CONTENTS

VOLUME IV

Modeling and Simulation of Dynamic Systems **1**
Inge Troch, *Vienna University of Technology, Austria*
Felix Breitenecker, *Vienna University of Technology, Austria*

1. Introduction
2. Systems, Processes and Models
3. Simulation
4. Classification of Systems and Models
   - 4.1. Properties of Systems and Models
   - 4.2. Properties of Models only
   - 4.3. Some Additional Remarks on the Properties 'Static' and 'Dynamic'
5. Modeling
   - 5.1. Some General Considerations
     - 5.1.1. Modeling and Modeler
     - 5.1.2. Modeling and Modeling Goals
     - 5.1.3. Model Structure
     - 5.1.4. Model Complexity
   - 5.2. Verification and Validation
   - 5.3. Numerical Aspects
   - 5.4. System Structure and Model Structure
   - 5.5. System Descriptions and Relations between Models
6. A Short History of Simulation
   - 5.6. Continuous-time Simulation
   - 5.7. Discrete-event Simulation

Some Basics in Modeling of Mechatronic Systems **44**
Andreas Kugi, *Chair of System Theory and Automatic Control, Saarland University, Germany*

1. Introduction
2. System Variables and System Elements
   - 2.1. Energy Storage Elements
     - 2.1.1. Generalized Kinetic Energy
     - 2.1.2. Generalized Potential Energy
     - 2.1.3. The General Case
   - 2.2. Coupling Elements
     - 2.2.1. Electromechanical Example - Solenoid Valve
     - 2.2.2. Hydromechanical Example - Hydraulic Piston Actuator
   - 2.3. Static Elements
     - 2.3.1. Mechanical Example - The Rayleigh Dissipation Function
3. Kirchhoff Networks
   - 3.1. Kirchhoff's Laws
   - 3.2. Tellegen's Theorem
   - 3.3. Fundamental Matrices
4. Port-Hamiltonian Systems
   - 4.1. Electromechanical Example - Solenoid Valve
   - 4.2. Hydromechanical Example - Hydraulic Piston Actuator

Modeling and Simulation of Distributed Parameter Systems **85**
A. Vande Wouwer, *Faculté Polytechnique de Mons, Belgium*

1. Introduction

2. Modeling of distributed parameter systems
2.1. Model Derivation Basic Principles
2.2. More PDEs – Classifications
2.2.1. PDE order
2.2.2. Linearity, Quasilinearity and Nonlinearity
2.2.3. Elliptic, parabolic and hyperbolic PDEs
2.2.4. Convection - Diffusion (Dispersion) - Reaction PDEs
2.2.5. Boundary conditions
2.3. Parameter Estimation
2.4. Model simplification and reduction
3. Simulation of distributed parameter systems
3.1. Analytical solution procedures
3.2. Spectral methods and weighted residual approximations
3.3. Spatial discretization
3.4. Time integration
3.5. Early versus Late Lumping

Modeling and Simulation of Large-Scale Hybrid Systems **109**
Manuel A. Pereira Remelhe,*Universiät Dortmund, Germany.*
Sebastian Engell, *Universiät Dortmund, Germany.*

1. Introduction
2. General Concepts
3. System Representations and Software Tools
3.1. Representations of Discrete Event and Continuous Systems
3.2. Representations for Hybrid Systems
4. Object-oriented Modeling of Physical Systems
4.1. Hybrid Elements
4.2. Hybrid Systems Arising from Physical Abstractions
4.3. Equation-Based Modeling of Discrete Event Systems
5. Integration of Complex Discrete Event and Object-Oriented Models
5.1. Modeling Aspects
5.2. Numerical Aspects
6. Ongoing Research and Future Challenges

Modeling and Simulation of Dynamic Systems using Bond Graphs **129**
Peter C. Breedveld, *University of Twente, Enschede, The Netherlands.*

1. Introduction
2. Early history
3. Modeling and simulation of dynamic behavior of physical systems
4. Key aspects of the port-based approach
5. Bond Graph Notation
5.1. Introduction
5.2. Node types
5.3. Constitutive relations
5.4. Relation to other representations
5.5. Systematic conversion of a simple electromechanical system model into a bond graph representation
5.6. Causality
5.6.1. Notation
5.6.2. Causal port properties
5.6.3. Causality assignment
5.6.4. Conversion of a causal bond graph into a block diagram
5.6.5. Causal paths
5.6.6. Generation of a set of mixed algebraic and differential equations

5.6.7. Linear analysis
5.6.7.1. Introduction
5.6.7.2. Impedance analysis using bond graphs
5.7. Hierarchical modeling
5.7.1. Word bond graphs
5.7.2. Multibonds
5.7.3. Multiport generalizations
6. Port-based modeling and simulation of dynamic behavior of physical systems in terms of bond graphs: a simple example
7. Future trends

Rapid Prototyping for Model, and Controller Implementation **175**
Peter Schwarz, *Fraunhofer Institute for Integrated Circuits IIS, Design Automation Division EAS Dresden, Germany*
Jörg Uhlig, *Institute of Automation and Computer Control, Ruhr-University Bochum, Germany*

1. Definition of Rapid Prototyping
2. Goals
3. General solution
3.1. Implementation in Software
3.2. Implementation in Hardware
3.3. Real-time simulation, Hardware-in-the-loop (HIL)
4. Simulation acceleration
5. Conclusions

Modeling Languages for Continuous and Discrete Systems **198**
Peter Schwarz, *Fraunhofer Institute for Integrated Circuits IIS, Design Automation Division EAS Dresden, Germany*

1. Aims of Modeling Languages
2. Historical background
3. A Modeling Approach
3.1. Physical background
3.2. The Multi-Port Approach
4. Modeling Languages
4.1. VHDL-AMS
4.2. Modelica
5. A comparison of VHDL-AMS and Modelica
6. Conclusions

Simulation Software - Development and Trends **233**
F. Breitenecker, *Vienna University of Technology, Vienna, Austria*
I. Troch, *Vienna University of Technology, Vienna, Austria*

1. Introduction
2. Continuous Roots of Simulation
3. CSSL Structure in Continuous Simulation
3.1. Structure of the Model Frame
3.2. Requirements for the Experimental Frame
4. Numerical Algorithms in Simulation Systems
5. Simulation Software and CACSD Tools
6. Analysis Methods in Simulation Systems
7. Implicit Models -Algebraic Loops -Differential-Algebraic Equations
8. Discrete Elements in Continuous Modeling and Simulation
9. Hybrid modeling and simulation - Combined Modeling and Simulation

10. Simulation in Specific Domains
11. Developments beyond CSSL
12. Discrete Event Simulation
    12.1. Statistic Roots and Events
    12.2. Modeling Concepts in Discrete Simulation
    12.3. Random Number Generators
13. Object-oriented Approaches to Modeling and Simulation
14. Choice and Comparison of Simulation Software
    14.1. Hints for Simulator Choice
    14.2. Comparison of Simulation Tools
15. Conclusion

Index **281**

About EOLSS **287**