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Consensus and Synchronization in Complex Networks

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Preface

Synchronization, as one of the most captivating cooperative phenomena in nature, is observed in biological, chemical, physical, and social systems. Its study has a history that spans several centuries, starting with Huygens' observation of synchronizing pendulum clocks. Synchronization has been shown to be an important process in the persistence of species, in the functioning of heart pacemaker cells, yeast cells, neurons in the cat visual cortex, cognitive tasks in humans, and in conscious processing. In humans, conscious processing of stimuli was associated with precise synchronization (phase-locking) of gamma oscillations across widely distributed cortical areas, whereas unconsciously processed stimuli evoked only local gamma oscillations. Visual and acoustic interactions make fireflies flash, crickets chirp, and an audience clap in synchrony. On the other hand, synchronization plays an important role in several neurological diseases like epilepsy and pathological tremors.

Synchronization and similar concepts also abound in technical sciences and engineering, including computer science (distributed computing), control theory (observer designs), and communications and electrical engineering. In distributed systems and networks, it is often necessary for some or all of the nodes to calculate some function of certain parameters. For example, sink nodes in sensor networks may be tasked with calculating the average measurement value of all the sensors. Another example is the case of multi-agent systems, where all agents communicate with each other to coordinate their speed and direction. When all nodes calculate the same function of the initial values in the system, they are said to reach consensus. Such problems have received extensive attention in the computer science and control communities leading to the development of various protocols. Similar concepts include state agreement, rendezvous, and observer design in control theory and gossip algorithms in computer science.

Mathematical framework for describing synchronization and consensus in natural and technical sciences is similar. For this reason this book collects chapters on various topics about synchronization and consensus. There is a great body of work studying synchronization phenomena, but we are not aware of any book in which synchronization and consensus are presented jointly allowing the reader to learn about similarities and differences of both concepts in a single book. Ten chapters are carefully selected that reflect current state of the art of synchronization and consensus in networked systems. Two chapters dealing with a novel application of synchronization concepts in machine learning are included. Consensus formation among a small group of expert models of an objective process is challenging because the separate models have already been optimized in their own parameter spaces. Recently, consensus formation in a connectionist framework is addressed, by introducing connections, with coefficients to be determined, between some restricted set of pairs of corresponding variables in the different expert models. There is an algorithm for data assimilation from new observations into the running models, as in meteorology, which can be cast as an instance of synchronization: the model synchronizes with truth based on limited, intermittent connection to observations. Similarly, synchronization can accomplish consensus formation among models when the separate models are connected. By applying machine learning techniques, as well as methods from nonlinear dynamics, one can adapt the connection coefficients linking the corresponding variables in the different models. This radically new computational approach to the simulation and prediction of complex, real systems has been developed by bringing together experts from different disciplines: nonlinear dynamics, machine learning, and climate science, as documented in two chapters of this book.

This is the brief outline of the book. The first chapter, entitled “Consensus theory in networked systems” by D. Smilkov and A. Stanoev, reviews consensus theory in networked systems. Convergence analysis and connections between spectral and structural properties of complex networks and the convergence rate of consensus algorithms are carried out for distributed algorithms on directed weighted networks for continuous- and discrete-time cases. The second chapter deals with control of networks of coupled dynamical systems, which by considering the control signal as the state of a virtual dynamical system can be studied as a synchronization problem. This chapter entitled “Control of networks of coupled dynamical systems” is written by C. W. Wu. The main focus of this chapter is to link the control effectiveness to various properties of the underlying graph. Next two chapters deal with consensus algorithms in multi-agent systems. In “Distributed consensus and coordination control of networked multi-agent systems” by F. Yan and G. Chen, the authors review part of distributed coordination control of general mobile multi-agent systems, including consensus, formation control, and distributed estimation-control of networked multi-agent systems. The chapter “Consensus of networked multi-agent systems with delays and fractional-order dynamics” by J. Lu, J. Shen, J. Cao, and J. Kurths studies the effects of input delay, communication delay, fractional-order dynamics, and directed information flow on the consensus behavior of networked multi-agent systems.

The fifth chapter “Synchronization in complex networks: properties and tools” reviews synchronization in complex networks and describes its properties and tools. It is written by M. Biey, F. Corinto, I. Mishkovski, and M. Righero and reviews the basic concepts of synchronization in complex networks, which is illustrated by several examples of identical and nearly identical oscillators. “Enhancing synchronizability of complex networks via optimization" is the title of the sixth chapter. Written by C. Yang, Q. Jia, and W. K.S. Tang, this chapter discusses two major synchronization problems: the first one is to obtain the best network that exhibits an optimal synchronization, while the numbers of nodes and edges are fixed. The second one is on pinning control: given a network, how to select a fraction of nodes and assign the appropriate control gains so that all the nodes in the network follow some predefined dynamics. In the next chapter "Synchronization-based parameter estimation in chaotic dynamical systems" by I. Trpevski, D. Trpevski, and L. Basnarkov, the authors examine methods for synchronization-based parameter estimation in chaotic dynamical systems. The eighth chapter "Data assimilation as artificial perception and supermodeling as artificial consciousness" by G. S. Duane argues that data assimilation could be viewed as artificial perception and supermodeling as artificial consciousness.

Finally the last two chapters examine a novel concept in machine learning (so-called super modeling) based on synchronization of coupled systems and its application to climate modeling. The ninth chapter "Supermodeling dynamics and learning mechanisms" by W. Wiegerinck, M. Mirchev, W. Burgers, and F. Selten introduces the concept in which the improved modeling is proposed by dynamically combining the models and constructing the supermodel. The supermodel parameters are learned from historical observations. The concept is illustrated with several examples: three-dimensional Lorenz 63 and Lorenz 84 models, as well as a 30-dimensional two-layer atmospheric model. In the final chapter "On the limit of large couplings and weighted averaged dynamics," the authors W. Wiegerinck, W. Burgers, and F. Selten consider the case where coupling coefficients are sufficiently large, so that the different oscillators will have their state variables strongly tied together and variables of the different oscillators will rapidly become (almost) synchronized. In this way, the dynamics of the network is approximated by the dynamics of weighted averages of the vector fields of the different oscillators.

The book is aimed at a broad audience of scientists and engineers, ranging from advanced undergraduate students to senior practitioners, who work in the field of synchronization and related phenomena. I hope the reader will find the book useful and will enjoy reading it as much as I enjoyed editing its chapters.

Skopje and San Diego, July 2012 Ljupco Kocarev

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