

# Distributed Algorithms

An Intuitive Approach

Wan Fokkink

The MIT Press  
Cambridge, Massachusetts  
London, England

---

# Contents

|  |    |
|--|----|
| <b>Preface</b> .....                                       | ix |
| <b>1 Introduction</b> .....                                | 1  |
| <hr/>  |    |
| <b>I Message Passing</b>                                   |    |
| <hr/>  |    |
| <b>2 Preliminaries</b> .....                               | 7  |
| <b>3 Snapshots</b> .....                                   | 13 |
| 3.1 Chandy-Lamport algorithm .....                         | 14 |
| 3.2 Lai-Yang algorithm .....                               | 15 |
| <b>4 Waves</b> .....                                       | 19 |
| 4.1 Traversal algorithms .....                             | 19 |
| 4.2 Tree algorithm .....                                   | 23 |
| 4.3 Echo algorithm .....                                   | 24 |
| <b>5 Deadlock Detection</b> .....                          | 27 |
| 5.1 Wait-for graphs .....                                  | 27 |
| 5.2 Bracha-Toueg algorithm .....                           | 29 |
| <b>6 Termination Detection</b> .....                       | 37 |
| 6.1 Dijkstra-Scholten algorithm .....                      | 38 |
| 6.2 Weight-throwing algorithm .....                        | 39 |
| 6.3 Rana's algorithm .....                                 | 40 |
| 6.4 Safra's algorithm .....                                | 42 |
| <b>7 Garbage Collection</b> .....                          | 47 |
| 7.1 Reference counting .....                               | 47 |
| 7.2 Garbage collection implies termination detection ..... | 50 |
| 7.3 Tracing .....  | 51 |

|           |   |     |
|-----------|---|-----|
| <b>8</b>  | <b>Routing</b>  | 53  |
| 8.1       | Chandy-Misra algorithm                                  | 53  |
| 8.2       | Merlin-Segall algorithm                                 | 55  |
| 8.3       | Toueg's algorithm                                       | 58  |
| 8.4       | Frederickson's algorithm                                | 61  |
| 8.5       | Packet switching  | 65  |
| 8.6       | Routing on the Internet                                 | 67  |
| <b>9</b>  | <b>Election</b>   | 73  |
| 9.1       | Election in rings                                       | 73  |
| 9.2       | Tree election algorithm                                 | 77  |
| 9.3       | Echo algorithm with extinction                          | 79  |
| 9.4       | Minimum spanning trees                                  | 80  |
| <b>10</b> | <b>Anonymous Networks</b>                               | 87  |
| 10.1      | Impossibility of election in anonymous rings            | 87  |
| 10.2      | Probabilistic algorithms                                | 88  |
| 10.3      | Itai-Rodeh election algorithm for rings                 | 89  |
| 10.4      | Echo algorithm with extinction for anonymous networks   | 91  |
| 10.5      | Computing the size of an anonymous ring is impossible   | 93  |
| 10.6      | Itai-Rodeh ring size algorithm                          | 94  |
| 10.7      | Election in IEEE 1394                                   | 96  |
| <b>11</b> | <b>Synchronous Networks</b>                             | 101 |
| 11.1      | A simple synchronizer                                   | 101 |
| 11.2      | Awerbuch's synchronizer                                 | 102 |
| 11.3      | Bounded delay networks with local clocks                | 105 |
| 11.4      | Election in anonymous rings with bounded expected delay | 106 |
| <b>12</b> | <b>Crash Failures</b>                                   | 111 |
| 12.1      | Impossibility of 1-crash consensus                      | 112 |
| 12.2      | Bracha-Toueg crash consensus algorithm                  | 113 |
| 12.3      | Failure detectors                                       | 115 |
| 12.4      | Consensus with a weakly accurate failure detector       | 116 |
| 12.5      | Chandra-Toueg algorithm                                 | 116 |
| <b>13</b> | <b>Byzantine Failures</b>                               | 121 |
| 13.1      | Bracha-Toueg Byzantine consensus algorithm              | 121 |
| 13.2      | Mahaney-Schneider synchronizer                          | 125 |
| 13.3      | Lamport-Shostak-Pease broadcast algorithm               | 127 |
| 13.4      | Lamport-Shostak-Pease authentication algorithm          | 130 |
| <b>14</b> | <b>Mutual Exclusion</b>                                 | 135 |
| 14.1      | Ricart-Agrawala algorithm                               | 135 |
| 14.2      | Raymond's algorithm                                     | 137 |
| 14.3      | Agrawal-El Abbadi algorithm                             | 140 |

---

**II Shared Memory**

---

|   |     |
|---|-----|
| <b>15 Preliminaries</b>                         | 145 |
| <b>16 Mutual Exclusion II</b>                   | 147 |
| 16.1 Peterson's algorithm                       | 147 |
| 16.2 Bakery algorithm                           | 150 |
| 16.3 $N$ registers are required                 | 152 |
| 16.4 Fischer's algorithm                        | 152 |
| 16.5 Test-and-test-and-set lock                 | 153 |
| 16.6 Queue locks                                | 155 |
| <b>17 Barriers</b>                              | 161 |
| 17.1 Sense-reversing barrier                    | 161 |
| 17.2 Combining tree barrier                     | 162 |
| 17.3 Tournament barrier                         | 165 |
| 17.4 Dissemination barrier                      | 168 |
| <b>18 Self-Stabilization</b>                    | 171 |
| 18.1 Dijkstra's token ring for mutual exclusion | 171 |
| 18.2 Arora-Gouda spanning tree algorithm        | 175 |
| 18.3 Afek-Kutten-Yung spanning tree algorithm   | 177 |
| <b>19 Online Scheduling</b>                     | 181 |
| 19.1 Jobs                                       | 181 |
| 19.2 Schedulers                                 | 182 |
| 19.3 Resource access control                    | 188 |
| <b>Pseudocode Descriptions</b>                  | 193 |
| <b>References</b>                               | 221 |
| <b>Index</b>                                    | 225 |