

# SIDRA PhD Summer School 2018

## Optimization Methods for Decision Making over Networks

Bertinoro – July 12-14, 2018

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### Topic and scope

The well functioning of our modern society rests on the reliable and uninterrupted operation of large scale complex infrastructures, which are more and more exhibiting a network structure with a high number of interacting components/agents. Energy and transportation systems, communication and social networks are a few yet prominent examples of such large scale multi-agent networked systems. Depending on the specific case, agents may act cooperatively to optimize the overall system performance or compete for shared resources. Based on the underlying communication architecture, and the presence or not of a central regulation authority, either decentralized or distributed decision making paradigms are adopted. In both cases, one ends up studying the behavior of each agent when affected by some aggregate effect of the other agents' decisions, or a small subset of neighboring agents.

In recent years, decision making in multi-agent networks has become a compelling topic of research and has attracted significant attention in the control systems community. Some of the topics presented in this course are part of the OPT4SMART project funded by the European Research Council and the UnCoVerCPS project funded by the European Commission, both under the Horizon 2020 research and innovation programme.

Systems and control theoretic approaches have been proposed to devise effective solutions to a variety of problems ranging from smart grid operation, control of large populations of aggregated loads or electric vehicles for ancillary services, traffic control in intelligent transportation systems, congestion control in communication networks, and also for the analysis of opinion dynamics in social networks.

This course aims at building a mathematical background for the analysis and design of decision making algorithms in cooperative and noncooperative multi-agent systems, and at providing a unifying framework for studying and analyzing decision making problems that arise in contemporary societal and technological challenges.

Expected learning outcomes are a strengthened knowledge in optimization; an insight in the analysis and design of multi-agent distributed/decentralized optimization algorithms; knowledge of the basic principles in operator theory and of an operator theoretic perspective on convergence problems in iterative algorithms; and familiarization with multi-agent problems of contemporary interest.

## Structure

The course is structured in the following four parts.

### 1. Motivation and illustrative applications

Introduction to decision making problems in networked multi-agent systems with applications in smart grid, energy management of a building district, machine learning, cooperative robotics, electric vehicles charging coordination.

These applications not only will serve as a motivation, but will also set a common ground to highlight the main complexity issues arising in multi-agent systems, namely, scalability due to the large scale nature of these problems, heterogeneity of the agents and privacy. A distinction between cooperative and noncooperative agent strategies will also be made depending on the considered application.

### 2. Mathematical tools

Background on

- (a) convex analysis, optimization and duality theory
- (b) operator theory basics

(c) fixed point algorithms

These tools constitute the theoretical backbone for the analysis and design of cooperative and noncooperative algorithms that arise in multi-agent decision making problems.

### 3. Cooperative and noncooperative decision making

(a) Cooperative optimization: primal-based algorithms.

Topics covered are decentralized gradient and scaled projected gradient methods, Jacobi algorithm, and Gauss–Seidel algorithm, distributed proximal and (sub-)gradient methods, and constraint exchange methods. The background notions on convex optimization and fixed point algorithms provided in part 2 will be used.

(b) Cooperative optimization: duality-based algorithms.

Topics covered are distributed dual decomposition and distributed alternating direction method of multipliers (ADMM). The background notions on duality theory and dual algorithms provided in part 2 will be used.

(c) Noncooperative equilibrium seeking algorithms.

Topics covered are Nash equilibrium seeking via best-response dynamics and operator-splitting algorithms. The background notions on operator theory and fixed-point arguments provided in part 2 will be used.

The selected topics in this part provide a wide coverage of cooperative and noncooperative algorithms that arise in the multi-agent decision making. More advanced topics are addressed in part 4.

### 4. Advanced topics and vistas

This part will deal with advanced solutions for multi-agent decision making. It will also provide a glance at the bridge between the two perspectives when game equilibria result in social welfare, starting from one of the motivating applications.

## Schedule

### Thursday – July 12, 2018 (morning)

Optimization over networks: main problem set-ups and motivating examples.

Foundations of optimization theory: convex analysis, iterative algorithms for unconstrained and constrained problems, optimality conditions for inequality/equality constrained problems.

### Thursday – July 12, 2018 (afternoon)

Duality and dual algorithms for convex problems. Decomposition schemes and parallel implementation.

Operator theory and fixed point algorithms and their connection with optimization theory.

**Friday – July 13, 2018 (morning)**

Cooperative decision making: primal-based and duality-based distributed optimization algorithms.

**Friday – July 13, 2018 (afternoon)**

Interpretation of distributed optimization algorithms as fixed-point iterations. Noncooperative decision making: equilibrium seeking algorithms.

**Saturday – July 14, 2018 (morning)**

Novel challenges in optimization over networks, advanced methods and vistas.