Preface

A central theme in the study of dynamic systems is the modelling and control of uncertain systems. While 'uncertainty' has long been a strong motivating factor behind many techniques developed in the modelling, control, statistics and mathematics communities, the past decade, in particular, has witnessed remarkable progress in this area with the emergence of a number of powerful new methods for both modelling and controlling uncertain dynamic systems. The specific objective of this book is to describe and review some of these exciting new approaches within a single volume. Our approach was to invite some of the leading researchers in this area to contribute to this book by submitting both tutorial papers on their specific area of research, and to submit more focussed research papers to document some of the latest results in the area. We feel that collecting some of the main results together in this manner is particularly important as many of the important ideas that emerged in the past decade were derived in a variety of academic disciplines. By providing both tutorial and research papers we hope to be able to provide the interested reader with sufficient background to appreciate some of the main concepts from a variety of related, but nevertheless distinct fields, and to provide a flavor of how these results are currently being used to cope with 'uncertainty.' It is our sincere hope that the availability of these results within a single volume will lead to further cross-fertilization of ideas and act as a spark for further research in this important area of applied mathematics.

It is a huge challenge to completely characterize methods for dealing with 'uncertainty' in a concise manner, and it is impossible to document all of the methods that have emerged over the past decade. The work that is included in this book is work that to a large extent is due to the widespread availability of cheap computation power. Identification paradigms based upon non-parametric statistics and Monte Carlo simulation that were once considered too impractical to be of interest to engineers, are now the subject of great interest in the community, and form the basis of many practically useful nonlinear system identification techniques. Similarly, complex supervisory (switching) control strategies that were also once considered too complex to manage in practical situations are now providing the basis for the control of uncertain and rapidly time-varying dynamic systems. Switching control strategies can also be considered Multi-Agent or Multiple Model systems, although each research area has tended to use different tools, and to apply their methods to different application areas. It is our hope that this book provides, in particular, a rigorous snapshot of some of the developments that have taken place in these areas over the past decade, and also presents state-of-the art research in selected areas of switching and learning systems. In the context of this overall objective, our aim was to produce a book that would be of use to a graduate researcher wishing to undertake research in this vast field, and that would have both introductory chapters and leading-edge research, together with example applications of the methods. Toward this aim, we divided the book into three parts:

Part I introduces the challenges in switching systems for feedback control systems, with a broad overview by K. Narendra. This is followed by a review of some of the stability issues that arise in supervisory control systems by Shorten, Mason and Wulff. Grancharova and Johansen then survey explicit approaches to constrained optimal control for complex systems, which is of particular interest for practical application.

Part II covers the use of Gaussian Process priors in feedback control contexts. Recently it was observed that when the number of submodels in a multiple-model system increases towards infinity, the system tends towards a Gaussian process. Gaussian Process priors were also found to be well-suited to nonlinear regression tasks, and were very competitive with methods such as artificial neural networks. There has, to date, been very little published work in the combination of Gaussian Process priors in feedback control contexts. This series of papers is intended to provide an overview of the ways in which the approach can be used, and its effectiveness. One of the challenges in the use of Gaussian Process priors which has to be overcome before they are likely to be accepted for control purposes is their high computational cost for medium to large data sets. Quiñonero-Candela and Rasmussen introduce Gaussian Process priors, discuss the link with linear models, and propose a reduced rank GP approach that would reduce the computational load. The topic of efficient GPs for large data sets is continued in the following chapter by Shi et al. which provides an alternative approach, one also of interest in applications where the nonlinear system is convolved with a known system before measurement. An adaptive variant of single-step-ahead model-predictive control is presented by Sbarbaro and Murray-Smith, showing how Gaussian Process priors are well suited for cautious control, while simultaneously learning about a new plant. In order to use Gaussian processes in multiple-step-ahead control, the issue of propagation of uncertainty in time-series predictions needs to be resolved. An approach to this for Gaussian processes is presented in Girard and Murray-Smith. The following chapter by Kocijan provides an illustrative example of the use of Girard's propagation algorithm in a model-predictive control setting, controlling a simulated pH process.

Part III is composed of papers making more specific research contributions or applying switching and learning techniques to a range of application domains. Vilaplana et al. present the results of tests of a new controller for cars equipped with 4-wheel steer-by-wire, and provides a very clear application example of the individual channel design approach. This is followed by two chapters on applications in communications systems: Wong et al. present a geometric approach to designing minimum-variance beamformers that are robust against steering vector uncertainties; Xiao et al. consider allocation of communication resources in wireless communication channels, demonstrating their approach on the design of a networked linear estimator and on the design of a multivariable networked LQG controller. Ragnoli and Leithead present a theoretical contribution, investigating inconsistencies in the theory of linear systems. Tresp and

Yu present an introduction to nonparametric hierarchical Bayesian modelling with Dirichlet distributions, and apply this in a multiagent learning context for a recommendation engine, allowing a principled combination of content-based and collaborative filtering. Roweis and Salakhutdinov investigate simultaneous localization and surveying with multiple agents, based on the use of constrained Hidden Markov models, allowing agents to navigate and learn about an unknown static environment. In the final chapter, Williamson and Murray-Smith present an application of adaptive nonlinear control methods to user interface design. The Hex system is a gestural interface for entering text on a mobile device via a continuous control trajectory. The dynamics of the system depend on the language model and change as new letters are entered such that users are supported without being constrained.

The book documents the work behind presentations at the European Summer School on Multi-Agent Control, held at the Hamilton Institute in Maynooth, Ireland, in September 2003. The meeting was partially supported by the EC-funded research training network *MAC: Multi-Agent Control*, and included many of the outcomes of the project. The participants in the summer school brought insight, techniques and language from very diverse theoretical backgrounds to bear on a range of leading-edge applications. We hope that the publication of this book will bring these exciting cross-disciplinary developments to a broader audience.

October 2004 Roderick Murray-Smith, Robert Shorten
Glasgow and Maynooth

Organization

The Maynooth Summer School was jointly organized by the EC-funded research training network *MAC: Multi-Agent Control*, and the Hamilton Institute, NUI Maynooth.

Conference Chair	Robert Shorten (Hamilton Institute, Ireland)
Network Coordinator	Roderick Murray-Smith (Glasgow University, UK and Hamilton Institute, Ireland)
Local Organizing Committee	Rosemary Hunt Oliver Mason Kai Wulff (Hamilton Institute, Ireland)