Preface

Existing computational tools for control synthesis and verification do not scale well to today's large-scale networked systems. Recent advances, such as sum-of-squares relaxations for polynomial nonnegativity, have made it possible to numerically search for Lyapunov functions and to certify measures of performance; however, these procedures are applicable only to problems of modest size.

In this book we address networks where the subsystems are amenable to standard analytical and computational methods but the interconnection, taken as a whole, is beyond the reach of these methods. To break up the task of certifying network properties into subproblems of manageable size, we make use of *dissipativity* properties which serve as abstractions of the detailed dynamical models of the subsystems. We combine these abstractions to derive network level stability, performance, and safety guarantees in a compositional fashion.

Dissipativity theory, which is fundamental to our approach, is reviewed in Chap. 1 and enriched with sum-of-squares and semidefinite programming techniques, detailed in Appendices A and B respectively.

Chapter 2 derives a stability test for interconnected systems from the dissipativity characteristics of the subsystems. This approach is particularly powerful when one exploits the structure of the interconnection and identifies subsystem dissipativity properties favored by the type of interconnection. We exhibit several such interconnections that are of practical importance, as subsequently demonstrated in Chap. 4 with case studies from biological networks, multiagent systems, and Internet congestion control.

Before proceeding to the case studies, however, in Chap. 3 we point out an obstacle to analyzing subsystems independently of each other: the dissipativity properties must be referenced to the network equilibrium point which depends on all other subsystems. To remove this obstacle we introduce the stronger notion of *equilibrium independent dissipativity*, which requires dissipativity with respect to any point that has the potential to become an equilibrium in an interconnection.

In Chap. 5 we extend the compositional stability analysis tools to performance and safety certification. Performance is defined as a desired dissipativity property for the interconnection, such as a prescribed gain from a disturbance input to a performance output. The goal in safety certification is to guarantee that trajectories do not intersect a set that is deemed unsafe.

Unlike the earlier chapters that use a fixed dissipativity property for each subsystem, in Chap. 6 we combine the stability and performance tests with a simultaneous search over compatible subsystem dissipativity properties. We employ the Alternating Direction Method of Multipliers (ADMM) algorithm, a powerful distributed optimization technique, to decompose and solve this problem. In Chap. 7 we exploit the symmetries in the interconnection structure to reduce the number of decision variables, thereby achieving significant computational savings for interconnections that are rich with symmetries.

In Chap. 8 we define a generalized notion of dissipativity that incorporates more information about a dynamical system than the standard form in Chap. 1. This is achieved by augmenting the system model with a linear system that serves as a virtual filter for the inputs and outputs. This dynamic extension is subsequently related to the frequency domain notion of *integral quadratic constraints* in Chap. 9. We conclude by pointing to further results that are complementary to those presented in the book.

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