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Mathematical Engineering

A special issue at the occasion of the 85th birthday of Prof. Thomas Kailath

Professor Thomas Kailath reaches the age of 85 this year. He has been one of the towering pioneers of what one could call 'Mathematical Engineering', that is *the use of mathematics to solve engineering problems*, most notably in the fields of Communications, Systems and Control, Signal Processing and even VLSI Design. Tom Kailath's mathematical basis is in Matrix Algebra and Information Theory. As a master and doctoral student in the 1960's, he already developed a keen interest in the combination of mathematics and engineering by his contributions to the then budding field of modern communication, providing crucial results in detection theory, a key component of any professional digital communication system. Thanks to the progress in micro-electronics and in particular the spectacularly increasing availability of computing resources on few square millimeters of silicon 'real estate', advanced computations on signals became generally feasible, and it should not be surprising that Tom Kailath moved to exploit his algorithmic ideas into many areas of signal processing, ranging from Control to Lithography, and of course keeping up with the development of Communications. Let us just mention here: the famous 'square root algorithms' for Kalman filtering and the 'ESPRIT algorithm' for the estimation of the direction of arrival of an electromagnetic wave.

Mathematical engineering is the art of solving engineering problems using mathematical means. Many physical and natural phenomena can be characterized by precise mathematical laws, and their evolution or 'behavior' hence becomes computable. The same holds for many engineering problems. In modern times, engineering has moved way beyond the direct application of physical laws and has created the need for original mathematical theory to allow for the development of ever more performing systems, thus motivating the emergence of engineering sciences. Here is a list of some major engineering developments made possible by mathematics (among many others):

- telecommunications based on Fourier theory and Information theory;
- automatic control based on mathematical system theory and linear algebra;
- medical imaging based on the Radon transform and matrix algebra;
- random data communication over the internet based on Bayesian statistical analysis;
- large scale simulation of environmental effects based on numerical mathematics.

In many engineering fields, original mathematical theory had to be developed to properly characterize the engineering situation. More accurately: original mathematical theory was the motor behind the development of these fields. It would not have been possible to put a man on the moon without adequate optimization, estimation and control theory, nor could an accurate assessment of the state of internal body organs be made without the further development and deepening of Fourier and Radon theory, or could VLSI chips be designed without new ways of handling Boolean algebra and system theory.

The need for original mathematical analysis for engineering problems has greatly increased in recent times, in parallel to the massive development of new engineering fields, especially in the very wide general area of information generation and management. The fast increase of the complexity of the systems we use, and the need for ever more refined intelligence (as the ability to gather information, evaluate it, derive conclusions from observations and putting in place effective controls) in a large variety of areas requires the development of ever more refined mathematical means.

Modern fields of endeavor requiring novel mathematical efforts include, for example, the handling of large data sets, sensor networking, deep learning, autonomous driving, large scale environmental modeling, and many more. In all these cases, mathematical engineering starts out with the development of effective models (the accurate but as simple as possible modeling of engineering phenomena is a major issue in itself), followed by the development of adequate mathematical tools to handle the models and to steer their evolution. This process is perhaps best exemplified by autonomous driving, which still has a long way to go before it can rival the cognitive abilities of a driving human (the reliability of an automatic car driver is still a factor of one hundred or more off mark, and it will require a major mathematical effort to solve just this problem).

The present issue on Mathematical Engineering is intended both as an account on recent developments and a tribute to the contributions of Tom Kailath in a broad array of fields. Most if not all authors have tried to present not only new results, but have endeavored to put these in the context of an accessible theoretical framework, connecting them to the underlying algebraic principles. The papers have, in this way, both a didactical and a motivational interest, hopefully leading to new ideas and research issues. The authors have all been pioneers in the development of their fields of interest, in most cases inspired by original ideas, work and contacts with Prof. Tom Kailath (most authors indicate the connection).

A tribute to Prof. Tom Kailath cannot be complete without mentioning his inspirational role for several generations of students, colleagues, visitors to the ISL Laboratory at Stanford University that he created and directed for many years, not to mention the many often intense contacts he had over the world with research groups that he visited, where he spent sabbaticals and conducted joint research. Science and technology progress through results, of course, but, at a more profound and facilitating level, through human interactions. These require great communication and intellectual skills, in particular the ability to look beyond self-interest and to act inclusively to the benefit of all. Let this issue be a testimony to Tom's effectiveness as a great communicator in addition to being a great scientist and engineer.

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