Mathematical Cybernetics: Hybrid, Stochastic and Decentralized Systems

An International Workshop in Honour of Professor Peter E. Caines

Program: 28 May-29 May, 2015

Place: Carleton University, Ottawa, Canada

Chair: Minyi Huang

Organizing Committee Members: Charalambos D. Charalambous, Arman C. Kizilkale, Nevroz Sen.

Day 1 - Thursday, 28 May, 2015

Morning Session

Room 206, Tory Building

Chairpersons: Minyi Huang and Arman Kizilkale.

Time	Title	Speaker
09:00 - 09:15	Welcome and Workshop Overview	Minyi Huang, Carleton University
09:15 - 10:00	Opening Address to the Workshop	Murray Wonham, University of Toronto
10:00 - 10:30	Enforcement of Opacity by Judicious Event Insertions – or – How to Keep a Secret by Talking a Lot	Stephane Lafortune, University of Michigan
10:30 - 11:00	Linear Stochastic Control with Quadratic Cost and State and Control Dependent Noise	Tyrone Duncan, University of Kansas
11:00 - 11:30	**Morning Break**	
11:30 - 12:00	Fight the Power	Sean Meyn, University of Florida
12:00 - 12:30	Mixing Properties of the Page-Hinkley Detector	László Gerencsér, Hungarian Academy of Sciences
12:30 - 13:00	Nonlinear Filtering Problems in Mean Field Game Theory	Nevroz Sen, McGill University
13:00 - 14:30	**Lunch Break**	

Afternoon Session

Room 206, Tory Building

Chairpersons: Roland Malhame and Charalambos D. Charalambous

Time	Title	Speaker
14:30 - 15:00	In-Block Controllability of Affine Systems on Polytopes	Mohamed Helwa, McGill University
15:00 - 15:30	Discrete Time Linear Exponential Quadratic Gaussian Control	Bozenna Pasik-Duncan, University of Kansas
15:30 - 16:00	Fundamental limits of remote estimation of Markov processes under communication constraints	Aditya Mahajan, McGill University
16:00 - 16:30	**Afternoon Break**	
16:30 - 17:00	Opinion Dynamics and Social Power Evolution	Peng Jia, UC Santa Barbara
17:00 - 17:30	Mean Field Control for Load Shaping in Power Systems	Arman Kizilkale, École Polytechnique de Montreál
17:30 - 18:00	Mean Field Capital Growth with Relative Consumption	Minyi Huang, Carleton University

Dinner: 19:30 - 22:30

Shanghai Restaurant: 651, Somerset Street West, Ottawa

Arrival between 19:00 -19:30

Day 2 - Friday, 29 May, 2015		
Morning Session **Room 206, Tory Building** **Chairpersons: Aditya Mahajan and Stephane Lafortune**		
Time	**Title**	**Speaker**
09:00 - 09:30	Mean-Field Game Strategies for a Major-Minor Agent Optimal Execution Problem	Mojtaba Nourian, Bank of Montreal
09:30 - 10:00	Approximate Optimality of Finite State and Action Models in Stochastic Control with Borel Spaces	Serdar Yuksel, Queen's University
10:00 - 10:30	Linear Stochastic Systems: A White Noise Space Approach	David Levanony, Ben-Gurion University of the Negev
10:30 - 11:00	**Morning Break**	
11:00 - 11:30	Decentralized Sufficient & Necessary Optimality Conditions for Cooperative Multi-Agent Stochastic Differential Decision Problems	Charalambos D. Charalambous, University of Cyprus
11:30 - 12:00	Dynamic Collective Choice: A Mean Field Game Formulation	Roland Malhame, GERAD École Polytechnique de Montreál

Table of Abstracts.

1. Minyi Huang, *Workshop Overview.*

2. Murray Wonham, *Opening Address to the Workshop.*
   CYBERNETIC
   IMAGES
   CYBERNÉTIQUES

   Abstract. We begin with homage to cybernetic giants of the past, including Homer, Chuang Zi, Cornelis Drebbel, Thomas Hobbes, and Mark Twain. After skipping lightly over recent history - for lack of time and space regretfully omitting many and impressive contributions - we present a compelling vision of the future, embracing global cyberphysics and other novelties.
   Acknowledgments. This presentation would not have been possible without the help of PowerPoint and the Internet.

3. Stéphane Lafortune, *Enforcement of Opacity by Judicious Event Insertions – or – How to Keep a Secret by Talking a Lot.*

   Abstract. Opacity is a confidentiality property that arises in the analysis of security properties in networked systems. It characterizes whether a "secret" of the system can be inferred by an intruder who knows the system model and partially observes the system behavior. In this work, we describe a new strategy to enforce opacity by using an "insertion function" at the output of the system. We describe how to synthesize a valid insertion function when one exists. Then, we address the problem of synthesizing an "optimal" insertion function (with respect to given insertion costs). We illustrate our results on an example where a user of location-based services wishes to keep her location secret from the servers she queries.
   This is joint work with Yi-Chin Wu at the University of Michigan.

4. Tyrone Duncan, *Linear Stochastic Control with Quadratic Cost and State and Control Dependent Noise.*

   Abstract. A control problem for a linear stochastic system with stochastic coefficients, linear state and control dependent noise, and a quadratic cost functional is formulated and solved. A stochastic Riccati equation is described that is used to obtain an explicit optimal control in a direct way using the Doob-Meyer decomposition of a submartingale for the running cost.

5. Sean Meyn, *Fight the Power.*

   Abstract. The Music Heard in Montreal 1980s Rings More Clearly Today.

6. László Gerencsér, *Mixing Properties of the Page-Hinkley Detector.*

   Abstract. We consider the problem of detecting an eventual change in the dynamics of a stochastic process, such as an EEG record. In the simplest case we have two sets of i.i.d. data with known distributions prior to and after the change. We present a simple derivation of the classic Page-Hinkley detector for this case together with its basic properties. A novel

feature that we establish is that under mild technical conditions the Page-Hinkley detector is L-mixing. As a byproduct we get sharp upper bounds for the almost sure false alarm rate.
The result extends to change detection for dependent data under certain conditions. The key to such extensions is the validity of an exponential moment inequality. The talk will be concluded with examples and open questions.

7. Nevroz Sen, *Nonlinear Filtering Problems in Mean Field Game Theory.*

   Abstract. We consider partially observed stochastic dynamical systems whose state equations are of McKean-Vlasov type SDE and hence contain a measure term where the measure term is also random. Such SDEs are used to model the state dynamics of the agents in Mean Field Games framework with Major and Minor agents. We present nonlinear filtering equations in both normalized and unnormalized forms and, for some cases, for the conditional densities. Joint work with Peter E. Caines.

8. Mohamed Helwa, *In-Block Controllability of Affine Systems on Polytopes.*

   Abstract. In this talk, we first introduce the study of in-block controllability (IBC) of affine systems on polytopes, which formalizes controllability under state constraints. In particular, for a given affine system and a given full-dimensional polytope, representing the safety and performance state constraints, we study whether all the states in the interior of the given polytope are mutually accessible through its interior by applying uniformly bounded control inputs. By exploring the geometry of the problem, we provide easily checkable necessary and sufficient conditions for IBC of affine systems on polytopes. Then, we briefly discuss how to use this result to study controllability and build hierarchical control structures of piecewise affine hybrid systems, and to systematically solve approximate mutual accessibility problems of nonlinear systems on polytopes. We conclude the talk by presenting some future directions on IBC.

9. Bozenna Pasik-Duncan, *Discrete Time Linear Exponential Quadratic Gaussian Control.*

   Abstract. An explicit optimal control for the discrete time linear exponential quadratic Gaussian control problem is obtained which does not use the methods of dynamic programming or stochastic maximum principle and provides some insight into the terms that occur in the Riccati difference equation that determines the optimal feedback control. The method to obtain the explicit optimal control and optimal cost is algebraic.

10. Aditya Mahajan, *Fundamental limits of remote estimation of Markov processes under communication constraints.*

    Abstract. The fundamental limits of remote estimation of Markov processes under communication constraints are presented. The remote estimation system consists of a sensor and an estimator. The sensor observes a discrete-time Markov process, which is a symmetric countable state Markov source or a Gauss- Markov process. At each time, the sensor either transmits the current state of the Markov process or does not

transmit at all. Communication is noiseless but costly. The estimator estimates the Markov process based on the transmitted observations. In such a system, there is a trade-off between communication cost and estimation accuracy. Two fundamental limits of this trade-off are characterized for infinite horizon discounted cost and average cost setups. First, when each transmission is costly, we characterize the minimum achievable cost of communication plus estimation error. Second, when there is a constraint on the average number of transmissions, we characterize the minimum achievable estimation error. Transmission and estimation strategies that achieve these fundamental limits are also identified.

11. Peng Jia, *Opinion Dynamics and Social Power Evolution.*

    Abstract. This talk considers the evolution of self appraisal, social power and interpersonal influences for a group of individuals who discuss and form opinions about a sequence of issues. An empirical model is presented, which combines the averaging rule by DeGroot to describe opinion formation processes and the reflected appraisal mechanism by Friedkin to describe the dynamics of individuals self appraisal and social power. This DeGroot-Friedkin model predicts the evolution of the influence network governing the opinion formation process. Especially, the model predicts that the social power ranking among individuals is asymptotically equal to their centrality ranking, that social power tends to accumulate at the top of the hierarchy, and that an autocratic (resp. democratic) power structure arises when the centrality scores are maximally non-uniform (resp. uniform).

12. Arman C. Kizilkale, *Mean Field Control for Load Shaping in Power Systems.*

    Abstract. Load control has traditionally been viewed as a useful tool for peak load reduction in power systems. With the increasing renewable energy penetration in the grid, load control is also considered as a tool to exploit the storage in dispersed devices naturally present in power systems such as electric water heaters to mitigate generation variability. Tapping into the storage dispersed across the power system is challenging because of the large number of devices that need to be coordinated to produce desirable system level behavior. In this work a mean field game theoretic based control architecture is proposed as a load control mechanism to limit the required flows of information, and produce local constraints conscious decentralized individual controls which aggregate to a desired mean behavior. A diffusion model for individual space heaters and a Markovian jump-driven model for individual electric water heating loads are employed where the mean field effect is mediated through the quadratic cost function parameters under the form of an integral error. The corresponding system of mean field Nash equilibrium inducing equations is developed, existence and uniqueness properties, and numerical simulation results are presented. This is a joint work with Roland P. Malham/'e

13. Minyi Huang, *Mean Field Capital Growth with Relative Consumption.*

    Abstract. We consider continuous time mean field consumption-accumulation games. The capital stock of each agent evolves according to the Cobb-

Douglas production function subject to consumption and stochastic depreciation. The individual HARA-type utility depends on both the own consumption and relative consumption. We analyze the fixed point problem of the mean field game and examine the impact of the relative performance on the consumption behaviour. (Joint work with Son Luu Nguyen of University of Puerto Rico).

14. Mojtaba Nourian, *Mean-Field Game Strategies for a Major-Minor Agent Optimal Execution Problem.*

    Abstract. We introduce, for the first time, a mean-field game framework for a multiple agent optimal execution problem with continuous trading. This modeling generalizes the classical single agent optimal liquidation problem to a setting with (i) a major agent who is liquidating a large portion of shares, and (ii) a number of minor agents (high-frequency traders (HFTs)) who detect and trade along with the liquidator. As in the classical framework, all agents are exposed to temporary price impact and attempt to balance their impact against price uncertainty. Unlike most other works, we account for the permanent price impact that order-flow from all agents have on the mid-price and this induces a distinct cross interaction between major and minor agents. This formulation falls into the realm of stochastic dynamic game problems with mean-field couplings in the dynamics, and we analyze the problem using a mean-field game approach. We obtain a set of decentralized feedback trading strategies for the major and minor agents, and express the solution explicitly in terms of a deterministic fixed point problem. For a finite N population of HFTs, the set of major-minor agent mean-field game strategies is shown to have an epsilon-Nash equilibrium property where epsilon $\to 0$ as $N \to \infty$.
    This is joint work with Sebastian Jaimungal (University of Toronto).
    Reference: http://papers.ssrn.com/sol3/papers.cfm?abstract_=2578733

15. Serdar Yuksel, *Approximate Optimality of Finite State and Action Models in Stochastic Control with Borel Spaces.*

    Abstact. Quantization arises in networked control and stochastic control in the context of informational constraints. In stochastic control, quantization also arises in developing approximate representations of Borel state/action space models with finite models, for discounted or average cost problems. Since for Markov decision processes with uncountable spaces the computation of optimal policies is known to be prohibitively difficult, quantized models allow for efficient computational algorithms once it can be established that these models are sufficiently good approximations. In this talk, we will present general conditions under which finite models can be used to efficiently compute approximately optimal policies. These conditions are satisfied by systems which may be weakly continuous, setwise continuous or continuous under total variation for both average and discounted cost problems, and are also applicable to partially observable Markov decision processes. In addition, we obtain explicit and information theoretically tight rates of convergence in approximation performance as the quantization rate increases. Some examples and future directions will be discussed (joint work with Naci Saldi and Tamas Linder).

16. David Levanony, *Linear stochastic systems: A white noise space approach.*

    Abstract. We offer a novel approach to the modeling and subsequent study of linear stochastic systems. Specifically, we consider linear systems with random coefficients, mapping stochastic inputs into stochastic outputs. System parameters, as well as input and output processes, are set within the white noise probability space. Input-output relations are then re-modeled by replacing the standard product with the Wick product. A family of generalized transfer functions is defined. Necessary and sufficient BIBO stability conditions are established for a Wick-convolution I/O system. Finally, observable and controllable pairs are characterized for the corresponding state-space realizations.

17. Charalambos D. Charalambous, *Decentralized Sufficient & Necessary Optimality Conditions for Cooperative Multi-Agent Stochastic Differential Decision Problems.*

    Abstract. Necessary and sufficient decentralized optimality conditions are presented for stochastic differential decision problems with multiple Decision Makers (DMs) or Agents aimed at optimizing a common pay-off.
    The necessary conditions consist of forward and backward stochastic differential equations, and a set of conditional variational Hamiltonians with respect to the information structures of the DMs.
    The sufficiency states that decentralized Person-by-Person optimality implies decentralized global optimality, if the Hamiltonian is convex in the action spaces of the DMs.

18. Roland Malhame, *Dynamic Collective Choice: A Mean Field Game Formulation.*

    Abstract. Collective choice problems are concerned with situations involving a large number of agents making socially influenced discrete choices. Examples are opinion crystallization in elections, teenagers' smoking decisions in schools, the choice by an individual of a mode of transportation, nesting decision making in eusocial insects, etc We abstract such situations as a dynamic non cooperative game in which a large number of agents are to settle on individual paths leading to one of a set of possible destinations, while paying all along a penalty for deviating from the social path as represented by the mean trajectory resulting from all agent choices. Existence of possibly multiple mean field game solutions is established when letting the population size grow to infinity, and it is shown that each of these dictates a decentralized feedback policy which induces an epsilon-Nash equilibrium for the finite population problem. The equilibria are each characterized by a vector lambda characterizing the way the population splits, for a given level of social pressure, between the potential destination points.
    This is work in collaboration with Rabih Salhab and Jérôme Le Ny.