

# Nonblocking Supervisory Control of State Tree Structures

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**Abstract**—It 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. In this paper we propose to manage complexity by organizing the system as a state tree structure (STS). STS are an adaptation of statecharts to supervisory control theory. Based on STS we present an efficient recursive symbolic algorithm that can perform nonblocking supervisory control design (in reasonable time and memory) for systems of state size  $10^{20}$  and higher. The resulting controllers are tractable and readily comprehensible.

**Index Terms**—Discrete-event systems, nonblocking supervisory control, state tree structure (STS), symbolic computation.

## I. INTRODUCTION

**T**HE central problem of supervisory control theory (SCT) is that of optimal nonblocking supervisory control [1]. This problem is well known to be NP-hard [2]; specifically it is unlikely that any algorithm can be found to solve it that circumvents state space explosion that is exponential in the number of system components. This means that realistic industrial problems (say with state set sizes of  $10^{20}$  and higher), if formulated naively, may well exceed the computational capacity available.

It is, therefore, attractive to explore structured system architectures with the property that, if the given system can be modeled in the selected framework, the required computations can be carried out with greater efficiency than by a naive ‘monolithic’ approach. To this end, Statecharts [3] is a modeling tool which offers a compact representation of both hierarchy (vertical) and concurrency (horizontal) structure in finite state machines (FSM). Here the system state space is structured top-down into successive layers of cartesian products (AND superstates) alternating with disjoint unions (OR superstates). On this basis, Wang [4] introduced *state tree structures* (STS) consisting of a hierarchical state-space or *state tree* (ST), equipped with dynamic modules called *holons* (inspired by [5] and [6]). In [4], however, the global dynamics (semantics) of STS was not described formally and only safety specifications were considered. Furthermore, AND states had to be converted by synchronous product of factors into OR states at a higher level before computations could effectively be carried out. Unfortunately, if the root state is an AND superstate, such simple treatment of AND states

may result in the collapse of the entire hierarchy. [7] formalized Wang’s model in linguistic terms, but was similarly restricted to a purely OR state expansion.

Statecharts also underlie the *asynchronous hierarchical state machine* (AHSM) model of [8], but shared events among AND components were ruled out. An efficient algorithm was given to solve reachability problems by exploiting the hierarchical structure and asynchronism. However, [8] did not present a systematic control synthesis approach. Marchand *et al.* [9] introduced another simplified version of statecharts, *hierarchical finite state machines* (HFSM). However, HFSM ruled out shared events, were apparently restricted to be OR structures at the topmost level, and allowed only specifications of special forbidden state type.

All cited works on statecharts attempt to avoid either AND structure or shared events among components. In [10] and [11], the authors introduced a state-based STS framework that treated both AND and OR states on a more equal footing, and in AND states allowed shared events among the factors.

To design controllers for the STS framework, we exploit a well-known computational representation of state set: the *binary decision diagram* (BDD) [12], a directed graph representation of propositional logic formulas. A BDD is appealing because, for a fixed order of arguments (variables), it is a canonical form, and makes such tasks as testing for set membership or set equality highly efficient. After representing sets by BDD, the computational complexity of our synthesis is no longer polynomial in the model’s state size, but in the number of nodes in the relevant BDD. As with other approaches to solving NP-hard problems, in the worst case the number of BDD nodes ( $\# \text{ nodes}$ ) grows exponentially in the number of variables and, therefore, is comparable to the number of states ( $\# \text{ states}$ ) of the set it represents (see the multiplier example of [12]). However, with STS, we propose an efficient encoding scheme such that in many cases  $\# \text{ nodes} \ll \# \text{ states}$ . This makes the introduction of BDD into the STS framework very attractive.

In [13], Balemi *et al.* presented a BDD-based symbolic computation of the optimal (maximally permissive nonblocking) supervisor for an example of  $10^6$  states. However, computational capability was limited by the unstructured (flat) system model. Later Zhang [14] developed S(mart)TCT based on *integer decision diagrams* [15] (IDD), a BDD-like decision diagram. STCT could handle systems with more than  $10^{20}$  states. However, his work focused on a synchronous product structure with buffer-like components. In this paper, we develop a complete symbolic approach for the optimal supervisor design of STS.

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# Nonblocking Supervisory Control Of State Tree Structures

**JR Anderson**



## **Nonblocking Supervisory Control Of State Tree Structures:**

## **Nonblocking Supervisory Control Of State Tree Structures** Book Review: Unveiling the Magic of Language

In an electronic digital era where connections and knowledge reign supreme, the enchanting power of language has become much more apparent than ever. Its ability to stir emotions, provoke thought, and instigate transformation is really remarkable. This extraordinary book, aptly titled "**Nonblocking Supervisory Control Of State Tree Structures**," compiled by a very acclaimed author, immerses readers in a captivating exploration of the significance of language and its profound effect on our existence. Throughout this critique, we will delve to the book's central themes, evaluate its unique writing style, and assess its overall influence on its readership.

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### **Table of Contents Nonblocking Supervisory Control Of State Tree Structures**

1. Understanding the eBook Nonblocking Supervisory Control Of State Tree Structures
  - The Rise of Digital Reading Nonblocking Supervisory Control Of State Tree Structures
  - Advantages of eBooks Over Traditional Books
2. Identifying Nonblocking Supervisory Control Of State Tree Structures
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in a Nonblocking Supervisory Control Of State Tree Structures
  - User-Friendly Interface
4. Exploring eBook Recommendations from Nonblocking Supervisory Control Of State Tree Structures
  - Personalized Recommendations
  - Nonblocking Supervisory Control Of State Tree Structures User Reviews and Ratings

- Nonblocking Supervisory Control Of State Tree Structures and Bestseller Lists
- 5. Accessing Nonblocking Supervisory Control Of State Tree Structures Free and Paid eBooks
  - Nonblocking Supervisory Control Of State Tree Structures Public Domain eBooks
  - Nonblocking Supervisory Control Of State Tree Structures eBook Subscription Services
  - Nonblocking Supervisory Control Of State Tree Structures Budget-Friendly Options
- 6. Navigating Nonblocking Supervisory Control Of State Tree Structures eBook Formats
  - ePub, PDF, MOBI, and More
  - Nonblocking Supervisory Control Of State Tree Structures Compatibility with Devices
  - Nonblocking Supervisory Control Of State Tree Structures Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Nonblocking Supervisory Control Of State Tree Structures
  - Highlighting and Note-Taking Nonblocking Supervisory Control Of State Tree Structures
  - Interactive Elements Nonblocking Supervisory Control Of State Tree Structures
- 8. Staying Engaged with Nonblocking Supervisory Control Of State Tree Structures
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Nonblocking Supervisory Control Of State Tree Structures
- 9. Balancing eBooks and Physical Books Nonblocking Supervisory Control Of State Tree Structures
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Nonblocking Supervisory Control Of State Tree Structures
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Nonblocking Supervisory Control Of State Tree Structures
  - Setting Reading Goals Nonblocking Supervisory Control Of State Tree Structures
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Nonblocking Supervisory Control Of State Tree Structures
  - Fact-Checking eBook Content of Nonblocking Supervisory Control Of State Tree Structures
  - Distinguishing Credible Sources

13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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