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Review of

Stability Analysis of Discrete Event Systems

by K.M. Passino and K.L. Burgess

A volume in the Wiley Series on Adaptive and Learning Systems for Signal Processing, Communications, and Control (S. Haykin, series ed.),
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Discrete event systems (DES) are systems the evolution of which is governed by the occurrence of events. This is in contrast to continuous variable systems where the evolution is governed by the progress of time or the ticks of a clock. Typical examples of DES are manufacturing systems, computer networks, traffic systems, public transportation systems, and systems consisting of queuing lines. Initially, the study of DES was mainly based on the use of ad hoc procedures and computer simulation. Recently, qualitative techniques for the analysis and synthesis of DES have emerged. In this interesting book the authors present a stability analysis framework for DES. Stability plays an important role in the proper operation of a dynamical system. In a manufacturing context we may, e.g., need to know whether the number of parts in a queuing buffer will remain bounded so that the buffer does not overflow or so that the inventories do not become overly large. The most important feature of the stability framework presented in this book is that it is largely based on the use of Lyapunov functions. This also provides a link with the well-developed field of stability analysis for conventional linear and nonlinear systems.

The book is organized as follows: Chapter 1 provides a short introduction to DES and gives an outline of the focus of the book. Chapter 2 presents some DES models. In the central chapter of the book, Chapter 3, the authors explain how to characterize and analyze stability properties of DES. Chapters 4 to 6 present some extensive case studies: load balancing in computer networks, scheduling of manufacturing systems, and intelligent control systems. Furthermore, each chapter contains an overview at the beginning, and a summary, suggestions for further reading, and a few exercises at the end. Although the book is reasonably self-contained, some knowledge on stability theory for nonlinear systems (especially Lyapunov stability theory), and — to a lesser extent — discrete-time systems and automata theory is a useful prerequisite.

In the following paragraphs we will concisely highlight the most important aspects that are considered in each of the chapters of the book.

Chapters 1 gives a brief introduction to DES. It presents several types of DES and explains why there is a need for analysis of DES apart from the currently often used heuristic ad hoc methods. This is followed by an overview of the contents of the book and an explanation of the three goals of the book: presenting some modeling approaches for DES, providing several stability properties and methods to assess them, and showing how stability analysis is conducted for complex examples.

There exist several modeling frameworks for DES. In Chapter 2 of the book, the authors present two fairly general models for DES: one is based on automata, and the other is Petri nets. These frameworks are used throughout the book. Nevertheless, in the subsequent chapters some additional models (such as, e.g., a simplified model that is easier to analyze) will be introduced if the need arises.

Chapter 3 is the central chapter of the book. In this chapter the authors introduce several characterizations of stability for DES such as stability in the sense of Lyapunov, asymptotic stability, asymptotic stability in the large, exponential stability, exponential stability in the large, stability in the sense of Lagrange, uniform boundedness and uniform ultimate boundedness. They provide sufficient conditions for these properties to hold. All these conditions depend on the specification of a "Lyapunov function" (note that the definition of Lyapunov function used in this book is a DES generalization of the conventional Lyapunov function used in nonlinear stability theory).

Chapter 4 considers load balancing systems, i.e., systems consisting of a network of load processors (e.g., computers in a network) that are connected together so that any processor on the network is capable of passing a portion of its load to any processor to which it is connected. The techniques introduced in Chapter 3 are used to deal with several load balancing problems in computer networks (with or without delays; and with discrete, continuous or virtual loads).

In Chapter 5 the Lyapunov stability framework is applied to scheduling in flexible manufacturing systems (FMS). FMS are interconnected networks of machines that can be configured in many ways to process many different types of parts. Apart from machines, the FMS considered here can also contain other network elements such as bounded transport delays, multiplexers, demultiplexers and stream modifiers (i.e., buffers with an embedded part flow and release time control policy). The key idea is that it can be shown that a variety of network elements have bounded buffers levels (which corresponds to a stability property) if they are properly scheduled. Some scheduling approaches that are treated, are: clear a fraction, clear average oldest buffer, and random part selection. Furthermore, the approach is modular and based on local scheduling of network elements. In that way a distributed approach to FMS scheduling is achieved in the sense that each network element will have its own scheduler and will not need "global" information, i.e., information about the other networks elements. The authors also present techniques to compute bounds on the buffer levels in the FMS. Apart from the distributed scheduling approach, they also introduce and analyze a class of global scheduling policies. Finally, the performance of several scheduling policies (both distributed and centralized) is compared for several examples such as a highly re-entrant line, a feedforward line, and some cellular structures.

The topic of Chapter 6 is a class of intelligent control systems called expert control systems. An expert control system is a computer program that is designed to emulate the expertise of a human in performing control activities. A rule-based expert controller is based on a knowledge base (consisting of if-then rules) in combination with a rule-matching, rule-selection and activation component (the inference engine). The authors show how such a rule-based expert controller can be described by a DES model. They also present some approaches to knowledge-base design. Then they show that it is possible to characterize and formally analyze reachability, cyclic behavior and stability properties for the expert controller and the total system (i.e., the closed-loop system consisting of the controlled system and the expert feedback controller). Finally, the techniques are applied to the design and analysis of an expert controller for a surge tank and an FMS. At the end of the chapter the authors briefly discuss a possible extension to hybrid systems, i.e., systems that can be modeled using a mix of conventional differential (or difference) equation models with DES models.

In summary, this book gives a fairly complete overview of the state of the art of Lyapunov stability theory for DES with several examples and case studies, which are mainly situated in the computing and manufacturing field.

One of the few less positive remarks that could be made about this book is that students that are not very familiar with conventional Lyapunov stability theory for nonlinear systems, may wonder why not much is said about methods for selection of Lyapunov functions for DES. Only towards the end of the book (on p. 164, in Chapter 6) it is explained that "... it is often possible to intuitively define an appropriate Lyapunov function (years of use have shown this). However, specifying the Lyapunov function is sometimes a difficult task."

As regards the use of this book as a textbook for courses, I would not suggest to use this book below graduate level, for the following reasons:

- The structure of many sections of the book is in the definition-theorem-proof-example format, which makes it less tractable for students that do not have a good mathematical background or for students that are not familiar with this way of working.
- There is not much recapitulation of the given definitions, and newly introduced concepts are not described from different points of view. Sometimes the students have to wait until the examples are treated before the exact meaning of some definitions becomes clear.
  Teachers that use this book as a textbook in their course are thus recommended to take this into account. In the lectures they could, e.g., introduce additional small examples to explain new concepts or give additional descriptions.

Nevertheless, for good students at the graduate and post-graduate level this book will be a good and complete introduction to the state of the art of Lyapunov-based stability analysis for DES. They will especially like the extensive list of references at the end of each chapter (there are 110 references in total) and the suggestions for further reading.

Furthermore, the authors also very clearly explain the intent and the structure of the book and the connections and dependencies between the chapters of the book. They have also taken care to introduce structure in the book and to provide readers that are only interested in a particular topic (e.g., stability analysis for computer networks) a clear road-map that is suited to their needs.

In conclusion, this interesting book is a very nice addition to the literature. It sheds more light on the fledgling field of stability analysis for DES and hybrid systems and it also provides new ideas for interesting research directions. As such it is recommended literature for both graduate students and researchers interested in or working on DES.