SIDRA Summer School, Bertinoro 2022

Network Systems in Science and Technology

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Aim: Recent years have witnessed the emergence of a discipline of study focused on *modeling, analyzing, and designing dynamic phenomena over networks*. We refer to such systems as network systems (they are also equivalently referred to as multi-agent or distributed systems). This emerging discipline is rooted in graph theory, control theory, and matrix analysis — and it is increasingly relevant because of its broad set of application domains. Network systems appear naturally in scientific domains, including (i) social networks and mathematical sociology, (ii) electric, mechanical and physical networks, and (iii) animal behavior, population dynamics, and ecosystems. Network systems are designed in the context of networked control systems, robotic networks, power grids, and transmission and traffic networks, to name a few.

This 15h summer course will review a comprehensive theory of linear network systems and will propose a contraction theory framework for extensions to nonlinear models. Motivating examples will be drawn from scientific and engineering application domains. For more information, see the syllabus below. Lecture notes are freely available on the lecturer website.

Course prerequisites: Background: linear algebra and a course on linear control. Familiarity with nonlinear stability theory (Lyapunov functions) is useful, but not required.

Syllabus

10 lectures of 1.5h each: 09:00-10:30 11:00-12:30 15:00-16:30 17:00-18:30.

Thu July 7th (4 lectures, 6h), Fri July 8th (4 lectures, 6h), and Sat July 9th (2 lectures, 3h, only morning)

Lecture	*Reference*	*Topic*
L1.	LNS.Chp1:	Introduction and examples
L2.	LNS.Chp2:	Review of matrix theory and Perron–Frobenius theory
L3.	LNS.Chp3+4:	Algebraic graph theory and averaging dynamics
L4.	LNS.Chp5+6:	Laplacian matrices and continuous-time averaging
L5.	LNS.Chp8:	Diffusively coupled systems
L6.	LNS.Chp10:	Network flow systems and Metzler matrices
L7:	CTNN.Chp1:	Introduction to nonlinear networks, induced norms and lognorms
L8.	CTNN.Chp2:	Contracting systems
L9:	CTNN:Chp2:	Contracting systems: neural networks and Lur'e models
L10:	CTNN.Chp3:	Monotone systems: traffic models

References Two sets of lecture notes are freely available online. The first document focuses on linear network systems, the second on nonlinear models.

(LNS:) F. Bullo. *Lectures on Network Systems*. Kindle Direct Publishing, 1.6 edition, January 2022. ISBN 978-1986425643. URL http://motion.me.ucsb.edu/book-lns

(CTNN:) F. Bullo. *Contraction Theory for Nonlinear Networks*. Lecture Notes, 0.7 edition, April 2022. URL http://motion.me.ucsb.edu/book-ctnn (Will be available by June 1, 2022)