Distributed Event-driven Simulation - Scheduling Strategies and Resource Management

Overeinder, B.J.

Citation for published version (APA):

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: https://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

UvA-DARE is a service provided by the library of the University of Amsterdam (http://dare.uva.nl)
Contents

1 Introduction ........................................ 1
  1.1 Rationale ........................................ 1
  1.2 Modeling and Simulation .......................... 3
    1.2.1 Systems and System Environment .......... 3
    1.2.2 Components of a System .................... 3
    1.2.3 Model of a System ........................... 4
    1.2.4 Experimentation and Simulation .......... 4
    1.2.5 A Closer Look at System Models ............ 6
    1.2.6 Model Execution: Time-Driven versus Event-Driven ... 7
    1.2.7 World Views in Discrete Event Simulation .... 8
  1.3 Parallel Computing ............................... 9
    1.3.1 Parallel Architectures ...................... 9
    1.3.2 Resource Management: Scheduling and Load Balancing ... 11
  1.4 Problems and Challenges ........................ 13
  1.5 Outline of Thesis ................................ 14

1 Scheduling Strategies .................................. 17

2 Issues in Parallel Discrete Event Simulation ........ 19
  2.1 Introduction ...................................... 19
  2.2 Basic Concepts ................................... 21
    2.2.1 Need for Logical Processes ................ 21
    2.2.2 The Curse of Causality ....... 22
  2.3 Conservative Methods ............................. 24
    2.3.1 Deadlock Avoidance ......................... 25
    2.3.2 Deadlock Detection and Recovery ............ 26
    2.3.3 Performance of Conservative Methods ....... 27
  2.4 Optimistic Methods ................................ 28
    2.4.1 Virtual Time ................................ 29
    2.4.2 The Basic Time Warp Mechanism .......... 30
    2.4.3 Rollback Strategies ......................... 32
    2.4.4 State Saving ............................... 34
    2.4.5 Optimism Control ............................ 37
    2.4.6 Global Virtual Time Algorithms ............. 41
  2.5 Summary and Discussion ........................... 44
## Contents

### 3 The APSIS Time Warp Kernel

3.1 Introduction ............................................. 49
3.2 Parallel Discrete Event Simulation Environments ................. 50
   3.2.1 Languages ........................................... 51
   3.2.2 Libraries ........................................... 53
3.3 Design of the APSIS Environment ................................ 55
   3.3.1 Requirements and Design Goals .......................... 55
   3.3.2 Overview ........................................... 56
   3.3.3 The Application Programming Interface .................... 57
   3.3.4 The Software Architecture .............................. 62
3.4 Extensions to the Time Warp Kernel ................................ 65
   3.4.1 Event Retraction ...................................... 66
   3.4.2 Incremental State Saving ................................ 67
3.5 Implementation Aspects of the Time Warp Simulation Kernel .. 68
   3.5.1 Simulation Kernel and Data Structures ..................... 68
   3.5.2 Synchronization ....................................... 70
   3.5.3 Fossil Collection and Irrevocable Events .................. 72
   3.5.4 The Global Virtual Time Computation ....................... 73
3.6 Summary and Discussion ..................................... 74

### 4 APSE: Average Parallelism, Profile, and Shape Evaluation

4.1 Introduction ............................................... 77
4.2 Characterization of Parallelism in Applications ................. 78
   4.2.1 The Average Parallelism Metric ........................ 79
   4.2.2 The Space-Time Model ................................ 80
   4.2.3 Critical Path Analysis ................................ 83
4.3 Design and Implementation of APSE ................................ 84
   4.3.1 Conceptual Tool Structure ............................. 84
   4.3.2 Overview of APSE ..................................... 85
4.4 Experiments, Validation, and Assessment ......................... 91
   4.4.1 Unidirectional Ring ................................... 91
   4.4.2 Bidirectional Ring .................................... 94
4.5 Related Work ............................................... 97
4.6 Summary and Discussion ..................................... 99

### 5 Parallel Asynchronous Cellular Automata

5.1 Introduction ............................................... 103
5.2 Asynchronous Cellular Automata ................................ 104
   5.2.1 Cellular Automata .................................... 104
   5.2.2 Asynchronous Cellular Automata ........................ 105
   5.2.3 The Asynchronous Cellular Automata Model ............... 106
   5.2.4 Parallel Simulation of Cellular Automata Models .......... 107
5.3 Ising Spin Systems .......................................... 109
   5.3.1 The Ising Spin Model .................................. 109
   5.3.2 The Dynamics in the Ising Spin Model .................... 111
5.4 Optimistic Simulation of Continuous-Time Ising Spin Systems .. 114
## Contents

5.5 Parallel Performance and Scalability .................................. 118  
5.5.1 Relative Parallel Performance and Scalability ................. 118  
5.5.2 Absolute Parallel Performance and Scalability ............... 126  
5.6 Summary and Discussion .............................................. 130  

6 Self-Organized Critical Behavior in Time Warp ...................... 133  
6.1 Self-Organized Criticality ........................................... 133  
6.2 Self-Organized Criticality in Time Warp Dynamics ............... 135  
6.2.1 Slowly Driven, Interaction-Dominated Threshold Systems .... 135  
6.2.2 Physical and Computational Critical Behavior ............... 137  
6.3 A First Indication of Self-Organized Criticality in Time Warp .... 138  
6.4 Finite-Size Scaling Effects ........................................ 142  
6.4.1 Influence of lattice size ....................................... 142  
6.4.2 Varying the Number of Processors .......................... 143  
6.4.3 Different Virtual Time Window Sizes ....................... 147  
6.5 Summary and Discussion ............................................ 149  

II Resource Management .................................................. 151  

7 Dynamic Load Balancing of Execution Threads ...................... 153  
7.1 Introduction ......................................................... 153  
7.2 Background and Design Aspects .................................... 155  
7.2.1 Trends in Hardware ........................................... 156  
7.2.2 Trends in Software ............................................ 157  
7.3 The Polder Metacomputer Experimental Framework ............... 159  
7.3.1 Resource Management in the Polder Metacomputer ........... 160  
7.3.2 The Curse of Dynamics ....................................... 161  
7.4 Dynamite: Process Migration in Message Passing Environments .. 162  
7.4.1 The PVM System .............................................. 164  
7.4.2 Design Aspects of Process Migration in Dynamite ........... 165  
7.5 Implementation Aspects of the Dynamite Environment .......... 166  
7.5.1 The Scheduler ................................................ 166  
7.5.2 Consistent Checkpointing Through Critical Sections ....... 168  
7.5.3 The Migration Protocol ...................................... 169  
7.5.4 Packet Routing and Direct Connections ..................... 171  
7.6 Performance Evaluation ............................................ 172  
7.6.1 Measuring DPVM Communication Overhead ................... 173  
7.6.2 Checkpoint and Migration Overhead .......................... 175  
7.6.3 NAS Parallel Benchmarks .................................... 177  
7.6.4 The GRAIL Finite-Element Model Simulation ............... 180  
7.7 Summary and Discussion ............................................ 184  

8 Summary and Conclusions ............................................. 187  

Bibliography ............................................................... 191
<table>
<thead>
<tr>
<th>Publication</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publications</td>
<td>209</td>
</tr>
<tr>
<td>Dutch Summary/Nederlandse Samenvatting</td>
<td>213</td>
</tr>
<tr>
<td>Nawoord</td>
<td>217</td>
</tr>
<tr>
<td>Index</td>
<td>219</td>
</tr>
</tbody>
</table>