2-day Symposium Open and Interconnected Systems Modeling and Control celebrating Jan Willem's 70th birthday

Program

September 16, 2009

09h00-09h10 Welcome by Bart De Moor (K.U.Leuven, Belgium)

09u10-09h35 **Behaviors in the Sobolev Spaces**
Shiva Shankar (Chennai Mathematical Institute, Siruseri, India)

In this talk I initiate the theory of behaviours in the Sobolev spaces. I show that such behaviours have properties quite distinct from behaviours in the spaces studied so far by considering the classical examples of grad, curl and div.

09h35-10h00 **Back to the origins : State and first order representations for multidimensional systems**
Paula Rocha (University of Aveiro, Portugal)

This talk goes back to the origins of my PhD work supervised by Jan Willems and addresses what then was, and still is now, a most challenging question: the problem of characterizing the representations that describe Markovian and state multidimensional (nD) systems.

Contrary to happens for 1D systems, discrete nD Markovian systems are not necessarily representable by first order equations, but an answer to what happens in the continuous case has not yet been fully given.

10h00-10h25 **Formation Control**
A. Stephen Morse (Yale University, USA)

Current interest in cooperative control of groups has led to the rapid increase in the application of graph theoretic ideas together with more familiar dynamical systems concepts to problems of analyzing and synthesizing a variety of desired group behaviors such as maintaining a formation, swarming, rendezvousing, or reaching a consensus. One line of research which illustrates the combined use of these concepts, is concerned with maintaining in a "directed" formation, a group of mobile autonomous agents. A formation is *directed* if each agent *i* can sense only the relative position of its "leaders" where by an agent *i's leaders* are meant other designated agents in the formation whose distances from agent *i* it is the responsibility of agent *i* to maintain. The graph G of such a formation is a directed graph in which (*i, j*) is an arc from *i* to *j* just in case agent *j* is a leader of agent *i*. A directed formation is maintained by requiring each agent in the formation to maintain prescribed distances to all of its leaders and by stipulating that the undirected version of the formation's graph is "rigid." The problem of devising provably correct local controls for each agent which maintain a directed formation is formidable and is at present unresolved. On the other hand, the problem is resolved for several interesting classes of formations. The aim of this talk is to describe what some of these classes are and to explain how formations from these classes behave under local control.

10h25-10h40 coffee break

10h40-11h20 **Turning toward a new direction in system theory**
Rudolph E. Kalman (Zürich, Switzerland)

11h20-11h45 **Arithmetic and Geometry**
Paul A. Fuhrmann (Ben-Gurion University of the Negev, Israel)

The talk will focus on functional models and realization theory as a bridge between the arithmetic of polynomial matrices and the geometry of subspaces in general, and their role in geometric control and behaviors in particular.

11h45-12h10 **Weakly Invertible Lossless Linearly Embedded Maximal Systems**
Vincent Blondel (Université Catholique de Louvain, Belgium)

We present open problems and propose partial solutions for questions related to asynchronous linear systems. For these systems only some of the states are updated at every time step. The question we consider are : Do all resulting trajectories remain bounded? How fast do trajectories grow in the worst case ? Some of these questions have not yet received satisfactory answers so far. In particular, there are no known efficient methods for computing the maximal rate of growth for such systems. In this talk, we describe some of these problems and present a solution for the special case of matrices with nonnegative entries.

We then describe the fascinating « Weakly Invertible Lossless Linearly Embedded Maximal Systems ». These systems are totally asynchronous and nevertheless behave very efficiently with various input/output representations. We exhibit some of the most useful properties of these system and show why these are known as "Jewels After Nonlinearity".

12h10-13h40 lunch

13h40-14h05 **Interpolatory model reduction of large-scale systems**
Athanasios C. Antoulas (RICE University, USA)

We will present an overview of recent advances in model reduction of large-scale systems, using interpolatory methods. These include model reduction with preservation of passivity, optimal H2 model reduction and model reduction from input-output data.

14h05-14h30 **Law of large numbers, heavy-tailed random variables, and financial crises**
Mathukumalli Vidyasagar (University of Texas at Dallas, U.S.A.)

Recent events in the world's financial markets have caused many to question the relevance and/or accuracy of currently used models for financial market movements, and the consequent strategies for hedging against adverse movements in asset prices. By studying the version(s) of the law of large numbers for heavy-tailed random variables (defined as a r.v. that has a first moment but not a finite second moment), I will try to draw a few conclusions: (i) If the asset returns represent an i.i.d. sequence (or even a weakly dependent sequence) of heavy-tailed r.v.'s, then the tail probability estimate for "rare" events is completely different than the case of r.v.'s with finite second moment. (ii) Paradoxically, the likelihood of a "rare" event is actually easier to estimate with heavy-tailed r.v.'s. (iii) Finally and most important, strategies for risk assessment and hedging with heavy-tailed r.v.'s can be substantially simplified to the so-called "one-period" case.

14h30-14h55 **A behavioral approach to the regulation problem**
Kiyotsugu Takaba (Kyoto University, Japan)

This talk is concerned with the regulation problem of finding a controller which drives the plant output to zero in the presence of a disturbance generated from an exosystem. This has been one of the most important problems in control theory for a long time. Meanwhile, the behavioral approach pioneered by J.C. Willems provides us more insight and flexibility in modeling and analysis of dynamical systems by characterizing them in terms of behaviors, i.e. sets of all admissible trajectories. From a behavioral viewpoint, we clarify the structure of the regulation problem by deriving a representation-free condition for the existence of a controller achieving the regulation requirement. By the term ``representation-free", we mean that the condition does not depend on any particular system representations. Moreover, we study how this condition is expressed when the plant and the exosystem are described by some particular representations such as the state-space model.

14h55-15h20 **Structure and estimation of stationary reciprocal models**
Giorgio Picci *(University of Padova, Italy)*

In this talk we shall discuss stationary reciprocal processes defined on a finite interval. These processes can be seen as a special class of Markov random fields restricted to one dimension. Non stationary reciprocal processes have been extensively studied in the past especially by Krener, Levy and co-workers. However the specialization of the non-stationary results to the stationary case does not seem to have been pursued in sufficient depth in the litarature. We shall show that stationary reciprocal processes admit constant parameter descriptor-type representations of a certain kind which can be seen as a natural non-causal extension of the linear state space models used in stationary time series analysis. There is a rich structure associated to these models which includes a special form of spectral analysis and generalizes many known concepts and techniques known in linear stochastic systems theory. One should stress that reciprocal processes (and in particular stationary reciprocal processes) are especially useful for describing phenomena which naturally live in a finite region of the “time” (or space) line and estimation or identification of these models starting from observed data is a completely open problem which can in principle lead to many interesting applications in signal processing.

Under certain assumptions (in particular Gaussian distribution) it is shown that the maximum likelihood estimation of reciprocal models leads to a special Covariance selection problem of the kind studied by the statistician M. Dempster in the early seventies. It turns in particular out that covariance selection for stationary reciprocal models is equivalent to a special matrix band extension problem of the kind studied by Dym, Gohberg and co-workers, for symmetric positive-definite block-circulant matrices. This problem is still open and suprisingly tricky.

15h20-15h45 **Safe Adaptive Control**
Brian D.O. Anderson *(Australian National University and National ICT Australia)*

Multiple model adaptive control and iterative identification and controller redesign are two examples of situations where controllers can be switched discontinuously, and without exact knowledge of the plant. The talk will show that unplanned instability can easily occur when the new controller replaces the old controller, but that it is possible to perform an experimental test tolerant of significant noise to verify, before its insertion, that the proposed new controller will not destabilize the plant. Recent work has started to examine the further task of advance verification that there will not be substantial degradation of performance, and in another direction, recent work is considering the ability to deal with nonlinear controllers.

15h45-16h05 coffee break

16h05-16h30 **On the approximation of N-d signals and systems: a tensor approach**
Siep Weiland (Technical University Eindhoven, The Netherlands)

Systems that have space and time as independent variables occur in all fields of science and engineering and are usually described by partial differential equations. The construction of approximate models for these systems is a difficult, but essential problem that will be addressed in this presentation. Specifically, we address the problem of reduced order modeling of systems with multiple independent variables. We identify solutions of N-d systems with tensors. A number of tensor decompositions will be proposed and analyzed and it will be shown how these decompositions can be used in the construction of approximations of N-d signals and systems.

16h30-16h55 **Controller synthesis with dynamic integral quadratic constraints**
Carsten W. Scherer *(Delft University of Technology, The Netherlands)*

Recent years have witnessed a variety of techniques for the systematic design of robust estimators or feed-forward controllers based on convex optimization. Much attention has been paid to methods involving parameter-dependent Lyapunov functions whose application is limited to linear parameter-varying systems. Such restrictions are less severe for approaches relying on linear fractional system representations which allow the inclusion of more general uncertain components such as static non-linearities. The related algorithms allude to classical multiplier techniques.

In this presentation we discuss recent developments on robust controller synthesis techniques that involve dynamic multipliers. Under the mere hypothesis that the control channel of the generalized plant is not affected by uncertainties it will be shown that one can systematically design robust controllers by convex optimization. Apart from the technical solution we sketch various applications of this structurally unifying result and we point out paths for generalizations.

16h55-17h20 **Steady-state behaviors and output regulation of nonlinear systems.**
Alberto Isidori (Washington University of St. Louis, USA)

Recent advances on the problem of output regulation for nonlinear systems repose on a newly-developed notion of steady state behaviors of a nonlinear system. This notion, which utilizes an enhanced version of the concept of limit set, provides a natural tool for the extension to nonlinear systems of a very classical notion in linear feedback design. Forcing a prescribed steady-state response in given nonlinear system can be cast as a problem of robust stability of an augmented system in which the exogenous variables are themselves part of the model and this is a fundamental step in design of any controller that solves the problem of output regulation.

17h20-17h45 **Path Integrals, Bezoutians and Stability**
Yutaka Yamamoto (Kyoto University, Japan)

There is an effective way of constructing a Lyapunov function without recourse to a state space construction. This is based upon an integral of special type called a path integral, and this approach is particularly suited for behavior theory. The theory successfully exhibits a deep connection between Lyapunov theory and Bezoutians. This paper extends the theory to a class of distributed parameter systems called pseudorational. A new construction of Lyapunov functions via an infinite-dimensional version of Bezoutians is presented. An example is given to illustrate the theory.

18h10 Reception in the City Hall

20h00 Official banquet

September 17, 2009

09h00-09h25 **Exact identification of lossless systems**

Paolo Rapisarda (University of Southampton, U.K.)

We illustrate an algorithm to exactly identify a lossless system from a given trajectory. Performing a rank-revealing factorization of a Gramian matrix constructed from the data, a state sequence corresponding to the given data can be computed. The computation of the system state-space equations is then performed solving a system of linear equations.

09h25-09h50 **Conservation laws and interconnection systems**

Arjan J. van der Schaft (University of Groningen, The Netherlands)

Physical systems modeling, aimed at network modeling of complex multi-physics systems, has belonged to the core of systems and control since the fifties and sixties of the previous century.

With the reinforcement of the 'systems' legacy, the growing recognition that 'control' is not confined to developing algorithms for processing the measurements of the system into control signals (but instead is concerned with the design of the total controlled system), and facing the complexity of modern technological and natural systems, systematic methods for large-scale physical systems modeling capturing their basic physical characteristics are needed more than ever, both for analysis and control.

In this talk we discuss a framework for modeling multi-physics systems which emphasizes the role of conservation laws. Modeling based on conservation laws is prevalent in a distributed-parameter context in many areas, but is also underlying the basic structure of lumped-parameter systems such as electrical circuits. While the natural framework for formulating Kirchhoff's laws for electrical circuits is the circuit graph we will show how distributed-parameter conservation laws can be discretized by using the proper generalization of the notion of graph to 'higher-dimensional networks', called k-complexes in algebraic topology. Furthermore, we show how these discretized conservation laws define a power-conserving interconnection structure, which, when combined with the (discretized) constitutive relations, defines a finite-dimensional port-Hamiltonian system. The resulting system is a discretization of the corresponding distributed-parameter port-Hamiltonian system. This does not only provide a systematic way of modeling interconnected systems (both lumped- and distributed-parameter), but also highlights their physical properties (often reflected in their conservation laws) and points to the 'right' choice of variables to describe them.

09h50-10h15 **Finding roots of multivariate polynomials is an eigenvalue problem**

Bart De Moor (K.U.Leuven, Belgium)

Finding the zeros of multivariate polynomials with real coefficients is an old problem, the description and solution of which goes back to Sylvester and Bezout, among others.

The problem is key in algebraic geometry, not in the least because of the numerous applications in numerical (multi-)linear algebra, system theory, identification and control, optimization, (algebraic) statistics etc.

Little is it known that, behind the scene, the whole theory and solution algorithms, can be derived using linear algebra and realization theory. The number of solutions corresponds to the corank of a certain affinely structured matrix, build from the coefficients, while the sets of zeros can be obtained from the eigenvalues of a certain realization problem.

Basically, we show that all optimization problems with multivariate polynomial objective functions and constraints, can be solved as a (large) eigenvalue problem. To find the global optimum, we only need to calculate the minimal eigenvalue of a certain matrix. In particular, prediction error methods and structured total least squares problems, are eigenvalue problems.

10h15-10h30 coffee break

10h30-11h10 Smooth Variational Problems need not Result in Smooth Feedback Controls
Roger W. Brockett (Harvard University, USA)

Although it has been observed in the past that regulator problems with a quadratic penalty on the control and some higher order penalty on the state do not, typically, lead to smooth optimal feedback controls, the author is unaware of "textbook" examples which are both explicitly solvable and lay some claim to being generic. In this talk I will present one such family of problems and relate the solution to familiar ideas in linear algebra, geometric control, and topics in the theory of integrable systems.

11h10-11h35 **Time-domain description of behaviors over finite fields**
Jan W. Polderman (University of Twente, The Netherlands)

We consider autonomous behaviors over a finite field with characteristic values that do not necessarily belong to the field. The time domain description of the behavior is given in a suitable field extension of the base field. The problem that we consider is how to derive a description completely within the base field. For the case of behaviors over the reals there is a common splitting field for all irreducible polynomials, the complex field. Complex trajectories induce real trajectories by restricting coefficients of complex conjugate exponentials to be complex conjugate as well. For the case of finite fields the situation is more complicated as there does not exist a single finite field extension in which all polynomials over the base field split. In this paper we describe a systematic procedure to obtain explicit expressions for all trajectories in the behavior whose components take values in the base field.

11h35-12h00 **Connecting informative experiments, the information matrix and the minima of a Prediction Error Identification criterion**

Michel Gevers (Université Catholique de Louvain, Belgium)

We present, in a Prediction Error Identification (PEI) context, the connections that exist between the identifiability of the model structure, the informativity of the data, the information matrix and the existence of a unique global minimum of the PEI criterion. By introducing the concept of informative data at a particular parameter value, we are able to establish a number of equivalences and connections between these four ingredients of the identification problem, for both open-loop and closed-loop identification.

12h00-13h30 lunch

13h30-13h55 **Interactive statistical mechanics and nonlinear estimation**
Sanjoy K. Mitter (Massachusetts Institute of Technology, USA)

We discuss connections between non-equilibrium statistical mechanics and optimal non-linear filtering . The latter concerns the observation-conditional behaviour of Markov processes and thus provides a tool for investigating statistical mechanics with partial observations. These allow entropy reduction illustrating Landauer's principle in a quantitative way . The joint process comprising a signal and its nonlinear filter is irreversible in its invariant distribution which therefore corresponds to a non-equilibrium stationary state of the associated joint system. Macroscopic entropy and energy flows are identified for this state. (joint work with Nigel Newton)

13h55-14h20 **Nonparametric preprocessing in system identification, a powerful tool**
Johan Schoukens, G. Vandersteen, K. Barbé, R. Pintelon (Vrije Universiteit Brussel, Belgium)

In this presentation we present a nonparametric method for estimating the plant and noise transfer functions of a linear dynamic system. The method is based on the recent insight that leakage errors in the frequency domain have a smooth nature that is completely similar to the initial transients in the time domain. This not only allows us to understand better the existing classic methods, but also opens the road to new better performing algorithms. The presentation includes the output error setup, the errors-in-variables setup, and measurements under feedback conditions.

14h20-14h45 **Reachability properties of discrete-time positive switched systems**
Maria Elena Valcher (University of Padova, Italy)

A switched linear system consist of a family of (linear) subsystems and a switching law, specifying when and how the switching among the various subsystems takes place. If we constrain each subsystem to be positive, by this meaning that its state and input-to state matrices have positive or at least nonnegative entries, then we obtain the class of switched positive systems.

Switched positive systems deserve investigation both for theoretical reasons and for practical applications. Indeed, switching among different system models naturally arises as a way to mathematically formalize the fact that the system laws change under different operation conditions. Indeed, different discrete-time positive systems, which arise when discretizing linear differentieal equations describing processes whose state variables are temperatures, pressures, population levels, etc., or when providing a discrete-time model for the time evolution of productions levels or stocked amounts of some good, may undergo different working conditions and, consequently, switch among different mathematical models.

14h45-15h10 **Generalized linear dynamic factor models – An approach via singular autoregressions**
Manfred Deistler (Vienna University of Technology, Austria)

We consider generalized linear dynamic factor models. These models have been developed recently and they are used for high dimensional time series in order to overcome the "curse of dimensionality". We present a structure theory with emphasis on the zeroless case, which is generic in the setting considered. Accordingly the latent variables are modeled as a singular autoregressive process and (generalized) Yule Walker equations are used for parameter estimation.

15h10-15h30 coffee break

15h30-15h55 **Data-driven simulation and control**
Ivan Markovsky (University of Southampton, U.K.)

The classical approach for solving control problems is model based: first a model representation is derived from given data of the plant and then a control law is synthesized using the model and the control specification. We present an alternative approach, called data-driven, that circumvents the explicit identification of a model representation. Data-driven control is based on a method for computing the response of a system to a given input and initial conditions directly from a trajectory of the system, without identifying the system from the data. The results are derived assuming exact data and the control signal is constructed off-line.

15h55-16h20 **Optimal Robust Stabilization in Behavioral Framework**

Harry L. Trentelman (University of Groningen, The Netherlands)

Given a nominal control system, together with a fixed neighborhood of this system, the problem of robust stabilization is to find a controller that stabilizes all systems in that neighborhood (in an appropriate sense). If a controller achieves this design objective, we say that it robustly stabilizes the nominal system. In this paper we formulate the robust stabilization problem in a behavioral framework, with control as interconnection. We use both rational as well as polynomial representations for the behaviors under consideration. We obtain necessary and sufficient conditions for the existence of robustly stabilizing controllers using the theory of dissipative systems. We will also find a smallest upper bound on the radii of the neighborhoods for which there exists a robustly stabilizing controller. This smallest upper bound is expressed in terms of certain storage functions associated with the nominal control system.

16h20-16h40 Closing remarks