Nonblocking Supervisory Control of Hierarchical Timed State-Tree Structures and Possible Extensions

A discrete-event system (DES) is discrete in time and in state space, and event-driven rather than time-driven. Typical examples can be found in flexible manufacturing systems, communication protocols, embedded reactive systems, traffic control systems, and multi-agent systems. Here a DES can no longer be formally described by differential or difference equations, and therefore new control theories must be investigated. Supervisory Control Theory (SCT), proposed by Ramadge and Wonham (RW), is a formal framework for the modeling and control of DES. However, it is well known that the optimal is well known that the nonblocking supervisory control problem is NP-hard, subject in particular to state space explosion that is exponential in the number of system components. With a structured state space, state-tree structures (STS) is a powerful framework that can be used to model hierarchical DES components with hierarchy (vertical) and concurrency (horizontal) structures. By encoding into binary decision diagrams (BDD) to compute the supervisors of STS, the state explosion problem faced by the supervisory control of DES is managed.

Since 2015, Dr. Xi Wang has been developing a novel STS framework “hierarchical timed STS (HTSTS)”, in which the equipped time of events is hierarchical, inspired by time scale such as “hour, minute, and second” in our daily life. HTSTS provides possibilities of computing the supervisors for large-scale real-world systems. An HTSTS model contains two parts: the (untimed) activity part and the timer part. Both are hierarchical and modeled via top-down approaches. In order to manage the state explosion problem, the lower level system behaviors can be abstracted to a state of the higher level when it is unnecessary. The speed ratio between clocks on adjacent hierarchical levels of the HTSTS can be adjusted by users freely.

The timing strategy of the existing timed DES (TDES) framework is just like we merely use “second” to organize the events in our daily life. Unlike TDES whose timed events are governed by a unique clock, for HTSTS, we use “hour, minute, and second” instead of merely “second” to organize events. Thus, HTSTS can be used to model large-scale hierarchical systems by assigning different time scales on different hierarchical levels. This framework allows users to think locally instead of globally. The modelling principle can manage the state explosion problem in the supervisory control of DES by reducing the state space of a DES significantly. Generally, a large-scale real-world system could be decomposed into several hierarchical levels and the time scales on different levels are different from each other. The supervisory control of HTSTS is also based on BDD, which manages the state explosion problem significantly.

Several possible extensions of STS and HTSTS include: 1) optimal real-time scheduling based on nonblocking supervisory control of DES and STS; 2) level-wisely nonblocking supervisory control of STS; and 3) some ongoing and possible extensions of above research topics.