

Preface

In writing this monograph our goal has been to present a thorough treatment of the supervisor localization approach to distributed control synthesis of discrete-event dynamic systems. The monograph is intended for graduate students specializing in control of discrete-event systems, researchers involved in distributed control over networked multi-agent systems, and computer scientists (particularly in distributed algorithms, artificial intelligence) interested in control-theoretic methods.

In this monograph a single distributed control problem is solved: given a discrete-event system comprised of multiple agents and some imposed control specifications, synthesize local controllers for each individual agent such that the resulting collective controlled behavior satisfies the specifications and is optimal (in the sense of maximally permissive behavior) and nonblocking (i.e., distinguished target states remain reachable). Our solution to this problem is a top-down procedure that we call *supervisor localization*: first, synthesize a monolithic supervisor (or a heterarchical array of modular supervisors) that satisfies the imposed specifications and is optimal and nonblocking; then, decompose the supervisor into local controllers for individual agents while preserving the optimal and nonblocking controlled behavior. The distributed control problem is formulated in several different settings: language-based, state-based, and timed; in each case, a corresponding localization solution is provided. The underlying mathematical idea is to exploit a quotient structure of the synthesized supervisor, by means of aggregating its dynamics according to the control information of each individual agent. The discrete nature of the dynamics plays an essential role in enabling a clear-cut separation of the control logics of individual agents.

The top-down style of supervisor localization is in sharp contrast with the bottom-up approaches more frequently used to address distributed control, not only in discrete-event but in other types of dynamic systems. Indeed, by adopting the top-down direction we seek a method that always synthesizes correct and optimal distributed control strategies for whatever control specifications are imposed, as opposed to designing an *ad hoc* distributed control rule to perform only a particular task. Supervisor localization is thus a general method for distributed control synthesis, independent of the imposed control specifications.

The book is organized as follows. Chapter 1 introduces the background, including a review of the literature and existing control architectures. Chapter 2 presents the fundamental results: the distributed control problem is formulated and supervisor localization proposed as the solution. Moreover, a localization algorithm is designed for computing local controllers, and properties of localization are analyzed. Chapter 3 introduces an alternative localization scheme which allows more flexible allocation of local controllers. This scheme is demonstrated with examples in multi-robot formations, manufacturing workcells, and distributed algorithms. Chapters 4–6 deal with localization in large-scale systems. In Chaps. 4 and 5, localization is combined with an efficient heterarchical supervisor synthesis, resulting in a heterarchical localization procedure; this procedure is successfully applied to synthesize distributed control of a benchmark case study, Production Cell. In Chap. 6, an efficient state-based framework for supervisor synthesis called *state tree structures* is adopted for supervisor localization. This leads to a more efficient symbolic localization algorithm, which is demonstrated with a large-scale example, Cluster Tool. In Chap. 7, the distributed control problem is formulated for timed discrete-event systems; timed supervisor localization is presented as a solution that addresses temporal specifications in addition to logical ones. Finally in Chap. 8, we state our conclusions and suggest future topics in supervisor localization that have emerged from this research. The framework that supervisor localization is based on is supervisory control theory: specifically, in Chaps. 2–5 the Ramadge-Wonham language model, in Chap. 6 the Ma-Wonham state model, and in Chap. 7 the Brandin-Wonham timed model.

Supervisor localization originated with the first author’s Master’s research during 2006–2008; the results of Chaps. 2 and 4–6 appeared in his Master’s thesis. Further developments (Chaps. 3 and 7) were completed during the first author’s postdoctoral research, 2011–2013. The monograph organizes the results of supervisor localization in the past 8 years into a self-contained volume. Supplementary materials such as software and examples are available on the Internet at:

<https://sites.google.com/site/supervisorlocalization>

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