PARALLEL AND DISTRIBUTED SIMULATION SYSTEMS

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To
Jan, Emily, and Alex

CONTENTS

PREFACE

These are exciting times in the parallel and distributed simulation field. After many years of research and development in university and industrial laboratories, the field has exploded in the last decade and is now seeing use in many real-world systems and applications. My goal in writing *Parallel and Distributed Simulation Systems* is to give an in-depth treatment of technical issues concerning the execution of discrete event simulation programs on computing platforms composed of many processors interconnected through a network. The platform may range from tightly coupled multiprocessor computer systems confined to a single cabinet or room to geographically distributed personal computers or specialized simulators (for example, video game systems) spread across the world. This technology can be used to speed up the execution of large-scale simulations, for example simulations of the next generation of the Internet, or to create distributed synthetic environments for training or entertainment.

My goal in writing this book was to bring together into one volume the fundamental principles concerning parallel and distributed simulation systems that today are scattered across numerous journals and conference proceedings. The intended audience includes managers and practitioners involved in research and/or development of distributed simulation systems. The book can serve as a textbook for an advanced undergraduate or a graduate level computer science course. The book might be of interest in other disciplines (for example, industrial engineering or operations research) although the principal emphasis is on issues concerning parallel and distributed computation. Prior knowledge of discrete event simulation parallel, or distributed computation would be helpful, but is not essential as the book will include brief introductions to these fields.

Contents

The book is divided into three parts. The first provides an introduction to the field. Chapter 1 describes typical applications where this technology can be applied, and gives an historical perspective to characterize the communities that developed and refined this technology. Background information concerning parallel and distributed computing systems is reviewed. Chapter 2 reviews fundamental concepts in discrete event simulation to provide a common basis and terminology that is used in the remainder of the book.

The second part is primarily concerned with parallel and distributed execution of simulations, primarily for analysis applications such as to design large, complex systems. Here the goal is to use multiple processors to speed up the execution. Much of the material in these four chapters is concerned with synchronization algorithms that are used to ensure a parallel execution of the simulation yields the same results as a sequential execution, but (hopefully!) much more quickly. Two principal approaches to addressing this issue are called conservative and optimistic synchronization. Chapter 3 is concerned with the former, and Chapters 4 and 5 with the latter. Chapter 6 is concerned with an altogether different approach to parallel execution called time parallel simulation that is only suitable for certain classes of simulation problems, but can yield dramatic performance improvements when it can be applied.

The third part is concerned with distributed virtual environments (DVEs). Here the emphasis is on real-time simulations, that is, to create virtual environments into which humans may be embedded, for example, for training or entertainment. Chapter 7 gives an introduction to this area, focusing primarily on two efforts within the defense community, namely Distributed Interactive Simulation (DIS) and the High Level Architecture (HLA) where much of this technology was developed and has been applied. Chapters 8 and 9 are concerned with two specific issues in DVEs. Chapter 8 covers the problem of efficiently distributing data among the participants of the DVE. The first half of the chapter is an introduction to computer networks which provide the underlying communication support for DVEs. The second half is concerned with techniques to effectively utilize the networking infrastructure, particularly for large-scale simulations with many interacting components. Finally, Chapter 9 revisits the problem of time synchronization in DVEs as well as the problem of ensuring that the different computers participating in the simulation have properly synchronized clocks.

Part I lays the groundwork for the remainder of the book, so should be read first. Parts II and III can be read in either order. I have used this book as the text in a 10-week course in parallel and distributed simulation taught at Georgia Tech, and plan to use it when we transition to 15-week semesters. Alternatively, this book could be used for part of a course in discrete event simulation. When used in this manner, instructors may wish to skip Chapters 5 and 6, and the first half of Chapter 8 to obtain a more abbreviated treatment of the subject material.

Software

Interested readers may wish to try out some of the algorithms discussed in this book. Although software is not included with the text, it is available. In particular, the Georgia Tech Time Warp (GTW) software discussed in Chapter 5 and an implementation of a subset of the High level Architecture Run Time Infrastructure are freely available for education and research purposes. Information concerning this software is available at http://www.cc.gatech.edu/computing/pads. To obtain a copy of either or both of these software packages, you may contact me via electronic mail at fujimoto@cc.gatech.edu.

Acknowledgments

Obviously, this book would not be possible without the many technical contributions by numerous individuals in both academia and industry. I have attempted to recognize as many of these contributors as possible in the bibliography and references to additional reading materials. Regrettably, the field has expanded to the extent that anything approaching a complete listing of the contributors is impossible.

I am in debt to many individuals who contributed directly to the development of this book. In particular, many useful comments on early drafts were provided by students in my graduate class on parallel and distributed simulation taught at Georgia Tech. Specific detailed comments from Glenn Oberhauser and Katherine Morse are also appreciated. I am grateful to several funding agencies that sponsored my research in parallel and distributed simulation; some of the results of this work are included in this text. These agencies include the Ballistic Missile Defense Organization, the Defense Advance Research Projects Agency, the Defense Modeling and Simulation Office, the National Science Foundation, SAIC, Mitre Corporation, Bellcore, Army Research Office, the Office of Naval Research, and the Strategic Missile Defense Command.

Finally, I owe the greatest gratitude to my family, who provided continued support and understanding despite the countless evenings and weekends of dealing with my absence due to this project which came to be known simply as “the book.” This manuscript would never have been completed were it not for their love and devotion.

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