Language Stability of Timed Discrete Event Systems

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A system in which asynchronous occurring of discrete events changes the state is called a discrete event systems (DES). A DES is a dynamic system that evolves in accordance with the abrupt occurrence, at possibly unknown irregular intervals, of physical events. DESs arise in the domains of manufacturing, robotics, vehicular traffic, logistics (conveyance and storage of goods, organization and delivery of services), and computer and communication networks. Typical applications are found in computer networks, flexible manufacturing system (FMS), operating systems, database systems, and so on. An event may correspond to the arrival or departure of a customer in a queue, the completion of a task or the failure of a machine in a manufacturing system, transmission of a packet in a communication system, or the occurrence of a disturbance or change of setpoint in a complex control system. By the requirement for the effective control of such DESs, there have been many researches on DESs from various viewpoints. Especially, many of them are dealing with modeling and analysis of DESs. Many techniques have been proposed for some individual problems such as the mutual exclusion problem and the concurrency control problem. In accordance with the development of the computer application technology, large-scale DESs appear in real applications. It has been required to develop a unified methodology for the modeling and control of such large and complicated DESs. Therefore, many researchers pay attention to system-theoretic approaches to the analysis of DESs. As models of DESs, there are performance models such as queuing networks, and logical models such as formal language, automaton, and Petri nets. In general, if we analyze the control problem in which only the order of occurring events is important (e.g., the mutual exclusion problem and the concurrency control problem), logical models are suitable for the theoretical analysis.

A theoretical framework for controlling discrete event systems (DESs) was given by Ramege and Wonham in the latter half of the 1970's and their framework is called the supervisory control scheme. In this framework, a DES is controlled by a controller, called a supervisor. A DES is described by an automaton, and the specification for it is given as a language over the set of events. Then the controlling is to restrict behavior of the system so that it agrees with the specification. For example, we can apply the supervisory control scheme to the mutual exclusion problem in such a manner that the supervisor restricts state transitions to every state in which more than the given number of resources are shared by processes. The supervisory control scheme proposed by Ramadge and Wonham has changed the situation of ad hoc design/analysis of DESs, and gives an approach similar to that by the control theory for continuous systems. This framework is now a basis in the theoretical study of DESs. In this paper, we focus on the stability of DESs. We study effective definition of stability of DESs based on the Ramage-Wonham scheme, and show an algorithm to compute a controller that makes the system stable. There are roughly two kinds of ideas on stability of DESs, one is defined on the set of legal states, and the other is defined on the set of legal trajectory of events. The first type of stabilities, called state stabilities, were proposed by

Breve et al. and Ozveren et al. The second type of stabilities, called language stabilities, were proposed by Kumar et al. Breve et al. proposed the following concept of stability and stabilizability for DESs: the system is stable if it visits one of the legal states after finitely many state transitions from arbitrary initial state and stays forever in the set of legal states; a stabilizable system is one for which there exists a supervisor so that the supervised system is stable.

Ozveren et al. proposed the following concept of stability for DESs: the system is stable if after starting from any arbitrary initial state it visit the legal subset of states infinitely often; a system that can be made stable in the above context by the synthesis of an appropriate supervisor is called stabilizable. The requirement of this stability is weaker than that by Brave et al.

These notion of stability and stabilizability of DESs has been presented in terms of the legal and illegal states of the system. Kumar et al. are defined stability and stabilizability in term of the behavior of the systems. Their definition is as follows: the system is language-stable if its behavior eventually coincides with the legal behavior; if a supervisor exists such that the supervised system is language-stable, then system is called language-stabilizable. In real applications, we often need to deal with timing constraints, such as time delay and deadline. For this purpose, a DES model with timing constraints, called timed discrete event systems (TDESs), is recently proposed. There are only a few researches on the stability of TDESs. It has not sufficiently been discovered Yang et al. proposed a definition of stability for TDESs as an extension of one by Brave et al. for DESs. This stability requires the system to converge to a given set of legal states, but it does not take timing information into consideration. Mochiyama et al. proposed a new concept of stability for TDESs based on the Ozveren's stability. In this stability, they require the system to visit a given set of legal state frequently. Moreover, degree of stability is measured by the maximum time necessary for returning to the set of legal states. However, the description ability of this stability seems still insufficient because the stability is defined only on the states. In this paper, we proposed new concept of stability for DESs and TDESs. In the proposed stability, we require the system to execute one of the next events of the legal language within finitely many times. Moreover, degree of stalibility is measured by the maximum time necessary for executing the next event of the legal language.

The paper is organized as follows. Basic notation of DESs and TDESs is described in Section 2. Existing definitions of stability defined in terms of states and language, and the new definition of stability for DESs are shown in Section 3. Existing definitions of stability defined in terms of states, the new definition of stability for TDESs, and an algorithm for checking the stability of TDESs are shown in Section 4. Control policies that make the system stable are discussed and an example is shown for illustrating the stabilization in Section 5. We show an optimal controller guaranteeing a given degree of stability in the sense of minimally restrictive. Finally in Section 6, a brief summary of this paper is provided.