Prof. John Lygeros
Control and Computation

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Mission

We aim to link novel control theory methods, through efficient computational implementation, to challenging applications. Recent theoretical research has concentrated on reachability and optimal control, in particular characterization of the solutions in terms of dynamic programming. The computational solution of dynamic programming problems is known to suffer from the curse of dimensionality. We aim to alleviate this drawback through approximate dynamic programming, by formulating the problems as infinite dimensional linear programs, whose solution can be approximated in a provably accurate and empirically efficient way. For the approximation step we reply on methods from randomized optimization, which we are extending to address technical difficulties of infinite dimensional programs and improve computational performance by exploiting problem structure. The same methods are also used for stochastic model predictive control and for fault detection in large-scale systems.

The group has a track record in diverse application areas. Of particular recent interest have been applications to energy systems: scheduling of reserves, building efficiency, and demand response schemes. The solutions we provide for these problems are based on our theoretical work on stochastic model predictive control and randomized optimization. In biology, we have been working on modeling, analysis, and control of cell populations, based on methods from stochastic hybrid systems. Other current applications are on safety and security (surveillance, building evacuation, cyber-security of SCADA systems) based on methods from reachability theory implemented through approximate dynamic programming and randomization.

Our philosophy of solid theoretical foundations leading to solutions for real life problems is also reflected in our teaching which includes a 4th semester class on Signals and Systems and theoretically minded MSc classes.
The same philosophy is also evident in the projects offered to MSc and BSc students, which range from theory to experimental validation.

Curriculum Vitae

Prof. John Lygeros
Professor of Control and Computation
Head of the Automatic Control Laboratory

Degrees/Higher Education
1996: PhD, Electrical Engineering University of California, Berkeley, USA
1991: MSc, Systems Control Imperial College, London, UK
1990: B. Eng. Electrical Engineering Imperial College, London, UK

Professional Career
2010-present: Professor of Control and Computation, Department of Information Technology and Electrical Engineering, D-ITET, ETH Zurich
2009-present: Head, Automatic Control Laboratory, Department of Information – Technology and Electrical Engineering, D-ITET, ETH Zurich
2006-2009: Associate Professor of Control and Computation, Department of Information Technology and Electrical Engineering, D-ITET, ETH Zurich
2003-2006: Assistant Professor, Department of Electrical and Computer Engineering, University of Patras, Greece
2000-2003: Lecturer, Department of Engineering, University of Cambridge, UK
1998-1999: Research Engineer (part-time), SRI International, Menlo Park, CA, USA
1997-1999: Postdoctoral Research Associate, University of California, Berkeley, USA
1996-1997: Postdoctoral Research Associate, Laboratory for Computer Science, MIT, USA

Professional Activities
- Member of the IEEE Control System Society Board of Governors 2012-present
- Member of the Scientific Steering Committee of the Newton Institute, Cambridge, UK, 2012-present
- Treasurer of IFAC, 2013-present
- International Program Committee Chair, European Control Conference 2013
- Program Chair, Hybrid Systems Computation and Control 2014
- Associate Editor, IEEE Transactions on Automatic Control, 2006-2009

Awards
2016: Credit Suisse Award for Best Teaching;
IEEE Control Systems Society George S. Axelby Outstanding Paper Award
2012 & 2009: "Golden Owl" Teaching Award of ETH Zurich

Membership in Societies
Fellow of the IEEE. Member of IET and the Technical Chamber of Greece

Research Activities and Achievements

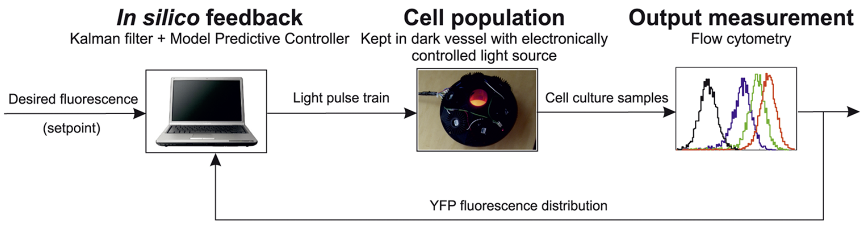
The group is conducting theoretical research on reachability (for deterministic or stochastic systems), optimal control (including stochastic model predictive control) and population control. The first two directions are intimately connected. The work of our group has demonstrated that reachability problems, such as ensuring that the state of a system remains in a given "good" set or reaches a desired target set, can be formulated as optimal control problems with unconventional cost functions. A dynamic programming principle can then be developed to characterize the solution. Depending on the system in question the characterization can be in terms of a partial differential equation (PDE, for continuous time systems, deterministic or stochastic) or a Bellman recursion (for discrete time systems). This enables the computational solution of the original reachability problem using, for example, numerical PDE solvers. Our group has contributed fundamental results for all these system classes.

One difficulty with dynamic programming for continuous state systems is the so-called "curse of dimensionality": the numerical computation needed to approximate the solution to a given accuracy grows exponentially in the dimension of the problem. In an attempt to ameliorate this difficulty our group has been developing approximate dynamic programming methods. The starting point is a transformation of the PDE or Bellman recursion into an infinite dimensional linear program. This is followed by a guaranteed accuracy approximation of the linear programs by finite dimensional counterparts. The key ingredients of the approximation are a projection to a finite dimensional decision space followed by a relaxation using randomization methods. This line of work has motivated us to look into randomized optimization, where we have contributed novel methodological (value approximation guarantees) and computational (reduced sample complexity bounds by exploiting problem structure) results.

A different theoretical research direction deals with population systems, large-scale systems that comprise a number of subsystems, possibly with local interactions. The challenge here arises from the fact that, at a macroscopic level, one interacts with the system through population level signals, measurements, and commands. Theoretical research on this topic is motivated by biology (where one interacts with a cell culture using light, or chemical signals), electricity demand response schemes (where one interacts with a population of controlled loads through, e.g., price signals) and transportation (where one interacts with highway traffic through variable speed limits and ramp metering lights). Over the past year we have been looking into modeling, estimation and control methods for such population systems. For modeling and estimation much of the research has been motivated by biology, in particular biochemical systems modeled by the chemical master equation. For control, inspiration has come from mean field games, which provide a way of thinking about the evolution of subsystems through their interaction with the average of a population.

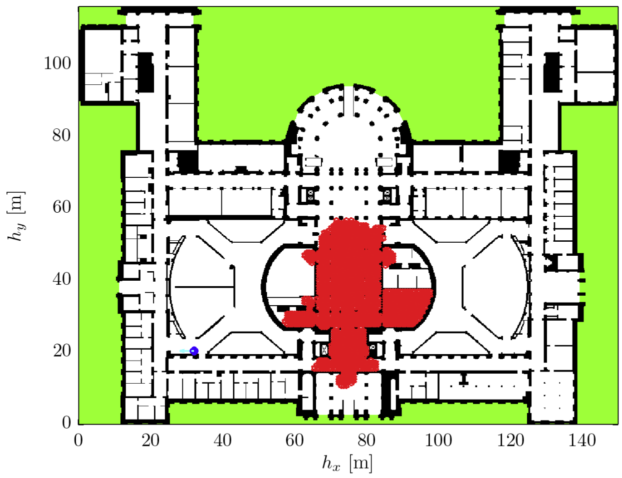
The theoretical research directions come together in a variety of applied problems. Much of our recent research has concentrated on electrical energy systems. One avenue has been the deployment of stochastic model predictive control methods to the problem of reserve procurement in the presence of large renewable integration. The methodological step here has been the interpretation of the problem as a chance constraint optimization problem, enabling its solution through receding horizon, randomized optimization methods. Case studies suggest that our results achieve comparable cost to state of the art methods, but considerably reduce the risk and amount of load shedding or "spilled" renewable energy. A second energy related direction has been the development of demand response schemes to provide flexibility and facilitate the integration of renewables. Our approach to this problem has been based on the population control ideas outlined above.

We have also applied our population methods to problems in biology. Much of the effort has been devoted to understand intrinsic and extrinsic variability in biochemical systems and to capture it using variants of the chemical master equation. Based on this starting point, we developed parameter inference and optimal experiment design methods that can cope in this highly uncertain environment. The methods have been experimentally validated on biological systems in yeast, in close collaboration with molecular biologists. Our best known result in this context has been the development of an in silico feedback control concept, to in vivo regulate protein concentration in yeast through light signals computed by model predictive control; this effort not only resulted in a high profile publication, but also received considerable attention in the popular press.



In silico control of cell populations

Finally, we have applied our theoretical research to problems in safety and security. One effort in this direction has been the development of fault detection and isolation methods for intrusion (cyber-attack) detection in the SCADA systems supervising electrical energy transmission. These methods build on our research on randomized optimization, were developed through a joint project with ABB, and have been patented by our group members. In a parallel effort, we also worked on the development of building evacuation procedures based on our stochastic reachability results; this effort originated from an MSc project and also led to a patent. Related to this is our research on autonomous camera surveillance, also based on stochastic reachability methods. This work (developed in collaboration with Videotec S.p.a.) poses considerable computational challenges due to the dimension of the problem and has served as the main motivation for the development of approximate dynamic programming methods. Currently these methods are being extended for application to a lecturer tracing and recording system, developed in collaboration with ETH Multimedia Services.



Escape from the ETH main building: optimal building evacuation based on stochastic reachability