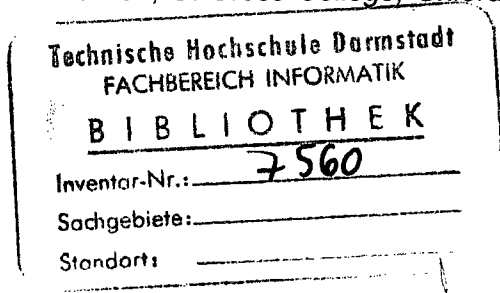


# DISTRIBUTED ALGORITHMS AND PROTOCOLS

Michel Raynal

*Professor of Computer Science  
IRISA (INRIA-CNRS, University of Rennes), France*

*Translated by Jack Howlett, St Cross College, Oxford*



JOHN WILEY & SONS

Chichester · New York · Brisbane · Toronto · Singapore

# CONTENTS

Preface

ix

<b>1</b>	<b>Introduction to distributed algorithms</b>	<b>1</b>
1	<i>Parallelism and distribution</i>	1
2	<i>Networks and distributed systems</i>	2
	2.1 General and local networks	2
	2.2 Characteristics of distributed systems	3
	2.3 What should be distributed, and why?	4
3	<i>Distributed algorithms</i>	5
	3.1 Basic elements: processes, communication paths	5
	3.2 Features of distributed algorithms	8
	3.3 Classifying distributed algorithms	10
4	<i>Some concepts and techniques</i>	10
	4.1 The approach to design	10
	4.2 Concepts and techniques	11
	4.3 Communication + ordering = control	14
	<i>References</i>	15
<b>2</b>	<b>Election and mutual exclusion algorithms</b>	<b>19</b>
1	<i>Introduction</i>	19
2	<i>The mutual exclusion problem</i>	19
3	<i>The Ricart and Agrawala/Suzuki Kasami algorithm</i>	21
	3.1 Overview of other algorithms	21
	3.2 Assumptions	21
	3.3 Principle of the algorithm	22
	3.4 The algorithm	22
	3.5 Proof of the algorithm	24
	3.6 Messages and time-stamping	25
4	<i>An algorithm for regenerating the token</i>	26
	4.1 A token circulating on a logical ring	26
	4.2 Loss of token: Misra's algorithm	26
5	<i>Elective algorithms</i>	29
	5.1 Introduction	29
	5.2 The Chang and Roberts algorithm	30
	5.3 The Hirschberg and Sinclair algorithm	33
	5.4 The algorithm of Dolev, Klawe and Roden	37
	5.5 Other algorithms	40
	<i>References</i>	41

<b>3</b>	<b>Algorithms for detection and resolution of deadlock</b>	<b>43</b>
1	<i>Introduction</i>	43
1.1	The problem of deadlock	43
1.2	Characterization of deadlock situations	44
2	<i>Distribution of a centralized algorithm: Lomet's algorithms</i>	49
2.1	Global and local states	49
2.2	Lomet's first algorithm: replication of the global state	50
2.3	Lomet's second algorithm: use of partial state information	51
3	<i>The Rosenkrantz, Stearns and Lewis algorithm</i>	53
3.1	Principle of the algorithm: use of time-stamping	53
3.2	'Wait-die' method	54
3.3	'Wound-wait' method	55
3.4	Comments on these algorithms	55
4	<i>Algorithms for detecting deadlocks</i>	56
4.1	Proposed methods	56
4.2	Algorithms with centralized control	57
4.3	Algorithms with hierarchical control	57
4.4	Algorithms with distributed control	58
5	<i>Deadlocks due to communications: algorithm of Chandy, Misra and Haas</i>	58
5.1	Resumé: features of the problem	58
5.2	Assumptions and principles underlying the algorithm	59
5.3	The CMH algorithm	59
5.4	Other algorithms	64
	<i>References</i>	64
<b>4</b>	<b>Algorithms for detecting termination</b>	<b>67</b>
1	<i>Introduction: the problem of termination</i>	67
1.1	Distributed termination	67
1.2	Termination and deadlock	68
1.3	Principles underlying the solutions	69
2	<i>Use of diffusing computation: algorithm of Dijkstra and Scholten</i>	69
2.1	Assumptions	69
2.2	Basis of the algorithm	71
2.3	The algorithm	71
2.4	Comments on the algorithm, proof of validity	72
3	<i>Termination on a ring: algorithm of Dijkstra, Feijen and van Gasteren</i>	74
3.1	Assumptions	74
3.2	Principles of the algorithm	74
3.3	Actions at a site	75
3.4	The algorithm	76
3.5	Disadvantages: Topor's algorithm	77
4	<i>Misra's algorithm</i>	78
4.1	Basis and assumptions	78

4.2	The token in Misra's algorithm	79
4.3	The algorithm	79
4.4	Some comments	81
5	<i>Use of time-stamping: Rana's algorithm</i>	81
5.1	Context and assumptions	81
5.2	Principle of the algorithm	82
5.3	The algorithm	84
5.4	Proof of correctness	85
6	<i>A note on some other algorithms</i>	87
	<i>References</i>	87
<b>5</b>	<b>Protocols for data transfer</b>	<b>89</b>
1	<i>Introduction</i>	89
2	<i>Protocols for the implementation of CSP</i>	90
2.1	The CSP language: a short introduction	90
2.2	Silberschatz's protocol	93
2.3	Bernstein's protocol	96
2.4	Other protocols	103
3	<i>Methods for reliable broadcasting of messages</i>	103
3.1	The problem	103
3.2	Context of the problem, assumptions	104
3.3	Principles of protocol	104
3.4	Schneider, Gries and Schlichting's protocol	106
3.5	Comments	109
	<i>References</i>	110
<b>6</b>	<b>Management of distributed data</b>	<b>113</b>
1	<i>Introduction</i>	113
1.1	Nature of the data	113
1.2	Distribution of data	114
1.3	Problems to be discussed	115
2	<i>Consistency of duplicated data</i>	115
2.1	Context of the problem	115
2.2	Detection of mutual inconsistency: algorithm of Parker <i>et al.</i>	116
2.3	Maintaining mutual consistency	122
2.4	Initializing a new site	127
3	<i>Distribution of control algorithms</i>	128
3.1	Introduction	128
3.2	Construction of a total ordering	128
3.3	Distributed atomicity	130
	<i>References</i>	133
<b>7</b>	<b>Problems of gaining consensus in the presence of uncertainties (or how to avoid Byzantine quarrels)</b>	<b>137</b>
1	<i>The problem of consensus</i>	137
1.1	The problem and its formulation	137

	1.2 Features of the solutions	139
2	<i>The Lamport, Shostak and Pease algorithm</i>	141
	2.1 Assumptions	141
	2.2 A criterion for impossibility	142
	2.3 Underlying principles of the solution	143
	2.4 The algorithm	144
	2.5 Proof of correctness	147
	2.6 Complexity of the algorithm	148
	2.7 Other assumptions concerning the network	149
	2.8 Other algorithms	150
3	<i>Solutions using signed messages</i>	151
	3.1 Assumptions, importance of signatures	151
	3.2 The Lamport, Shostak and Pease algorithm	152
	3.3 The Dolev and Strong algorithm	154
	3.4 The Dolev and Reischug algorithms	156
4	<i>Broadcasting in a bus-connected system</i>	157
	4.1 The problem: assumptions	157
	4.2 The Babaoglu and Drummond algorithm	158
5	<i>Conclusion</i>	160
	<i>References</i>	162