

Distributed Systems

Third edition

Version 3.02 (2018)

(Contains minor corrections in comparison to 3.01)

Maarten van Steen
Andrew S. Tanenbaum

Get a free copy of this book at:

<https://www.distributed-systems.net/index.php/books/ds3/>

CONTENTS

Week 1

Preface	xi
1 Introduction	1
1.1 What is a distributed system?	2
Characteristic 1: Collection of autonomous computing elements	2
Characteristic 2: Single coherent system	4
Middleware and distributed systems	5
1.2 Design goals	7
Supporting resource sharing	7
Making distribution transparent	8
Being open	12
Being scalable	15
Pitfalls	24
1.3 Types of distributed systems	24
High performance distributed computing	25
Distributed information systems	34
Pervasive systems	40
1.4 Summary	52

Week 4

2 Architectures	55
2.1 Architectural styles	56
Layered architectures	57
Object-based and service-oriented architectures	62
Resource-based architectures	64
Publish-subscribe architectures	66
2.2 Middleware organization	71
Wrappers	72
Interceptors	73
Modifiable middleware	75
2.3 System architecture	76

	Centralized organizations	76
	Decentralized organizations: peer-to-peer systems	80
	Hybrid Architectures	90
2.4	Example architectures	94
	The Network File System	94
	The Web	98
2.5	Summary	101
3	Processes	103
3.1	Threads	104
	Introduction to threads	104
	Threads in distributed systems	111
3.2	Virtualization	116
	Principle of virtualization	116
	Application of virtual machines to distributed systems	122
3.3	Clients	124
	Networked user interfaces	124
	Client-side software for distribution transparency	127
3.4	Servers	128
	General design issues	129
	Object servers	133
	Example: The Apache Web server	139
	Server clusters	141
3.5	Code migration	152
	Reasons for migrating code	152
	Migration in heterogeneous systems	158
3.6	Summary	161
4	Communication	163
4.1	Foundations	164
	Layered Protocols	164
	Types of Communication	172
4.2	Remote procedure call	173
	Basic RPC operation	174
	Parameter passing	178
	RPC-based application support	182
	Variations on RPC	185
	Example: DCE RPC	188
4.3	Message-oriented communication	193
	Simple transient messaging with sockets	193
	Advanced transient messaging	198
	Message-oriented persistent communication	206
	Example: IBM's WebSphere message-queuing system	212
	Example: Advanced Message Queuing Protocol (AMQP)	218

4.4	Multicast communication	221
Application-level tree-based multicasting	222	
Flooding-based multicasting	226	
Gossip-based data dissemination	229	
4.5	Summary	234
5	Naming	237
5.1	Names, identifiers, and addresses	238
5.2	Flat naming	241
Simple solutions	241	
Home-based approaches	245	
Distributed hash tables	246	
Hierarchical approaches	251	
5.3	Structured naming	256
Name spaces	256	
Name resolution	259	
The implementation of a name space	264	
Example: The Domain Name System	271	
Example: The Network File System	278	
5.4	Attribute-based naming	283
Directory services	283	
Hierarchical implementations: LDAP	285	
Decentralized implementations	288	
5.5	Summary	294
6	Coordination	297
6.1	Clock synchronization	298
Physical clocks	299	
Clock synchronization algorithms	302	
6.2	Logical clocks	310
Lamport's logical clocks	310	
Vector clocks	316	
6.3	Mutual exclusion	321
Overview	322	
A centralized algorithm	322	
A distributed algorithm	323	
A token-ring algorithm	325	
A decentralized algorithm	326	
6.4	Election algorithms	329
The bully algorithm	330	
A ring algorithm	332	
Elections in wireless environments	333	
Elections in large-scale systems	335	
6.5	Location systems	336

Weeks 7-8

GPS: Global Positioning System	337
When GPS is not an option	339
Logical positioning of nodes	339
6.6 Distributed event matching	343
Centralized implementations	343
6.7 Gossip-based coordination	349
Aggregation	349
A peer-sampling service	350
Gossip-based overlay construction	352
6.8 Summary	353
7 Consistency and replication	355
7.1 Introduction	356
Reasons for replication	356
Replication as scaling technique	357
7.2 Data-centric consistency models	358
Continuous consistency	359
Consistent ordering of operations	364
Eventual consistency	373
7.3 Client-centric consistency models	375
Monotonic reads	377
Monotonic writes	379
Read your writes	380
Writes follow reads	382
7.4 Replica management	383
Finding the best server location	383
Content replication and placement	385
Content distribution	388
Managing replicated objects	393
7.5 Consistency protocols	396
Continuous consistency	396
Primary-based protocols	398
Replicated-write protocols	401
Cache-coherence protocols	403
Implementing client-centric consistency	407
7.6 Example: Caching and replication in the Web	409
7.7 Summary	420
8 Fault tolerance	423
8.1 Introduction to fault tolerance	424
Basic concepts	424
Failure models	427
Failure masking by redundancy	431
8.2 Process resilience	432

Week 10

Resilience by process groups	433
Failure masking and replication	435
Consensus in faulty systems with crash failures	436
Example: Paxos	438
Consensus in faulty systems with arbitrary failures	449
Some limitations on realizing fault tolerance	459
Failure detection	462
8.3 Reliable client-server communication	464
Point-to-point communication	464
RPC semantics in the presence of failures	464
8.4 Reliable group communication	470
Atomic multicast	477
8.5 Distributed commit	483
8.6 Recovery	491
Introduction	491
Checkpointing	493
Message logging	496
Recovery-oriented computing	498
8.7 Summary	499
9 Security	501
9.1 Introduction to security	502
Security threats, policies, and mechanisms	502
Design issues	504
Cryptography	509
9.2 Secure channels	512
Authentication	513
Message integrity and confidentiality	520
Secure group communication	523
Example: Kerberos	526
9.3 Access control	529
General issues in access control	529
Firewalls	533
Secure mobile code	535
Denial of service	539
9.4 Secure naming	540
9.5 Security management	541
Key management	542
Secure group management	545
Authorization management	547
9.6 Summary	552
Bibliography	555