ELEC Spring Doctoral School Invited Lecture 2012

"Computational inference in dynamical system"

Dr. Thomas Schön, Linköping University, Sweden

6-7 june 2012 from 08:00 to 12:00 hrs Auditorium P.Janssens, Building K 2nd Floor VUB

Abstract:

The overall aim in this part of the course is to provide an introduction to the theory and application of computational methods (some of them only a couple of years old) for inference in dynamical systems. More specifically, the computational methods we are referring to are sequential Monte Carlo (SMC) methods (particle filters and particle smoothers) for nonlinear state inference problems and expectation maximisation (EM) and Markov chain Monte Carlo (MCMC) methods for nonlinear system identification.

Dealing with the nonlinear system identification problem will require nonstandard combinations of these methods. We will work almost exclusively with state-space models, linear models to introduce the methods and nonlinear models to illustrate the capabilities of the methods. It is our firm belief that even if you aim for solving nonlinear problems, you should always make sure that the method under study is capable of solving basic linear problems first. If that cannot be done, the method does not stand a chance in solving the nonlinear problem either. Furthermore, a good understanding of linear models is important in order to be able to understand nonlinear models. Our aim throughout this course is introduce the methods by answering simple questions relating to linear systems and then (most importantly) show that the methods are capable of tackling nonlinear problems as well.

After a brief introduction we will derive general expressions for computing filtering and various smoothing densities for the states in nonlinear dynamical models. The basic strategies employed in both maximum likelihood (ML) and Bayesian system identification are then reviewed. After this short starting phase, we derive the EM algorithm and show how to use it to compute ML estimates in linear systems. We then turn our attention to the MCMC methods and show how these methods can be used to solve the linear system identification problem. This involves some interesting developments requiring the use of the matrix-Normal and the inverse-Wishart distributions and the so called simulation smoothers.

The linear models have so far served the purpose of testing grounds for introducing the EM and the MCMC methods. However, it is now time to leave the linear models behind and turn

our attention to nonlinear models instead. The SMC methods (focusing on the particle filter) will be introduced and the basic theory is provided. We will also show how the particle filter has been used to solve some nontrivial nonlinear filtering problems we have been working on together with various companies. The particle smoother is briefly introduced.

Finally, we will show how the methods introduced above can be used to solve various problems in nonlinear system identification. We start by showing how to compute ML estimates using EM (involving particle smoothers and nonlinear optimisation) and show how this can be used to solve various problems, including some Wiener identification problems. Depending on how much time we have towards the end, we might also introduce a very recent (and exciting) development called the particle MCMC (PMCMC) method. Using PMCMC we are capable of solving nonlinear Bayesian system identification problems by a nontrivial combination of the MCMC methods and the SMC methods.

One particular PMCMC algorithm will be illustrated by solving a rather challenging Wiener problem, where a non-monotonic nonlinearity is identified using a nonparametric description. This final part will also be presented (necessarily more compressed though) at SYSID in July (also conveniently located in Brussels as you all know).

Overview

Part 1 - Getting started

1.1 Brief introduction (explaining what we will do during these 8 hours and provide some basic model assumptions)
1.2 Derive the general expressions for computing the filtering and various smoothing densities for the states in nonlinear dynamical systems.

Part 2 - EM and MCMC explained via linear system identification

2.1 Derive the expectation maximisation (EM) for computing maximum likelihood (ML) estimates
2.2 Identification of linear, Gaussian state-space (LGSS) models using EM
2.3 Markov chain Monte Carlo methods. General properties, introducing the Metropolis-Hastings sampler and the Gibbs sampler in general and illustrate their use on identification of LGSS models.

Part 3 - Nonlinear state inference using sequential Monte Carlo (SMC)

3.1 Particle filtering (introduced via importance sampling). Theory and applications.
3.2 Particle smoothing (PS)

Part 4 - Nonlinear system identification

4.1 Computing ML estimates using EM and PS. Use Wiener system identification as one example.
4.2 Computing Bayesian estimates using particle Markov chain Monte Carlo (PMCMC) methods

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Invited Lecturer

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Thomas B. Schön was born in Jönköping (Sweden) on December 25, 1977. He is an Associate Professor with the Division of Automatic Control at Linköping University (Linköping, Sweden). He received the B.Sc. degree in Business Administration and Economics in Jan. 2001, the M.Sc. degree in Applied Physics and Electrical Engineering in Sep. 2001, the Lic. Eng. degree in Automatic Control in Oct 2003 and the Ph.D. degree in Automatic Control in Feb. 2006, all from Linköping University. He has held visiting positions with the University of Cambridge (UK) and the University of Newcastle (Australia). He is a Senior member of the IEEE.

Schön's main research interest is nonlinear inference problems, especially within the context of dynamical systems, solved using probabilistic methods. This covers broad aspects of machine learning, signal processing, system identification and sensor fusion. He pursue both basic research and applied research, where the latter is typically carried out in collaboration with industry. More information about his research can be found from his home page.