A General Architecture for Decentralized Supervisory Control of Discrete-Event Systems

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Abstract. We consider a generalized form of the conventional decentralized control architecture for discrete-event systems where the control actions of a set of supervisors can be “fused” using both union and intersection of enabled events. Namely, the supervisors agree a priori on choosing “fusion by union” for certain controllable events and “fusion by intersection” for certain other controllable events. We show that under this architecture, a larger class of languages can be achieved than before since a relaxed version of the notion of co-observability appears in the necessary and sufficient conditions for the existence of supervisors. The computational complexity of verifying these new conditions is studied. A method of partitioning the controllable events between “fusion by union” and “fusion by intersection” is presented. The algebraic properties of co-observability in the context of this architecture are presented. We show that appropriate combinations of fusion rules with corresponding decoupled local decision rules guarantee the safety of the closed-loop behavior with respect to a given specification that is not co-observable. We characterize an “optimal” combination of fusion rules among those combinations guaranteeing the safety of the closed-loop behavior. In addition, a simple supervisor synthesis technique generating the minimal prefix-closed controllable and co-observable superlanguage is presented.

Keywords: supervisory control, decentralized architectures, decision fusion, computational complexity, supervisor synthesis

1. Introduction

We consider control problems for discrete-event systems where a set of “local” supervisors, each with its own sensing and actuation capabilities, cooperate in order to achieve a given desired controlled behavior. Such decentralized control architectures are of considerable interest as they arise in a large variety of networked systems. Mobile ad hoc communication networks, integrated sensor networks, networked control systems, and automated vehicular systems are all examples of networked systems. Networked systems are informationally-decentralized and event-driven dynamic systems where groups of individual “agents” (i.e., local supervisors) interact in order to accomplish a common set of objectives.

Our control problems for networked systems are posed in the framework of the theory of supervisory control of discrete-event systems (cf. Ramadge and Wonham, 1989) and Chapter 3 in Cassandras and LaFortune, 1999). In the conventional decentralized control architecture studied in supervisory control (Cieslak et al., 1988; Rudie and Wonham,
1992), the control actions of the local supervisors are fused using intersection of locally enabled events. We will refer to this architecture as the conjunctive architecture.

Most of the results on decentralized supervisory control are based on the conjunctive architecture (Barrett, 1999; Cieslak et al., 1988; Jiang and Kumar, 2000; Kozak and Wonham, 1995; Kumar and Shayman, 1997; 1998; Lin and Wonham, 1988; Ricker, 1999; Rudie and Willems, 1995; Rudie and Wonham, 1992; Takai, 1998; Takai and Kodama, 1994; Willner and Heymann, 1991). A notable exception is the work in Prosser (1996), where decentralized supervision with different fusion rules is considered. In that work, new event fusion rules are introduced and a synthesis technique guaranteeing the safety of the supervised language under various event fusion rules is developed.

In this paper, we go beyond the approach of Prosser (1996) and consider a generalized form of the conjunctive architecture where the control actions of a set of supervisors can be fused using both union and intersection of enabled events. Under this general architecture, the local supervisors decide a priori that some controllable events are processed by “fusion by union” (of enabled events) and other controllable events are handled by “fusion by intersection” (of enabled events).

The contributions of this paper are as follows.

1. Necessary and sufficient conditions for the existence of a set of local supervisors that achieve a given legal language are given in Section 3. These conditions characterize the class of languages achievable under the general architecture and introduce a generalized version of the notion of co-observability of Rudie and Wonham (1992).

2. In Section 4, we compare the classes of languages achievable under the conjunctive, disjunctive, and general architectures. (When the decision fusion rule is “fusion by union” (of enabled events), the resulting architecture is called “disjunctive”.) The class of languages achievable under the general architecture strictly includes those of the conjunctive and disjunctive architectures.

3. Section 5 presents computational complexity results. We show that the existence conditions of Section 3 can be verified in polynomial time. Moreover, a polynomial time technique to partition the set of controllable events in the general architecture is given.

4. The algebraic properties of co-observability (as defined in Section 3) are presented in Section 6. These properties show that the supremal and infimal co-observable elements of a class of languages need not exist, in general.

5. A simple decentralized supervisor synthesis technique decoupling the synthesis of local supervisors is developed under the general architecture. Because of the intentional separation of the design of the local decision rules, this technique circumvents the difficulties caused by the dependency of local decision rules in the design of decentralized supervisors.

6. Equipped with the above synthesis technique, we present in Section 7.1 a rule for partitioning the set of controllable events (between “fusion by union” and “fusion by