visiting Professor at MIT.)

2. John P. Greschak, "Reconstructing Convex Sets," January 1985. (Independent researcher, polytempic music.)

3. Ryan R. Kim, "Analysis of Multiple Wavelength Chromatographic Data," May 1985 (Mechanical Engineering).

4. Xi-Cheng Lou, "An Algebraic Approach to Analysis and Control of Time Scales in Linear Systems," September 1985 (co-supervised with Prof. A.S. Willsky). (Professor in the Information Systems and Operations Management Department, California State University, San Marcos.)

5. Malik Elbuluk, "Resonant Converters: Topologies, Dynamic Models and Control," September 1986 (co-supervised with Prof. J.G.Kassakian). (Professor in the ECE Department, University of Akron.)

6. Seth R. Sanders, "Nonlinear Control of Switching Power Converters," January 1989. (Professor in the EECS Department, University of California, Berkeley; IEEE Fellow.)

7. W. Clem Karl, "Reconstructing Objects from Projections," January 1991. (Professor in the ECE and BME Departments, Boston University; IEEE Fellow; Editor-in-Chief of the IEEE Transactions on Image Processing.)

8. Miguel Vélez-Reyes, "Decomposed Algorithms for Parameter Estimation," September 1992. (Distinguished Professor and Chair, ECE Department, University of Texas at El Paso.)

9. Aleksandar M. Stankovic, "Random Pulse Modulation with Applications to Power Electronic Converters," February 1993. (Alvin H. Howell Professor in the ECE Department, Tufts University; IEEE Fellow.)

10. Rami S. Mangoubi, "Robust Estimation and Failure Detection," January 1995 (Aero & Astro. Engineering, co-supervised with Dr. Brent Appleby, Draper). (Principal Investigator at Draper Laboratories.)

11. Ganesh Ramaswamy, "Modal Structures and Model Reduction, with Application to Power System Equivalents," May 1995. (Was Manager, Conversational Biometrics, IBM's T.J. Watson Research Center. Deceased.)

12. Christoforos Hadjicostis, "Coding Approaches to Fault Tolerance in Dynamic Systems," August 1999. (Was tenured Associate Professor at the University of Illinois, Urbana-Champaign; now Professor and Dean, School of Engineering, University of Cyprus.)

13. Chalee Asavathiratham, "The Influence Model: A Tractable Representation for the Dynamics of Networked Markov Chains," October 2000. (WorldQuant, Bangkok.)

14. Matthew Secor, "Geometric Modeling and Analysis of Dynamic Resource Allocation Mechanisms," December 2000. (Was with Laurel Networks, now with Google.)

15. Babak Ayazifar, "Graph Spectra and Modal Dynamics of Oscillatory Networks," October 2002. (Teaching Professor in the EECS Department, University of California, Berkeley, after 2 years with the law firm of Ropes & Gray, Boston. Winner of 2012 IEEE Mac Van Valkenburg Early Career Teaching Award.)

16. Sandip Roy, "Moment-Linear Stochastic Systems and Applications," July 2003. (Tenured Associate Professor of Electrical Engineering at Washington State University.)

17. Ernst Scholtz, "Observer-Based Monitors and Distributed Wave Controllers for Electromechanical Disturbances in Power Systems," September 2004. (Global R&D Strategy Manager and Group VP, ABB, Zurich.)

18. Tushar Parlikar, "Modeling and Monitoring of Cardiovascular Dynamics for Patients in Critical Care," June 2007 (co-supervised with Dr. Thomas Heldt). (Senior Patent Agent at Google; formerly Patent Agent with Ropes & Gray, Boston)

19. Victor Preciado, "Spectral Analysis for Stochastic Models of Large-Scale Complex Dynamical Networks," September 2008. (Raj and Neera Singh Assistant Professor of Electrical and Systems Engineering, University of Pennsylvania.)

20. Carlos Gomez-Uribe, "Systems of Chemical Reactions in Biology: Dynamics, Stochasticity, Spatial Effects and Model Reduction," September 2008 (co-supervised with Prof. Leonid Mirny). (Initially with Google, now VP for Product Innovation at Netflix.)

21. Laura Zager, "Infection Processes on Networks with Structural Uncertainty," September 2008. (Patent Attorney with Patent Capital Group, Portland; previously Patent Agent with Ropes & Gray, Boston.)

22. William Richoux, “Separability as a Modeling Paradigm in Large Probabilistic Models,” February 2010. (Statistician, Google.)

23. Faisal M. Kashif, “Modeling and Estimation for Non-invasive Monitoring of Intracranial Pressure and Cerebrovascular Autoregulation,” April 2011 (co-supervised with Dr. Thomas Heldt). (R&D engineer, previously with Masimo, currently with Google.)

24. Shamim Nemati, “Modeling, Identification and Control of Human Ventilatory Dynamics.” December 2012 (co-supervised with Dr. Atul Malhotra). (Assistant Professor of Biomedical Informatics, Emory University.)

25. Paul Azunre, “A Parallel Branch-and-Bound Algorithm for Thin-Film Optical Systems, with Application to Realizing a Broadband Omnidirectional Antireflection Coating for Silicon Solar Cells,” September 2014 (co-supervised with Prof. Marc Baldo). (Oracle; and Founder, Algorine, Austin TX.)

Visualization and Privacy Protection of Big Data

S. Y. Kung

Due to its quantitative (volume/velocity) and qualitative (variety/veracity) changes, big data to many of us resembles something like "the elephant to the blind men". Visualization of the massive and messy big data, metaphorically speaking, enables the blind men to "see" the data. On the other hand, in big data era, it is increasingly important to build information systems that can ensure the protection of *private data. For example, i*n collaborative learning environments, individual data are uploaded to the cloud to be shared by the other participants, causing leakage of privacy.

*Our first focus will be placed upon t*he curse of high feature dimensionality which may cause computational complexity and over-training. An effective solution is dimension reduction, which impacts both visualization and privacy. The prominent Principal Component Analysis (PCA aims at best recoverability of the original data in the Euclidean Vector Space (EVS). In contrast, Discriminant Component Analysis (DCA) can be viewed as a supervised PCA in a Canonical Vector Space (CVS). Via an intricate interplay between discriminant distance in CVS (dictated by the major eigenvalues) CVS anti-recoverability in EVS (dictated by the minor eigenvalues), DCA offers a compression scheme which maximizes privacy protection of personality rights in collaborative learning environment.

Another effective safety mechanism is to allow individual to withhold and mask (the most personal and private) features from the collaborative learner. This calls for the adoption of kernel learning machine (KLM). The success of KLM depends on the kernel function chosen to characterize the pairwise similarity of two (vectorial or nonvectorial) objects. More specifically, we shall extend PCA/DCA to their corresponding kernel models with a novel partial correlation kernel tailor designed for IDA. Our experimental study confirms robust performance of our *Kernel Approach to Incomplete Data Analysis* (KAIDA). For example, with nearly half of the features being masked, the accuracies remain very close to what attainable by fully-specified data. The effectiveness of dimension reduction by DCA raises the promising potential of combining features extracted via kernel learning and deep learning machines.

In conclusion, big data brings the math back to the center of IT technologies and this has everything to do with *the TK phenomenon*. *Happy Birthday, Tom!!*

Biography

S.Y. Kung is a Professor at Department of Electrical Engineering in Princeton University. His research areas include machine learning, data mining and analysis, statistical estimation, system identification, wireless communication, VLSI array processors, genomic signal processing, and multimedia information processing. He was a founding member of several Technical Committees (TC) of the IEEE Signal Processing Society, and was appointed as the first Associate Editor in VLSI Area (1984) and later the first Associate Editor in Neural Network (1991) for the IEEE Transactions on Signal Processing. He has been a Fellow of IEEE since 1988. He served as a Member of the Board of Governors of the IEEE Signal Processing Society (1989-1991). Since 1990, he has been the Editor-In-Chief of the Journal of VLSI Signal Processing Systems. He was a recipient of IEEE Signal Processing Society's Technical Achievement Award for the contributions on "parallel processing and neural network algorithms for signal processing" (1992); a Distinguished Lecturer of IEEE Signal Processing Society (1994); a recipient of IEEE Signal Processing Society's Best Paper Award for his publication on principal component neural networks (1996); and a recipient of the IEEE Third Millennium Medal (2000). He has authored and co-authored more than 500 technical publications and numerous textbooks including ``VLSI Array Processors'', Prentice-Hall (1988); ``Digital Neural Networks'', Prentice-Hall (1993); ``Principal Component Neural Networks'', John-Wiley (1996); ``Biometric Authentication: A Machine Learning Approach'', Prentice-Hall (2004); and ``Kernel Methods and Machine Learning”, Cambridge University Press (2014).

What can Aliens infer about Humans from the Internet?

Vwani Roychowdhury
Electrical Engineering Department
UCLA

Abstract:
I have been working for the past decade on what I prefer to label as "The Alien's Human Problem" -- How much of human knowledge and representations can an alien race learn if they sent a probe that captured all the Peta bytes of data that are being generated on the Internet. The major challenge is to develop a scalable unsupervised learning platform that searches for structures or objects in this Internet Scale data set comprising textual, visual and human activity logs, and then find relationships among these structures or objects to create maps. This is the Holy Grail problem of the so-called Big Data challenge. We will provide examples and frameworks that have been developed and commercialized to solve many of the underlying problems. The associated tools use concepts from complex networks, machine learning theory, mathematics, and physics and show how and why large-scale data facilitates the learning process.

Consider for example the field of computer vision, where object discovery and representation lies at the very heart of the field, and therefore it has attracted widespread interest in the past several decades. Early efforts were largely based on single template models, bag-of-visual-word models, and part-based models. To represent the intra-class variety of the same type of object and address partial occlusion problem in images, more complex object representations, like attribute-based and part-based models, have been proposed. The advent of the Internet, however, enables one to obtain a comprehensive set of images describing the same object as viewed from different angles and perspectives, and its natural association with other objects. This opens up new opportunities and challenges: Given that for the first time we have millions of exemplars of an object embedded in its natural context, can one effectively mimic human-like cognition and build up prototypes (comprising parts, their different views, and their spatial relationships) for each object category? The well-known supervised approach relies heavily on well labeled image datasets and, (i) it is still prohibitively hard for image labeling to catch up with the speed of image crawling, and (ii) it does not lead to succinct prototype models for each category, which can then be used to locate object instances in a query.

In my group's recent work, we investigated the open problem of constructing part-based object representation models from very large-scale image databases *in a completely unsupervised manner*. To achieve this goal, we first define a network model from a full Bayesian setting. This augmented network model has spatial information in it, and is scale invariant throughout any image resolution variations in the learning set. This network model is able to find visual templates of the same part with dramatically different visual appearances, which, in existing models, have to be added manually or using text information from the Internet. We show that the global spatial structure of the underlying and unknown objects can be restored completely from the recorded pairwise relative position data. We also developed an approach to learn the graphical model in a completely unsupervised manner from a large set of unlabeled data, and the corresponding algorithm to do detection using the learned model. We also apply our algorithm to various crawled and archived datasets, and show that our approach is computationally scalable and can construct part-based models much more efficiently than those presented in the recent computer vision literature. *Similar results for creating a textual collective brain of the human race will be discussed (*see *www.netseer.com)*.

Vwani Roychowdhury
Biographical Sketch

Ever since I joined Prof. Kailath's research group at Stanford as a twenty-two year old, I have been in awe of Prof. Kailath's illustrious career, his contributions in multiple areas of academia and industry, and above all, the amazing ease and personal grace with which he always seemed to navigate the intellectual landscape. Whether it is attracting graduate student talent, or getting into a new field of research, or transferring technology and making an engineering impact, it all seems to happen almost spontaneously around him. In fact, he has made it seem so effortless that collecting some of the most prestigious and exclusive awards in the scientific world seems like an obvious outcome for him. Having now lived in Hollywood for almost twenty years, my choice of analogies has become considerably biased, and in my estimate, he has surpassed the equivalent of an Honorary Oscar for lifetime achievement, the gold standard for stratospheric achievement in the "industry."

Until I started writing this bio, however, I hadn't realized that my conscious admiration has also been working subconsciously, and I seemed to have embarked on a career path that one may term as an *aspirational TK estimator*. The estimator, however, has stayed just that, aspirational, and is highly inconsistent in the sense that it flouts the basic bias-variance tradeoff property: It is highly negatively biased and yet retains a high variance. Inconsistent estimator notwithstanding, the influence and aspirations are very apparent. Perhaps, the most valuable thing I learned is to be intellectually fearless and follow my own instincts about research topics, no matter how daunting or how entrenched the target field of interest might be. As a result, I have worked and published in a wide range of areas including basic physics, mathematics, computational complexity and computer science, and engineering applications.

The overarching theme in my research work is to understand and model the fundamental principles of information processing and computation, and then to utilize the findings to design novel computing and communication systems. I view every system -- physical, biological, engineered, or societal – as an information processing and computing system, driven by a succinct set of universal laws. Such a pursuit, by its very nature, not only requires one to synthesize mathematical and analytical tools from different research fields, but also to delve deep into the details of different disciplines' systems. Both are required before the discipline can be parsed and modeled through the lens of information science and computation principles. A sampling of my continuing research interests, spanning the past one-and-half decades, will include:

1. *Quantum Computing and Information Science*: I have worked on several topics, including Quantum Key Distribution and quantum encryption, universal and fault tolerant bases for quantum computing, foundations of quantum mechanics, such as entanglement quantification and manipulation, and the new and exciting topic of Algorithmic Cooling.
2. *Nanocomputing and Limits of Classical Computation*: Worked on device models for classical (binary) computing that do not use transistors, and instead use principles of

collective and emergent computations. One of the results shows why ultra-small nanodevices will not help in prolonging Moore's scaling laws.

3. *Complex Emergent Systems, including the Internet, Cellular/biological, Social Media and Networks:* Did pioneering work on modeling and exploiting organic structures and the processes that lead to the development of the Internet, Peer-to-Peer networks, Biological systems such as cells, and social networks.
4. *Machine Learning, Adaptive Systems, and Statistics:* Did pioneering work in analyzing and modeling Internet-Scale data. Applications include new methods for extracting knowledge from the billions of web pages or the 100's of millions of images that are available on the web. These contributions led to the founding of two silicon-valley startups, NetSeer Inc. (www.netseer.com) and StileEye Inc. (www.stileeye.com).

My research work seems to draw frequent attention from popular media, and a number of media outlets have covered my work, including, The Guardian, The Boston Globe, Fox News, CBS News, Forbes, The Democratic Underground, NewScientist, Nature, MIT Technology Review, and Scientific American, as well as countless tweets and blogs.

Ph.D. Students: 1. *Dr. Hong Pan* (Brigham and Women's Hospital, Harvard Medical School), 2. *Dr. Chanchal Chatterjee* (EMC^2), 3. *Dr. Robert Granart* (JPL/CalTech), 4. *Dr. Oscar Boykin* (Twitter Inc.), 5. *Dr. Riccardo Boscolo* (NetSeer Inc.) 6. *Dr. Yumao Lu* (Bing/Msft) 7. *Dr. Jesse Bridgewater* (Twitter Inc.), 8. *Dr. Behnam Rezaei* (NetSeer Inc.), 9. *Dr. Qian Zhong* (Google Inc.), 10. *Dr. Milan Bradonjic* (Bell Labs.), 11. *Dr. Joseph Kong* (Trulia Inc.), 12. *Dr . Sudhir Singh* (Intel Inc.), 13. *Dr. Zicong Zhou* (Twitter Inc.), 14. *Dr. Roja Bandari* (Twitter Inc.), 15. *Dr. Lichao Chen* (Twitter Inc.).

Post-Doctoral Fellows and Research Associates: 1. *Dr. M P Anantram* (University of Washington) 2. *Dr. Farrokh Vatan* (JPL/Caltech), 3. *Dr. P Pradhan*, 4. *Dr. Tal Mor* (Technion, Israel), 5. *Dr. Somshubhro Bandyopadhyay* (Bose Institute, India), 6. *Dr. Sibasish Ghosh* (Chennai), 7. *Dr. Zengjiu Kang*, 8. *Dr. Joachim Dahl*, 9. *Dr. Jianbo Gao*, 10. *Dr. Heng Fan*, 11. *Dr. Hong Qian* (Google Inc.), 12. *Dr. Federico Spedalieri* (ISI/USC), 13. *Dr. Mikhail Simkin* (UCLA), 14. *Dr. Nima Khajenouri* (NetSeer Inc.), 15. *Dr. Akshay Wadia*, 16. *Dr. Oscar Boykin* (Twitter Inc.), 17. *Dr. Riccardo Boscolo* (NetSeer Inc.), 18. *Dr. Roja Bandari* (Twitter Inc.), 19. *Dr. Jesse Bridgewater* (Twitter Inc.), 20. Dr. C. Chatterjee (EMC^2), 21. Dr Nima Sarshar (InPowered Inc.).

Edge-sign prediction in Social Networks

Prof. Theodora Varvarigou, NTUA

1 Summary

Signed social networks, are those in which the relationship between their members carries a notion of the disposition of one member towards another. The options are often polarized, with dispositions being doubles such as like/dislike or trust/distrust. Predicting the signs of such links is crucial for many real-world applications, such as recommendation systems and they move one step ahead of the typical link prediction approaches being used so far for the same purpose.

Note that for a long time now, the type of relationship between people in a social network could be explained by social science theories that are based on the concepts of "balance" and "status". The structural balance theory [1] dictates that in social networks of three nodes, the balance of the network depends on whether the number of links depicting a positive disposition between network members is odd. On the other hand, the status theory [2] claims that labeled links aren't just signs of friendship or enmity but rather impose a hierarchy based on user status.

Recent studies [3] have identified that there are equally generalizable methods that can explain or infer the sign of a certain relationship which rely on the network structure. In fact experiments with epinions, Slashdot and Wikipedia datasets [4] demonstrated that the sign of an edge in a social network can be accurately identified if we study the structure of the social network around the edge in question. In particular, sub-graph occurrence frequency may tell a lot about the relationships between the network members. This conclusion opens up a great deal of opportunities for the development of social network applications.

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Professor **Theodora Varvarigou**[1] received the B. Tech degree from the National Technical University of Athens, Athens, Greece in 1988, MS degrees in Electrical Engineering (1989) and Computer Science (1991) from Stanford University and her Ph.D. from Stanford University as well, in 1991. She worked at the AT&T Bell Labs, Holmdel, New Jersey between 1991 and 1995. Between 1995 and 1997 she worked as an Assistant Professor at the Technical University of Crete, Chania, Greece. Since 1997, she has been a faculty member at the National Technical University of Athens.

The main fields of research interest of Prof. Varvarigou are in the areas of Cloud computing, Internet of Things and Social Analytics. In these areas, she has published more than 250 research articles in leading journals and conferences, collecting over 2500 citations to her work. She has been a member of the European Next Generation Grid Expert group as well as the European Cloud Computing Expert group, with the role of consulting the European Commission in issues regarding research and innovation in the respective fields.

Prof. Varvarigou has founded and leads the Distributed, Knowledge and Media Systems (DKMS[2]) Laboratory in NTUA with which she has won grants for over 50 collaborative research projects -many of which she has coordinated- over the last 17 years. Prof. Varvarigou has supervised 24 PhD students and leads a group of 30 researchers. From 2007-2012 she has served as the Director of the Engineering-Economics Systems MSc program at NTUA.

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Will Machine Learning Change the System Identification Paradigm?

Lennart Ljung
Linkoping, Sweden

Abstract:
State-of-the-Art System Identification works with well-defined model structures and Maximum-likelihood type parameter estimation algorithms. This paradigm is well founded and supported by theory, algorithms, software and industrial applications. Machine Learning tackles essentially the same family of problems, and has been very successful in attracting wide interest, with a (seemingly) different box of tools. The question is what impact this will have on the system identification community. This presentation looks at a few aspects of this question, primarily at the roles of regularization, kernel methods, and Gaussian process regression.

A more technical outline:
In machine learning and function learning a central concept has been to use reproducing kernel Hilbert spaces and Bayesian estimation of Gaussian processes. Viewing linear system estimation as a problem to ”learn” the impulse response function, these concepts lead to a model structure free or non-parametric approach. That has the advantage that the often difficult decisions on model structure parameters (”orders”) are avoided.

In discrete time, the impulse response of a stable system can be well approximated by a high-order FIR (finite impulse response) model. It is a simple least squares linear regression problem to estimate such a model. To counteract the high variance of estimates in large models, the flexibility of the high order FIR model must be curbed by adding a **regularization term** to the least squares criterion. This is a quadratic form in the FIR parameters, defined by a positive definite matrix. The matrix corresponds to the kernel in the reproducing kernel Hilbert space formulation.

So, in this case the learning approach really is regularized least squares estimation of FIR models. The catch is of course to find a good structure for the regularization matrix and to tune its parameters appropriately. This corrsponds to the model structure selection in state-of-the art system identifiction. In the presentation, useful such structures are suggested, along with effective tuning methods (”empirical Bayes”). It is shown that this method can outperform conventional parametric approaches for identification of stable linear systems.

Read all the technical details in:
Gianluigi Pillonetto, Francesco Dinuzzo, Tianshi Chen, Giuseppe De Nicolao and Lennart Ljung:
Kernel methods in system identification, machine learning and function estimation: A survey. Automatica Vol 50 (2014), pp 657-682

Biography

Lennart Ljung received his PhD in Automatic Control from Lund Institute of Technology in 1974. Since 1976 he is Professor of the chair of Automatic Control In Linkoping, Sweden. He has written numerous papers and several books on System Identification and Estimation and is the author of Mathwork's System Identification Toolbox for MATLAB

He has initiated and been director of a chain of broad research centra in Sweden: ISIS (1995-2005), VISIMOD (2002-2007), MOVIII (2006-2012), CADICS (2008-2010, center still continues), LINK-SIC (2007-2010, center still continues), ELLIIT (2009-2013, center still continues). He is emeritus since 2013.

Lennart Ljung has held visiting positions at Stanford (Postdoc at ISL 1974-75 and visiting professor at ISL 1980-81) at MIT (1985-86), at Berkeley (2005) and at the University of Newcastle, Australia (2011 and 1014).

He is an IEEE Fellow, an IFAC Fellow and an IFAC Advisor. He is as a member of the Royal Swedish Academy of Sciences (KVA), a member of the Royal Swedish Academy of Engineering Sciences (IVA), an Honorary Member of the Hungarian Academy of Engineering, an Honorary Professor of the Chinese Academy of Mathematics and Systems Science, and a Foreign Member of the US National Academy of Engineering (NAE).

He has received honorary doctorates from the Baltic State Technical University in St Petersburg, from Uppsala University, Sweden, from the Technical University of Troyes, France, from the Catholic University of Leuven, Belgium and from Helsinki University of Technology, Finland.

In 2002 he received the Quazza Medal from IFAC, and in 2003 he received the Hendrik W. Bode Lecture Prize from the IEEE Control Systems Society, and he was the 2007 recipient of the IEEE Control Systems Award.

Super-resolved system identification

Helmut Bölcskei

We start with a historic perspective of nonparametric system identification dating back to the pioneering work by Kailath and Bello in the 1960s. Building on these results, we then study the problem of identifying linear time-varying (LTV) systems with unknown spreading function support region. Perhaps surprisingly, there is no penalty for not knowing the spreading function support region prior to identification. The proof of this result reveals deep connections between LTV system identification, compressed sensing, and spectrum-blind sampling. We next consider the problem of identifying LTV systems characterized by a (possibly infinite) discrete set of delays and Doppler shifts. We prove that stable identifiability is possible if the upper uniform Beurling density of the delay-Doppler support set is strictly smaller than 1/2 and stable identifiability is impossible for densities strictly larger than 1/2. The proof of this density theorem reveals an interesting connection to interpolation in the Bargmann-Fock space and to Donoho's approach to super-resolution of discrete measures. Finally, we discuss methods for solving the system identification problem at hand, revealing connections to the ESPRIT algorithm.

Biography

Helmut Bölcskei was born in Mödling, Austria on May 29, 1970, and received the Dipl.-Ing. and Dr. techn. degrees in electrical engineering from Vienna University of Technology, Vienna, Austria, in 1994 and 1997, respectively. In 1998 he was with Vienna University of Technology. From 1999 to 2001 he was a postdoctoral researcher in the Information Systems Laboratory, Department of Electrical Engineering, and in the Department of Statistics, Stanford University, Stanford, CA. He was in the founding team of Iospan Wireless Inc., a Silicon Valley-based startup company (acquired by Intel Corporation in 2002) specialized in multiple-input multiple-output (MIMO) wireless systems for high-speed Internet access, and was a co-founder of Celestrius AG, Zurich, Switzerland. From 2001 to 2002 he was an Assistant Professor of Electrical Engineering at the University of Illinois at Urbana-Champaign. He has been with ETH Zurich since 2002, where he is a Professor of Electrical Engineering. He was a visiting researcher at Philips Research Laboratories Eindhoven, The Netherlands, ENST Paris, France, and the Heinrich Hertz Institute Berlin, Germany. His research interests are in information theory, mathematical signal processing, machine learning, and statistics.

He received the 2001 IEEE Signal Processing Society Young Author Best Paper Award, the 2006 IEEE Communications Society Leonard G. Abraham Best Paper Award, the 2010 Vodafone Innovations Award, the ETH "Golden Owl" Teaching Award, is a Fellow of the IEEE, a 2011 EURASIP Fellow, was a Distinguished Lecturer (2013-2014) of the IEEE Information Theory Society, an Erwin Schrödinger Fellow (1999-2001) of the Austrian National Science Foundation (FWF), and was included in the 2014 Thomson

Reuters List of Highly Cited Researchers in Computer Science. He served as an associate editor of the IEEE Transactions on Information Theory, the IEEE Transactions on Signal Processing, the IEEE Transactions on Wireless Communications, and the EURASIP Journal on Applied Signal Processing. He was editor-in-chief of the IEEE Transactions on Information Theory during the period 2010-2013. He served on the editorial board of the IEEE Signal Processing Magazine and is currently on the editorial boards of "Foundations and Trends in Networking" and "Foundations and Trends in Communications and Information Theory". He was TPC co-chair of the 2008 IEEE International Symposium on Information Theory and serves on the Board of Governors of the IEEE Information Theory Society.

Multipath Fingerprinting: Exploiting multipath for accurate indoor localization

Mati Wax

Summary

Localization of an emitter in rich multipath environments, indoors and outdoors, is a challenging problem. In such environments there is typically *no line-of-sight propagation* between the emitter and the receivers and as a result the traditional localization techniques which presume line-of-sight propagation between the emitter and the receivers – such as those based on angle-of-arrival (AOA), time-of-arrival (TOA), differential-time-of-arrival (DTOA), etc. – are ill-suited.

To cope with this problem, a new localization technique based on pattern recognition was introduced by Wax *et al.* [1]-[6]. The basic premise of this technique, referred to as multipath fingerprinting, is that in rich multipath environments the characteristics of the multipath rays impinging on the antenna array – their directions-of-arrival and their differential-time-delays – provide a unique and robust "fingerprint" of the emitter's location. As any pattern recognition technique, this technique involves two phases. First, in an off-line phase, a fingerprint capturing the multipath rays impinging on the antenna array is extracted for every location in the coverage area, and stored in a database. Then, in the on-line phase, the multipath fingerprint of the emitter to be localized is extracted from the antenna array and matched to the fingerprints stored in the database. The location whose fingerprint best matches the extracted fingerprint is selected as the emitter location.

Another localization technique based on pattern recognition was introduced by Bahl and Padmanabhan [7] and by Laitinen *et al.* [8]. This technique uses the values of received signal strength (RSS) obtained at several base-stations as a location fingerprint. The problem is that the RSS suffers from high variability along a distance of a wavelength because of constructive and destructive interferences of the multipath signals. As a result, the accuracy of this technique in typical indoors environments is limited to 3-5 meters and requires 3-5 overlapping base-stations [9]. A somewhat similar fingerprinting technique was introduced by Nypan *et al.* [10], based on using the channel impulse response (CIR) as a location fingerprint. The CIR fingerprint also suffers from high variability along a distance of a wavelength because of constructive and destructive interferences of the multipath signals. In fact, the high variability of the CIR in rich multipath environments is what enables the spatial multiplexing in the MIMO operation. As a result, the accuracy of the CIR fingerprinting in typical indoors environments is limited to 2 - 3 meters and requires 3 to 5 overlapping base stations [11]–[12].

In this talk we present the latest work on multipath fingerprinting, Wax *et al.* [13]-[14], focusing on indoor localization. Multipath fingerprinting, as any pattern recognition technique, involves two steps – fingerprint extraction and fingerprint matching. We present two different fingerprint extraction methods, both based on a low-dimensional subspace of the spatial-temporal covariance matrix of the signals received by the antenna array, known as the *signal-subspace*. This subspace is implicitly defined by the directions-of-arrival and the differential-delays of the multipath rays characterizing the emitter location, thus capturing the location fingerprint without requiring the explicit computation of the directions-of-arrival and the differential delays, which is a very complex multi-dimensional nonlinear problem. The first method, referred to as Signal Subspace Projection (SSP), extracts a projection matrix which best describes this subspace. The second method, referred to as Maximum Discriminative Projection (MDP), extracts the most discriminative projection matrix, making each projection matrix as different as possible from the other projections in the database. We also introduce two different fingerprint matching criteria. The first, referred to as Plain matching, is a "maximum likelihood" criterion following naturally from the extraction criterion. The second, referred to as Similarity Profile matching, is based on matching the whole "likelihood function" of the Plain matching to a set of "similarity profiles", which are pre-computed for each location and stored in the database. The "similarity profile" which best matches the "likelihood function", in the Least-Squares sense, is selected as the emitter's location. This matching copes better with ambiguities, occurring in challenging scenarios, but is computationally more complex.

We demonstrate the performance of multipath fingerprinting in typical indoor environments by both simulated and real data. The localization accuracy demonstrated is much superior to the other fingerprinting techniques, reaching 1 meter using only *a single base-station*.

The ability of multipath fingerprinting to accurately localize an emitter using only a single base-station is of significant practical importance. Indeed, this implies that any indoor wireless deployment, be it WiFi or LTE, can be used for *both communication and localization,* with no additional deployment. In contrast, the requirement of the other fingerprinting techniques that every location in the coverage area be covered by 3-5 base stations implies a much denser and more costly deployment – much beyond what is needed for communication – and a much more complex operation.

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MATI WAX - CURRICULUM VITAE

EDUCATION

Ph.D. – Stanford University, Electrical Engineering, 1985.
Thesis: Detection and Estimation of Superimposed Signals.
Supervisor: Prof. Thomas Kailath.
M.Sc – Technion, Israel Institute of Technology, Electrical Engineering, 1975.
Thesis: Improved bounds on the Accuracy of Parameter Estimators.
Supervisor: Prof. Jacob Ziv.
B.Sc. – Technion, Israel Institute of Technology, Electrical Engineering, 1969.
Graduated Cum Laude.

EXPERIENCE

2012- 2013: Chief Technology Officer, Alvarion, Israel.
Leading the research and development of the company's WiFi product line, including a sophisticated interference cancellation system for enhancing the WiFi base station performance in highly interfered environments, and an innovative indoor position location system based on its "Multipath Fingerprinting" technology.

2000-20011: Founder and Chief Technology Officer, Wavion, Yoqneam, Israel.
Founding the company and leading the research and development of the company's pioneering WiFi base-stations product line – the world's first base station leveraging Beamforming and SDMA (MU-MIMO) technologies. Leading the product development from conception and chip design to hardware and software implementation, up to field tests and delivery

1997-1999: Co-Founder and Chief Technology Officer, US Wireless, San Ramon, CA.
Leading the research and development of the company's position location product for cellular system, based on its innovative "Multipath Fingerprinting" technology. Leading the product development from conception and algorithm development to hardware and software implementation, up to field tests and delivery

1985-1996: Head, Signal Processing Center, Rafael, Haifa, Israel.
Leading the research and development of the company's SIGINT product line, including direction finding systems, position location systems and surveillance systems. Leading the products' development from conception and algorithm development to hardware and software implementation, up to field tests and delivery

1984: Visiting Scientist, IBM Research Laboratories, San Jose, CA.
Research in pattern recognition and statistical signal processing.

1981-1983: Research Assistant, Stanford University, Stanford, CA.
Research in array signal processing and spectral estimation.

1975-1980: Project leader, Rafael, Haifa, Israel.
Leader of a large-scale surveillance project involving communications and control systems. Leading the project through all its phases, from conception, through hardware and software development, up to the final field-tests and delivery.

1974: Group Leader, AEL, Bnei-Brak, Israel.
Development of microwave components and subsystems.

1970-1973: Electronic Officer, Israel Defense Forces.
Development of communications and telemetry systems.

AWARDS AND HONORS

2011: Plenary talk WITMSE 2011, Helsinki, Finland
2008: Plenary talk IEEE SAM 2008, Darmstadt, Germany
1994: Fellow of IEEE
1994: Research Fellow, Rafael.
1994: Rafael Award for excellent research.
1989: Senior Member IEEE.
1988: Rafael Award for brilliant solution.
1985: Best Paper Award, IEEE Transaction on Signal Processing.
1981: Israel Defense Award granted by the President of Israel.

PUBLICATIONS AND PATENTS

Papers: Over 70 papers in journals and conferences.
Patents: 16 patents allowed.
Google Scholar Profile:
http://scholar.google.com/citations?user=x5jW7voAAAAJ&hl=en

Physical Layer Security Games

Lee Swindlehurst
University of California Irvine

The fundamental principle behind physical layer security is to exploit the inherent randomness of noise and communication channels to limit the amount of information that can be extracted at the 'bit' level by an unauthorized receiver. With appropriately designed coding and transmit precoding schemes in addition to the exploitation of any available channel state information, physical layer security schemes can enable secret communication over a wireless medium without the aid of an encryption key. However, since they can operate essentially independently of the higher layers, physical layer techniques can also be used to augment already existing security measures. Such a multilayered approach is expected to significantly enhance the security of modern data networks, whether wired or wireless.

Since security problems involve independent agents with opposing goals, their analysis often admits a game theoretic formulation. In this talk, we investigate two examples of game theory applied to understand the trade-offs associated with balancing the allocation of resources to address both security and communications performance.

In the first example, we consider a MIMO communication link in the presence of an adversary with the dual capability of either passively eavesdropping or actively jamming any ongoing transmission, with the objective of causing maximum disruption to the ability of the legitimate transmitter to share a secret message with its receiver. The legitimate transmitter now faces the dilemma of establishing a reliable communication link to the receiver that is robust to potential jamming, while also ensuring confidentiality from interception. Since it is not clear *a priori* what strategies should be adopted by the transmitter or adversary per channel use, a game-theoretic formulation of the problem is a natural solution due to the mutually opposite interests of the agents. We show how to formulate the MIMO wiretap channel with a jamming capable eavesdropper as a two-player zero-sum game, we characterize the conditions under which the strategic version of the game has a pure-strategy Nash equilibrium, we derive the optimal mixed strategy profile for the players when the pure-strategy Nash equilibrium does not exist, and we study the extensive or Stackelberg version of the game where one of the players moves first and the other responds, and we also characterize the various equilibrium outcomes for this case under perfect and imperfect information. Details on this work can be found in [1].

The second example focuses on a common scenario in wireless communications: the interference channel (IFC). A common IFC scenario involves two basestations, each communicating with a separate cell-edge user in proximity to each other. The problem is often formulated as one of attempting to maximizing the sum rate to the two users or minimizing the mutual interference from the interfering basestation, but instead we approach the problem from the point of view of keeping each user's information as secret as possible from the other. The game theoretic aspect of this problem enters in how the two basestations choose to share information, if at all. In particular, should each basestation selfishly attempt to improve the secrecy of its own link without consideration of the other, or should they cooperate to improve the overall secrecy of the network? We show that cooperation is always the best approach, and illustrate ways in which this cooperation can take place in terms of shared channel state information. We show that the best performance is achieved when the basestations altruistically allocate a portion of their own resources to keep their user "in the dark" about the signal sent to the other user. Additional information about various physical layer security applications can be found in [3]-[4].

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[2] A. Fakoorian and A. Swindlehurst, "MIMO Interference Channel With Confidential Messages: Achievable Secrecy Rates and Precoder Design," *IEEE Trans. on Information Forensics and Security,* vol.6, no.3, pp.640-649, Sept. 2011.

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Biography
A. Lee Swindlehurst
http://newport.eecs.uci.edu/~swindle/

After receiving his B.S. and M.S. degrees in Electrical Engineering from Brigham Young University (BYU), Lee Swindlehurst had the great honor and distinct pleasure of joining TK's research group in the fall of 1986. He has fond memories of sharing Durand 110 with other TK illuminati including Dick Roy, Bjorn Ottersten, Marc Goldburg, Reuven Ackner, Guanghan Xu, Jóhanna Gísladóttir. Particularly memorable was the shared excitement of the 1989 Loma Prieta earthquake, which sent us all scrambling out of the office and down the stairs (not the smartest response for a bunch of Stanford Ph.D.'s). While at Stanford, Lee did research on direction-of-arrival estimation for sensor arrays, and enjoyed TK's generous support to attend conferences and meet interesting people from around the world. Lee left Stanford in 1990 to go back to BYU, this time as a new assistant professor. He was on the faculty of the Department of Electrical and Computer Engineering at BYU from 1990-2007, where he eventually became a Full Professor and served as Department Chair from 2003-2006. During 1996-1997, he held a joint appointment as a visiting scholar at both Uppsala University, Uppsala, Sweden, and at the Royal Institute of Technology, Stockholm, Sweden (visiting former classmate and TK student Bjorn Ottersten). From 2006-07, he was on leave working as Vice President of Research for ArrayComm LLC in San Jose, California (a company founded by another TK alum, Dick Roy). In 2007, he joined the University of California Irvine, where he is currently the Associate Dean for Research and Graduate Studies in the Henry Samueli School of Engineering, and a Professor of Electrical Engineering and Computer Science. He is also currently serving as a Hans Fischer Senior Fellow in the Institute for Advanced Studies at the Technical University of Munich. His research interests include sensor array signal processing for radar and wireless communications, detection and estimation theory, and system identification, and he has over 250 publications in these areas.

Dr. Swindlehurst is a Fellow of the IEEE, a past Secretary of the IEEE Signal Processing Society, past founding Editor-in-Chief of the *IEEE Journal of Selected Topics in Signal Processing,* and past member of the Editorial Boards for the *EURASIP Journal on Wireless Communications and Networking*, *IEEE Signal Processing Magazine*, and the *IEEE Transactions on Signal Processing*. While at BYU, he received the Engineering Educator Award, and the Karl G. Maeser Research and Creative Arts Award. He is a recipient of several paper awards, including the 2000 IEEE W. R. G. Baker Prize Paper Award, the 2006 and 2010 IEEE Signal Processing Society's Best Paper Awards, the 2006 IEEE Communications Society Stephen O. Rice Prize in the Field of Communication Theory, and is co-author of a paper that received the IEEE Signal Processing Society Young Author Best Paper Award in 2001.

Ph.D. Students Supervised

Jiankan Yang (1995)
Development and Analysis of Signal Copy and Blind Equalization Algorithms

Jacob Gunther (1998)
Recursive Blind Equalization Based on Cyclostationarity and Structured Kernels
Professor, Electrical and Computer Engineering, Utah State University, Logan UT

Xiangyang Zhuang (2000)
Blind Channel Equalization and Estimation for Wireless Communications
Wireless Product R&D, Intel Corporation, Santa Clara CA

Christian Peel (2004)
Studies in Multiple-Antenna Wireless Communications
Wireless Communications Engineer, Tarana Wireless Inc., Santa Clara CA

Quentin Spencer (2004)
Transmission Strategies for Wireless Multi-User, Multiple-Input, Multiple-Output Communication Channels
Senior Data Scientist, Neustar Inc., Champaign IL

Pengcheng Zhan (2007)
Optimizing Wireless Network Throughput: Methods and Applications
Staff System Engineer, Qualcomm Inc., Santa Clara, CA

David Casbeer (2009)
Decentralized Estimation in a Multi-Static UAV Radar Tracking System
Research Engineer, Air Force Research Laboratory, Wright-Patterson Air Force Base OH

David Larsen (2009)
Studies on the Performance and Impact of Channel Estimation in MIMO and OFDM Systems

Shun Chi Wu (2012)
Space-Time Biosignal Processing - Interference Mitigation, Feature Extraction, Source Localization and Brain Connectivity Analysis
Assistant Professor, Dept. & Institute of Engineering & System Science, National Tsing Hua University, Hsinchu, Taiwan

Amitav Mukherjee (2012)
Competition, Coexistence, and Confidentiality in Multiuser Multi-antenna Wireless Networks
Research Engineer, Ericsson Research, San Jose CA

Jing Huang (2013)
Cooperative Communication for Wireless Physical Layer Security

Senior Systems Engineer, Qualcomm Inc., Santa Clara CA

Seyed Ali Akbar Fakoorian (2013)
Cooperation and Competition in MIMO Multi-User Networks with Confidential Messages
Senior System Engineer, Qualcomm Inc., San Diego CA

Jie Chen (2015)
Resource Allocation in Communication, Quantization, and Localization
Research Specialist, Nokia Networks, Arlington Heights IL

Feng Jiang (2015)
Physical Layer Optimization for Wireless Sensing and Network Connectivity
Wireless Systems Engineer, Broadcom Corporation, Sunnyvale CA

Renewable and Storage Integration in Distribution Networks
Is consumer-based integration good for consumer?

Lang Tong, Irwin and Joan Jacobs Professor of Engineering
School of Electrical and Computer Engineering
Cornell University, Ithaca, NY 14850

The power grid is facing an imminent transformation brought by disruptive technologies such as home energy storage, electric vehicles as mobile storage devices, and photovoltaics. The rise of renewable integration by consumers coupled has led the so-called death spiral hypothesis for retail utilities in which the decline of consumption due to behind the meter renewable integration triggers upward pressure on the rate of electricity that induces further consumer adoption of renewable and storage.

We examine two models of integration of renewables and storage in distribution networks. The first is a centralized utility-based model in which the utility owns the renewable generation as part of its portfolio of energy resources. The second is a decentralized consumer-based model in which each consumer owns the renewable generation and is allowed to sell surplus electricity back to the utility in a net-metering setting. Similar models for storage are also considered. The essential question is whether consumer-based decentralized integration ultimately benefits the consumer.

Biography

Lang Tong is Irwin and Joan Jacobs Professor of Engineering at Cornell University. He received Bachelor's degree in Automation from Tsinghua University in 1985 and his doctorate degree from the University of Notre Dame in 1990. In 1991, he was a Postdoctoral Research Affiliate at the Information Systems Laboratory, Stanford University, under the supervision of Professor Thomas Kailath. Prior to joining Cornell in 1998, he was an Assistant Professor at the West Virginia University and an Associate Professor at the University of Connecticut at Storrs.

Lang Tong's research spans in multiple application domains, including statistical signal processing, communications, and most recently, power and energy systems. He received paper awards from the IEEE Signal Processing Society, the IEEE Communication Society, and the IEEE Circuits and Systems Society. His current research focuses on engineering and economic problems in energy systems, including renewable integration, large scale charging of electric vehicles, cyber physical security in smart grids, and data analytics in power systems. He is a Fellow of IEEE.

Healing the Earth's Climate

Sailesh Rao

This talk discusses quantitative evidence that climate change on Earth can be arrested and even reversed through a grassroots movement similar to what Mahatma Gandhi orchestrated in India a century ago.

Biography

Sailesh Rao has been working on alleviating climate change with the non-profit, Climate Healers, for the past 8 years. He was selected as a Karmaveer Puraskaar Noble Laureate by the Indian Confederation of NGOs (iCONGO) and is a recipient of the Distinguished Alumnus Award from IIT Madras in 2013. Sailesh is the author of the 2011 book, "Carbon Dharma: The Occupation of Butterflies," and is currently working on a follow-up book.

Great Ideas and Beautiful Minds

Juan Ahonen-Jover

On a different type of presentation, Juan examines the contributions of a few luminaries and a characteristic that they share. He then discusses how he applied the lessons learned as a Ph.D. student of Prof. Kailath to a different career path.

Biography

Juan arrived to the United States with a Fulbright Fellowship in 1980. After completing his Ph.D. in December 1985 and a Masters in Engineering Management (in combination with the Business School) at Stanford, Juan joined Bell Labs as a Member of the Technical Staff. In reality, he was an infiltrated marketeer helping find a direction for their medical ventures.

When he recommended that for technical and business reasons there was not a prosperous future for that business in AT&T, he was promoted to manage the business planning for other technical ventures in the company. Later seeking more experience in one of the premier marketing companies, he moved to American Express as director of strategic planning and later of worldwide marketing.

Following the big company experience, Juan entered the entrepreneurial world, joining Sailesh Rao, another of Prof. Kailath's students, on a venture that had a successful exit.

After that, Juan focused on social entrepreneurship: moving from doing well to doing good---instead of affecting lives with new Ethernet chips that moved bits increasingly faster, Juan decided to enter the philanthropic world to affect the lives of people in other ways, such as to ensure that lesbian, gay, bisexual and transgender people had the same fundamental rights as everybody else in the United States. This work led to many initiatives including a powerful network of donors and politicians (*eQualityGiving*), a virtual symposium (*eQualityThinking*), a manifesto about equality *(The Dallas Principles*), a tool to keep the politicians accountable *(Act On Principles),* and a campaign for marriage equality (*Loving Everywhere*).

Not having written a book since his early 20's, Juan come back with *The Gay Agenda 2012*, a comprehensive guidebook to equality, which like any good guidebook is updated yearly (currently preparing the fifth year edition).

Understanding the importance of clean elections for a government of the people, Juan was asked to join a national task force to determine if there was fraud in the 2004 presidential election. As part of this effort, he created a new methodology to improve the reliability of election results, based on principles from control theory.

After waiting for 27 years, Juan and Ken were finally given a civil marriage license. Adopting the academic lifestyle, they spend several months a year traveling the world and the rest of the time contemplating life under a palm tree in their main home in the Florida Keys (which was on the cover of *Florida Design).* They share their home with their princess, Barbian, who just turned 15.

Geometric Algebra: a "Hyper-Euclidean" Extension of Complex Algebra and Quaternions with application to Monitoring of Electric Power Quality

Hanoch Lev-Ari

Department of Electrical and Computer Engineering
Northeastern University, Boston, MA

The (associative and distributive) product of two elements of a given Euclidean space $\mathcal{V}$ can be defined for 2D spaces by using complex numbers, and for 3D spaces by using the vector cross-product. Geometric algebra (GA) [1, 2] provides a natural extension of complex numbers, vector calculus and quaternions beyond 3D spaces. Its elements are called *multi-vectors*: each multi-vector consists of components known as r*-vectors*, for $0 \leq r \leq n$: the set of all r-vectors is a Euclidean space. In particular, 0-vectors are (real) scalars, and 1-vectors are the usual vectors. The integer r is known as *grade*, while n denotes the dimension of the *generating* (i.e., original) Euclidean space $\mathcal{V}$. The dimension of the grade-r subspace is $\binom{n}{r}$, so that the dimension of the complete GA is 2^n. Every geometric algebra is a direct sum of $n+1$ mutually-orthogonal Euclidean (sub)spaces, one for every possible grade. In particular the grade-1 subspace coincides with the generating Euclidean space $\mathcal{V}$.

The application of GA to monitoring of electric power quality relies on the fact that the voltage and current of an m-phase power system, viz.,

$$v(t) \stackrel{\text{def}}{=} [\, v_1(t) \;\; v_2(t) \;\; \ldots \;\; v_m(t) \,] \quad , \qquad i(t) \stackrel{\text{def}}{=} [\, i_1(t) \;\; i_2(t) \;\; \ldots \;\; i_m(t) \,] \tag{1}$$

can be interpreted as elements in a (Hilbert) space of m-phase, square-integrable, T-periodic waveforms, with the inner product defined by

$$\langle\, x(\cdot) \,,\, y(\cdot) \,\rangle \stackrel{\text{def}}{=} \frac{1}{T} \int_T x(s)\, y^\top(s)\, ds \tag{2}$$

where the superscript $^\top$ denotes transposition [3, 4]. For instance, in this terminology the rms value of the polyphase voltage $v(t)$ is expressed as $\|v(\cdot)\| \equiv \sqrt{\langle\, v(\cdot) \,,\, v(\cdot) \,\rangle}$, the average (real) power delivered to the load is $P = \langle\, v(\cdot) \,,\, i(\cdot) \,\rangle$, and the apparent power is $S = \|v(\cdot)\|\, \|i(\cdot)\|$. The difference $S^2 - P^2$ is known as the "power quality gap" (also the Lagrange gap), and has been the target of various decomposition strategies (see e.g., [3, 5, 6, 7].

The apparent power in a sinusoidal single-phase system has only two components – the real power P and (Budeanu's) reactive power Q. Hence, it can be described by the so-called complex apparent power $P + \jmath Q$ [8], because $|P + \jmath Q|^2 = P^2 + Q^2 = \|v(\cdot)\|^2 \|i(\cdot)\|^2 \equiv S^2$. Here $\|v(\cdot)\|$, $\|i(\cdot)\|$ denote the rms values of the polyphase voltage and current waveforms, respectively (see discussion following (2)), and the product $\|v(\cdot)\|\, \|i(\cdot)\|$ is the well-known scalar apparent power. In contrast, notice that polyphase and/or polyharmonic waveforms give rise to a multicomponent apparent power, such as in the 5-component decomposition [7]

$$S^2 \;\equiv\; \|v(\cdot)\|^2\, \|i(\cdot)\|^2 = P^2 + S_g^2 + Q^2 + S_b^2 + S_\perp^2 \tag{3}$$

In view of its number of components, this decomposition cannot be described in terms of complex numbers (which have only two components) or even quaternions (which have one real and three "imaginary" components).

The key concept of GA is the *geometric product* of two multivectors. In particular $\mathbf{x}^2 = \|\mathbf{x}\|^2$ for any 1-vector $\mathbf{x}$. The entire geometric algebra is generated by linear combinations of geometric products of multiple 1-vectors. The GA generated by a suitable choice of a (finite-dimensional) space of polyphase waveforms of limited harmonic content allows us to introduce an *apparent power multi-vector* $\mathbb{S}$, defined as the geometric product of voltage and current 1-vectors, so that $\|\mathbb{S}\|^2 = \|v(\cdot)\|^2 \, \|i(\cdot)\|^2 - S_\perp^2$. Moreover, we can use the natural decomposition of the geometric product (into a sum of an inner product and a wedge-product [1]) to decompose the multi-vector $\mathbb{S}$ into a sum of four mutually-orthogonal multi-vectors, each one representing a physically-meaningful power component, viz.,

$$\mathbb{S} = P \oplus \mathbb{S}_g \oplus Q\,\mathcal{J} \oplus \mathbb{S}_b\,\mathcal{J}$$

such that $\|\mathbb{S}_g\| = S_g$, $\|Q\,\mathcal{J}\| = |Q|$, and $\|\mathbb{S}_b\,\mathcal{J}\| = \|\mathbb{S}_b\| = S_b$. Here $\mathcal{J}$ denotes the unit *pseudo-scalar* of the geometric algebra, with properties such as $\|\mathbb{A}\,\mathcal{J}\| = \|\mathbb{A}\|$ for every multi-vector $\mathbb{A}$, and $\mathcal{J}^2 = (-1)^{n(n-1)/2}$. Our construction involves minimal computation, and relies on the intrinsic *separation by grades* within the geometric algebra we consider. Each component of our apparent power multivector can be conveniently evaluated in terms of voltage and current phasors [9]. Consequently, our apparent power decomposition (3) can be readily extended to transient waveforms by employing dynamic phasors, without any significant modification of our geometric algebra framework [10].

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[10] H. Lev-Ari and A.M. Stanković, "A Geometric Algebra Approach to Decomposition of Apparent Power in General Polyphase Networks," *41-st North American Power Symposium,* Starkville, MS, Oct. 2009.

Biography

Dr. Hanoch Lev-Ari is a professor of Electrical and Computer Engineering Department at Northeastern University, Boston, MA, and past director of the Center for Communications and Digital Signal Processing (CDSP) at this university. He received his BS (summa cum laude) and his MS from the Technion, Israel Institute of Technology, and his PhD from Stanford University, all in electrical engineering. Before joining Northeastern University, he was an Adjunct Research Professor of Electrical Engineering with the Naval Postgraduate School, Monterey, CA, a Senior Research Associate with the Information Systems Laboratory at Stanford University, and a Research Scientist with Integrated Systems, Inc.

Dr. Lev-Ari is a Fellow of the IEEE and a member of SIAM. He served as an associate editor of *Circuits, Systems and Signal Processing*, and of the *IEEE Transactions on Circuits & Systems I*, and has consulted with Saxpy Computer Corporation, ADE Corporation, and TechOnLine University. He also served as a technical program co-chair of the *43rd North American Power Symposium* in 2011. He has advised to completion 17 PhD dissertations and 15 MS theses.

His present interests include adaptive filtering under the non-stationary regime, dynamic time-frequency analysis, and multi-rate/multi-sensor networked state estimation; with applications to identification of time-variant systems, customized dynamic phasors, dynamic power decomposition, and adaptive power flow control in polyphase power systems.

His past research has involved a number of mathematical techniques and a variety of applications in signal processing and linear systems, including: lossless cascade models for multiple-input/multiple-output systems; extension of maximum-entropy techniques to multi-dimensional signal processing; and characterization of structured matrices.

Webpage: http://www.ece.neu.edu/people/lev-ari-hanoch

CAN LU AND QR BE RECONCILED?

PATRICK DEWILDE

Very early in his hyper-distinguished career, Tom Kailath discovered the "square root algorithm", which turned out the method of choice for computing the Kalman estimation filter [1]. Together with Israël Gohberg and Israël Koltracht, he also discovered that outer decompositions of a kernel in a Fredholm equation would yield algorithms for solving it in a numerical efficient way (linear in the dimensions of the kernel, quadratic in the order of the outer approximation) [2]. The connection was soon made with state space representations of the kernel, leading to the theory for solving so called (generalized) semi-separable or quasi-separable set of equations efficiently, which are systems represented by a time-varying state space model, as is the case with the Kalman filter.

In the early years of the twentieth century, the theory of meromorphic matrix functions was developed by a bunch of mathematicians: Hardy, Hankel, Schur, Caratheodory, Nevanlinna, Pick, Takagi and a few more, and a central concept that arose in this theory was "invariant subspaces" and its related "inner-outer" factorization. Interpreted in terms of transfer functions, the latter amounts to the factorization of a (time invariant) transfer function in a causal unitary phase function (the inner part) and a causally invertible "minimal phase" function (at least under certain invertibility conditions). The inner-outer factorization proved to be the numerical corner stone of the theory of matrix functions.

Often in parallel, and reaching to the middle of the twentieth century, numerical methods were developed to solve systems of linear equations, giving rise to the field of "numerical linear algebra" with its host of attractive, i.e., numerically stable methods. In this presentation, I want to concentrate on two generic methods: LU-factorization (to factorize a matrix into a lower factor L and an upper factor U), and QR-factorization, in which a matrix is factored into a unitary matrix Q and an "upper" matrix R. The LU-factorization does not necessarily exist, but if it does, it would normally be computed using a variant of Gaussian elimination, in which the determinants of subsequent principal minors are computed recursively (the so called "pivots") and used in the recursion. On the other hand, the QR-factorization always exists (modulo some tolerance on the upper factor R, which may have an "echelon" form), but it does not yield a factorization in lower-upper, or, equivalently, causal-anticausal. The LU-factorization as described entails numerical computations that may become unstable, while QR will always be numerically stable (backward stability).

The counterpart of LU-factorization in classical transfer function theory is called "spectral factorization", while that of QR-factorization is "inner-outer factorization". It turns out that a more general theory exists that encompasses both cases: the matrix case of linear algebra, and the transfer function case of classical matrix-function theory [4]. Not surprisingly, this more general treatment is based on time-varying state space representations (or, in the mathematics context, on the notion of "nested algebras" of Arveson). The Kalman filter in this theory turns out to be nothing else than a straight inner-outer factorization, be it on a rather special case (and its properties can easily be proven that way too). It is then also easy to see that Kailath's "square-root algorithm" is the determination of an inner and an outer factor using stable orthogonal transformations recursively, which also provide a (low complexity) state space representation for the two factors, with the inverse of the outer factor as the Kalman estimation filter.

Up to this point, there is a disturbing dichotomy: spectral factorization and its equivalent LU-factorization require potentially unstable numerical methods, while QR-factorization is capable to solve state estimation problems with optimal stability, using inner-outer factorization via a square-root algorithm. The question is: is there a connection between the two? I shall show in the presentation that, indeed, LU-factorization (and spectral factorization) can be achieved in a fully stable numerical way, using two subsequent inner-outer factorizations. In this algorithm, the computation and use of the pivots is avoided, although they can easily be derived from the computed quantities. In other words: "two Kailaths = one Gauss"! This result was published a couple of years ago, and up to now it appears that it was not known so far [3].

In the wake of these results, a number of considerations and further perspectives may be itemized:

- the two inner-outer factorizations mentioned are valid and numerically stable whether or not the LU-factorization exists (actually, concrete conditions for its existence are provided), but what the result produces in the cases LU does not exist has not been considered so far;
- the standard way of using QR-factorization in the semi- or quasi-separable context is the computation of an LRU-factorization, with L and U unitary factors that act both sides of an upper factor R. However, in the LU-factorization case, the factorization is of the type "LUR", with unitary factors (one causal or lower the other anti-causal or upper) acting on the *same* side;
- there is an elementary (non-state-space) version of the algorithm for the non-separable case, but it has not been worked out in detail yet;
- the algorithm proposed also leads to a seemingly new method for (numerically stable) spectral factorization in the traditional matrix-function theory [5];
- and a final remark: inner-outer factorization is a "square-root" algorithm, it leads to a Riccati equation when squared. However, it does not make sense to solve that Riccati equation directly, certainly not in the matrix or time-varying case, but also not in the time-invariant case (where an addtional fixed-point problem has to be solved, making the time-invariant case intrinsically more complex than the time-varying case).

Tom Kailath and I share since many years a common interest: the use of addition and multiplication to solve numerical and system problems. It seems that the possibilities for new results derived from this minimalistic philosophy do not seem exhausted at all!

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A BIOGRAPHY OF INTERACTIONS

PATRICK DEWILDE

I met Tom Kailath for the first time during an exam, actually: an interview, for the Stanford Ph.D. Qualifyings, in December 1968. Although I do not remember our precise topic of conversation (it must have been on stochastic filtering), I do remember the spirit of scientific interest and motivation that Tom communicated. Although I did not work with him on my doctoral research (it was primarily with Bob Newcomb and later also with Rudy Kalman), we occasionally met, as Tom's office was opposite that of Bob's on the first floor of the ERL building, and they shared a secretary (I believe it was already Barbara McKee at the time.) Our interests had not really crossed yet.

My next visit to Stanford would be totally different. I was at that time a lecturer at Lagos University (Nigeria), and I wanted to (1) attend a conference in the United States (the first MTNS, at that time called OTNS for "Operator Theory for Networks and Systems" organized by Bob Newcomb in Maryland) and (2) visit Tom at Stanford University, in order to sharpen my knowledge of stochastics and filtering. As I did not have any travel funds, my father paid for the trip and the visit. This was the beginning of an intense collaboration that would determine my scientific career from that point on, but also lead to an intense friendship with Tom, his wife Sarah and their family, and to many future interactions all over the world. I became a post-doctoral student of Tom!

During this visit, Tom had already moved to the ground floor of the Space Science Building Durand where, as director of ISL (Information Systems Laboratory) he occupied a large office that, however, was barely large enough to contain his immense collection of books, stacked on shelves reaching to the ceiling, if not laying around in stacks on the floor. I was allowed to sit next door in a small office shared with other visitors, and was immediately integrated in Tom's almost daily colloquium, where one of his students or visitors would present a topic of interest, often a new one. I was assigned to present the book of Geronimo on "Orthogonal Polynomials", whose reading was an absolute shock for me: I immediately recognized the algorithmic gist of Darlington Synthesis, a topic in Network Theory that I had intensely studied during my Ph.D. time, now placed in a totally different, this time mathematical context. Soon, further connections with inverse scattering and the early literature on interpolation (in particular Schur's algorithm) became clear, and, wonder above wonder, also the connection with estimation theory!

Needless to say, this formed the basis for a whole lot of new research, and it was Tom's unstoppable interests in anything new that had provided the first impetus. Our friendship consolidated quickly, and I had the extreme pleasure to be the host of Tom, his family and a bunch of his students as guests of the Catholic University of Leuven for six months in 1977 (also the basis of new interactions and friendships, in particular with George

Verghese, Hanoch Lev-Ari, Sun-Yuan Kung and Augusto Vieira). Gracefully, Tom and Sarah accepted a less-than-acceptable initial housing situation in Leuven, but soon the university could accommodate them in the beautiful Leuven Beguinage, with its charming houses, presently a Unesco protected site. Later during Tom's stay I became a professor at Delft University in the Netherlands, and, in addition to all our scientific interactions, Tom and his students became expert painters of our new house in Bleiswijk (Tom's spouse Sarah mentioned that it was the first time in his life that he had a paint brush in his hands.).

During the thirty-one years I was working in Delft, I had the pleasure of many visits to Tom and Stanford university, several times even a full summer, allowing us to work on various topics and exchange ideas. Tom's friends became my friends, and also to some extent vice-versa. Let me mention the long time collaborations we had with Isral Gohberg, Harry Dym, Yves Genin, Bill Helton, Gene Golub and Mao Najim, just to mention some. Tom even connected me with Mark Krein, whom he could visit in Odessa. However, my planned visit did not materialize as my visa was refused (in Holland) by the Soviet authorities. Let me also mention the very helpful assistance Tom delivered to a number of my own Ph.D. students, some of whom became intense visitors of Tom's group as well: Paul Van Dooren, Ed Deprettere and Alle-Jan van der Veen in particular.

We engaged in many activities together, organizing extensive workshops that would provide both relaxed and intensive means of exchange of ideas and collaborations between the many researchers who shared our interests. In particular: many workshops in Stanford organized by Tom; Aussois, Bonas and Saint-miliion organized together in Europe; and then several others, in particular in India. They proved to be ideal vehicles to put everybody abreast of developments. Already in those days, Tom became a frequent recipient of major prizes, and he always made me the favor of inviting me to attend, which lead me, often accompanied by my wife Anne, to Sorrento, Bangalore or Stanford to participate in major scientific events. As the crown jewell, he made us know intimately and appreciate his country of origin, India, with its immense culture and beauty.

It should be clear from the preceding that I am very much indebted to Tom for providing some of the best experiences of my life, both scientifically and culturally. This sort of culminated when we were jointly awarded a "Humboldt Research Prize" at the Technical University of Munich, thanks to the invitation and proposal by Klaus Diepold. Tom and I prepared our program for Munich during one of my frequent stays at Tom's elegant and comfortable house in Stanford. Unfortunately, the subsequent visit to Munich proved to be very painful, due to the discovery of the terminal illness of Sarah. A few years later Tom lost his charming wife and we (my wife Anne and I), a very dear friend.

Many years have passed since our first encounter. To be precise: 47. It would be hard to summarize what our manifold of interactions have produced in detail, but at a more general level, I can say that they have been extremely motivating to me, both at the personal and the scientific level: my life would have been very different without them. For this undeserved but highly appreciated present I am extremely grateful.

Probability revisited: learning distributions from samples

S. Kamath A. Orlitsky V. Pichapati A. T. Suresh

Abstract

One of the most natural and important questions in statistical learning is the rate at which a distribution be approximated from its samples. Surprisingly, this question has so far been resolved for only one loss, KL-divergence, and even then using an ad hoc, poorly understood estimator. We determine the best approximation rate, either exactly or to first order for the ℓ_2^2, ℓ_1, χ^2 loss measures, and all smooth loss measures when the probabilities are bounded away from zero, thereby providing a more coherent understanding of the rate at which distributions can be approximated from their samples.

Summary

Many natural phenomena are believed to be of probabilistic nature. Written text, spoken language, stock prices, genomic composition, disease symptoms, physical characteristics, communication noise, traffic patterns, and many more, are commonly assumed to be generated by some unknown underlying distribution.

It is therefore practically important to approximate a distribution based on its observed samples. Namely, given samples from an unknown distribution p, to find a distribution q that is close to p. Surprisingly, despite many years of statistical research, some of the most basic questions have remained unanswered.

The simplest rigorous formulation of this problem may be in terms of min-max performance. Any distribution $p = (p_1, \ldots, p_k)$ over $[k] \stackrel{\text{def}}{=} \{1, \ldots, k\}$ corresponds to an element of the simplex $\Delta_k \stackrel{\text{def}}{=} \{p \in \mathbb{R}^k : p_i \geq 0, \sum_{i=1}^k p_i = 1\}$. For two distributions $p, q \in \Delta_k$, let $L(p, q)$ be the *loss* when the true distribution p is approximated by the estimate q. The right loss function L typically depends on the application. For example, for compression and investments, the relevant loss is often the Kullback Leibeler (KL) divergence, for hypothesis testing and classification, the pertinent loss measure is typically the ℓ_1 distance, and other applications use ℓ_2, Hellinger, chi-squared, or other losses.

Let $[k]^*$ be the set of finite sequences over $[k]$. A *distribution estimator* is a mapping $q : [k]^* \to \Delta_k$ associating with each observed sample $x^n \in [k]^*$ a distribution $q(x^n) = (q_1(x^n), \ldots, q_k(x^n))$ over $[k]$. The least (over estimators) worst-case (over distributions) expected (over samples) loss is

$$r_{k,n}^{\text{L}} \stackrel{\text{def}}{=} \min_q \max_{p \in \Delta_k} \mathop{\mathbb{E}}_{X^n \sim p} L(p, q(X^n)).$$

Determining the min-max loss for a given loss function L, and the optimal estimator achieving it, is of significant practical importance. For example, an estimator with small KL-loss could improve compression and stock-portfolio selection, while an estimator with a small ℓ_1 loss could result in better classification.

Yet as above, very little is know about $r_{k,n}^{\text{L}}$. The only loss function for which $r_{k,n}^{\text{L}}$ has been determined even to the first order is KL-divergence that just eleven years ago was shown for fixed k to grow with n as

$$r_{k,n}^{\text{KL}} \sim \frac{k-1}{2n}.$$

Yet the estimator used is somewhat impenetrable, and the proof that it works, while similar estimators with different parameters do not, relies on a computer calculation of the loss at the simplex boundary.

We generalize the study to a much broader class of losses. We first consider three important loss functions and determine their behavior either exactly or to the first order with correct constant factor. For the ℓ_2^2 distance $\ell_2^2(p,q) \stackrel{\text{def}}{=} \sum_{i=1}^k (p_i - q_i)^2$, we show that

$$r_{k,n}^{\ell_2^2} = \frac{1 - \frac{1}{k}}{(\sqrt{n}+1)^2},$$

Observe that the ℓ_2^2 loss decreases to 0 with n uniformly over all alphabet sizes k. For the remaining divergences we consider, the rate at which the loss decreases with the sample size n will depend on k.

For the chi-squared loss, $\chi^2(p,q) \stackrel{\text{def}}{=} \sum_{i=1}^k \frac{(p_i - q_i)^2}{q_i}$, we show that for any fixed k, as n increases,

$$r_{k,n}^{\chi^2} \sim \frac{k-1}{n}.$$

One of the most important distances in machine learning is ℓ_1, $\ell_1(p,q) \stackrel{\text{def}}{=} \sum_{i=1}^k |p_i - q_i|$. If distributions can be estimated to ℓ_1 distance δ, then an element can be classified to one of two unknown distributions with error probability that is at most 2δ above that achievable with prior knowledge of the distributions.

It is part of folklore that $r_{k,n}^{\ell_1} = \Theta(\sqrt{\frac{k-1}{n}})$. We show that for every fixed k, as n increases,

$$r_{k,n}^{\ell_1} \sim \sqrt{\frac{2(k-1)}{\pi n}}.$$

Finally we consider the min-max loss with the commonly-used family of f-divergence loss functions. Let $f : \mathbb{R}_{\geq 0} \mapsto \mathbb{R}$ be convex and satisfy $f(1) = 0$, then $D_f(p||q) \stackrel{\text{def}}{=} \sum_{i=1}^k q_i \cdot f\left(\frac{p_i}{q_i}\right)$. Many important losses are f-divergences. For example, relative entropy obtained via $f(x) = x \log x$; χ^2 divergence via $f(x) = (x-1)^2$; Hellinger divergence $H(p||q) = \sum_{i=1}^k \left(\sqrt{p_i} - \sqrt{q_i}\right)^2$ via $f(x) = (1 - \sqrt{x})^2$; the ℓ_1 distance (or total variation distance) via $f(x) = |x - 1|$.

We discuss the difficulty with providing a single formula for all f-divergences and show that the challenge arises from distributions that are close to the boundary of the simplex Δ_k, specifically probability distributions that assign probability roughly $\frac{1}{n}$ to some elements. Yet we show that under the common assumption that excludes these extreme distributions and considers only distributions bounded away from the boundary of the simplex, the min-max loss as well as the optimal estimators have a simple form. Let $r_{k,n}^f$ denote the min-max f-divergence for all distributions in Δ_k, and let $\hat{r}_{k,n}^f(\delta)$ denote the same for distributions in the simplex interior, i.e. satisfying $p_i \geq \delta > 0$, for all i. We show that under a mild smoothness condition on the convex function f, namely sub-exponentiality and thrice differentiability in the neighborhood of $x = 1$, the asymptotic loss is determined by the second derivative of f at 1,

$$\hat{r}_{k,n}^f(\delta) \sim f''(1) \cdot \frac{k-1}{2n}.$$

This result provides a simple, unified, understanding of the min-max loss for a large family of f-divergences.

Biography

Alon Orlitsky received B.Sc. degrees in Mathematics and Electrical Engineering from Ben Gurion University in 1980 and 1981, and M.Sc. and Ph.D. degrees in Electrical Engineering from Stanford Universityin 1982 and 1986.

From 1986 to 1996 he was with the Communications Analysis Research Department of Bell Laboratories. He spent the following year as a quantitative analyst at D.E. Shaw and Company, an investment firm in New York city. In 1997 he joined the University of California San Diego, where he is currently a professor of Electrical and Computer Engineering and of Computer Science and Engineering.
His research concerns information theory, statistical modeling, and machine learning.

From 2011 to 2014 Alon directed UCSD's Center for Wireless Communications, and since 2006 he has directed the Information Theory and Applications Center. He is currently the senior vice president of the Information Theory Society. He has co-organized numerous programs on information theory, machine learning, and statistics, including the Information Theory and Applications Workshop that he started in 2006 and has helped organize since.

Alon is a recipient of the 1981 ITT International Fellowship and the 1992 IEEE W.R.G. Baker Paper Award, and co-recipient of the 2006 Information Theory Society Paper Award. He co-authored two papers for which his students received student-paper awards: the 2003 Capocelli Prize and the 2010 ISIT Student Paper Award. He is a fellow of the IEEE, and holds the Qucalcomm Chair for Information Theory and its Applications at UCSD.

Graduated students

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Krishna Viswanathan
Shengjun Pan, Google
Sajama, BlackRock
Narayana Prasad Santhanam, University of Hawaii
Junan Zhang, Oregon Health and Science University

Structured Signal Recovery: Where Least-Squares Meets Non-Smooth Optimization

Babak Hassibi
California Institute of Technology

The classical least-squares problem has figured prominently in many of Professor Kailath's contributions (Kalman filtering, Chandrasekhar recursions, displacement structure, array signal processing, etc., to name a few). In its simplest form, given noisy observations

$$y = Ax + v,$$

where $A \in \mathcal{R}^{m\times n}$ is a known measurement matrix and $v \in \mathcal{R}^m$ is an unkown noise vector, we would like to estimate the unknown signal $x \in \mathcal{R}^n$ via

$$\hat{x} = \arg\min_x \|y - Ax\|_2.$$

Since the mid 90's there has been great interest in the statistics, signal processing and machine learning communities to estimate "structured signals" (such as sparse, constant modulus, low rank, etc.) from noisy observations. This is often achieved by adding a convex, but *non-smooth*, regularizer $f(\cdot)$ to the least-squares cost to obtain

$$\hat{x} = \arg\min_x \|y - Ax\|_2 + \lambda f(x), \tag{1}$$

where $\lambda \geq 0$, is a regularizer parameter. For example, for sparse signals $f(\cdot)$ is the l_1 norm, for constant modulus signals the l_∞ norm, and for low rank matrices the nuclear norm. Such methods have gained popularity (in compressed sensing, say) and are often referred to as the generalized LASSO.

While solving (1) is not an issue (it is, after all, simply a convex program), much less is known about properties of the solution. For example:

1. What is the mean-square error $E\|x - \hat{x}\|_2^2$?

2. How best to choose the regularizer λ?

both of which are of great interest to theorists and practitioners.

We develop a very general framework to address these questions (and much more). The idea is to rewrite (1) in the ostensibly more complicated form

$$\min_x \max_{\|u\|_2 \leq 1} u^T(y - Ax) + \lambda f(x), \tag{2}$$

which we refer to as a *primary optimization problem* (PO). More generally, for any $G \in R^{m\times n}$ with iid $N(0,1)$ entries, we define the PO as:

$$\Phi(G) = \min_{x\in S_x} \max_{u \in S_u} \; u^T Gx + \psi(x,u).$$

Correspondingly, for any $g \in R^m$ and $h \in R^n$ with iid $N(0,1)$ entries, we define the *auxilliary optimization problem* (AO) as:

$$\phi(g,h) = \min_{x\in S_x} \max_{u \in S_u} \; g^T u\|x\|_2 + h^T x\|u\|_2 + \psi(x,u).$$

In [1], we show that when S_x and S_u are convex sets, at least one of which is compact, and $\psi(x,u)$ is a convex-concave function, then properties of the PO, such as the optimal cost, the norm of the solution, etc., can be directly inferred from the corresponding properties of the (much easier to analyze) AO.

For example, let A have iid $N(0,\frac{1}{n})$ and v have iid $N(0,\sigma^2)$ entries, respectively. Then this approach allows one to explicitly compute the optimal λ and to show that, for large m and n:

$$\lim_{\sigma\to 0} E\|x-\hat{x}\|_2^2 = \frac{\omega^2(f,x)}{m-\omega^2(f,x)}\sigma^2,$$

where $\omega^2(f,x)$ is the *expected squared distance of a n dimensional iid $N(0,1)$ vector to the cone of the sub-differential of $f(\cdot)$, evaluated at the true x*, and is referred to as the "squared Gaussian width". It represents the minimum number of measurements required to recover a structured signal from linear observations and can often be straightforwardly computed. For example, for k-sparse signals it is $2k\log\frac{2n}{k}$, for BPSK signals it is $\frac{n}{2}$, and for $n\times n$ rank r matrices it is $3r(2n-r)$.

Depending on time, I will talk about how the origins of these results go back to Gaussian comparison lemmas due to Slepian (1962) and Gordon (1988), and to work by my former student, Mihailo Stojnic. I will also talk about various generalizations to arbitrary σ, arbitrary cost functions (beyond least-squares), other measurement ensembles, and nonlinear measurements and quantization.

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Babak Hassibi

Bio

Babak was a member of TK's group from 1991 to 1998 (5 years as a graduate student and 2 as a postdoc). At Stanford, he worked on H^∞ control and a few other topics (and co-wrote two books with TK and Ali Sayed). Prior to that he obtained his BS from the University of Tehran; immediately afterwards (from 1998 to 2001) he was a Member of the Technical Staff at the Mathematical Sciences Research Center at Bell Laboratories, Murray Hill, NJ, working on wireless communications. Since 2001 he has been at Caltech where he is currently the Gordon M. Binder/Amgen Professor of Electrical Engineering and where he was Executive Officer of the Electrical Engineering Department from 2008 to 2015. With his younger brother, Arjang (another Stanford alum), he has attempted a couple of bio-related startups and is still (patiently) waiting to see whether anythings pans out. His research interests span different aspects of communications, signal processing and control. Among other awards, he is a recipient of the David and Lucille Packard Foundation Fellowship, and the Presidential Early Career Award for Scientists and Engineers (PECASE). He lives in San Marino, CA, with his wife and 13 year-old (boy-girl) twins.

Students

1. Masoud Sharif (PhD 2005) — Boston University (Associate Professor)
   Broadband Wireless Broadcast Channels: Throughput, Performance and PAPR Reduction (winner of Wilts Prize for best thesis in EE)

2. Yindi Jing (PhD 2005) — University of Alberta (Associate Professor)
   Space-Time Code Design and Its Application in Wireless Networks

3. Radhika Gowaikar (PhD 2006) — Qualcomm
   Wireless Networks: New Models and Results

4. Amir Dana (PhD 2006) — Qualcomm
Performance Limits and Design Issues in Wireless Networks

5. Vijay Gupta (PhD 2006) — University of Notre Dame (Associate Professor)
Distributed Estimation and Control in Networked Systems

6. Michela Munoz-Fernandez (PhD 2006) — JPL NASA
Coherent Optical Array Receiver for PPM Signals under Atmospheric Turbulence

7. Chaitanya Rao (PhD 2007) — NEC Research
Asymptotic Analysis of Wireless Systems with Rayleigh Fading

8. Mihailo Stojnic (PhD 2007) — Purdue University (Assistant Professor)
Optimization Algorithms in Wireless and Quantum Communications

9. Weiyu Xu (PhD 2009) — University of Iowa (Assistant Professor)
Compressive Sensing for Sparse Approximations: Constructions, Algorithms and Analysis (winner of Wilts Prize for best thesis in EE)

10. Ali Vakili (PhD 2009) — Goldman Sachs
Random Matrix Recursions in Estimation, Control and Signal Processing

11. Sormeh Shadbakht (PhD 2010) — Goldman Sachs
Entropy Region and Network Information Theory

12. Mohammad Amin Khajehnejad (PhD 2012) — D.E. Shaw
Combinatorial Regression and Improved Basis Pursuit for Sparse Estimation (winner of Wilts Prize for best thesis in EE)

13. Elizabeth Bodine-Baron (PhD 2012) — RAND Corporation
Peer effects in social networks: Search, matching markets, and epidemics

14. Ravi Teja Sukhavasi (PhD 2012) — Qualcomm
Distributed control and computing: Optimal estimation, error-correcting codes, and interactive protocols

15. Subhonmesh Bose (PhD 2014) — University of Illinois, Urbana-Champaign (Assistant Professor)
An Integrated Design Approach to Power Systems: From Power Flows to Electricity Markets

16. Samet Oymak (PhD 2014) — UC Berkeley (Simons Fellow)
Convex Relaxation for Low-Dimensional Representation: Phase Transitions and Limitations (winner of Wilts Prize for best thesis in EE)

17. Hyung Jun Ahn (PhD 2014) — LG Research
Random Propagation in Complex Systems: Nonlinear Matrix Recursions and Epidemic Spread

18. Wei Mao (PhD 2015) — UCLA (postdoc)
Information-theoretic Studies and Capacity Bounds: Group Network Codes and Energy Harvesting Communication Systems

19. Matthew Thill (PhD 2015) — Northrup Gruman
Algebraic Techniques in Coding Theory: Entropy Vectors, Frames and Constrained Coding

20. Masoud Farivar (PhD 2015) — Uber
Control for Distribution Systems with Renewables

Postdocs

1. Haris Vikalo (2003-2007): UT Austin (Associate Professor)
2. Frederique Oggier (2005-2007): Nanyang Technological University (Associate Professor)
3. Masoud Sharif (2005): Boston University (Associate Professor)
4. Farzad Parvaresh (2007-2008): Isfahan University (Assistant Professor)
5. Benjamin Recht (2007-2008): University of California, Berkeley (Associate Professor)
6. Salman Avestimehr (2008-2009): USC (Associate Professor)
7. Alex Dimakis (2008-2009): UT Austin (Assistant Professor)
8. Sormeh Shadbakht (2010-2011): Goldman Sachs
9. Elizabeth Baron-Bodine (2012): RAND Corporation
10. Shirin Jalili (2012): Bell Labs
11. James Saunderson (2015): Monash University (Assistant Professor)

Fraction-Free inversion and factorization of Toeplitz and quasi-Toeplitz matrices

Yuval Bistritz

Tel Aviv University

Abstract.

The well known Levinson algorithm for a Hermitian Toeplitz matrix obtains the inverse of a the matrix and its upper-lower triangular decomposition. The Schur algorithm obtains triangular factorization of the matrix itself. The talk will present fraction-free versions for these algorithms including the cases of not Hermitian quasi-Toeplitz matrices. The fraction-free property means that for a matrix with Gaussian (i.e. complex) integer and real integer entries, the algorithms can be carried out over the respective integral domain and is an efficient integer algorithm (having essentially linear growth of the size of integers). The new algorithms are more suitable for symbolic computation and can be used to defy numerical inaccuracy in the many system and signal processing problems that involve these structured matrices.

Fraction-Free inversion and factorization of Toeplitz and quasi-Toeplitz matrices

Yuval Bistritz
Tel Aviv University

In a paper published in LAA in 1988 [1], Bistritz and Kailath presented fast (i.e. order n^2 flops) algorithms for the inversion and factorization of not Hermitian Toeplitz and quasi-Toeplitz matrices, say $\mathbf{R}_n$. Its novel points were: (i) The extension of the Schur and the Levinson algorithms to not-Hermitian matrices that need pairs of recursions (ii) Their illustration by “left” and “right” pairs of transmission lines (iii) A generalized fast algorithm that produced a factorized $\mathbf{R}_n^{-1}$ also for not admissible QT matrices (iv) Putting the Levinson algorithm for not symmetric Toeplitz matrix in a correct perspective by deducing it as a redundancy of the double recursions that characterize not symmetric cases (the algorithm was known before but its “anomalous” form missed a good explanation).

In order to draw a bit more attention to [1] (ok, I shall try provide more reasons...), my talk will consider fraction-free (FF) versions for (most of) the algorithms considered in it. The presentation will be based on some published conference papers [2]-[4] and a just submitted journal paper [5]. The fraction-free property means that for a matrix with Gaussian (i.e. complex) integer entries, $\mathbf{R}_n \in \mathbb{Z}_{\mathbb{G}}^{(n+1,n+1)}$, or real integer entries, $\mathbf{R}_n \in \mathbb{Z}^{(n+1,n+1)}$, the algorithms can be carried out over the respective integral domain becoming an efficient integer algorithm (one that features restrained growth of the size of integers). The presented FF algorithms are not limited to integer input. They possess some properties that make them interesting for also not integer matrices. However, for integer input they exhibit the mentioned integer preserving property. Due to the exactness of integer computation, the algorithms provide error-free solution for integer matrices, a property that may be rendered to combat degradation in numerical accuracy due to rounding error also for not integer matrices.

The talk will go from the not-symmetric QT matrix down to the Hermitian case, the Toeplitz case and the both Hermitian and Toeplitz case. As a glimpse, here is how the FF Levinson algorithm looks for the a Hermitian Toeplitz matrix.

Assume $\mathbf{R}_n \in \mathbb{C}^{(n+1,n+1)}$ is a Hermitian Toeplitz matrix with $[r_0, r_1, \ldots, r_n]$ as its first row. Let $f_m(z) = \sum_{i=0}^{m} f_{m,i} z^i$, use * and ^{T} to denote complex conjugate and transpose, respectively, and let $f_m^\sharp(z) = \sum_{i=0}^{m} f_{m,m-i}^\star z^i$.

FF Levinson for Hermitian Toeplitz (special case)

Initiation. Set $\varepsilon_{-1} = 1$, $f_0(z) = 1$ and $\varepsilon_0 = r_0$.

Recursion. For $m = 1, \ldots, n$,

$$\delta_m = [f_{m-1,0}, \ldots, f_{m-1,m-1}]\,[r_1, \ldots, r_m]^T \tag{1a}$$

$$f_m(z) = \frac{\varepsilon_{m-1} z f_{m-1}(z) - \delta_m f_{m-1}^\sharp(z)}{\varepsilon_{m-2}} \tag{1b}$$

$$\varepsilon_m = \frac{\varepsilon_{m-1}^2 - |\delta_m|^2}{\varepsilon_{m-2}} \tag{1c}$$

Theorem 1 *For a Hermitian Toeplitz matrix* $\mathbf{R}_n \in \mathbb{Z}_{\mathbb{G}}{}^{(n+1,n+1)}$ *or* $\in \mathbb{Z}^{(n+1,n+1)}$*, the algorithm is FF over* $\mathbb{Z}_{\mathbb{G}}$ *or* $\mathbb{Z}$*, respectively. Namely, all the polynomials coefficients and parameters are integers (in the* $\mathbb{Z}_{\mathbb{G}}$ *or* $\mathbb{Z}$ *respectively) and the computation can be completed over the respective integral domain.*

Let $\ell(b)$ measure the size of an integer $b \in \mathbb{Z}_{\mathbb{G}}$ (the definition for size of integers is close to the number of bits required to present it) and let ℓ_m present the maximal $\ell(f_{m,i})$ among the coefficient of $f_m(z)$. Then ℓ_m in the algorithm grows linearly with m,

$$\ell_m = mB\,,\, m = 1,\ldots,n \tag{2}$$

where B represents the size of the longest entry of the integer matrix. This property combined with the fact that the algorithm is still fast (order n^2 flops) makes it an efficient integer algorithm (by a measure that counts roughly the number of binary operations required to carry out the computation).

Here are some additional properties of the algorithm that hold also for a not integer Hermitian Toeplitz matrix.

Property 2 *The algorithm solves successively the equations*

$$\mathbf{R}_m\,[f_{m,0},\cdots,f_{m,m}]^T = [0,\cdots,0,\varepsilon_m]^T\ ,m{=}0,\ldots,n \tag{3}$$

Property 3 *It produces the factorization (an integer factorization for integer* $\mathbf{R}_n$*)*

$$\mathbf{R}_n^{-1} = \mathbf{F}_n\mathbf{E}_n^{-1}\mathbf{F}_n^H \tag{4}$$

(^{H} *denotes conjugate transpose) where*

$$\mathbf{F}_n{=}\begin{bmatrix} 1 & f_{1,0} & \cdots & f_{n,0} \\ 0 & f_{1,1} & \cdots & f_{n,1} \\ \vdots & & \ddots & \\ 0 & 0 & \cdots & f_{n,n} \end{bmatrix} \tag{5}$$

and

$$\mathbf{E}_n = diag\,[\varepsilon_{-1}\varepsilon_0, \varepsilon_0\varepsilon_1, \varepsilon_1\varepsilon_2,\cdots,\varepsilon_{n-1}\varepsilon_n] \tag{6}$$

Property 4 *All* $\varepsilon_m \in \mathbb{R}$ *(obviously). Furthermore,*

$$\varepsilon_m = \det \mathbf{R}_m\,, \quad m = 0,\ldots,n$$

Property 5 *The familiar reflection coefficients can be recovered by* $k_m = \frac{\delta_m}{\varepsilon_{m-1}}$ *(at the end of exact integer computation in case of an integer matrix)*

As mentioned, I plan to also present FF Schur algorithms.

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Yuval Bistritz

Yuval Bistritz was a postdoc of TK for two years starting in September 1984. He received the B.Sc. in physics and the M.Sc. and PhD in electrical engineering (Summa Cum Laude), in 1973, 1978, and 1983, respectively, all from Tel Aviv University where he is now a professor in the school of electrical engineering. His PhD research won him the 1984 Weizmann fellowship award for postdoctoral research.

Toward completing his PhD research, he presented a new stability test for discrete linear systems in an MTNS held in Israel in 1983 and submitted its generalization into a method to determine zero location of a polynomial with respect to the unit-circle to the Proceeding of the IEEE (where it appeared in December 1984). The test has become known as the “Bistritz test”. It introduced an unexpected alternative to the formulation of Schur-Cohn and Jury and it outstands as the most efficient algorithm to solve the problem. By a lucky coincidence, TK held in 1984 a visiting position in the department of theoretical mathematics at the Weizmann institute in Israel. Yuval came to meet him there, discussed with TK the new stability method and persuaded him to become his post doc at Stanford. The insight of TK on the impact of the new approach on his studies at that time proved to be correct. The posdoc years at Stanford led (in collaboration with Hanoch Lev-Ari) to new and more efficient alternatives (“immittance” algorithms) to the classical (“scattering”) Levinson, Schur and Lattice algorithms and some further research in stability theory also by others (Debajioti Pal) in TK’s group.

Before returning to Tel Aviv University in 1987, Yuval also spent one year as a research scholar at AT&T Bell Laboratories, Murray Hill NJ, working there with Bishnu Atal on speech coding. From 1994 to 1996 he was again in the Stanford vicinity (on time to attend TK’s 60 birthday celebration) serving as consultant for speech processing algorithms to DSP Group in Santa Clara. His immittance spectral pair (ISP) parameters for speech coding have become part of several speech coding standards since 2004 (ITU-T G.722.2.)

He made some additional significant contributions to stability theory. Most notably, he showed that testing 2-D stability can be carried out by a finite number of 1-D zero location tests. He has been consultant to industry and received the distinguished researcher award from the Israeli Technological Committee in 1992. He is Fellow of the IEEE and the recipient of the 2015 IEEE Vitold Belevitch Circuits and Systems Award. The award honors the individual with fundamental contributions in the field of circuits and systems.

Decoding Genetic Variations: Algorithms for Haplotype Assembly

Haris Vikalo

Rapid advances in high-throughput DNA sequencing have enabled unprecedented studies of genetic variations. Information about variations in the genome of an individual is provided by haplotypes, ordered collections of polymorphisms on a chromosome. Knowledge of haplotypes is instrumental in finding genes associated with diseases, drug development and evolutionary studies. Haplotype assembly from high-throughput sequencing data is an NP-hard problem rendered challenging due to errors and limited lengths of sequencing reads. Our key observation is that the minimum error-correction formulation of the haplotype assembly problem is identical to the task of deciphering a coded message received over a noisy channel – a classical problem in the mature field of communication theory. Exploiting this connection, we develop novel haplotype assembly schemes and study the problem from an information-theoretic perspective. An alternative formulation of haplotype assembly as a structured matrix factorization will also be discussed.

Biography

Haris Vikalo received the B.S. degree from the University of Zagreb, Croatia, in 1995, the M.S. degree from Lehigh University in 1997, and the Ph.D. degree from Stanford University in 2003, all in electrical engineering. He held a short-term appointment at Bell Laboratories, Murray Hill, NJ, in the summer of 1999. From January 2003 to July 2003 he was a Postdoctoral Researcher, and from July 2003 to August 2007 he was an Associate Scientist at the California Institute of Technology. Since September 2007, he has been with the Department of Electrical and Computer Engineering, the University of Texas at Austin, where he is currently an Associate Professor. He is a recipient of the 2009 National Science Foundation Career Award. His research interests include signal processing, machine learning, bioinformatics, and communications.

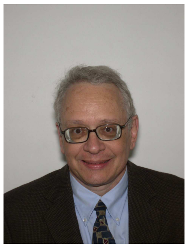
Direct complex envelope sampling of bandpass signals with nonuniformly interleaved 2-channel ADCs

Bernard C. Levy (joint work with A. Van Selow and Mansoor Wahab)

Due to their lower hardare complexity, direct bandpass sampling front ends have become attractive for software defined radio and radar applications. However, if a single ADC is used, and B represents the occupied bandwidth of the signal of interest (which differs from its maximum frequency), alias-free reconstruction of the bandpass signal is not guaranteed for all sampling frequencies Ω_s above the Nyquist frequency $2B$. A much higher sampling rate if often needed to ensure that aliasing does not take place between the negative and positive frequencies of the bandpass signal to be sampled. As early as 1953, Kohlenberg recognized that a simple way of overcoming this difficulty consists of using second-order sampling, i.e. time-interleaved sampling, where two separate ADCs operating with a time skew sample the signal with frequency $\Omega'_s = \Omega_s/2$. In this case, except for certain forbidden values of the timing offset between the two ADCs, the bandpass signal can be reconstructed from the two time-interleaved sample sequences for all sampling frequencies Ω_s above $2B$.

Whereas earlier works have focused on reconstructing the bandpass signal itself from its samples, for modulated signal, it is usually of greater interest to obtain the sampled in-phase and quadrature (I and Q) signal components, i.e., the sampled complex envelope of the signal. In this talk, I will consider the computation of the sampled complex envelope of a bandpass signal from the sequences produced by a two-channel time-interleaved ADC (TIADC) with timing offset dT'_s, where $0 < d < 1$ and $T'_s = 2\pi/\Omega'_s$ denotes the sub-ADC sampling period. No assumption is made about the carrier frequency Ω_c, signal bandwidth B, sampling frequency Ω_s and timing offset d, except that the sampling frequency Ω_s should be above $2B$ and the carrier frequency $\Omega_c > B/2$, which ensures that the signal considered is a bandpass signal. It is shown that the evaluation of the sampled complex envelope requires the implementation of two FIR real filters. As mentioned earlier, certain timing offsets are forbidden, and precise a characterization of the forbidden offsets is provided.

One feature of the proposed reconstruction technique is that as the carrier frequency becomes larger, the reconstruction method becomes progressively more sensitive to timing offset mismatches between the two sub-ADCs. To overcome this problem, a blind calibration method will be outlined.



Bernard Levy's Stanford Memories and Biographical Sketch

I grew up in France and graduated from Mines ParisTech in 1974. Originally founded by Louis XVI, this school had evolved from its original mining mission into a general engineering school with a primary focus on Industrial Engineering. During the second year, I became interested in the field of signals, systems and control which was taught by two freshly returned PhDs from Stanford, Pierre Faurre, who had had been supervised by Rudi Kalman, and Pierre Bernhard, who had been supervised by John Breakwell in the Dept. of Areonautics and Astronautics. For my 3rd year project, Pierre Faurre assigned me the stochastic realization problem for cyclostationary random processes. This topic was about 15 years ahead of its time since the tools developed by my UC Davis colleague Bill Gardner to study cyclostationary processes became only available much later. During this period I became familiar with the sequence of papers written by TK and his students on innovations and their applications to filtering, smoothing and detection. I was very impressed by the inherent beauty of the innovations concept and decided to head to Stanford for my PhD studies.

Stanford was far more of a "Farm" than it is now, and the Palo Alto area was more informal than it is now. Some local landmarks such as Peninsula Creamery or Chef Chu remain, but others have disappeared, such as Cafe Meursault, where I have fond memories of an afternoon spent drinking Vouvray with Freddy Bruckstein and Jean Marc Delosme. The class of incoming ISL graduate students in 1974 was very impressive and included in particular SY Kung, Abbas El Gamal, and my future roommmate Erik Verriest. Lennart Ljung was visiting TK as a postdoc, and we were joined the following year by George Verghese. Ben Friedlander had arrived about 2 years earlier. Although TK's research focus still included filtering and detection, he was in the middle of writing his linear systems theory book, and I found myself sharing an office with SY Kung and George Verghese. All of us ultimately wrote systems theory dissertations and spent many hours teaching each other all the fine points of matrix fraction descriptions, Bezout identities, and system equivalence. We were often engaged in heated cultural and political discussions, but remained strong friends and collaborated on a wide range of research topics, such as 2D systems (the topic of my thesis), or singular/desciptor systems (George's thesis). The most impressive aspect of TK's group at the time was the constant flow of long-term and short term visitors. I remember Lennart Ljung giving a sequence of lectures on recursive identification and teaching us the key ideas behind the ODE method. He was followed the following year by Brian Anderson, who could solve complicated problems in an almost effortless way, and was accompanied by his PhD student Bob Bitmead. Next was Patrick Dewilde, followed by Yves Genin who both had a big influence in recasting fast algorithms from a scattering viewpoint. Seminar speakers and short-term visitors included Howard Rosenbrock, Peter Whittle, Len Silverman, John B. Thomas, among many others. From my perspective, this was almost like heaven on earth. What I learnt most from TK is how to adapt and remain constantly flexible to pick up new ideas and not to overcommit to one line of attack in solving research problems. This was a rather difficult lesson to learn since the French style of research is more linear and rigid. Another manifestation of TK's constant ability to adjust and think on his feet was during lectures. Truth be told, he probably did not spend long hours preparing his lectures on filtering and detection, and on more than one occasion, students in the audience would see him drifting on the wrong path. We usually did not let him know that something was amiss, and a few minutes later, when he would realize something was not right, by using first principles he would move back to the correct spot and proceed to the right conclusion in an effortless manner. It almost looked like magic, and I probably learned more from TK's lecture improvisations than from meticulously prepared presentations.

After leaving Stanford, I joined MIT first as a researcher, and then one year later as a faculty member. It was during that time that Sanjoy Mitter and his student Debra Allinger proved the innovations conjecture, consisting of showing that innovations form a Wiener process, thus bringing the study of innovations to a conclusion. Almost 30 years ago I joined the ECE Department at UC Davis. It is fair to say that over time, my research interests have probably deviated less from TK's than many of his other students. In the 1980s and 1990s, I investigated the estimation of noncausal random processes, such as reciprocal processes and random fields. Over the last 10 years, I have also studied robust estimation, filtering and detection with a Kullback Leibler tolerance. In the filtering case, this leads to connections with risk-sensitive filtering and in the detection case to a class of detectors different from the censored likelihood-ratio class of Huber (the new class creates a dead zone and flattens the likelihood ratio). In the 1980s, with several students, I studied 2-D and 3-D inverse acattering problems, and in particular developed inversion methods based on correlating incident and time-reversed scattered fields (this concept, which was already not new at the time, was subsequently reinvented first as matched field filtering and later as time reversal signal processing) and on generalizations of tomography to projections on conic surfaces. A more recent area of research includes the application of statistical processing techniques to finding and correcting imperfections in analog circuits. My interest in this area, which has been called "digitally assisted analog" by Boris Murmann of Stanford, is a byproduct of my service as ECE Dept. Chair at UC Davis. Two of my analog circuits colleagues, Paul Hurst and Steve Lewis, would often drop by to offer advice on how to run the Department, but the conversation would often move to technical areas, and I realized that many of the problems they were studying were really parameter estimation and adaptive filtering problems.

About ten years ago, I wrote a book on signal detection, and was informed by TK at the time that he had in fact an almost complete unpublished draft of a detection book. In the 1960s and early 70s, signal detection was primnarily formulated in the continuous time, and i expect that like TK's papers of the period, this draft probably involved a heavy reliance on stochastic integration. Modern detection works are far less technical and are usually formulated in discrete-time, but involve a heavy dose of asymptotic statistics and a greater focus on sequential and adaptive decision rules.

My former students include Ahmed Tewfik, currently the ECE Dept. Chair at UT Austin, and Lisa Poyneer of LLNL. Lisa's thesis was on extreme adaptive optics and developed the algorithms used for atmospheric turbulence cancellation in the Gemini Planet Imager deployed last year in Chile. The algorithm relies on Kalman filtering in the Fourier mode domain. Lisa received the Allen G. Marr Prize for Best PhD dissertation at UC Davis in 2008 and in 2010 was inducted the Alameda County Women's Hall of Fame. Finally, another of my PhD students, Jay Kuo of USC, is listed on the Math Genealogy Website as the most prolific thesis adviser (126 PhDS as of 2015). TK is not far behind at 74, but I am pretty certain that his students had a bigger impact! More information can be found at: http://www.ece.ucdavis.edu/∼levy.

LTI - RLC circuits in Willems's behavioral framework

Dedicated to the Memory of Jan Willems

Erik I. Verriest*

Abstract

We apply Willems's methodology [3] of tearing, zooming, and linking to model the behavior of passive linear resistive circuits first. It is shown that circuit analysis is very simple if the elements are described not by potentials across and currents through the elements, but rather by the potentials at the nodes and the external currents into the nodes. For simple resistive components this gives a description with a 2×2 matrix, which is more complex than the scalar constitutive laws governing the potential across and current through. However this description has an advantage in performing the analysis of more complicated circuits by simple operations like joining two nodes, splicing at nodes, and minimalization. The purpose is to present necessary and sufficient conditions that govern the terminal voltage/current behavior of such a circuit. In its simplest form, these conditions require the matrix that relates the voltage vector to the current vector to be *symmetric hyperdominant with zero excess*. We also discuss the decomposition of a resistive circuit into a set of indecomposable components.

Next, these results are extended for simple R, C or L components circuits. A constructive procedure is given by joining purely resistive, capacitive or inductive sub-circuits to show that the behavior is represented by a rational matrix which is symmetric, positive real, with zero row and column sums and hyperdominant with zero-excess *on the positive real axis*. Sufficiency is still unsettled.

Introduction

We view an electrical circuit as a device that interacts with its environment through a finite number of wires (henceforth called *terminals* and denoted by $t_1, t_2, \ldots, t_{|\mathbb{T}|}$), as illustrated in the figure. Associated with each terminal, there is a *potential* and a *current* (by convention counted positive

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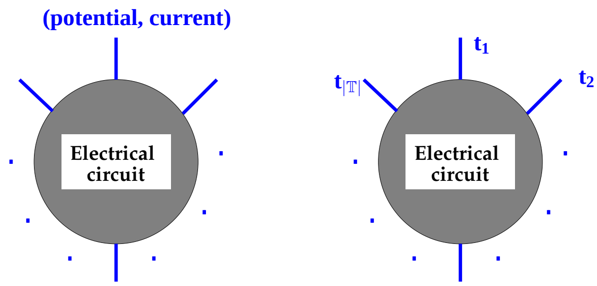
This is joint work with Jan while I was on sabbatical at the KUL-Leuven, Leuven, Belgium.



when it runs into the circuit). Even though only potential differences are physically measurable, we consider the terminal potentials and the currents as the essential quantities which describe how a circuit interacts with its surroundings. This is formalized by the use of *digraphs with leaves* [4].

In the first part of this presentation we restrict attention to memoryless circuits, where only the instantaneous behavior matters. The set of pairs $(P,I) \in \mathbb{R}^{|\mathbb{T}|} \times \mathbb{R}^{|\mathbb{T}|}$ that are compatible with the internal structure of the circuit and resistor values forms a subset $\mathscr{B} \subseteq \mathbb{R}^{|\mathbb{T}|} \times \mathbb{R}^{|\mathbb{T}|}$ called the *terminal behavior* of the circuit. $(P,I) \in \mathscr{B}$ means that the circuit allows the vectors (P,I) of terminal variables, while $(P,I) \notin \mathscr{B}$ means that the circuit forbids the vectors (P,I) of terminal variables. In [5] we studied which subsets $\mathscr{B} \subseteq \mathbb{R}^{|\mathbb{T}|} \times \mathbb{R}^{|\mathbb{T}|}$ as the terminal voltage/current behavior of an interconnection of a finite set of linear nonnegative resistors. See also [1]. Assuming that potentials and currents are expressed in some units (say, volts and amps), we obtain that the instantaneous interaction of the circuit with its surroundings is specified by a matrix $G \in \mathbb{R}^{|\mathbb{T}| \times |\mathbb{T}|}$.
The second part, presented in [2], concerns the investigation of the behavior of RLC circuits where now $(P,I) \in \mathscr{B} \subseteq (\mathbb{R}^{|\mathbb{T}|} \times \mathbb{R}^{|\mathbb{T}|})^{\mathbb{R}}$. For insights on ports and their role in energy transfer, see [4].

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Biography

Erik I. Verriest received the degree of 'Burgerlijk Electrotechnisch Ingenieur' from the State University of Ghent, Ghent, Belgium in 1973 with a thesis on the stability of systems with several equilibria, and the MSc and PhD degrees from Stanford University in 1975 and 1980, respectively. He was with the Control Systems Laboratory and the Hybrid Computation Centre, Ghent, Belgium, working on process simulation and control in 1973-74. His doctoral research at Stanford was on the algebraic theory and balancing for time varying linear systems and sensor arrays. He joined the faculty of Electrical and Computer Engineering at Georgia Tech in 1980 and spent the 1991-92, 1993-94 and 1994-95 academic years at Georgia Tech Lorraine. He was on leave at the KU Leuven, Leuven, Belgium in the Fall of 2008 and the Julius Maximilian Universität in Würzburg, Germany in the Fall of 2015. He has also held short visiting positions at the University of South Florida (1980), Stanford University (1981) the Université catholique de Louvain, Louvain-la-Neuve, Belgium (1991). He taught 28 different topics in his 35 years at GT, ranging over mathematics, stochastics, signal analysis and processing, circuits theory, communication, and control. His earlier research centered on the application of the theory of systems over finite fields in cryptography, data compression, sensitivity analysis of array algorithms with applications in estimation and control, algorithms for optical computing. His present interests are in mathematical system theory. He contributed to the theory of periodic and hybrid systems, delay - differential systems, model reduction for nonlinear systems, control with communication constraints, locomotion and optimal control. He served on several IPC's and is a member of the IFAC Committee on Linear Systems and the IFAC Committee on Optimal Control. He is director of the Mathematical System Theory Laboratory (MASTLab), a Fellow of the IEEE and an elected (2012) member of the Royal Flemish Academy of Belgium for Science and the Arts.

Erik I. Verriest

Students

PhD Students supervised/co-supervised

Jose Ramos: Thesis: A Stochastic Realization and Model Reduction Approach to Streamflow Modeling, December 1985. [Co-advised with Prof. S. G. Rao, School of Civil Engineering.] Present Position: Nova Southeastern University, Computer Science, Fort Lauderdale, Florida, Associate Professor. University and Purdue University, Professor.

W. Steven Gray: Thesis: A Geometric Approach to the Parametric Sensitivity of Dynamical Systems, August 1989. Present Position: Old Dominion University: Professor. Thesis nominated for the Sigma Xi Best Thesis Award by the School of Electrical Engineering. Dr. Gray received a Presidential Fellowship at Georgia Tech.

P. Baeil Park: Thesis: Canonical Forms for Time-Varying Multivariable Linear Systems and Periodic Filtering and Control Applications, December 1991. Present Position: IBM Federal Systems Company, Rockville, MD. Senior Systems Engineer.

Dong-Ryeol Shin: Thesis: Optimal Control of a Finite State Markov Process under Counting Observation and Applications to Integrated Networks, June 1992. Present Position: Sung Kwun Kwan University, Korea. Dean of Information and Communication Engineering. Thesis nominated for the Sigma Xi Best Thesis Award by the School of Electrical Engineering.

Brad Lehman: Thesis: Vibrational Control of Nonlinear Time-Delay Systems, June 1992. [Co-advised with Prof. Jack Kale, School of Mathematics]. Present Position: Northeastern University. Professor. Dr. Lehman received a Presidential Faculty Fellow Award.

Woihida Aggoune: Thesis: Contribution à la Stabilisation de Systèmes Non Linéeaires: Application aux Systèmes Non Réguliers et aux Systèmes à Retards. June 1999. [Co-advised with Prof. G. Sallet, Dep. de Mathematique, Universite de Metz, and INRIA Lorraine, Metz, France, 1994-1997]. Present Position: Ecole Nationale Superieure de lElectronique et de ses Applications, Cergy-Pontoise, France. Professor.

Mile Milisavljevic: Thesis: Information Driven Techniques with Applications in Control Systems, Signal Processing, Telecommunications and Stochastic Finance, May 2001. Cicada Semiconductor, Austin, TX. Present Position: Bain & Company, Houston, TX. Manager. This thesis won the Sigma Xi Best Ph.D. Thesis Award in 2002.

Deryck Yeung: Thesis: Maximally Smooth Transition: The Gluskabi Raccordation, August 2011. Present Position: Penn State Erie, The Behrend College,Pennsylvania, Lecturer in Electrical and Computer Engineering

Jackie H Crawford III; Thesis: Factors that Limit Control Eectiveness in Self-excited Noise Driven Combustors, March 2012. [Co-advised with Professor Tim Lieuwen, AE]. Present Position: Raytheon Missile Systems. Senior Systems Engineer.

Basit Memon: Fullbright Scholar. Thesis: Graceful Connections in Dynamical Systems - An Approach to Gait Transitions in Robotics, December 2014. Thesis nominated for the Sigma Xi Best Thesis Award by the School of Electrical Engineering. Present Position: School of Habib university, Karachi, Pakistan, Assistant Professor

Present PhD Students

Nak-seung Patrick Hyun: Advisement started Summer 2012. Research in Mathematical System Theory.

Aftab Ahmed: Fullbright Scholar. Advisement started Fall 2012. Research on Delay Systems.

Ben Davis Advisement started Fall 2013. [Co-advised with William Dale Blair, GTRI]. Research in Nonlinear Estimation for Radar Applications.

Naren Gupta
Co-Founder and Managing
Director Nexus Venture Partners

Naren Gupta co-founded Nexus Venture Partners in 2006.

Nexus Ventures is India's leading early and early-growth stage fund. Nexus invests in start-ups in technology, Internet, media and consumer and business services. We are a team of successful investors and entrepreneurs, who understand the unique challenges faced by entrepreneurs and know that it takes teamwork and exceptional execution for a company to succeed. We help our partner companies in recruiting talent, forging new alliances, opening doors to new customers, shaping strategy and connecting with best-of-breed executives, advisors, co-investors and board members. Naren's past investments include Numerical Technology (IPO:NMTC), Right Now (IPO: RNOW), ETEK Dynamics (IPO:ETEK), cloud.com (acquired by Citrix), Gluster (acquired by Red Hat), DimDim (acquired by Salesforce) and Netmagic Solutions (acquired by NTT). The fund is based in Menlo Park, CA with offices in Mumbai and Bangalore, India.

Prior to launching Nexus, Naren cofounded Integrated Systems Inc. (ISI), a leading embedded software company in 1980 and took it public in 1990. He served as ISI President/CEO until 1994 and as its Chairman till ISI merger with Wind River in 2000. He subsequently served as Vice-Chairman and interim CEO of Wind River Systems.

Naren is currently a trustee of the California Institute of Technology and a board member of Red Hat (NYSE:RHT). He has previously served on numerous public and private company boards.

Naren holds a B. Tech. from the Indian Institute of Technology (IIT) where he received the President's Gold Medal, an MS from the California Institute of Technology and a Ph.D. from Stanford University, all in engineering. He has been named distinguished alum at IIT and Caltech.

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Dr. Norman F. Krasner

Biography and Thoughts to be Elucidated

Biography

Dr. Krasner received his BSEE from MIT in 1968, MSEE in 1970 from Stanford and PhD, under Prof Kailath, in 1974.

From 1968 (as a coop student) until 1990 I worked for a variety of companies, governmental and commercial performing various engineering functions in the areas of communications research and design and digital signal processing. From 1990 to 1995 I was an independent consultant working on projects that ranged from radar and geolocation, to cable communication systems, to LAN design for gas meter readers, digital over the air TV, surround sound, and many others.

In 1995 I cofounded SnapTrack with Steve Poizner, which pioneered the development of Assisted GPS, which combines cellular transmissions and satellite navigation to provide dramatically improved performance of geolocation in terms of sensitivity, time to first fix and reliability.

I received the Thurlow Prize from the Institute of Navigation in 1999 for the development of Assisted GPS technology. Assisted GPS is widely used today and forms the basis of the majority of E911 location in todays cellphones

SnapTrack was acquired by Qualcomm in March 2000. Since that time Assisted GPS technology has been incorporated in the GPS chip sets that Qualcomm builds, and hence handsets, that Qualcomm has enabled. It is estimated that over 1 billion cellphones have been enabled with this technology.

Since leaving Qualcomm in 2005 I have been doing independent consulting, particularly in the improvement of various geolocation technologies. I hold over 80 patents.

Personal Thoughts about Tom Kailath

Tom demonstrated, by example and suggestion, scholarship and diversity

I recall him always asking what some solution means—does it make sense

Tom looked for patterns in things. If an answer to a problem looked too simple, there must be a better, and more general way to get to it.

When I was at Stanford I think Tom said he did not think of himself as an Engineer? (I think he said he could not fix a TV set). Then, what's with all these successful companies he founded? Somehow engineering came to him rather than the other way around.

Where is the book on Communications? I am patiently waiting. Tom once said writing books is for old people. Well I certainly would not call Tom old, but we need to discuss this.

Dr. Debajyoti Pal
Biography

Dr. Debajyoti (Debu) Pal has held the position of Senior Vice President and Chief Technology Officer at Ikanos Communications, Inc. since August 2009. He is a 30-year veteran of the communication and semiconductor industry, a copper broadband access pioneer and, one of the leading innovators in the areas of xDSL and G.fast (Gigabit over phone line) technologies. Dr. Pal has developed technology and chipset products for ADSL, VDSL, G.SHDSL (Symmetric DSL), Vectored VDSL, G.fast and FDD Gigabit Copper Access for Japan & Korea.

At Ikanos he has pioneered Gigabit Copper Access technology for Japan & Korea – 1Gbps+ speed over telephone lines while coexisting with legacy 30MHz VDSL2 lines in the same cable/binder.

Some of his other key accomplishments at Ikanos include development of lowest power/port & highest performance G.fast worldwide, development of Node Scale Vectoring (NSV) technology which cancels Far End Crosstalk (FEXT) across a node (up to 384 ports). Dr. Kevin Fisher and Dr. Nick Sands (both were former Ph.D. students of Prof. John Cioffi at Stanford) lead this project, while reporting to Dr. Pal. NSV is the 2013 winner of "Best Broadband Enabler Award" at the Broadband World Forum (BBWF). Dr. Pal pioneered "inSIGHT™ Broadband eXperience Manager" (BXM) – an IoT, WAN & LAN diagnostic suite. It runs on the CPE GW or the in the Cloud. inSIGHT™ BXM is the 2014 winner of the Solutions Product of the Year Award from TMC.

On the strategic front, he played a central role in convincing Alcatel-Lucent to partner with Ikanos on their Ultra Boardband products (G.fast, VPlus, Vectored VDSL2 etc.) based on superiority of Ikanos' technology (especially, vectoring and low power analog), over the competitors. Dr. Pal also actively acquired technology plus teams and successfully integrated them. These are, (a) Vector Silicon: A small company of Stanford Ph.D.s with key IP in Vectored VDSL2, (b) Renovus: A small company of Stanford PhDs with breakthrough IP in Ultra Low Power High Resolution & High Speed Data Converters (~10x lower power compared to the state of the art) and, (c) Sandbridge Core: Licensed industry's prized Software Defined Radio (SDR) DSP Core from Sandbridge technologies and hired a team of Sandbridge engineers.

He created university initiative at Ikanos by launching and managing a funded research program on Copper Broadband Access at IIT Delhi. Several professors, Ph.D. and M.Tech. students are involved in active research in the areas of G.fast, Vectoring, Noise Analytics etc. This program has so far generated many papers as well as U.S. patents.

Prior to Ikanos, Dr. Pal was Chief Technology Officer (CTO) of Tallwood Venture Capital. He originally joined the venture fund as an Executive in Residence in 2004. He focused on communications, networking, mixed signal semiconductors and MEMs investments as well as oversaw its technology roadmap. He evaluated over 200 business plans, drove due diligence and made investments in 5 companies; four of these have already been acquired. Last but not the least, he drove Tallwood's investment in Ikanos communications in 2009. It was a Private investment in Public Equity (PIPE) in Ikanos Communications Inc. (NASD: IKAN) along with concurrent asset purchase of Conexant Broadband Access. Ikanos is currently being acquired by Qualcomm Inc. and the acquisition is expected to close by the end of 2015.

As part of his CTO responsibilities, he was chartered with tracking technology disruptions and driving Tallwood's technology roadmap from an investment perspective. He ran strategic initiatives for investing in certain technology/market areas of interest, that led to a Series A or B and, incubation of a seed stage company. He also played a key role in formulating Tallwood's mobility/handset strategy. In particular he was responsible for driving "Radio Initiative", an internal initiative to build a long term vision to proactively invest in and/or seek out entrepreneurs/incubate startups that would define and create leaders for next generation of radios. This led to an investment in Sandbridge Technologies, a programmable multi-mode baseband chip company, and incubation of Renovus, a Stanford startup focusing on ultra-low power high resolution, high speed ADC, much needed for programmable ultra-low power RF transceivers. He also managed Tallwood's University initiative; a program for promoting entrepreneurship and identifying early stage ideas that could potentially lead to tomorrow's successful startups. Built relationships with the faculty at a number of major US Universities including Stanford, Berkeley, Carnegie Mellon, Caltech, UCLA, UCSD, and UT Austin.

Dr. Pal has more than 30 years of research and development and general management experience in semiconductors and communications. Prior to Tallwood, he cofounded Telicos Corp., a Silicon Valley startup developing technology and chipset for 10 Gigabit Ethernet over copper Physical Layer (10GBASE-T). Telicos secured $250K in seed funding from NEC Electronics Corp. and $90K in seed money from Tallwood Venture capital. The project was stopped in early 2004, due to lack of market visibility and uncertainty with timing and size of the market for 10GBE over copper based on Tallwood Venture Capital's recommendation.

Prior to Telicos, he was Vice President of Technology & Product Development of Virata/Globespan Virata. At Virata, Dr. Pal was responsible for the development of all Physical Layer Technologies and Chipset Products, including ADSL, HDSL2 and G.SHDSL. The products included multi-port CO products and CPE products including ADSL CPE router chip set.

In 1998 he cofounded (with Prof. Thomas Kailath of Stanford University) Excess Bandwidth Corporation, which developed HDSL2 and G.SHDSL semiconductor. Dr. Pal was the Chief Technology Officer and Vice President of Engineering until August 2000 when it was acquired by Virata (NASD: VRTA). Upon acquisition by Virata, assumed the responsibility of Physical Layer Chipset (All xDSL chipset products) development there while reporting to the President and COO. Prior to this, he held senior technical and technical management positions at Amati Communications, where he developed ADSL and VDSL technologies. Amati was acquired by Texas Instruments in early 1998. Before joining Amati in 1994, he spent many years working on digital communications and VLSI architectures at AT&T Bell Laboratories, Holmdel, NJ, USA. Dr. Pal started his career at Intel Corporation, where he was a member of the 80286 microprocessor design team. Dr. Pal holds eight granted U.S. patents, has published more than 30 technical papers. He was a Consulting Professor of Electrical Engineering at Stanford University between 1997 and 2009. Dr. Pal has been a Fellow of the IEEE since 2002. He received a B.Tech. (Hons.) degree in electronics and electrical communication engineering from the Indian Institute of Technology (IIT) Kharagpur, India, a M.S.E.E. degree from Washington State University and a Ph.D. in electrical engineering from Stanford University. In 2003, he was elected a Chartered Member of The Indus Entrepreneurs (TiE) for demonstrated industry leadership and entrepreneurship.

Glenn Gulak
Biography

Dr. Glenn Gulak is a Professor in the Department of Electrical and Computer Engineering at the University of Toronto. His present research interests are in the areas of algorithms, circuits, and CMOS implementations of high-performance baseband digital communication systems and, additionally, in the area of CMOS biosensors. He has received numerous teaching awards for undergraduate courses taught in both the Department of Computer Science and the Department of Electrical and Computer Engineering at the University of Toronto. He received his MASc and Ph.D. degrees from the University of Manitoba. He was a postdoctoral researcher from Jan. 1985 to Jan. 1986 in the Computer Systems Laboratory and from Jan. 1986 to Jan. 1988 in the Information Systems Laboratory at Stanford University. At the University of Toronto he has held the L. Lau Chair in ECE, the Edward S. Rogers Sr. Chair in ECE and a Canada Research Chair – Tier 1. He has served on the ISSCC Signal Processing Technical Subcommittee from 1990 to 1999, and served as the Technical Program Chair for ISSCC 2001. From 2001 to 2003, he was CTO and VP Engineering of Valence Semiconductor located in Irvine, California. He served on the Technology Directions Subcommittee for ISSCC from 2005 to 2008. He currently serves as the Vice-President of the Publications Committee for the IEEE Solid-State Circuits Society and as an elected member of the IEEE Publication Services and Products Board (PSPB).

Academic Website: www.eecg.toronto.edu/~gulak

Mohamed T. Hadidi
Biography

Mohamed T. Hadidi, Ph.D. Mohamed received his undergraduate degrees in Electrical Engineering and Mathematics from Cairo University, and his M.S. and Ph.D. in Electrical Engineering from Stanford University. Upon receiving his Ph.D. in 1983, Mohamed joined Mobil R&D at Mobil Dallas Research Lab, and following the Exxon-Mobil merger in 1999, worked at ExxonMobil Upstream Research Company (EMURC) until 2006. His main areas of research in seismic signal processing were signal enhancement, deconvolution and wavelet processing, and multiple attenuation (dereverberation, echo cancellation). At Mobil and ExxonMobil Mohamed developed with his colleagues leading-edge technologies in wavelet processing and multiple attenuation for which he was awarded four patents. He served on the Advisory Board of DELPHI, a Delft University Consortium covering seismic acquisition, processing, reservoir characterization, and reservoir monitoring, from 2002 to 2013. In 2008, Mohamed received on behalf of ExxonMobil the Distinguished Achievement Award of the Society of Exploration Geophysicists (SEG) for contributions by the SMART JV (of which Mobil was a member represented on the technical committee by Mohamed) to the advancement of seismic technology in multiple attenuation and wide-azimuth seismic acquisition and processing. In 2006, Mohamed was seconded by ExxonMobil to Abu Dhabi Company for Onshore Oil Operations (ADCO). In March 2013, Mohamed retired from Exxon Mobil, but continued working for ADCO as ADCO's seismic processing specialist.

Prof. POOGYEON PARK

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Summary

Prof. PooGyeon Park received his B.S. degree and M.S. degree in Control and Instrumentation Engineering from Seoul National University, Korea, in 1988 and 1990, respectively, and the Ph.D. degree in Electrical Engineering from Stanford University, U.S.A., in 1995. Since 1996, he has been affiliated with the Department of Electronic and Electrical Engineering at Pohang University of Science and Technology (POSTECH), where he is currently a professor. His current research interests include convex optimization theories and their applications in control, estimation and signal processing.

Education

Ph.D. (EE)	**Stanford Univ., Stanford, CA, USA**, Sep. 1995, Advisor: T. Kailath. *Convex Optimization Techniques in Control and Estimation*
M.S. (EE)	**Seoul National Univ., Seoul, Korea**, Feb. 1990, Advisor: W. H. Kwon. *A Study on Algebraic Riccati Equations and Their Applications to* $\mathcal{H}_\infty$ *Control*
B.S. (EE)	**Seoul National Univ., Seoul, Korea**, Feb. 1988, Advisor: W. H. Kwon. *Implementing a 16-bit micro-system with 'XINU' O/S*

Interest Areas

Control	LPV, RH, Fuzzy, Delay, Networked Control, and so on
Signal Processing	NLMS, APA, and robust algorithms in Adaptive Filtering
Detections	PDP-LCD Panel Fault Detection, Iron Panel Shape Detection

Honors and Awards

IJCAS Outstanding Service Award, 2013.
ICCAS Best Paper Award, 2011.
IROS'99 Academic Research Award, 1999.
Korean Government Scholarship for Overseas Study, 1990–1993.
Superior Academic Achievement Award, Seoul National University, 1989–1990.
Summa Cum Laude, Seoul National University, 1988.
Bronze Medal for the 12th Student Papers Contest, Korea Research Foundation, 1988.
Superior Academic Achievement Award, Seoul National University, 1986–1988.

SPaC (Signal Proc. & Control Systems) Lab.

Web address	http://spac.postech.ac.kr
Members	9 Ph.D. candidates, 5 M.S. candidates
Theory Teams	for Control Theories, for Adaptive Filtering Theories
Project Teams	for High-speed Inspection Systems, for Control Applications

Books

J. H. Chun, P. Park, W. H. Kwon, “Digital signal processing using Matlabm” Sigma Press, Seoul, May 1998 (translated and reorganized from “Disital signal processing using the ADSP-2102” by V. K. Ingle and J. G. Proakis in 1991).
J.W. Ko and P.G. Park, Reciprocally Convex Approach for the Stability of Networked Control Systems, Chapter 1 (pp.1-10) in Intelligent Control and Innovative Computing Springers (edited by Sio Iong Ao, Oscar Castillo, and Xu Huang), Springer, 201201.
S.H. Kim and P.G. Park, Control of T-S Fuzzy Systems Using Fuzzy Weighting-Dependent Lyapunov Functionby, Chapter 3 (pp.41-68) in Fuzzy Systems (edited by Ahmad Taher Azar), Intech, 201002.
S.H. Kim and P.G. Park, Stabilization of Networked Control Systems with Input Saturation, Chapter 22 (pp.405-416) in Ferroelectrics (edited by Indrani Coondoo), Intech, 201012.

Most cited papers (by Google Scholar, 20150725)

572 times cited **[1]** “Reciprocally convex approach to stability of systems with time-varying delays,” *Automatica*, vol.47(1), (2011.01)

1300 times cited **[2]** “Delay-dependent robust stabilization of uncertain state-delayed systems,” *Int. J. Control*, Vol.74(14), pp.1447 - 1455 (2001.09)

804 times cited **[3]** “A delay-dependent stability criterion for systems with uncertain time-invariant delays,” *IEEE Trans. Auto. Cntr.*, vol. 44, no. 2, pp. 876-878, (1999.02)

Fact 1 Opened a new area of control theory, **delay system theories**, by supplying
the first kind of Integral Inequality Lemma [3]
the second kind of Integral Inequality Lemma [2]

Fact 2 Recently developed another tool for delay system theories,
“**Reciprocal Convexity Inequlaity Lemma [1]** ” in 2011, which has shown tremenduous incremental in terms of the number of citations. Among **212,886 documents since 2010** (by Scopus on 25 July in 2015, subject area [engineering,mathematics, computer science] and source title [control, mathematics, automatica, automatic]), *including those in* ***Automatica*** *and* ***IEEE Trans. on Automatic Control***, **[64] in 2011** locates on **the first rank** as the most cited paper.

An Appreciation

by **Vwani Roychowdhury**

In a perceptive letter in 1995, James Gibbons, then the Dean of Engineering at Stanford, wrote to Thomas Kailath ("TK" to many): "your career has been an extraordinary success many times over, and for a different set of reasons each decade. I have never seen anything like it in 40 years of service at Stanford. … Naturally, we do not expect you to stop work just because it's your 60th birthday. ….The question is simply where your imagination will carry you next."

How prophetic! Since then, TK's imagination has indeed continued on its busy journey. Responding to a challenge from DARPA to show the value of control and signal processing in the area of semiconductor manufacturing, an application totally different from all his previous domains, his group developed successful control algorithms for the then new technology of rapid thermal processing of semiconductor wafers. The next challenge was the area of optical lithography, which was the bottleneck in semiconductor manufacturing technology, and at that time was facing an apparent (so-called 100 nanometer) barrier to the continued use of optical lithography to produce wafers with ever smaller critical dimensions. Combining ideas from communication theory and signal processing , his group proposed the concept of a double exposure patterning of phase shifting to extend the life of optical technology. Working with Motorola, a chip with 90 nm features was produced . With further high-resolution enhancement techniques, optical lithography is now being used to manufacture devices with critical dimensions of 14 nm.

Professor Kailath's life is a tale of many such instances of "TK-magic", strewn generously over the more than four decades of his professional life. After the first decade of individual contribution, with striking new results and approaches in signal detection and estimation theory, a new pattern emerged: targeting a challenging set of problems in a new field, inspiring a new set of associates and students to create a powerful team, followed by lasting contributions, rooted in rigorous mathematics.

It is a striking characteristic of TK's work that it not only provides solutions to the original problems, but also constructs new bridges among fields, thereby generating further insights and innovations. The result is an intricate web of intellectual threads and connections woven among many apparently disparate areas. A quick tour of the areas he has worked in shows an emphasis on information theory and communications in the 60's; linear systems, estimation and control in the 70's; VLSI design, sensor array signal processing and matrix displacement structure theory in the 80's; and applications to semiconductor manufacturing and wireless communications in the 90's; and all along, with continuing contributions to probability and statistics, linear algebra and operator theory.

Any tribute would be incomplete without mentioning his dedication to fostering a rigorous intellectual culture, while inspiring a stellar array of over a hundred doctoral and postdoctoral scholars, many of whom have gone on to become leaders in academia and in industry. Their research was enhanced by his attracting many leading scholars from around the world for short and long-term visits. Professor Kailath also led the Information Systems Laboratory from 1971-81, helping to build ISL into a brand name recognized around the world.

Our collective best wishes to Professor Kailath as he travels to wherever his imagination carries him next!

Curriculum Vitae-Thomas Kailath

Hitachi America Professor of Engineering, Emeritus
Information Systems Laboratory, Dept. of Electrical Engineering
Stanford, CA 94305-9510 USA
Tel: (650) 494-9401
Email: kailath@stanford.edu, profkailath@yahoo.com

Fields of Interest: Information Theory, Communications, Computation, Control, Linear Systems, Statistical Signal Processing, VLSI systems, Semiconductor Manufacturing and Lithography. Also Probability, Statistics, Linear Algebra, and Operator Theory.

Home page: www.stanford.edu/~tkailath

Born in Poona (now Pune), India, June 7, 1935.
In the US since 1957; naturalized: June 8, 1976

B.E. (Telecom.), College of Engineering, Pune, India, June 1956
S.M. (Elec. Eng.), Massachusetts Institute of Technology, June, 1959
Thesis: *Sampling Models for Time-Variant Filters*
Sc.D. (Elec. Eng.), Massachusetts Institute of Technology, June 1961
Thesis: *Communication via Randomly Varying Channels*

Positions

Sep 1957- Jun 1961 : Research Assistant, Research Laboratory for Electronics, MIT
Oct 1961-Dec 1962 : Communications Research Group, Jet Propulsion Labs, Pasadena, CA. Also Visiting Assistant Professor at Caltech
Jan 1963- Aug 1964 : Acting Associate Professor of Elec. Eng., Stanford University
(on leave at UC Berkeley, Jan-Aug, 1963)
Sep 1964-Jan 1968 : Associate Professor of Elec. Eng.
Jan 1968- Feb 1968 : Full Professor of Elec. Eng.
Feb 1988-June 2001 : First holder of the Hitachi America Professorship in Engineering
July 2001- : Hitachi America Professorship in Engineering, *Emeritus*; recalled to active duty to continue his research and writing activities.

He also held shorter-term appointments at several institutions around the world: UC Berkeley (1963), Indian Statistical Institute (1966), Bell Labs (1969), Indian Institute of Science (1969-70, 1976, 1993, 1994, 2000, 2002), Cambridge University (1977), K. U. Leuven (1977), T.U. Delft (1981), Weizmann Institute (1984), Imperial College (1989), MIT (1991), UCLA (2001),T. U. Munich(2003).
At Stanford, Kailath served as Director of the Information Systems Laboratory during a decade of rapid growth from 1971 to 1981, and built it into a world-leading center for communications, control and signal processing research. He served on the Executive Committee of the department from 1971 to 1987 and as Associate Chair from 1981 to 1987. He was also twice elected to the Senate of the University.

Academy Memberships

US National Academy of Engineering, 1984: *"for contributions to prediction and filtering and for leadership in engineering."*
American Academy of Arts and Sciences, 1994
US National Academy of Sciences, 2000
TWAS (Academy of Sciences of the Developing World), 1991-Foreign Associate
Indian National Academy of Engineering, 1997- Foreign Associate
Royal Spanish Academy of Engineering, 2003- Foreign Member
National Academy of Sciences, India, 2009-Foreign Member
Royal Society of London, 2009-Foreign Member
Indian Academy of Sciences, 2013-Honorary Fellow
Indian National Science Academy, 2014-Foreign Member

Honorary Degrees

1990: Linköping University, Linköping, Sweden
1992: Strathclyde University, Glasgow, United Kingdom
1999: University of Carlos III, Madrid, Spain
2003: University of Bordeaux I, Bordeaux, France
2004: Shanghai Jiao Tung University, Shanghai, China (Honorary Professor)
2009: Visvesaraya Technological University, Bangalore, India
2011: Technion-The Israel Institute of Technology, Haifa, Israel

Major Fellowships

Guggenheim Fellowship: held at Indian Institute of Science, Bangalore, 1970
Churchill College, Cambridge University: Life Fellow, 1977-
Michael Visiting Chair in Mathematics, Weizmann Institute, Israel, 1984
Royal Society Guest Research Fellowship, Imperial College, London, 1989
Senior Vinton Hayes Fellowship: MIT, 1991
Jawaharlal Nehru Professorship, Indian Institute of Science, 2000
Senior Humboldt Fellowship: held at Technical University of Munich, 2003

Professional Society Fellowships

IEEE, 1970: *"for creative contributions to, and inspired teaching of, information, communication and control theory"*
Institute of Mathematical Statistics, 1975:
SIAM (Society of Industrial and Applied Mathematics), 2009: *"for contributions to linear algebra, systems and control and their applications in engineering."*

Major Medals and Awards

US National Medal of Science, **2012**: *" for transformative contributions to the fields of information and system science, for distinctive and sustained mentoring of young scholars, and for translation of scientific ideas into entrepreneurial ventures that have had a significant impact on industry"*
Athanasios Papoulis Award, **European Signal Processing Society, 2012**:*"for outstanding lifelong contributions to signal processing research and teaching"*
Vladimir Karapetoff Outstanding Technical Achievement Award, IEEE Eta Kappa Nu Society, 2011: *"for outstanding research and teaching in the fields of telecommunications, information theory, signal processing, and linear systems"*.
BBVA Foundation Frontiers of Knowledge Award, 2010: "*for contributions to creating knowledge with transformative impact on the information and communication technologies that permeate everyday life.*"
Padma Bhushan, 2009: **third highest civilian honor of the Government of India**: "*for distinguished service to the nation in the field of science and engineering.*"
Blaise Pascal Medal, **European Academy of Sciences, 2009**: *"for lifelong contributions to information and communication sciences.*"
College of Engineering, Pune,2009: First inductee of the COEP Alumni Hall of Fame.
IEEE Medal of Honor, 2007: "*for exceptional contributions to the development of powerful algorithms for communications, control, computing and signal processing*."
IEEE Jack S. Kilby Signal Processing Medal, **2006**: "*for seminal contributions to the theory and applications of statistical signal processing*."
Silicon Valley Engineering Hall of Fame, **2006**
TiE (The Indus Entrepreneurs): Lifetime Achievement Award, 2005: "In recognition of your extraordinary lifetime achievements and contribution to scientific knowledge and for inspiring generations of engineers, entrepreneurs and academic leaders."
IEEE Information Theory Society: Claude Shannon Award, 2000: "for consistent and profound contributions to Information Theory."
J. Linear Algebra and its Applications,2001- Distinguished Editors Board.
J. Integral Equations and Operator Theory,2001 Honorary Editors Board.
American University of Beirut, 2002: Distinguished Scholar Award
Inaugural Simon Stevin Medal and Lecture,1996: "Research Universities: Looking Before and After", Delft University, the Netherlands.
IEEE Donald G. Fink Prize Paper Award, 1996: for the survey paper "A state-space approach to adaptive filtering", IEEE Signal Processing Magazine 11(3):18-60, July 1995- the first such award for any IEEE Magazine paper.

IEEE Education Medal, 1995: "for leadership in graduate engineering education through a classic textbook in linear systems and creative interdisciplinary research."
IEEE Circuits and Systems Society: Education Award, 1993: "for outstanding contributions to all facets of education in the fields of signal processing, linear system theory and VLSI design."
IEEE Signal Processing Society: Society Award, 1990: "for outstanding leadership and fundamental contributions to signal processing, including array processing and algorithms."
IEEE Signal Processing Society: Technical Achievement Award, 1988: "for contributions to a broad range of areas in signal processing including statistical spectral estimation, sensor array processing, and the design of VLSI array architectures."
American Control Council: John R. Ragazzini Education Award, 1988: "in recognition of outstanding contributions and distinguished leadership in automatic control education."
American Mathematics Society and SIAM,1998: Centennial Lecturer in Applied Mathematics.
Inst. of Electronics and Telecommunication Engineers, India,1986: Honorary Fellow.
National Federation of Asian Indian Organizations in the US,1986: Engineering Achievement Award.

Outstanding Paper Prizes

Outstanding Paper Prize for 1965-1966 of IEEE Information Theory Society
Outstanding Paper Prize for 1983 of IEEE Signal Processing Society
Intern. Federation of Automatic Control, Citation for Outstanding Contribution,1987.
Outstanding Paper Prize, IEEE Transactions on Semiconductor Manufacturing, 1993
Outstanding Paper Prize, European Signal Processing Society, 1994
IEEE Information Theory Society Golden Jubilee Paper Award,1998.

Companies co-founded with students

In 1980 : **Integrated Systems, Inc.,** a pioneer in software for computer-aided control. systems and later of embedded software. The company went public in 1990 and merged with Wind River Systems in 1999. Acquired by Intel in 2009.
In 1995: **Numerical Technologies, Inc**., developing resolution enhancement technologies for sub-wavelength optical lithography. It went public in April 2000; acquired by Synopsys, Inc., in 2003.
In 1998: **Excess Bandwidth Corporation**, designing chipsets for DSL (Digital Subscriber Line) systems; acquired in 2003 by Virata (of Cambridge, UK), later Conexant.
In 2004: **Clearshape Technologies, Inc**., DFM (design for manufacturing) solutions for 65nm and 45nm chip designs; acquired by Cadence in 2007.

The Annual Kailath Lectures and Colloquia

In 2005, to celebrate his 70th birthday, several past students endowed an Annual Kailath Lecture and Colloquium-see http://isl.stanford.edu/kailathlecture. The lecturers so far have been:

2005: Prof. Robert Gallager, MIT
2006: Prof. Jacob Ziv, Technion
2007: Prof. David Forney, MIT
2008: Prof. Rudolf Kalman, ETH
2009: Dr. Andrew Viterbi, Viterbi Group
2010: Prof. Leonard Kleinrock, UCLA
2011: Dr Irwin Jacobs, Qualcomm
2012: Prof. Elwyn Berlekamp, UC Berkeley
2014: Prof. Donald Knuth, Stanford
2015: Prof. Stanley Osher, UCLA

Recent Named Lectures (not including numerous keynote and plenary invited addresses)

American Math Society/SIAM Centennial Lecture in Applied Mathematics, 1988*: A Century of Signal Processing*
Charles Edison Lecture, University of Notre Dame, USA, 1991: *Do Real Engineers use Theory?*
Inaugural Simon Stevin Lecture, Technical University of Delft, The Netherlands, 1996: *Research Universities: Looking Before and After*.
25th Homi J. Bhabha Memorial Lecture, Institute of Electronics and Telecom Engineers, India, 2000: *Challenges in Telecommunications.*
Rustagi Memorial Lecture, Dept of Statistics, Ohio State University, 2001: *The Structure of Likelihood Ratios.*
Annual Linear Algebra and Applications Lecture, Dept of Mathematics, Univ. of Wisconsin, Madison, 2002: *Displacement Structure: Theory and Applications*.
Dean Lytle Endowed Lectures, University of Washington, Seattle, 2010
Prof. I. G. Sarma Memorial Lecture, Indian Inst. of Science, 2012: *From Wiener and Shannon to Fast Algorithms for Cell Phones.*
LACCEI (Latin American and Caribbean Consortium of Engineering Institutions),Guayaquil, Ecuador,2014: *The Process of making Breakthroughs in Engineering*
KAIST (Korea Advanced Institute for Science and Technology),Global Lecture Series on ICT, 2014: *Displacement Structure of Matrices and its Applications.*
Otto Toeplitz Memorial Lectures, Dept. of Mathematics, Tel Aviv University, Israel,1980 and 1990
Issai Schur Memorial Lectures, Dept. of Mathematics, Tel Aviv University, Israel, 1990

Other Professional Activities

1963- 2010: Editor, Prentice-Hall Series on Information Sciences & Systems
1967-1971: Comm. Theory Technical Comm., IEEE Communications Society
1971-1977: Board of Governors, IEEE Control Systems Society
1972-1978: Board of Governors, IEEE Information Theory Society
1972-1980: IEEE Press Board
1975 : President, IEEE Information Theory Society
1982-1985: IEEE Honorary Member Awards Committee
1986-1988: Air Force Office of Scientific Research Mathematics Advisory Board
1987-1988: Office of Naval Research Electronics Review Panel
1988-1990: National Science Foundation, Advisory Board, Microelectronics Systems Program
1988-2001: Technical Advisory Panel, Hitachi America Ltd.
1990-1993: Peer Review Committee, National Academy of Engineering
1990-1995: VLSI Signal Processing Committee, IEEE Signal Processing Society
1990-1997: DARPA Defense Sciences Research Council
1993-1995: Chairman, Wiener Prize Committee, American Mathematical Society
2002 : Class Membership Committee, National Academy of Sciences
1962- : Service on numerous editorial boards of journals in engineering, mathematics and statistics.
1962- : Keynote and Plenary Lectures at numerous conferences
1962- :Consultant over the years to several industries, including: Melpar, Sylvania, Ampex, General Electric, Lincoln Labs, Bell Labs, Mobil, Rockwell, IBM, Lockheed, Hitachi.
1962- : Consultant to several universities and research centers - in India, Australia, Israel, Kuwait, Holland.
1970-1972: Consultant to the Government of India on troposcatter communications

Blackwell, Chorin, Kailath Awarded National Medal of Science

From the Notices of the American Mathematical Society, Jan 2015-p.51

On October 3, 2014, President Obama announced the recipients of the National Medal of Science for 2014. Among the ten honorees are three mathematicians: Alexandre J. Chorin, University of California Berkeley; Thomas Kailath, Stanford University; and David Blackwell, University of California Berkeley, honored posthumously

The Work of Thomas Kailath

The Notices asked Roger Brockett of Harvard University to comment on the work of Kailath.

Brockett responded: "Tom Kailath is widely known for his work on stochastic processes, communication theory, and applications of signal processing techniques to problems in engineering. In the late 1960s he formulated the innovations conjecture, a key concept in theory of estimation of a stochastic process. The question raised involves how the sigma fields associated with a process consisting of a signal plus additive noise relates to the sigma fields associated with expected value of the process, conditioned on the knowledge of the signal plus noise. This work gave rise to a large literature extending over decades.

A second area, where, again, his work cast a long shadow, involves his extension of Levenson's work on the efficient solution of finite-dimensional Toeplitz systems. These systems arise in signal processing and, in particular, in the implementation of least squares estimation procedures originating with Wiener. Kailath continued the investigation of fast algorithms, taking the subject in other directions involving low rank perturbations of matrices and so forth.

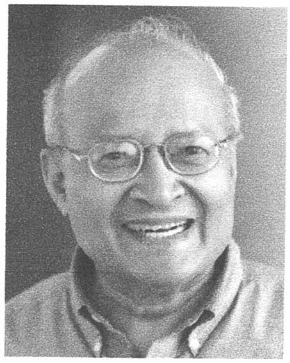
Initially, the manufacture of integrated circuits involved the repeated exposure of photosensitive materials to light, using various masks to realize specific patterns. As the scale of the structures became smaller, the wavelength of light posed an obstacle. Kailath and his collaborators developed procedures based on Fourier analysis to overcome these limitations and worked with industry to implement practical manufacturing procedures.

Kailath's PhD thesis at the Massachusetts Institute of Technology was devoted to the study of fading channels as they occur in communications. This work gained him a reputation of a rising star.

Throughout his career at Stanford he has had a great influence on future generations through his textbooks and his work with students and postdoctoral fellows."

Thomas Kailath was born in Pune, India, in 1935. He received his PhD in electrical engineering from the Massachusetts Institute of Technology in 1961. He was employed at the Jet Propulsion Laboratory in Pasadena before joining the faculty of Stanford University in 1963. In 2007 he was awarded the Medal of Honor of the Institute of Electrical and Electronics Engineers (IEEE). He has also received the IEEE Jack S. Kilby Signal Processing Medal (2006) and Donald G. Fink Prize Paper Award (1996), as well as the Padma Bhushan, a high civilian award of the Government of India. He has been a fellow of the IEEE since 1970 and is a member of the US National Academy of Engineering (NAE), the National Academy of Sciences (NAS), the American Academy of Arts and Sciences (AAAS), the Indian National Academy of Engineering, and the Silicon Valley Engineering Hall of Fame.

Intrinsically Hopeful


L.A. CICERO/STANFORD NEWS SERVICE

In November 2014, Prof. Thomas Kailath from Stanford University was presented with the National Medal of Science by U.S. President Barack Obama in Washington, D.C., during a ceremony honoring ten of the top American scientists and engineers. The medal was established by U.S. President Dwight Eisenhower in 1959, and the first medal was awarded by U.S. President John F. Kennedy in 1963.

Prof. Kailath is a Life Fellow of the IEEE and has been an IEEE Signal Processing Society member for more than 40 years. Throughout his career, he made significant contributions to signal processing. In the 1960s, he was mostly interested in signal detection before turning onto signal estimation in the 1970s. The ESPRIT algorithm is a well-known outcome of this line of research. In the 1980s, Prof. Kailath then focused on various aspects of array processing as well as the design of very-large-scale integration architectures for signal processing applications. His research team has, for instance, developed spatial multiplexing in multiple-input, multiple-output antenna systems, which is now used in Wi-Fi. In the 1990s, signal processing ideas were instrumental in his work on optical microlithography, when his team broke what was believed to be the 100-nm barrier in semiconductor manufacturing by Gordon Moore and several others. Some of these contributions are still standard industry practice at the present time. His technical achievements have been acknowledged over the years with top awards from both the IEEE Signal Processing Society and the IEEE Information Theory Society.

During the National Medal of Science ceremony, Prof. Kailath was recognized for "transformative contributions to the fields of information and system science, for distinctive and sustained mentoring of young scholars, and for translation of scientific ideas into entrepreneurial ventures that have had a significant impact on industry." A short remark by President Obama gave an even more personal flavor to the award ceremony. "As Thomas Kailath, one of our honorees today, says, 'Scientists are intrinsically hopeful and believe in grand answers, and that if we work hard enough we can find some of them in our lifetime.' And that's a good phrase: *intrinsically hopeful*. I'm intrinsically hopeful, I am [laughter]. That's who I am. That's who we are as a people, as Americans, as a nation." According to Prof. Kailath, the quotation originates from an offline discussion with a member of the staff who was asking about failures when he was talking about his contributions. He replied that he could not really recollect any major failure and then elaborated further saying the words quoted by the president or something close to it. Possibly, it resonated with the president because *hope* had been a major theme of his first election campaign.

SP

THOMAS KAILATH

Current Job: Hitachi America Professor of Engineering Emeritus, Stanford University, United States

Birthplace: Pune, India

Education: B.E. degree (1956) from the University of Pune, India; S.M. degree (1959) and Sc.D. degree (1961) from the Massachusetts Institute of Technology, United States

First Job: Counting seeds in a seed-packing facility

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