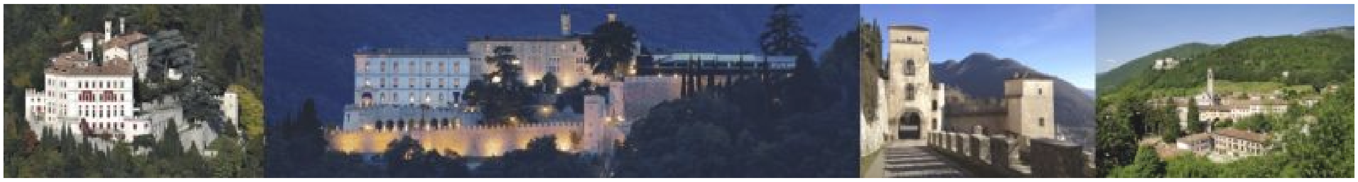

ERNSI WORKSHOP 2016

Cison di Valmarino, September 25th-28th

PROGRAM

Sunday, September 25th

4.00pm - Registration

8.00pm - Dinner (Sansovino Restaurant)

Monday, September 26th

7.30am Breakfast (Sansovino Restaurant)

8.50am Opening and Announcements

9.00am Tutorial Talk T1 *[Chair: H. Hjalmarsson]*
Bayesian methods in System Identification, C.E. Rasmussen

9.45am Regular Talk R1 *[Chair: H. Hjalmarsson]*
Identification of Network Connected systems with missing communication links, M. Verhaegen

10.15am Poster Teasers *[Chair: C. Rojas]* (Poster Session A)

10.30am Coffee Break and Poster Session A

12.15pm Regular Talk R2 *[Chair: C. Rojas]*
Missing data estimation approach to data-driven signal processing, I. Markovsky

12.45pm Lunch (La Fucina Restaurant)

2.15pm Plenary Talk P1 *[Chair: A. Chiuso]*
Now-Casting and the Real-Time Data Flow, D. Giannone

3.15pm Regular Talk R3 *[Chair: T. Schön]*
Convex Formulations for Identification of Nonlinear Systems with Qualitative Behaviour Constraints, I.R. Manchester

3.45pm Poster teasers *[Chair: T. Schön]* (Poster Session B)

4.00pm Coffee Break and Poster Session B

5.45pm Regular Talk R4 *[Chair: P. Van den Hof]*
The harmonic analysis of kernel functions, M. Zorzi (Regular Talk R4)

6.15pm Regular Talk R5 *[Chair: P. Van den Hof]*
Network Inference: from Theory to Applications in Biology, J. Goncalves (Regular Talk R5)

7.30pm Dinner (Sansovino Restaurant)

Tuesday, September 27th

7.30am Breakfast (Sansovino Restaurant)

9.00am Discussion Talk T2 *[Chair: B. Wahlberg]*
How far can we trust regional models we construct from observations?, M. Campi

9.45am Regular Talk R6 *[Chair: B. Wahlberg]*
Identifiability of dynamic networks with noisy and noise-free nodes, P. Van den Hof

10.15am Poster Teasers *[Chair: G. Pillonetto]* (Poster Session C)

10.30am Coffee Break and Poster Session C

12.15pm Plenary Talk P2 *[Chair: G. Pillonetto]*
Machine Learning of Motor Skills for Robots: From Simple Skills to Table Tennis and Manipulation, Jan Peters

1.15pm Lunch (La Fucina Restaurant)

2.45pm Guided Tour to the Castle

3.45pm Visit to a local winery (bus leaves at 3.45pm)

8.30pm Social Dinner (Teatro Sansovino)

Wednesday, September 28th

7.30am Breakfast (Sansovino Restaurant)

9.00am Regular Talk R7: *[Chair: C.E. Rasmussen]*
Particle Metropolis-Hastings for inference in non-linear state-space models, J. Dahlin

9.30am Regular Talk R8: *[Chair: C.E. Rasmussen]*
Kernel-based system identification in the frequency domain, J. Lataire

10.00am Regular Talk R9: *[Chair: C.E. Rasmussen]*
Clustering Time Series, O. Lauwers (Regular Talk R9)

10.30am Coffee Break

11.00am Regular Talk R10: *[Chair: R. Toth]*
Identification of Systems with Unknown Inputs Using Indirect Input Measurements, J. Linder

11.30am Regular Talk R11: *[Chair: R. Toth]*
Optimal experiment design for local LPV identification, X. Bombois

12.00pm Regular Talk R12: *[Chair: R. Toth]*
Identification of aerodynamic coefficients based on free-flight data, S. Dobre

12.30pm Lunch (La Fucina Restaurant)

Plenary Lectures (1h)

(P1) **Title:** Now-Casting and the Real-Time Data Flow

Authors: M. Bańbura, D. Giannone, M. Modugno, L. Reichlin *(ECB, Federal Reserve Bank of New York, Université Libre de Bruxelles, London School of Economics)*

Scheduled for: Monday September 26th, 2.15pm-3.15pm (1h)

Presenter: Prof. Domenico Giannone

Abstract: *The term now-casting is a contraction for now and forecasting and has been used for a long time in meteorology and recently also in economics. In this talk we survey recent developments in economic now-casting with special focus on those models that formalize key features of how market participants and policymakers read macroeconomic data releases in real-time, which involves monitoring many data, forming expectations about them and revising the assessment on the state of the economy whenever realizations diverge sizeably from those expectations.*

(P2) **Title:** Machine Learning of Motor Skills for Robots: From Simple Skills to Table Tennis and Manipulation

Authors: Jan Peters *(TU Darmstadt and Max Planck Institute for Intelligent Systems)*

Scheduled for: Tuesday September 27th, 12.15pm-1:15pm (1h)

Presenter: Prof. Jan Peters

Abstract: *Autonomous robots that can assist humans in situations of daily life have been a long standing vision of robotics, artificial intelligence, and cognitive sciences. A first step towards this goal is to create robots that can learn tasks triggered by environmental context or higher level instruction. However, learning techniques have yet to live up to this promise as only few methods manage to scale to high-dimensional manipulator or humanoid robots. In this talk, we investigate a general framework suitable for learning motor skills in robotics which is based on the principles behind many analytical robotics approaches. It involves generating a representation of motor skills by parameterized motor primitive policies acting as building blocks of movement generation, and a learned task execution module that transforms these movements into motor commands. We discuss learning on three different levels of abstraction, i.e., learning for accurate control is needed to execute, learning of motor primitives is needed to acquire simple movements, and learning of the task-dependent hyperparameters of these motor primitives allows learning complex tasks. We discuss task-appropriate learning approaches for imitation learning, model learning and reinforcement learning for robots with many degrees of freedom. Empirical evaluations on a several robot systems illustrate the effectiveness and applicability to learning control on an anthropomorphic robot arm. These robot motor skills range from toy examples (e.g., paddling a ball, ball-in-a-cup) to playing robot table tennis against a human being and manipulation of various objects.*

Tutorial and Discussion Talks (45 min)

(T1) **Title:** Bayesian methods in System Identification
Authors: Carl Edward Rasmussen *(University of Cambridge)*
Scheduled for: Monday September 26th, 9.00am-9.45am
Presenter: Carl Edward Rasmussen
Abstract: *Despite the fact that both Bayesian and classical methods are in common use for many problems in system identification, the fundamental differences in theory and practise are sometimes not widely appreciated. In this tutorial style presentation I will attempt to discuss some of the central properties of Bayesian procedure and contrast it to classical alternatives. Ill attempt to cover concepts such as estimation versus marginalisation, fitting and overfitting, regularisation, the role of the prior, the marginal likelihood, Occams Razor, model selection and the non-parametric limits. What are the consequences for practical use?*

(T2) **Title:** How far can we trust regional models we construct from observations?
Authors: Marco Campi and Simone Garatti *(Università di Brescia)*
Scheduled for: Tuesday September 27th, 9.00am-9.45am
Presenter: Marco Campi
Abstract: *In a regional model salient characteristics of a population are described in the form of a set. The goal of this talk is to touch some fundamental issues that arise when a regional model is constructed from observations. How many data points do we need to reliably describe a population? How does the reliability of the description depend on the complexity of the identification procedure? Are there universal methods to keep control on the approximation? Suppose that we ask a difficult question, but we accept the answer only when the answer turns out to be simple, that is, the identification procedure has high complexity, but we use the model only when the procedure returns a simple model. Can we then be as confident in the use of the model as when a simple question is asked in the first place? Addressing these issues is not only practically important, it also bears a deep interest at a philosophical level.*

List of Regular Presentations (30 min)

(R1) **Title:** Identification of Network Connected systems with missing communication links
Authors: M. Verhaegen (Delft)
Scheduled for: Monday September 26th, 9.45am-10.15am
Presenter: M. Verhaegen
Abstract: *We present a class of identification methods that enable to identify large network of coupled systems. These networks consists of coupled local dynamical (linear) systems with local inputs and outputs, and with its state also influenced by unknown interactions with the neighboring systems. The approach presented is that of the identification of structured large scale systems.*

(R2) **Title:** Missing data estimation approach to data-driven signal processing
Authors: Ivan Markovsky (VUB)
Scheduled for: Monday September 26th, 12.15pm-12.45pm
Presenter: Ivan Markovsky
Abstract: *In filtering, control, and other mathematical engineering areas it is common to use a model-based approach, which splits the problem into two steps:*
1) model identification and
2) model-based design.
Despite its success, the model-based approach has the shortcoming that the design objective is not taken into account at the identification step, i.e., the model is not optimized for its intended use.
In this talk, I show a data-driven approach, which combines the identification and the model-based design into one joint problem. The signal of interest is modeled as a missing part of a trajectory of the data generating system. Subsequently, the missing data estimation problem is reformulated as a mosaic-Hankel structured matrix low-rank approximation/completion problem.
The missing data estimation approach for data-driven signal processing and a local optimization method for its practical implementation are illustrated on examples of control, state estimation, filtering/smoothing, and prediction. Development of fast algorithms with provable properties in the presence of measurement noise and disturbances is a topic of current research.

Reference: I. Markovsky. A low-rank matrix completion approach to data-driven signal processing. Technical report, Vrije Univ. Brussel, 2016. Available from:
http://homepages.vub.ac.be/ imarkovs/publications/ddsp.pdf

(R3) **Title:** Convex Formulations for Identification of Nonlinear Systems with Qualitative Behaviour Constraints
Authors: Ian R. Manchester (University of Sydney, Australia)
Scheduled for: Monday September 26th, 3.15pm- 3.45pm
Presenter: Ian R. Manchester
Abstract: *This talk presents recent methods for nonlinear (and linear) system identification that allow imposition of behavioural constraints such as stability, monotonicity, passivity, or the existence of limit cycles. This represents a novel re-imagining of the idea of "grey box identification", wherein it is not equation structure that is partially specified but the qualitative behaviour of the resulting dynamical system. We show how to construct convex optimization problems guaranteeing such properties using tools such as Lagrangian relaxation, contraction analysis, and sum-of-squares programming. Scalable algorithms based on and custom interior point method and applications in neuroscience, robotics, and other fields will be discussed.*

(R4) **Title:** The harmonic analysis of kernel functions
Authors: M. Zorzi, A. Chiuso (University of Padova)
Scheduled for: Monday September 26th, 5.45pm-6.15pm

Presenter: M . Zorzi

Abstract: *Kernel-based methods gained popularity in system identification in the last years. According to these methods, the optimal model, described via the predictor impulse response, is searched in an very large model class which is characterized by the kernel function. The design of the kernel is still the most challenging and unexplored part of the procedure. In this talk we study, via the spectral representation of stochastic processes, the harmonic properties of kernel functions. Our hope is that this interpretation will allow to better understand the role of user choices, kernel structures and hyperparameters, thus leading to a more principled kernel design e.g. allowing to emphasise certain frequency bands and decay rates. Finally, we show how these features translate in terms of penalty term for the class of second order models.*

(R5) **Title:** Network Inference: from Theory to Applications in Biology

Authors: Jorge Goncalves (University of Luxembourg)

Scheduled for: Monday September 26th, 6.15pm-6.45pm

Presenter: Jorge Goncalves

Abstract: *A major goal of biological sciences is the identification of regions in genetic networks that underpin responses to stimuli, with the potential to identify drug targets or differences between cell types. This talk will describe recent developments, both from theoretical and application point of view, for the identification of dynamical biological networks. Theoretically, it gives conditions for network identifiability of networks with deterministic or stochastic inputs. For identification, it considers recent developments of efficient algorithms that impose sparsity constraints on the network and model complexity. Then, the talk describes the application of control systems tools, such as system identification and the gap metric, to improve our understanding of circadian clocks in Arabidopsis thaliana. In particular, this work is interested in explaining alterations in circadian clock period in the toc1-1 mutant and in response to the drug nicotinamide. Finally, the talk discusses the gap between theory and application and some of the theoretical challenges in biology.*

(R6) **Title:** Identifiability of dynamic networks with noisy and noise-free nodes

Authors: Paul Van den Hof, Harm Weerts and Arne Dankers (TU Eindhoven)

Scheduled for: Tuesday September 27th, 9.45am-10.15am

Presenter: Paul Van den Hof

Abstract: *Dynamic networks are structured interconnections of dynamical systems (modules) driven by external excitation and disturbance signals. In order to identify their dynamical properties and/or their topology consistently from measured data, we need to make sure that the network model set is identifiable. We introduce the notion of network identifiability, as a property of a parameterized model set, that ensures that module dynamics are uniquely related to the objects that can be uniquely estimated from data. In the classical prediction error framework, these objects are the predictor filters that constitute the one-step ahead output predictors. We generalize this situation to include the option of having noise-free node signals. The results can be used to specify which presence of excitation signals will result in a unique representation of the network dynamics in a particular network model parametrization. This uniqueness is necessary for detecting the topology of the network from measured data, and for consistently estimating the network dynamics. We combine aspects of the classical notion of system identifiability with a uniqueness-oriented parametrization concept, and extend this to the situation of highly structured model sets. All node signals in the network are treated in a symmetric way as both inputs and outputs. The presented concepts and theory allow for the incorporation of particular structural prior knowledge of the network structure.*

(R7) **Title:** Particle Metropolis-Hastings for inference in non-linear state-space models

Authors: Johan Dahlin, Andreas Svensson, Thomas B. Schön (Uppsala)

Scheduled for: Wednesday September 28th, 9.00am-9.30am

Presenter: Johan Dahlin

Abstract: *Markov chain Monte Carlo (MCMC) methods are an enabler for Bayesian inference in many different scientific fields. In this talk, we present how Markov chain Monte Carlo can be used for state and parameters inference in non-linear and non-Gaussian state space models. We focus on a popular and rather general MCMC method known as the particle Metropolis-Hastings (PMH) algorithm, which can be applied to a large range of problems. We present the PMH algorithm and discuss its advantages and problems when applied in a practical setting. Furthermore, we give an overview of some recent work for accelerating the PMH algorithm and limiting the amount of work needed to tune it. Finally, we present results from applying PMH to some real-world problems based on the recent workshop on nonlinear system identification benchmarks.*

(R8) **Title:** Kernel-based system identification in the frequency domain
Authors: John Lataire (VUB), Tianshi Chen (Linköping University)
Scheduled for: Wednesday September 28th, 9.30am-10.00am
Presenter: John Lataire

Abstract: *In the recent years, the system identification community has developed an interest in kernel-based methods. One particularity is that these methods allow to handle model structure and complexity selection in a convenient manner. Most existing methods have been implemented in the time domain. In this presentation, the peculiarities and advantages of formulating kernel-based system identification in the frequency domain will be highlighted, applied to the non-parametric estimation of transfer functions. These include*
i) the use of complex data,
ii) the possibility to work in a local frequency band,
iii) the use of non-parametric noise models, and
iv) the equal implementability of the method for discrete- and continuous-time systems.

(R9) **Title:** Clustering Time Series
Authors: Lauwers, Oliver and De Moor, Bart (KU Leuven)
Scheduled for: Wednesday September 28th, 10.00am-10.30am
Presenter: Oliver Lauwers

Abstract: *Adequate clustering of time series is an interesting and challenging research topic. Traditional clustering methods of other data types do not carry over trivially, as it is not clear what a good distance measure between time series is. Furthermore, it is often difficult to handle contributions from different parts of the dynamical systems involved, due to the fact that the time series has the convolution as the multiplicative operation. In this presentation, we will go over some of the problems involved with traditional time series clustering techniques, and introduce the Martin cepstrum distance measure and its relation to systems theory, canonical correlations and angles between subspaces of the generative systems of the time series. We show how this handles the problems mentioned above, and present some novel generalizations, that have not appeared in the literature yet. We end by proposing some future research paths.*

(R10) **Title:** Identification of Systems with Unknown Inputs Using Indirect Input Measurements
Authors: Jonas Linder and Martin Enqvist (Linköping University)
Scheduled for: Wednesday September 28th, 11.00am-11.30am
Presenter: Jonas Linder

Abstract: *A common issue with many system identification problems is that the true input to the system is unknown. Historically, the problem of unknown input identification has been studied mainly within three frameworks. The first framework involves approaches that are based on assumptions on the input (e.g. time-series analysis and blind identification). The second framework is based on direct measurements of the inputs (e.g. errors-in-variables identification). In the third framework, many measurements with the same input are*

used and the measurements are used to eliminate the unknown input (e.g. sensor-to-sensor identification). In this contribution, an indirect modeling framework that deals with estimation of systems where the input is partially or fully unknown is presented. In this framework, unknown inputs are eliminated by using additional measurements that directly or indirectly contain information about the unknown inputs. In this way, the original model is reformulated into an indirect model that describes different dynamics. However, in many cases, an estimator based on the resulting model can still be used to estimate the desired original dynamics or properties. Since the input of the indirect model contains both known inputs and measurements that could all be correlated with the same disturbances as the output, estimation of the indirect model has similar challenges as a closed-loop estimation problem. In fact, due to the generality of the indirect modeling framework, it unifies a number of already existing system identification problems that are contained as special cases.

(R11) **Title:** Optimal experiment design for local LPV identification
Authors: Xavier Bombois (CNRS), D. Ghosh, J. Huillery and G. Scorletti (Ecole Centrale de Lyon)
Scheduled for: Wednesday September 28th, 11.30am-12.00pm
Presenter: Xavier Bombois
Abstract: *In local LPV identification, a number of local LTI models of a Linear Parameter Varying (LPV) system are identified by performing identification experiments for fixed values of the scheduling variable. These local LTI models are then interpolated in order to yield a LPV model of the LPV system. In this talk, we are looking at ways to optimally choose the values of the scheduling variables at which the local identification experiments have to be performed as well as the excitation signals that have to be applied to the system during these local identification experiments. The objective of this optimal experiment design problem is to obtain a sufficiently accurate LPV model with the least injected power.*

(R12) **Title:** Identification of aerodynamic coefficients based on free-flight data
Authors: Simona Dobre, Marie Albisser, Claude Berner (ISL)
Scheduled for: Wednesday September 28th, 12.00pm-12.30pm
Presenter: Simona Dobre
Abstract: *Several methods exist, allowing the quantification of the aerodynamic coefficients of vehicles like ammunition, re-entry space vehicles or Unmanned Aerial Vehicles. These methods consist of gathering basic information through Computational Fluid Dynamics predictions, empirical or semi-empirical tools and wind-tunnel tests. However, the quantified aerodynamic coefficients present several limitations: lack of results in terms of the dynamic stability characterization, the determinations are based on simplified assumptions or valid only on a limited range of variation in terms of Mach number and incidence angles. In order to avoid these drawbacks, we consider the identification of these coefficients based on free flight data. The behavior of a vehicle in free flight can be represented as a continuous-time nonlinear state-space model, constructed based on the Newton-Euler equations. It is a six-degree-of freedom mathematical representation, composed of 12 state variables. The parameters of the models correspond to the aerodynamic coefficients characterizing the vehicle, which can be further expressed as function of several state variables. This paper details the estimation of these coefficients based on free flight measurements, which requires a grey-box identification procedure and where the measured signals correspond to 3D magnetic sensor and radar data. Several steps are required, like the polynomial description of the coefficients as a function of the Mach number and the total angle of attack, the a priori and a posteriori identifiability studies, followed by the estimation of the parameters in question, based on real experimental free flight measurements. This proposed model-based method, applied to the determination of the aerodynamic coefficients of a Re-entry space vehicle, improves the accuracy of the estimated coefficients.*

List of Posters

Posters Session A: Monday September 26th, 2016, 10.15am-12:15am

(A1) Title: Identification of uncertain-input systems
Authors: Riccardo Sven Risuleo (KTH)
Presenter: Riccardo Sven Risuleo
Abstract: *In this research, we study the identification of uncertain-input systems. Uncertain-input systems are the generalization of many classical system-identification problems, such as prediction error and regularized system identification, identification of Hammerstein and cascaded systems, blind system identification, as well as errors-in-variables problems and estimation with missing data. Using the Gaussian-process framework, we model the impulse response and the input signal in the uncertain-input system as realizations of Gaussian processes. The mean functions and covariance kernels of the Gaussian processes can be used to incorporate prior information about the system in the identification problem. We propose an empirical Bayes approach to estimate the minimum variance estimates of the input signal and the impulse response, as well as any other parameters of interest. To carry out the estimation, we propose an iterative method based on the Expectation-Maximization method. In this scheme, the E-step may not be available in closed form. In this case, we replace it with a Markov Chain Monte Carlo integration step based on Gibbs sampling. We present results and open problems of the method for the estimation of cascaded LTI systems.*

(A2) Title: Coupling of Particle Filters
Authors: Pierre E. Jacob, Fredrik Lindsten and Thomas B. Schön (Uppsala)
Presenter: Thomas Schön
Abstract: *Particle filters provide Monte Carlo approximations of intractable quantities such as point-wise evaluations of the likelihood in state space models. In many scenarios, the interest lies in the comparison of these quantities as some parameter or input varies. To facilitate such comparisons, we introduce and study methods to couple two particle filters in such a way that the correlation between the two underlying particle systems is increased. The motivation stems from the classic variance reduction technique of positively correlating two estimators. The key challenge in constructing such a coupling stems from the discontinuity of the resampling step of the particle filter. As our first contribution we consider two coupled resampling algorithms. They improve the precision of finite-difference estimators of the score vector and boost the performance of particle marginal Metropolis-Hastings algorithms for parameter inference. The second contribution arises from the use of these coupled resampling schemes within conditional particle filters, allowing for unbiased estimators of smoothing functionals. The result is a new smoothing strategy that operates by averaging a number of independent and unbiased estimators, which allows for 1) straightforward parallelization and 2) the construction of accurate error estimates. Neither of the above is possible with existing particle smoothers. The underlying paper is available here: https://arxiv.org/abs/1606.01156*

(A3) Title: Analysis of a simplified predictor approach for identification of nonlinear unstable systems
Authors: Roger Larsson (Saab/Linköping University) and Martin Enqvist (Linköping University)
Presenter: Roger Larsson
Abstract: *The identification of the flight dynamical characteristics of a fighter aircraft involves several challenges since such a system is nonlinear, unstable and operates in closed loop. In particular, one of the challenges when using the prediction-error method is to define a stable predictor model that can be used to estimate nonlinear aircraft models with several degrees of freedom. Here, the stability and accuracy properties of a relatively simple parameterized observer approach for direct system identification are analyzed.*

(A4) Title: High Dimensional Adaptive Online Learning
Authors: Sholeh Yasini and Kristiaan Pelckmans (Uppsala)
Presenter: Sholeh Yasini
Abstract: *We consider the game theoretic formulation of the online prediction problem. At each round* $t = 1, 2, \ldots, T$ *of the game: 1) the environment presents an input vector* $\mathbf{x}_t \in \mathbb{R}^d$*, 2) the player chooses* $\mathbf{w}_t \in \mathbb{R}^d$ *and predicts* $\hat{y}_t = \mathbf{w}_{t-1}^\top \mathbf{x}_t$*, 3) the environment reveals the true answer* y_t*, 4) the player incurs loss* $\ell_t(\hat{y}_t, y_t)$ *where* $\ell_t : \mathbb{R} \to \mathbb{R}_+$ *is a convex differentiable function. The difference between the total loss of the player and the total loss of the best reference predictor is known as* regret*, defined as*

$$\mathcal{R}_T = \sum_{t=1}^{T} \ell(\mathbf{w}_{t-1}^T \mathbf{x}_t, \mathbf{y}_t) - \inf_{\bar{\mathbf{w}} \in \mathcal{S}} \sum_{t=1}^{T} \ell(\bar{\mathbf{w}}^T \mathbf{x}_t, \mathbf{y}_t), \tag{1}$$

where $\mathcal{S}$ *is the set of reference solutions. The goal of the player is to have sublinear regret, i.e.* $\mathcal{R}_T = o(T)$*. Previous work obtained regret bounds for the online gradient descent and online second order algorithms grows as* $\mathcal{O}(\sqrt{dT})$ *and* $\mathcal{O}(d \log T)$*. However, these bounds deteriorate fast in terms of the dimension of the covariates* d*. We investigate here how the regret grows in high-dimentional online adaptive filtering where the dimension* d *is higher than the number of trials* T*. The idea is to employ the random projection and the Johnson-Lindenstrauss lemma, stating that, given an arbitrary set of* d *points in a (high-dimensional) Euclidean space, there exists a* $f : \mathbb{R}^d \to \mathbb{R}^k$ *(i.e., a linear mapping) of these points in a* k*-dimensional Euclidean space such that all pairwise distances are preserved within a factor of* $1 \pm \epsilon$ *if* $k \propto (\log d/\epsilon^2)$ *for* $\epsilon \in (0, 1)$*. We compare the performance of the proposed random online learning to the performance of the best fixed high-dimensional predictor in hindsight. In particular, we seek an upperbound to*

$$\mathcal{R}'_T = \sum_{t=1}^{T} \ell(\mathbf{w}_{t-1}^T f(\mathbf{x}_t), \mathbf{y}_t) - \inf_{\bar{\mathbf{w}} \in \mathcal{S}} \sum_{t=1}^{T} \ell(\bar{\mathbf{w}}^T \mathbf{x}_t, \mathbf{y}_t), \tag{2}$$

which deteriorates only proportional to $\log d$*.*

(A5) Title: State Estimation for Piecewise Affine State-Space Models
Authors: Rafael Rui, Tohid Ardeshiri, Henri Nurminen Alexandre Bazanella, and Fredrik Gustafsson (Linköping)
Presenter: Tohid Ardeshiri
Abstract: *We propose a filter for piecewise affine state-space (PWASS) models. In each filtering recursion, the true filtering posterior distribution is a mixture of truncated normal distributions. The proposed filter approximates the mixture with a single normal distribution via moment matching. The proposed algorithm is compared with the extended Kalman filter (EKF) in a numerical simulation where the proposed method obtains, on average, better root mean square error (RMSE) than the EKF.*

(A6) Title: Exponential weighting in Wiener system modeling
Authors: Pawel Wachel and Przemyslaw Sliwinski (Wroclaw University of Science and Technology)
Presenter: Pawel Wachel
Abstract: *Aggregation algorithm for modeling Wiener system based on prior identification outcomes (collected in a dictionary) is proposed. The method uses exponential weights to effectively mix models of linear dynamic and nonlinear static models of the genuine system blocks (that are arbitrary outcomes of prior identification trials). It is shown that the resulting model is almost as accurate as the best Wiener model built from a given collection: for a fixed number of dictionary components the cost of aggregation converges to zero with the rate O(1/N) whereas growing number of dictionary elements yields only logarithmic increase of the error.*

(A7) Title: Asymptotic Properties of the Marginal Likelihood Estimator for the Kernel-based Regularization Method
Authors: Biqiang Mu, Tianshi Chen and Lennart Ljung (Linköping)
Presenter: Biqiang Mu
Abstract: *Hyper-parameter estimation is a key step for the kernel-based regularization method. By far, the most effective method is the marginal likelihood maximization. It is interesting to investigate why the marginal likelihood estimator often behaves well. Some findings regarding the robustness property of the marginal likelihood estimator has been reported recently. In this contribution, we report our findings regarding the asymptotic properties of the marginal likelihood estimator.*

(A8) Title: Multidimensional Rational Covariance Extension with Approximate Covariance Matching
Authors: Axel Ringh (OPTSYS, KTH)
Presenter: Axel Ringh
Abstract: *: In this work we consider the use rational systems to model multidimensional stochastic processes obtained from noisy input data. In particular, we investigate how the framework for rational covariance extension can be adapted to handle noisy covariance estimates. The rational covariance extension problem can be solved by posting it as an optimization problem. In this problem a regularizing functional is used that promotes a rational form of the solution spectrum, and this functional is optimized subject to the constraint that the spectrum should match the given covariances. However, errors in covariance estimates impede the accuracy of solution and in some cases there does not even exist a spectrum consistent with the estimated covariance sequence. We extend our previous work by relaxing the exact matching, thereby allowing for noisy covariance estimates.*

(A9) Title: On Robust Application-Oriented Input Design: A risk theoretical approach
Authors: Afrooz Ebadat, Patricio E. Valenzuela and Mariette Annergren (Aut. Control, KTH)
Presenter: Afrooz Ebadat
Abstract: *We consider the influences of uncertainty on the application-oriented input design problem. In the application-oriented input design, the objective is to design an input signal to be used in an identification experiment where the obtained model will later be used in a control application. The input signal should be designed in such a way that the model results in acceptable control performance. The problem is usually formulated as a constrained optimization problem, where the constraint relies on both the parameters to be estimated and the true parameters. Thus a systematic approach to measure the uncertainty is required. Measuring uncertainty through a systematic approach is one of the challenges in system identification. In this work we use the notion of conditional value at risk to measure the uncertainty in the input design problem and a robust application-oriented input design problem is presented. The proposed robust scheme is evaluated on a simple numerical example which shows the success of the method in dealing with uncertainties.*

(A10) Title: An Expanded Fractional Approach for Wiener-Hammerstein Systems Identification
Authors: Giuseppe Giordano (Chalmers)
Presenter: Giuseppe Giordano
Abstract: *The Wiener-Hammerstein system is a block-oriented model structure, consisting of two linear dynamic blocks and a static nonlinearity in the middle. The identification of this class of systems is challenging due to the presence of two dynamic systems whose contributions to the overall behaviour are not easily separable. The key idea of the fractional approach is to parameterize the position of the dynamics of the best linear approximation (BLA), between the two linear subsystems, using fractional exponents. Two main drawbacks of this approach are the presence of exponential nonlinearities and the need of a frequency-domain description of the linear dynamics. In this contribution, a new formulation of the fractional approach is presented, where the*

fractional dynamics are expanded using Taylor series. In this way, the nonlinearities introduced by the fractional exponents are translated into polynomial nonlinearities (coefficients of the series) and a time-domain description of the linear dynamics can be retrieved. Furthermore, it is shown that the coefficients of the series expansion are pseudo-linear functions of the fractional exponents. A new identification algorithm is proposed, based on a constrained optimization problem, which leverages the pseudolinearity property in the definition of the constraints. Comparative results are also provided, showing that the estimation performance, on high order systems, is improved.

(A11) **Title:** Recursive nonlinear-system identification using latent variables
Authors: Per Mattsson, Dave Zachariah and Petre Stoica (Uppsala)
Presenter: Per Mattsson
Abstract: *In this presentation we discuss the identification of nonlinear systems with multiple outputs and inputs. We begin with a nominal predictor of the system and model the prediction errors using a latent variable framework. This framework includes many popular model structures, such as, piecewise ARX models, nonlinear ARX models with basis expansions, etc.*
Using the maximum likelihood principle we then derive a criterion for learning a refined predictor. The resulting optimization problem is tackled using a convex majorization-minimization approach. We also show that the convex optimization problem can be solved recursively, and thus we get an efficient algorithm that can be used online. The proposed method identifies parsimonious predictive models, and has been tested on both synthetic and real nonlinear systems.

(A12) **Title:** Extending the Best Linear Approximation Framework to the Process Noise Case
Authors: Maarten Schoukens, Rik Pintelon, Johan Schoukens (VUB)
Presenter: Maarten Schoukens
Abstract: *This work extends the definition of the standard Best Linear Approximation (BLA) framework, where the noise is considered to be present at the output of the system only, to the process noise case. It is shown that the BLA itself becomes dependent on the properties of the process noise. The stochastic nonlinear contributions and the noise contributions are re-defined, and a process noise contribution is introduced. Furthermore, some important properties of the stochastic nonlinear contributions, the process noise contributions and the noise contributions are proven within the process noise BLA framework.*

(A13) **Title:** Identification and decoupling of Wiener-Hammerstein models
Authors: Gabriel Hollander, Philippe Dreesen, Mariya Ishteva, Johan Schoukens (VUB)
Presenter: Gabriel Hollander
Abstract: *In the field of nonlinear system identification, a parallel Wiener-Hammerstein model offers a good balance between clarity and complexity. It consists of several parallel branches of static nonlinear blocks surrounded by linear time-invariant blocks. To identify such a model, a two-step method exists, where each step has been studied in detail. First a so-called coupled nonlinear function is identified, as well as the linear time-invariant blocks. Then, the nonlinearity is decoupled by finding appropriate transformation matrices and univariate nonlinear functions. ?A full identification scheme combining these two steps while keeping track of noise influence is the next step forward. Therefore, we applied the existing techniques to a specific computer-simulated case study. This work presents the total identification scheme, from start to finish, and compares different models. Errors of the final identified model are small, in the order of 0.7%relative to the output signal, when using a signal-to-noise ratio of 1%. This means the found model is able to describe the measured data accurately.*

(A14) Title: A polynomial nonlinear state space model for vortex-induced vibrations
Authors: J. Decuyper, T. De Troyer, M.C. Runacres, K. Tiels, J. Schoukens (VUB)
Presenter: Jan Decuyper
Abstract: *Due to flow instabilities, vortices are shed in the wake behind structures. As a result, the structure is excited by an alternating lift force. The corresponding fluid-structure interaction is called vortex-induced vibrations (VIV). VIV are known to happen when bluff bodies are submerged in a fluid stream, e.g. chimneys exposed to wind, pipelines on the seabed. When the frequency of vortex shedding approaches the natural frequency of the structure, a synchronization phenomenon kicks in resulting in a resonance state and possibly harmful amplitudes. Despite a growing amount of research, a full physical comprehension of the complex dynamical system has yet to be achieved. For now, one has to rely on time-consuming computational fluid dynamic (CFD) simulations to make predictions of the kinematics of the system with high fidelity. What lacks is an accurate, efficient model that comes at a low computational cost. A job for which system identification is especially well suited. We use CFD simulations of imposed cylinder oscillations in a fluid stream to generate time-series of the lift coefficient. The inherent non-linear nature of the relationship between the oscillation and the lift force makes modelling a challenging task. The model must for instance be able to reproduce the autonomous oscillation of the lift force, even in the static non-excited case. In this work a polynomial nonlinear state space model that relates the oscillation of the cylinder to the lift coefficient is identified and validated.*

(A15) Title: Linear Dynamic Network Reconstruction from Heterogeneous Datasets
Authors: Zuogong Yue and Jorge Goncalves (University of Luxembourg)
Presenter: Zuogong Yue
Abstract: *This poster shows a method to reconstruct linear dynamic network from heterogeneous datasets. In particular the datasets are 1) data from several replicates of an experiment; 2) measurements from linear dynamical systems subjected to different experimental conditions, e.g. changes/perturbations in parameters, different disturbances or noises. However, we need to assume that the underlying network topology, expected to be identified from data, keeps unchanged among all experiments. An ARMAX model is adopted to parameterize a general linear dynamic network representation (J. Goncalves' or P. Van den Hof's model description), which covers Granger Causality graph as a special case. The identification is performed by integrating all available datasets, which resorts to simultaneous group sparsity selections to assure both the sparsity of network topology and the consistency of topologies over datasets (not parameters). In terms of numerical computation, besides classical convexation methods, Sparse Bayesian Learning is also introduced to give a better solution to cardinality optimization. In terms of this treatment, simultaneous integration of various datasets in system identification has the potential to avoid non-identifiability issues typically arising when only a single dataset is used.*

(A16) Title: A frequency-domain parametric identification approach for position-dependent mechanical systems
Authors: Robin de Rozario, Robbert Voorhoeve, Tom Oomen (TUe)
Presenter: Robin de Rozario
Abstract: *Models are essential in precision motion control, for instance to predict performance variables online. In view of ongoing speed and accuracy requirements, position-dependent models are necessary for controlling such systems in the near future. The aim of this poster is to present a system identification procedure that delivers such position-dependent models that are suitable for control. The proposed method delivers a parametric, linear parameter varying model that incorporates mechanical system properties from first-principles modeling through an optimal, multi-step, local LTI identification approach based on frequency response measurements. The developed method is successfully implemented by estimating a position-dependent model of an*

Over-Actuated-Test rig, which is a prototype next-generation wafer stage, thereby confirming that proposed the identification method is well-suited for practical applications.

(A17) **Title:** Semi-supervised learning of NFIR systems
Authors: Simone Formentin, Mirko Mazzoleni, Matteo Scandella, Fabio Previdi (PoliMi and Università di Bergamo)
Presenter: Simone Formentin
Abstract: *High dimensional regression may yield poor performance even in very simple settings. Recent studies by Ljung and coauthors have shown that data can be constrained to a low dimensional manifold by using unlabeled points, leading to good fitting when labels are added in a transductive fashion. In the poster, we discuss how to apply such techniques to the inductive learning of nonlinear dynamical systems. In particular, we focus on NFIR and elaborate upon the problems arising when the regressor contains also the output data.*

(A18) **Title:** Robust Kalman Filtering under model uncertainty **Authors:** M. Zorzi (University of Padova)
Presenter: M. Zorzi
Abstract: *In this poster we face the robust filtering problem using the risk sensitive approach. We show how to extend the usual risk sensitivity filter to a family of risk sensitivity filters. In particular, we show the convergence of one of these risk-sensitive filters by placing an upper bound on the risk-sensitivity parameter. Finally, we show how to extend this family of risk sensitive filters to the case wherein the risk sensitivity parameter is time-varying and chosen at each time step in such a way that the least favorable statistics belongs to the ball centered about the nominal statistic and with a fixed radius c.*

(A19) **Title:**: Image modeling and ipainting based on 2D stochastic subspace system identification **Authors:** José A. Ramos, Guillaume Mercère and Philippe Carré
Presenter: Guillaume Mercère
Abstract: *Fitting a causal dynamic model to an image is a fundamental problem in image processing, pattern recognition, and computer vision. In this presentation, we introduce a 2-D stochastic state-space system identification algorithm for fitting a dynamic Roesser model to a colored image. The algorithm more precisely constructs a non-separable-in-denominator 2D Kalman filter model of the image. A dedicated subspace system identification algorithm is suggested to deal with this specific problem. Notice that, contrary to the subspace system identification techniques available in the literature, this new algorithm can handle non-separable 2D Roesser models. The algorithm is tested with different colored images with a specific attention to the problem of inpaiting,* i.e.*, the process of reconstructing lost or deteriorated parts of images.*

Posters Session B: Monday September 26th, 2016, 3.15pm-5:15pm

(B1) **Title:** Subspace identification of 2D systems: eliminating the states.
Authors: Robin Van Craen, Mauricio Agudelo, Bart De Moor (KU Leuven)
Presenter: Robin Van Craen
Abstract: *Ordinary differential/difference equations describe relations between inputs and outputs of dynamical systems in which there is only one independent variable (typically time). However, sometimes also other independent variables play a prominent role (e.g. spatial coordinates). This leads to multi-dimensional dynamical systems (nD systems), which can be described by partial differential/difference equations. We restrict ourselves to the subclass of discrete, linear, shift-invariant nD systems. In a lot of cases, the underlying dynamics are not known in advance and need to be estimated from the available data (inputs/outputs). We focus on subspace identification techniques, which try to estimate a state-space model by using subspaces spanned by matrices obtained from the data. A few intrinsic differences with 1D occur, which make the problem of subspace*

identification a lot more challenging than in the 1D case. In this poster we elaborate on these differences (e.g. multiple state-space models, non-local models, more difficult formulas for the Markov parameters). We also present a way to eliminate the states in a 2D Roesser model and hence starting from a state-space model, we show how we can obtain a difference equation. Also, the most important challenges we have to face in order to solve the identification problem are explained.

(B2) **Title:** Online semi-parametric learning for inverse dynamics modeling
Authors: D. Romeres, M. Zorzi and A. Chiuso (Univ. di Padova)
Presenter: Diego Romeres
Abstract: *This paper presents a semi-parametric algorithm for online learning of a robot inverse dynamics model. It combines the strength of the parametric and non-parametric modeling. The former exploits the rigid body dynamics equation, while the latter exploits a suitable kernel function. We provide an extensive comparison with other methods from the literature using real data from the iCub humanoid robot. In doing so we also compare two different techniques, namely cross validation and marginal likelihood optimization, for estimating the hyperparameters of the kernel function.*

(B3) **Title:** Closed-Loop Identification and Control of Flexible Orbital Space Structures
Authors: V. Pascu, H. Garnier, A. Janot (ONERA/Universitè de Lorraine)
Presenter: V. Pascu
Abstract: *The development of large flexible orbital space structures, such as remote manipulator systems and satellites with lightweight appendages, has brought to light at the end of the 20th century some of the most difficult challenges within the fields of structural dynamics and automatic control, still unsolved to a large extent. This poster provides an overview on the topic and invites workshop attendants for a discussion regarding how system identification and automatic control can further contribute to the improved integrated design of these technological products. Starting from the problem background, a unified framework for the identification and control of flexible space structures is formulated; the main research challenges, emphasizing the need for cross-fertilization between the automatic control field and the field of structural dynamics, both for robotics and for aerospace structures engineering, are further introduced; the presentation is concluded with a study showcasing the introduced concepts for the problem of combined position and active vibration control of a two-link remote manipulator system.*

(B4) **Title:** An identification procedure for the aerodynamic coefficient determination from free flight data. Application to a re-entry space vehicle
Authors: Marie Albisser, Simona Dobre, Claude Berner, Magalie Thomassin, Hugues Garnier (ISL/Universitè de Lorraine)
Presenter: Marie Albisser
Abstract: *The determination of aerodynamic coefficients for the characterization of the behavior of an object in flight remains one of the oldest, yet still of current interest, research project in the field of exterior ballistics. The present study investigates the identification of the aerodynamic coefficients of an Earth re-entry space vehicle based on measured data, gathered during free flight tests from different measurement techniques. In this framework, an identification procedure was developed, requiring several steps such as the description of the behavior of the vehicle in free flight as a nonlinear state-space model representation, the polynomial descriptions of the aerodynamic coefficients as a function of several state variables, the a priori and a posteriori identifiability analyses, followed by the estimation of the parameters from free flight measurements. To obtain a meaningful evolution of the coefficients valid for all test cases, a multiple fit strategy was considered for the estimation step. This approach makes it possible to provide a common set of aerodynamic coefficients that are*

determined from multiple data series simultaneously analyzed, and gives a more complete spectrum of the vehicle motion. Finally, the resulting estimated model is tested with new data sets to ascertain the model validity. The result show that the proposed description of the aerodynamic coefficients and the estimation strategy is relevant.

(B5) Title: On Smoothness and the RKHS in Nonlinear System Identification
Authors: Yusuf Bhujwalla, Vincent Laurain and Marion Gilson (Universitè de Lorraine/CNRS)
Presenter: Yusuf Bhujwalla
Abstract: *In this poster, we present a discussion of the role of smoothness in nonlinear system identification and the Reproducing Kernel Hilbert Space (RKHS). Smoothness is a defining characteristic for many different classes of functions, and is inherently linked with the model class. Consequently, accurately encapsulating a systems smoothness properties into a model is often required in both analysis and control. However, controlling smoothness in the RKHS is not straightforward. It depends on both the kernel selection and the regularisation, both of which are additionally constrained by other aspects of the identification problem (such as noise disturbances). Hence, the use of a smoothness-enforcing regulariser is discussed as a solution to this co-dependency. Here, the choice of kernel function is removed from the optimisation problem, allowing the smoothness of the model to be fully controlled by the regularisation term. A brief analysis of this optimisation scheme is presented - including the discussion of a suitable formulation for a representer in the presented optimisation scheme. As the choice of the kernel is now unconstrained in the model, an empirical method for the selection of a suitable kernel is given to faciliate the practical implementation of the proposed approach. Furthermore, a new method based on this alternative optimisation scheme is proposed, removing the need for a uniform smoothness assumption in the model. This allows improved control over the smoothness in particular regions, facilitating the detection of nonlinear structures. Simulation examples are provided to illustrate the theory developed and show how the methods discussed can be advantageous in practical identification problems.*

(B6) Title: Identifying a 3DOF Gyroscope using Linear Parameter-Varying State-Space Techniques
Authors: Pepijn Cox, Roland Toth (TUe)
Presenter: Pepijn Cox
Abstract: *The linear parameter-varying (LPV) modelling paradigm offers an attractive parsimonious model class that can capture moderate nonlinearities or time-varying effects of a data generating system, such as the highly nonlinear Quanser 3DOF Gyroscope. To apply newly developed LPV control synthesis methods on this Gyroscope, an LPV state-space (SS) model of the system is required, particularly with static, affine dependence on the scheduling parameter. However, deriving an LPV-SS representation from first principle modeling with discretization leads to large complexity models and, in addition, such model might not even capture all dominant behavior, e.g., dynamics caused by an unbalanced structure. Therefore, we tackle the problem using our state-of-the-art black-box LPV-SS identification paradigm in a global LPV setting (The global setting requires experimental data with an informative, varying scheduling signal, to capture the dynamics associated with it). Our efficient modular identification approach contains the following three steps: 1) estimate the Markov coefficient sequence of the underlying system using Bayesian identification, then 2) create an LPV-SS realization from the estimated coefficients by using an efficient Ho-Kalman like method, and 3) refine the LPV-SS model estimate from a maximum-likelihood point of view by gradient-based or expectation-maximization optimization. The efficiency of this novel method will be demonstrated on the Quanser 3DOF Gyroscope.*

(B7) Title: Bayesian Experiment Design for Formal Verification as a Stochastic Optimal Control Problem
Authors: S.Haesaert, P.M.J.Van den Hof, and A.Abate (TUe and University of Oxford)
Presenter: Sofie Haesaert
Abstract: *We are interested in the use of data-driven and inference-based techniques to verify or falsify system*

properties, such as safety or reachability requirements on the dynamics: these properties can be naturally formulated as specications in a given temporal logic. Towards this goal,the input signals exciting the system should be chosen to maximise the amount of information gained. We embrace a Bayesian experiment design formulation and, for the linearly parameterised models classes under consideration, we show that this can be reformulated as a stochastic optimal control problem over a Markov decision process. Thereby we formulate an optimal stochastic control problem to synthesise optimal experiment design policies. The work distinguishes itself from the standard experiment design problems for estimation, in that its main goal is not to estimate an optimal parameter. Instead, the overall goal of this work is to verify or falsify a property of the underlying system of interest. As such, there is only an indirect need to minimise the accuracy (and especially the variance) of the estimate. Additionally the obtained experiment policies allow for an online input selection dependent on the collection of past data.

(B8) **Title:** Identification of dynamic networks in the presence of algebraic loops
Authors: H.H.M. Weerts, P.M.J. Van den Hof, A.G. Dankers (TUe and University of Calgary))
Presenter: H.H.M. Weerts
Abstract: *A multivariable identification problem is approached from a dynamic network point of view. Two methods to identify a feedback interconnection model for the joint process $w(t)$ in the presente of external reference signals $r(t)$ are the direct method and the joint-IO method [Van den Hof et al., 2013]. These two methods lead to a biased estimate in case the network contains an algebraic loop. We formulate a new method inspired by the direct method and joint-IO method that leads to consistent estimates, even in case there is an algebraic loop in the network.*

In our approach [Weerts et al., 2016] we use a direct method with the predictor $\hat{w}(t|t-1) := \mathbf{E}[w(t)|w^{t-1}, r^t]$. All nodes are treated symmetrically, and the whole network is estimated at once. The predictor does not use instantaneous values $w(t)$ for prediction. Instead direct feedthrough terms of the transfer functions are estimated due to explicit use of external excitation r. The new predictor leads to consistent estimates, and provides an improvement in variance when compared to an instrumental variable method.

References

P. M. J. Van den Hof, A. G. Dankers, P. S. C. Heuberger, and X. Bombois. Identification of dynamic models in complex networks with prediction error methods - basic methods for consistent module estimates. Automatica, 49(10):29943006, 2013.

H.H.M. Weerts, P.M.J. Van den Hof, and A.G. Dankers. Identification of dynamic networks operating in the presence of algebraic loops. In Proc. 55st IEEE Conf. Decision and Control (CDC), 2016. (Submitted).

(B9) **Title:** Model completion of a nano-meter accurate planar actuator system
Authors: I. Proimadis, R. Toth (TUe)
Presenter: Ioannis Proimadis
Abstract: *The most commonly used design in planar actuator motors is based on the combination of a long and a short stroke motor to achieve nano-meter accuracy. In recent years an alternative approach based on a single stroke magnetically levitated planar motor was investigated combined with the design of lightweight movers that enable high accelerations based motion profiles. In the moving magnet configuration, the translator is free from any mechanical connection, thus enabling a simpler design and significant reduction of disturbances from the environment. The nonlinear, multiphysical dynamics, though, hinder the development of an accurate yet simple model of these systems for control purposes. Finite Element Methods (FEM) together with analytic, but static electromagnetic models can partially describe the dynamics of the system. Nonetheless, unforeseen dynamics or inherent assumptions in the followed approaches lead to the need for system identification techniques in terms of model completion. In this project, we are planning to follow Linear Parameter Varying*

identification approaches to grasp the position dependent dynamics of the setup, due to the fixed location of the actuators and the sensors with respect to the moving magnet translator.

(B10) **Title:** LRM for multivariable and position-dependent mechanical systems
Authors: Robbert Voorhoeve, Tom Oomen (TUe)
Presenter: Robbert Voorhoeve
Abstract: *Frequency domain identification is a key step in obtaining models of mechatronic systems. Such mechatronic systems are subject to increasing speed and accuracy requirements, and the consequences are at least twofold. First, to control lightly damped resonance modes, such systems are envisaged to be equipped with additional actuators and sensors, leading to large dimensional multivariable systems. Second, due to the motion tasks made in such systems, the resonant dynamics are typically position dependent. The aim of this poster is to present several recent extensions to local rational model (LRM) based frequency response function identification that are particularly suited to deal with large dimensional systems and position-dependent dynamics. The potential of the proposed approaches is shown in both simulations and experiments.*

(B11) **Title:** Variational Inference in Gaussian Processes for non-linear time series
Authors: Carl Edward Rasmussen (University of Cambridge)
Presenter: Carl Edward Rasmussen
Abstract: *Modelling non-linear dynamical systems from observations (system identification) is often a pre-requisite for designing good controllers. Despite the fundamental importance of this problem, good models and inference methods remain a technical challenge. The difficulties include having to deal with noisy and incomplete measurements and treating suitably flexible non-linear models. Sufficiently flexible models generally wont have succinct representations, and large numbers of free parameters requires principled approaches to issues such as overfitting. In this talk I will present a couple of recent developments in machine learning which together allows approximate fully Bayesian inference jointly over both latent states and non-linear transition models. This elegant and practical framework relies on variational inference in non-linear Gaussian process state space models.*

(B12) **Title:** Configuring the Numerical Optimization of the D-optimal Input Design problem for Block Structured Systems
Authors: Alexander De Cock and Johan Schoukens (VUB)
Presenter: Alexander De Cock
Abstract: *The field of optimal input design considers the problem of finding the most informative input signal out of the set of possible excitation signals given some prior knowledge about the system. In its most general form, finding an optimal input signal comes down to solving an optimization problem in which a scalar measure of the Fisher information matrix is maximized with respect to the parametrization of the input sequence. The complexity of this optimization problem strongly depends on the model structure, the input parametrization and the properties of the scalar information measure. In this study, the optimal input design is computed for block structured systems, which consist of a combination of linear time invariant blocks and static nonlinear blocks. The class of inputs is restricted to periodic bandlimited excitations and is parameterized in the time domain. Under these assumptions, the resulting optimization problem becomes nonlinear and non-convex. This type of optimization is very sensitive with respect to the solver and the design choices. Based on extensive simulation results, guidelines are extracted for the different design choices that have to be made during the optimization.*

(B13) Title: Optimal input design in the presence of prior knowledge
Authors: Georgios Birpoutsoukis, Xavier Bombois, Johan Schoukens (CNRS, Ecole Centrale de Lyon and VUB)
Presenter: Georgios Birpoutsoukis
Abstract: *During the last years it has become evident that the use of prior knowledge about the dynamics of a system can be very beneficial in the field of system identification. Characteristics such as stability and smoothness have been encoded in the form of a penalty on the estimated parameters for the impulse response of linear systems, while results have also been presented for the nonlinear case and the Volterra series. Introducing prior knowledge in the identification step gives rise to an important question: is it possible that the optimal excitation for a dynamic system is going to be altered, given that prior knowledge is used for the derivation of the model? Which direction is this going to take place in?*

(B14) Title: Improved nonparametric identification of a lightly-damped mechanical multiple-input multiple-output system
Authors: Dieter Verbeke, Johan Schoukens (VUB)
Presenter: Dieter Verbeke
Abstract: *Some years ago, the local polynomial method (LPM) was introduced for estimating the frequency response matrix (FRM) of dynamic multivariable systems (Pintelon et al., 2010). The local polynomial methods result in a nonparametric suppression of the noise and system transients (leakage) errors in the frequency response matrix and noise (co-) variance estimates. In this poster we will further discus signal processing techniques for improved nonparametric estimates related to the LPM. Essentially, rational approximations of transfer function and transients are made in a narrow band around each line in the frequency domain. The resulting estimation method is called the local rational method (LRM). The LRM holds the potential for superior performance when the system exhibits strongly resonant behaviour. In that case the systems transfer function and transient cannot be well approximated by polynomials. The first mention of LRM is found in McKelvey & Gurin (2012), where the approach is explored on the basis of numerical experiments on a simple single-input single-output (SISO) system. Our contribution w.r.t. that reference is twofold. On one hand, we treat MIMO systems and give some mathematical details. On the other hand we demonstrate the methods value on a benchmark identification problem with eight inputs and six outputs.*

R. Pintelon, J. Schoukens, G. Vandersteen, K. Barbe, Estimation of nonparametric noise and FRF models for multivariable systems part I: Theory, Mechanical Systems and Signal Processing Vol. 24, No. 3, Elsevier (2010), pp. 573 - 595.

T. McKelvey, G. Gurin, Non-parametric frequency response estimation using a local rational model, in Proceedings of the 16th IFAC Symposium on System Identification, Brussels, Belgium, 2012 July 11-13, pp. 49 - 54.

(B15) Title: PNLSS 1.0 A polynomial nonlinear state-space toolbox for Matlab
Authors: Koen Tiels (VUB)
Presenter: Koen Tiels
Abstract: *A polynomial nonlinear state-space (PNLSS) model is a natural extension of a discrete-time linear state-space model, where polynomial terms are added in the state update and output equation. A PNLSS model can exhibit many different nonlinear dynamic behaviors. Moreover, the modeling framework has been successfully applied in a large range of applications. At my poster, I will present PNLSS 1.0, a toolbox for Matlab that helps the user with the identification of a PNLSS model. New features will include the possibility to impose constraints (e.g. to impose structure) and the possibility to capture non-polynomial nonlinearities.*

(B16) **Title:** Black-box nonlinear identification of Li-ion battery cell
Authors: Rishi Relan, Koen Tiels, Jean-Marc Timmermans, Johan Schoukens (VUB)
Presenter: Rishi Relan

Abstract: *Lithium ion (Li-ion) batteries are attracting significant and growing interest because their high energy and high power density render them an excellent option for energy storage, particularly in hybrid and electric vehicles, as well as an ideal candidate for a wide variety of other applications. In order to develop a complete dynamic model of a lithium ion (Li-ion) batterys electrical behaviour, which is suitable for virtual-prototyping of battery-powered systems, accurate estimation of the state of charge (SoC) and state of health (SoH) is required. This in-turn depends on the quality of the models which are used for the estimation of these quantities. Hence, even before proceeding towards the modelling step, it is important to fully characterize and understand the electrical behaviour (in terms of linear and nonlinear behaviour) of the battery over its full operating range, so that a flexible and an accurate dynamic model can be developed. In this work, first the information about the linear and nonlinear behaviour of the battery is extracted from frequency domain non-parametric analysis. In order to do that, multiple experiments are performed over its full operating range in terms of (SoC) and temperature. Thereafter, a global nonlinear model is developed for the nonlinear regime of the batterys short term electrical response from these multiple operating point measurements.*

(B17) **Title:** A Simulated Maximum Likelihood Method for Estimation of Stochastic Wiener Systems
Authors: Mohamed Rasheed Hilmy Abdalmoaty and Hakån Hjalmarsson (Automatic Control, KTH)
Presenter: Mohamed Rasheed Hilmy Abdalmoaty

Abstract: *It is well known that the likelihood function of the observed outputs for the general class of stochastic Wiener systems is analytically intractable. However, when the distributions of the process disturbance and the measurement noise are available, the likelihood can be approximated by running a Monte-Carlo simulation on the model. We suggest the use of Laplace importance sampling techniques for the likelihood approximation. The algorithm is tested on a simple first order linear example which is excited only by the process disturbance. Further, we demonstrate the algorithm on an FIR system with cubic nonlinearity. The performance of the algorithm is compared to the maximum likelihood method and other recent techniques.*

(B18) **Title:** Innovation-based subspace identification in open- and closed-loop
Authors: Guillaume Mercère and Ivan Markosky
Presenter: Guillaume Mercère

Abstract: *The applicability of subspace-based system identification methods highly depends on the disturbances acting on the system. It is well-known,* e.g.*, that the standard implementations of the MOESP, N4SID or CVA algorithms yield biased estimates when closed-loop noisy data is considered. In this paper, we suggest pre-estimating the innovation term from the available data in order to bypass this difficulty. By doing so, the subspace-based identification problem can be written as a deterministic problem for which efficient methods exist. When the system description does not belong to the model class, a structured least-squares solution is proposed. The performance of the methods is illustrated through the study of simulation examples.*

(B19) **Title:**: A New Algorithm for Circulant Rational Covariance Extension and Applications to Finite-interval Smoothing **Authors:** Giorgio Picci and Bin Zhu
Presenter: Bin Zhu

Abstract: *The partial stochastic realization of periodic processes from finite covariance data has recently been solved by Lindquist and Picci based on convex optimization of a generalized entropy functional. The meaning and the role of this criterion have an unclear origin. In this paper we propose a solution based on a nonlinear generalization of the classical Yule-Walker type equations and on a new iterative algorithm which is shown to converge to the same (unique) solution of the variational problem. This provides a conceptual link to the variational principles and at the same time yields a robust algorithm which can for example be successfully* *applied to finite-interval smoothing problems providing a simpler procedure if compared with the classical Riccati-based calculations.*

Posters Session C: Tuesday September 27th, 2016, 10.15am-12:15am

(C1) **Title:** Efficient parameter estimation approach for rational function-type models applied to MRI
Authors: M. Björk, G. Ramos-Llordén, A.J. den Dekker, M. Verhoye, and J. Sijbers (Uppsala, Delft University of Technology and University of Antwerp)
Presenter: Marcus Björk
Abstract: *Rational function-type models, that is quotients of linear combinations of general functions of the input, can be used in many applications. Particu- larly, signal models in MRI can often be written in this form by a nonlinear change of variables (including a possible over-parameterization). Due to the quotient, estimating the linear coefficients is a nonlinear problem that is typ- ically solved by off-the-shelf minimization algorithms such as Gauss-Newton (GN) or Levenberg-Marquardt (LM). However, in the context of chemical engineering, an efficient fixed-point iteration approach to solve this prob- lem has been proposed1, which has interesting connections to GN. Here, we evaluate this fixed-point approach in the context of MRI, in particular, for es- timating the longitudinal relaxation time T1 from Spoiled Gradient Recalled Echo (SPGR) images. The overall estimation approach, which includes an invertible nonlinear transformation of the parameters, is named NOVIFAST, and provides an approximation of the maximum likelihood estimates. The results from NOVIFAST are compared in terms of accuracy, precision, and computation time, to the corresponding GN and LM-based approaches and a fast approximate technique designed for T1 estimation called DESPOT-12. It is shown that NOVIFAST obtains a performance similar to properly ini- tialized GN and LM approaches, at a computational cost comparable to the fast DESPOT-1 method, giving the best of both worlds.*

(C2) **Title:** Prediction Performance After Learning in Gaussian Process Regression
Authors: Johan Wågberg, Dave Zachariah, Thomas B. Schön, Petre Stoica (Uppsala)
Presenter: Johan Wågberg
Abstract: *This paper considers the quantification of the prediction performance in Gaussian process regression. The standard approach is to base the prediction error bars on the theoretical predictive variance, which is a lower bound on the mean square-error. This approach, however, does not take into account that the statistical model is learned from the data. We show that this omission leads to a systematic underestimation of the prediction errors. Starting from a generalization of the Cramr-Rao bound, we derive a more accurate measure of uncertainty for prediction of Gaussian processes and illustrate it using synthetic and real data examples. The paper is available at https://arxiv.org/abs/1606.03865*

(C3) **Title:** An approximate Bayesian computation approach to the Wiener Hammerstein benchmark
Authors: Andreas Svensson, Fredrik Lindsten, Thomas B. Schön (Linköping and Uppsala)
Presenter: Andreas Svensson
Abstract: *Identification of models with intractable data likelihoods is very challenging, both for maximum likelihood and Bayesian methods. Intractability of the likelihood means that it is not possible to evaluate* $p(data|parameters)$*. The Wiener Hammerstein benchmark falls into this category, due to the large source of stochastic process noise, compared to the almost negligible measurement noise. To deal with this challenge, we investigate how to apply the idea of approximate Bayesian computations (ABC). In ABC, a certain uncertainty is assumed for the measurement, despite the physical knowledge. Indeed, this assumption has to be made in a way to (i) gain a computationally tractable model, but also (ii) not to sacrifice the statistical efficiency of the inference more than necessary. Due to the dynamical model for the Wiener Hammerstein benchmark, the*

standard application of ABC does not give an efficient solution. We therefore explore non-standard implementations, using Particle Markov chain Monte Carlo methods. We relate our proposed method to the existing literature, and report convincing performance in terms of obtained model quality for the Wiener Hammerstein benchmark.

(C4) **Title:** Calibration of an inverted pendulum biomechanical model using inertial sensors
Authors: Fredrik Olsson and Kjartan Halvorsen (Uppsala)
Presenter: Fredrik Olsson
Abstract: *We present ongoing work about calibration of the position of inertial sensors worn by a human. Inertial sensors (accelerometers and gyroscopes) are often used in estimation and analysis of human motion. Biomechanical models, which describe the kinematic properties of the body parts and how they connect are essential in these applications. In order to use the model for tracking the motion, the relationship between the model and the sensors must be established. We use a three-linked inverted pendulum (IP) model as a biomechanical model, where the pendulum segments represent the lower leg, thigh and torso. Inertial sensors are placed on each pendulum segment and their positions are estimated using sensor fusion and the IP model. Measurement noise and bias can reduce the quality of the estimated sensor positions significantly. We will discuss how these errors can be characterized and compensated for to improve the accuracy of the calibration.*

(C5) **Title:** Robust Inference for State-Space Models with Skewed Measurement Noise
Authors: Henri Nurminen, Tohid Ardeshiri, Robert Pich, and Fredrik Gustafsson (Linköping)
Presenter: Tohid Ardeshiri
Abstract: *Filtering and smoothing algorithms for linear discrete-time state-space models with skewed and heavy-tailed measurement noise are presented. The algorithms use a variational Bayes approximation of the posterior distribution of models that have normal prior and skew-t-distributed measurement noise. The proposed filter and smoother are compared with conventional low-complexity alternatives in a simulated pseudorange positioning scenario. In the simulations the proposed methods achieve better accuracy than the alternative methods, the computational complexity of the filter being roughly 5 to 10 times that of the Kalman filter.*

(C6) **Title:** Fast Identification of Hidden Markov Models with Known Observation Probabilities
Authors: Robert Mattila (Department of Automatic Control, KTH)
Presenter: Robert Mattila
Abstract: *Hidden Markov Models (HMMs) are widely used in applications and theoretical frameworks as models for stochastic time series. Most of the current methods employed for identification of the parameters needed to specify an HMM utilize iterative likelihood maximization schemes. Such methods may experience problems with slow and/or only local convergence. Here, we consider an alternative approach using a method of moments. The special case of known sensor uncertainties is considered, which allows the problem to be cast as a convex optimization problem. We combine the resulting consistent estimate with one Newton step on the likelihood function to improve the resulting estimate. This yields a fast and competitive method to the standard Expectation-Maximization method.*

(C7) **Title:** ARX modeling of unstable Box-Jenkins systems
Authors: Miguel Galrinho and Niklas Everitt (Department of Automatic Control, KTH)
Presenter: Miguel Galrinho
Abstract: *The use of high-order polynomial models that are linear in the parameters is common in system identification to avoid the non-convexity of the prediction error method when applied to other model structures. A common and fairly general case is to use high-order ARX models to approximate Box-Jenkins structures. Then, a well known correspondence is made between the ARX polynomials and the plant and noise models in*

the Box-Jenkins structure. However, this commonly used result is only valid when the predictor is stable. In this contribution, we generalize these results to allow for unstable predictors due to an unstable plant. We show that high-order ARX models are appropriate for this situation as well. However, corrections must be made to correctly retrieve the noise model and noise variance.

(C8) **Title:** Particle-based Gaussian process optimization for input design in nonlinear dynamical models
Authors: Patricio E. Valenzuela (Department of Automatic Control, KTH)
Presenter: Patricio E. Valenzuela
Abstract: *We propose a novel approach to input design for identification of nonlinear state space models. The optimal input sequence is obtained by maximizing a scalar cost function of the Fisher information matrix. Since the Fisher information matrix is unavailable in closed form, it is estimated using particle methods. In addition, we make use of Gaussian process optimization to find the optimal input and to mitigate the problem of a large computational cost incurred by the particle filter, as the method reduces the number of functional evaluations. Numerical examples are provided to illustrate the performance of the resulting algorithm.*

(C9) **Title:** Filter-based regularisation for impulse response modelling
Authors: Anna Marconato, Maarten Schoukens, Johan Schoukens (VUB)
Presenter: Anna Marconato
Abstract: *In the last years, the success of kernel-based regularisation techniques in solving impulse response modelling tasks has revived the interest on linear system identication. In this work, an alternative perspective on the same problem is introduced. Instead of relying on a Bayesian framework to include assumptions about the system in the denition of the covariance matrix of the parameters, here the prior knowledge is injected at the cost function level. The key idea is to dene the regularisation matrix as a ltering operation on the parameters, which allows for a more intuitive formulation of the problem from an engineering point of view. Moreover, this results in a unied framework to model low-pass, band-pass and high-pass systems, and systems with one or more resonances. The proposed lter-based approach outperforms the existing regularization method based on the TC and DC kernels, as illustrated by means of Monte Carlo simulations on several linear modelling examples.*

(C10) **Title:** Identifying parallel Wiener-Hammerstein systems by decomposing Volterra kernels
Authors: Mariya Ishteva (VUB), Philippe Dreesen (VUB), David Westwick (University of Calgary), Johan Schoukens (VUB)
Presenter: Mariya Ishteva
Abstract: *To capture the nonlinear effects of the real world, the focus of system identification is shifting from linear to nonlinear dynamical models. Every nonlinear dynamic system with fading memory can be approximated with arbitrary precision by its Volterra kernel description, which is a generalization of the Taylor series for systems with memory. However, the Volterra series provides a non-parametric representation, which lacks physical and intuitive interpretation. To take advantage of the Volterra representation while aiming for an interpretable block-oriented model, we studied ways to impose the desired structure using tensor techniques. This poster presents our current progress and challenges on this task. We successfully generalized an existing tensor technique for identifying Wiener-Hammerstein systems to identifying the more challenging but more powerful parallel Wiener-Hammerstein systems. Tensor techniques, and in particular well-designed structured canonical polyadic decompositions, thus once again proved useful in the system identification community. The next step is to make the algorithm numerically stable and robust to noise.*

(C11) Title: Decoupling nonlinear black-box models using tensor methods
Authors: Philippe Dreesen, Mariya Ishteva, Johan Schoukens (VUB)
Presenter: Philippe Dreesen
Abstract: *Over the last decades, system identification has witnessed a tendency towards the use of nonlinear models. There are two promising approaches, namely black-box identification methods and block-oriented models.Block-oriented models consist of an interconnection of linear dynamical blocks and static nonlinearities. Both black-box models as well as block-oriented models have their advantages and disadvantages. Black-box state-space models can be computed relatively easily, and often provide a decent nonlinear description of a system. This comes at the expense of offering only a limited correspondence to the physical nature of the system, and often involving a very large number of parameters. Block-oriented models typically require much fewer parameters, and can correspond to a high extent to the underlying physical nature of the system. However, there are currently no universal identification methods that can reliably identify any given block-structure: tailored identification procedures need to be devised. The current work combines the best of two worlds by proposing a way to unravel given black-box models into parsimonious representations. This is done by performing a so-called decoupling of the nonlinear model. By probing the Jacobian of the nonlinearity in a number of sampling points, it can be shown that a decoupled representation can be found using the Canonical Polyadic Decomposition. In the decoupled representation the nonlinearities act upon single variables. This gives a drastic reduction in the number of parameters. Additionally it may offer insight into the nature of the nonlinearities. The decoupled representation is used to re-initialize a grey-box model, in which now the nonlinearity is parameterized using much fewer parameters, turning out to be able to further improve the model quality.*

(C12) Title: Realizability analysis of a block oriented nonlinear feed-back system
Authors: Alireza Fakhrizadeh Esfahani, Johan Schoukens, Koen Tiels (VUB)
Presenter: Alireza Fakhrizadeh Esfahani
Abstract: *In this work, the realizability of the sub-blocks in a nonlinear feedback system is assessed. The nonlinear feedback system under study consists of a Wiener-Hammerstein branch in the feedforward path, and a linear block in the feedback path. The uniqueness of this representation with respect to input/output data is studied. Under the assumption that all blocks in the model are causal and stable, it is examined whether or not it is possible to obtain a different model representation with the same input/output behavior. The study shows that imposing stability and causality of the sub-blocks is not always sufficient to obtain a unique representation.*

(C13) Title: Identification of linear dynamic network using Sparse Bayesian Learning
Authors: Junyang Jin (University of Cambridge)
Presenter: Junyang Jin
Abstract: *This poster shows the identi cation of linear time-invariant networks described by multivariable ARX models. With the identifiability guaranteed, an identi cation method that infers both the Boolean structure of the network and the internal dynamics between nodes is presented. The identi cation is performed directly from data and without any prior knowledge of the system, including its order. The method is to solve the identification using Sparse Bayesian Learning, both in terms of element (order of nonzero connections) and group sparsity (network topology). We propose a novel scheme that combines sparse Bayesian and sparse group Bayesian to promote the network sparsity. The resultant algorithm can be decomposed into a series of standard Sparse Group Lasso(SGL). The method and the developed toolbox can now be used to infer networks from a wide range of fields, including systems biology applications such as signalling and genetic regulatory networks.*

(C14) **Title:** Control and data-driven modelling using symbolic regression

Authors: Dhruv Khandelwal, Roland Tth, Paul M. J. Van den Hof. (TUe)

Presenter: Dhruv Khandelwal

Abstract: *This research aims at automating the process of system identification and control synthesis for complex systems by means of evolutionary symbolic tools that result in interpretable models and control laws, enabling compact and efficient controller implementations for complex physical systems. The work primarily focuses on building a new framework for computing data-driven models that incorporates symbolic regression analysis.The major handicap of the state-of-the-art of system identification is the selection of an actual model class and parameteriazation for the system to be captured. This involves imposing assumptions on the structural relationships of the model, which require vast experience from the user and often lead to costly iterative processes to arrive at valid structural knowledge. We seek to bypass the need for model (and noise) parameterization by using symbolic regression. Symbolic regression is a novel evolutionary optimization technique that searches for analytical expressions that fit measured numerical data. These expressions are built from fundamental blocks such as arithmetic operators, dynamic structures (shift operators), non-linearities, signal elements, and so on. Symbolic regression manipulates these basic blocks to find a solution in the model space that best explains the numerical data, according to an appropriately defined cost function. Thus, this method of identification is not restricted by assumptions on the structure of the model. The main objective of this project is to develop a novel software tool that automatically manipulates basic user-defined blocks in order to satisfy complex modelling or control objectives dictated by economical, performance and safety specifications.*

(C15) **Title:** An on-line compensation of input-additive disturbances: an evolving Gaussian process models approach

Authors: Mohamed A. H. Darwish and Roland Toth (TUe)

Presenter: Mohamed A. H. Darwish

Abstract: *Model-based control of non-linear systems offers various control strategies provided that an accurate system model is available. However, an accurate model of the whole system behaviour is often difficult to obtain. For instance, disturbances such as friction, cogging and forces due to gravity are difficult to model using first-principle knowledge due to their imprecise models and often time-varying nature. As a result, when such inaccurate models are used in, e.g., motor control scheme, the resulting control performance is generally not sufficient. To overcome this fundamental limitation, a control scheme is presented which uses a data-driven learning approach to learn the unknown, input-additive disturbances in the system behaviour. More specifically, the unknown disturbance is modeled as an evolving Gaussian process (GP) model, which is identified directly from the observed data and updated at every time instant to capture both the nonlinear and time-varying nature of such disturbances.*

(C16) **Title:** Recursive identification of time-varying physical parameters for a mechatronic system

Authors: Arturo Padilla, Hugues Garnier and Juan I. Yuz (Université de Lorraine and Universidad Técnica Federico Santa María

Presenter: Arturo Padilla

Abstract: *The physical properties of a mechatronic systems can vary with time due to, for instance, aging effects or temperature changes. The latter case is addressed in this work, where the physical temperature-varying parameters for a mechatronic actuator are directly estimated in a recursive fashion. There are a few challenges to overcome. One of them concerns the fact that physical constraints of the system, limit the imposed excitation, leading to estimates with large picks which do not represent the true parameter behaviour. In order to tackle this problem, estimator windup techniques are considered. Another issue is the observation of unmeasured variables required by the parameter identification. This poster will present these challenges in* *more detail and will also describe some results based on the use of a recursive es- timation procedure to directly track the physical parameter variations from the sampled measured data.*

(C17) **Title:** Benchmarking for Continuous-Time Transfer Function Model Identification
Authors: V. Pascu, H. Garnier, L. Ljung, A. Janot (Université de Lorraine, Linköping and ONERA)
Presenter: V. Pascu
Abstract: *The identification of continuous-time transfer function models of dynamical systems based on sampled measurements of input/output signals is a mature research topic that currently lacks a proper assessment framework for the performance of the different parameter estimation methodologies, due to a number of benchmarking difficulties. This poster invites workshop attendants for a discussion on the topic: the problem background is formulated, an overview of the current continuous-time transfer function model identification methods is given, followed by a discussion of the most important challenges towards creating a benchmark for their evaluation; finally, a case study that highlights the presented challenges is provided.*

(C18) **Title:** Frame prediction with ladder networks
Authors: Giulia Prando, Philipp Moritz, Michael I. Jordan (University of Padova and UC Berkely)
Presenter: G. Prando
Abstract: *Recently, the so-called "ladder network" has been introduced in the deep learning community as a tool for unsupervised and semi-supervised learning. A ladder network is an autoencoder equipped with connections between the decoder and the encoder at chosen layers of the network hierarchy. In this work we investigate the use of ladder networks in a supervised learning task, specifically in the context of frame prediction. Possible applications include video prediction and model-based reinforcement learning. Indeed, by introducing a dynamics model between the deepest layers of the autoencoder, the ladder network can model the transition map of an MDP with high-dimensional state space. Experiments on future frame prediction of Atari games and of videos in Sports1m dataset confirm the effectiveness of the approach.*

(C19) **Title:** Identifying nonlinear dynamics via Lagrangian relaxation of EM
Authors: Jack Umenberger, Johan Wågberg, Ian Manchester and Thomas B. Schön
Presenter: Jack Umenberger
Abstract: *In the application of the Expectation Maximization algorithm to identification of dynamical systems, internal states are typically chosen as latent variables, for simplicity. In this work, we propose a different choice of latent variables, namely, system disturbances. Such a formulation elegantly handles the problematic case of singular state space models, and is shown to (typically) improve the fidelity of bounds on the likelihood, leading to convergence in fewer iterations. To access these benefits we develop a Lagrangian relaxation of the nonconvex optimization problems that arise in the latent disturbances formulation, and proceed via semidefinite programming.*