

Calculation of this
edition outside the
Indian subcontinent is
UNAUTHORIZED

NINTH EDITION

COMPUTER ORGANIZATION AND ARCHITECTURE

DESIGNING FOR PERFORMANCE

WILLIAM STALLINGS

ALWAYS LEARNING

PEARSON



COMPUTER ORGANIZATION AND ARCHITECTURE DESIGNING FOR PERFORMANCE NINTH EDITION

Authorized adaptation from the United States edition, entitled *Computer Organization and Architecture: Designing for Performance, Ninth Edition*, ISBN 9780132936330, by William Stallings, published by Pearson Education Inc. © 2013, Pearson Education Inc.

Indian Subcontinent Version
© 2014 Dorling Kindersley (India) Pvt. Ltd

All rights reserved. This book is sold subject to the condition that it shall not, by way of trade or otherwise, be lent, resold, hired out, or otherwise circulated without the publisher's prior written consent in any form of binding or cover other than that in which it is published and without a similar condition including this condition being imposed on the subsequent purchaser and without limiting the rights under copyright reserved above, no part of this publication may be reproduced, stored in or introduced into a retrieval system, or transmitted in any form or by any means (electronic, mechanical, photocopying, recording or otherwise), without the prior written permission of both the copyright owner and the above-mentioned publisher of this book.

ISBN: 978-93-325-1870-4

First Impression

This edition is authorized for sale only in India, Bangladesh, Bhutan, Pakistan, Nepal, Sri Lanka and the Maldives. Circulation of this edition outside of these territories is UNAUTHORIZED.

Published by Dorling Kindersley (India) Pvt. Ltd., licensees of Pearson Education in South Asia.

Head Office: 7th Floor, Knowledge Boulevard, A-8(A), Sector 62, Noida 201 309, UP, India.
Registered Office: 11 Community Centre, Panchsheel Park, New Delhi 110 017, India.

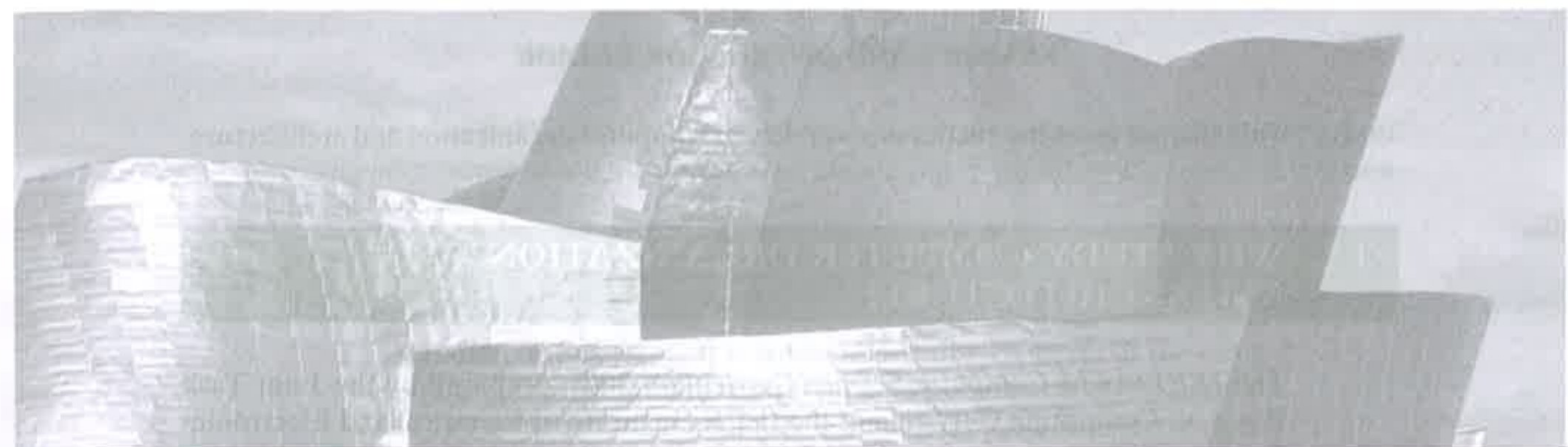
Printer: HT Media Ltd., Noida

Table of Contents

1. Reader's and Instructor's Guide	1
2. Introduction	5
3. Computer Evolution and Performance	15
4. A Top-Level View of Computer Function and Interconnection	65
5. Cache Memory	113
6. Internal Memory	161
7. External Memory	187
8. Input/Output	223
9. Operating System Support	267
10. Number Systems	311
11. Computer Arithmetic	321
12. Digital Logic	367
13. Instruction Sets: Characteristics and Functions	409



Instruction Sets: Addressing Modes and Formats	455
Processor Structure and Function	487
Instruction-Level Parallelism and Superscalar Processors	535
Parallel Processing	573
Multicore Computers	627
References	655
Index	667



READER'S AND INSTRUCTOR'S GUIDE

- 1 Why Study Computer Organization and Architecture?
- 2 Internet and Web Resources
Computer Science Student Resource Site

From Chapter 0 of *Computer Organization and Architecture: Designing for Performance*, Ninth Edition, William Stallings. Copyright © 2013 by Pearson Education, Inc. Published by Prentice Hall. All rights reserved.

WANG99 Wang, G., and Tafti, D. "Performance Enhancement on Microprocessors with Hierarchical Memory Systems for Solving Large Sparse Linear Systems." *International Journal of Supercomputing Applications*, Vol. 13, 1999.

WEIC90 Weicker, R. "An Overview of Common Benchmarks." *Computer*, December 1990.

WEIN75 Weinberg, G. *An Introduction to General Systems Thinking*. New York: Wiley, 1975.

WEIS84 Weiss, S., and Smith, J. "Instruction Issue Logic in Pipelined Supercomputers." *IEEE Transactions on Computers*, November 1984.

WEYG01 Weygant, P. *Clusters for High Availability*. Upper Saddle River, NJ: Prentice Hall, 2001.

WHIT97 Whitney, S., et al. "The SGI Origin Software Environment and Application Performance." *Proceedings, COMPCON Spring '97*, February 1997.

WHIT11 White, B., et al. *IBM zEnterprise 196 Technical Guide*. IBM Redbook SG24-5946-07, June 2011.

WILE03 Wilen, A.; Schade, J.; and Thronburg, R. *Introduction to PCI Express—A Hardware and Software Developers Guide*. Hillsboro, OR: Intel Press, 2003.

WILK65 Wilkes, M. "Slave Memories and Dynamic Storage Allocation." *IEEE Transactions on Electronic Computers*, April 1965. Reprinted in [HILL00].

WILL90 Williams, F., and Steven, G. "Address and Data Register Separation on the M68000 Family." *Computer Architecture News*, June 1990.

YEH91 Yeh, T., and Patt, N. "Two-Level Adapting Training Branch Prediction." *Proceedings, 24th Annual International Symposium on Microarchitecture*, 1991.

ZHAN01 Zhang, Z.; Zhu, Z.; and Zhang, X. "Cached DRAM for ILP Processor Memory Access Latency Reduction." *IEEE Micro*, July–August 2001.

INDEX

Page references followed by "f" indicate illustrated figures or photographs; followed by "t" indicates a table.

- !, 4, 44, 46, 52, 449–450, 452, 508, 568–569, 651, 658–660
- !!, 449–450, 452
- }, 371, 449–450, 452, 652
- !, 466–467
- &, 207, 405, 552, 558, 601, 635, 651, 662, 665
- <, 64, 316
- >, 22, 343, 414, 446–447, 568, 622–623
- +, 17, 22–23, 34, 51–52, 54, 56–57, 64, 117, 120, 129–131, 134–136, 152–153, 156–157, 172–175, 196, 208, 221, 236, 258, 308, 312–316, 324–326, 328–330, 335–340, 343, 349, 351–352, 358–359, 363–365, 370–378, 382–384, 390, 392, 413–414, 433, 440, 449–450, 458, 460–462, 481–482, 485, 505, 533, 546–547, 568–569, 609–612, 616, 622–624, 633, 652–653
- 1
- 1984, 429, 659, 661–663, 666
- 3
- 3D graphics, 43, 45, 440
- A
- Abort, 275, 302, 421, 526, 528–529
- abs, 565
- Absolute, 426
- Abstraction, 2
- Access, 116–117, 270, 421
- access, 4, 22, 25, 27, 35, 38–41, 56, 64, 83, 85–86, 88, 90, 94, 104, 109, 116–120, 122, 124, 127, 129–130, 132, 139, 141–144, 146, 149, 151–154, 156–159, 162–163, 177, 179–180, 182–185, 188, 195–199, 203–205, 208–209, 214, 218–221, 223–224, 229, 231–233, 252–253, 255–256, 267, 269–271, 293–298, 302–306, 309, 420–422, 443, 460–465, 468, 479, 485, 504, 509, 515, 573–579, 597–599, 605, 616, 619–622, 624, 642
- methods, 90, 224, 242, 511
- Setup, 177, 273
- Access control, 90, 267, 297–298, 302, 305–306
- database, 297
- operating systems, 267, 297, 306
- UNIX, 297
- Access time, 35, 56, 64, 116–120, 122, 127, 132, 142, 149, 151–153, 157, 159, 177, 184–185, 195–196, 204, 209, 214, 220–221, 293, 460, 575, 577, 621–622
- access times, 41, 118, 297, 602
- Accounting information, 281
- accumulator, 20, 23, 36, 60–61, 70–72, 233, 415, 445, 447, 470–472, 484, 486, 494–495, 499
- Accumulator (AC), 60, 70–71, 415
- accumulators, 17
- accuracy, 316, 358, 511, 640
- ACM, 2, 59–60, 148, 220, 361, 619, 655–665
- Action, 70, 73, 78, 211, 234, 310, 425, 436, 488, 583–584, 612
- Actual Size, 172
- actuators, 47, 198, 226
- ADA, 17, 410, 437
- adapters, 98, 202, 255–256, 649
- configuration, 98
- ADD instruction, 72, 481, 508, 568, 616
- add operation, 335
- Adders, 368, 388, 390–392, 407
- adding, 66, 72, 102, 143, 289, 330, 335, 339, 383, 390, 449, 482, 578, 602, 630
- Addition, 18, 35, 38, 40, 43–45, 47, 51, 85–86, 94, 106, 140, 166, 179, 195, 210–211, 224, 227, 240, 242, 261, 274, 278, 282, 295, 297, 309, 321, 330–335, 338–340, 347, 351–352, 354, 360, 362–363, 380, 388, 419, 426–427, 433, 438–440, 443, 446–447, 454, 464, 471, 489, 493, 499, 509, 518–519, 531, 534, 607–608, 616, 622, 625, 634–635
- Addition:, 352
- floating-point numbers, 351
- twos complement integers, 332, 335, 447
- address, 16, 19–20, 22–23, 33, 61, 68–73, 77–78, 81, 83–87, 89–93, 103–104, 106–109, 116–117, 121–127, 129–136, 140, 145, 147–151, 153, 164–171, 179–181, 184–186, 190, 192, 198, 209, 225, 229–234, 236, 238, 240, 242–243, 245–246, 248, 257, 266, 267, 281, 292–310, 386–388, 411–412, 414–417, 419–425, 429–431, 445–447, 450–454, 456–473, 475–479, 481–486, 489–494, 496–501, 509–514, 516–517, 519–523, 529–530, 532–534, 551–552, 560–563, 571, 579, 581, 603, 606
- Address field, 23, 107, 431, 456, 458–462, 464, 472–473, 484
- Address fields, 126, 150, 460, 470, 521
- Address lines, 86–87, 91–93, 108, 123, 140, 167, 170–171, 184, 225, 230, 238, 240, 243, 386, 388, 520
- Address registers, 109, 490, 494
- Address space, 103–104, 109, 127, 186, 233–234, 295–297, 300, 305, 309, 386, 458–460, 588
- Addresses, 21–22, 49, 62, 68, 103, 107, 114, 125–127, 130, 149–152, 177, 207, 229, 233, 256, 263, 288–290, 298, 301–305, 308–309, 357, 386, 409, 414–417, 432, 459–462, 464, 467, 470, 482, 491, 494, 515, 530, 532, 623
- accumulator (AC), 415
- base, 289–290, 298, 303–305, 461, 464, 467, 472, 475, 478, 491, 494, 515, 562
- cache memory, 114, 125–127, 130, 147, 149–152
- fields, 107, 126, 149–150, 298, 416, 456, 460, 470, 478, 482
- IP, 552, 555
- logical, 68, 125–127, 147, 149, 256, 289–290, 309, 409, 417, 419, 464
- machine instructions, 126, 233, 417, 456, 491, 552
- main memory, 21, 62, 68, 103, 126–127, 130, 147, 149–152, 177, 233, 263, 288–290, 298, 301–303, 308–309, 432, 456, 459–461, 496, 623
- map, 103, 130
- memory, 21–22, 49, 62, 68, 103, 107, 114, 125–127, 130, 149–152, 177, 207, 229, 233, 256, 263, 288–290, 298, 301–305, 308–309, 386, 415–417, 432, 459–462, 464, 467, 470, 482, 491, 494, 515, 530, 532, 623
- network, 256
- number of, 114, 125, 127, 150–151, 177, 229, 256, 263, 298, 305, 308–309, 357, 386, 409, 414–416, 459–462, 470, 475, 491, 562, 623
- partitioning, 288, 290, 308
- physical, 126–127, 147, 149, 256, 289–290, 301–303, 305, 308–309, 552
- real, 49, 298, 309, 459–460
- relative, 62, 289–290, 461, 464, 515, 532, 555
- spaces, 103, 309, 482
- virtual, 125–127, 147, 149, 152, 256, 298, 301–305, 308–309, 417, 456, 459, 562
- Addressing, 3, 22, 36, 44, 103, 116–117, 127, 167, 210, 233, 256–257, 263, 300, 424, 444, 452, 454, 455–486, 496, 498, 515, 524, 579–580, 635
- blocks, 116–117, 127, 263, 462, 579
- broadcast, 256
- Host, 210, 256–257, 470
- indirect, 3, 263, 455–460, 462, 465, 471–472, 476, 483–485, 490, 496, 498, 524
- interface, 210, 233, 256, 515, 580
- level, 103, 116, 163, 210, 257, 300, 416, 459, 463, 476, 483, 520–521, 524
- memory management, 300, 458
- mode, 263, 416, 424, 454, 457–458, 460, 462–465, 468, 472–473, 475–476, 478–479, 484–486, 491, 515, 520
- multicast, 256
- Port, 257, 263, 424
- prefix, 476–478
- private, 579

9, 209, 260, 273, 408, 621, 650
return, 227
s, 217
238, 248
51, 58-60, 67, 76, 79-80, 83, 93, 104,
121, 123-124, 127, 132, 134, 138, 140,
-144, 150, 153, 159, 167, 171, 191,
-206, 222, 236, 238, 243, 256, 263-264,
-272, 278-279, 283, 290, 295-296, 305,
338-339, 351, 354-355, 357-358,
-393, 417-420, 432-433, 452, 461-462,
-466, 505-507, 513, 532, 534, 561-563,
-587, 590-592, 595, 597, 621, 658-659,
-663
93, 104, 204, 270, 272, 283, 351, 354,
511
lies, 59
-29, 46, 51, 162-165, 167, 172, 179, 185,
-209
ne, 209
-29, 162-163, 165-167, 171-172, 211,
1, 162-163, 165
rocessing unit, 3, 14, 18, 25, 66
rocessing unit (CPU), 14, 18, 25
etic and logic unit (ALU), 14
l unit, 14, 18
mming languages, 25
ms, 25
rs, 14
re, 25
25
g, 252, 254, 293, 610, 616
7, 24, 33, 39-40, 45, 50, 56, 91, 93, 119,
-152, 191, 280, 289, 328, 344, 352-353,
407, 423, 429, 482, 512, 521, 524, 526,
s, 26-27, 32, 96, 195, 206, 223-224, 230,
248-249, 252, 256, 258-261, 265, 577,
588
223, 246, 248-249, 265, 579
256
4
r data, 469
strings, 418, 454
rs, 7, 74, 227, 249, 263-265, 408, 409,
-418, 428-429, 446, 469, 638
n, 264
f, 74
1, 7, 74, 227, 249, 429
g, 446, 469
7, 81, 97, 106, 122, 173-176, 186, 206,
231-233, 263, 352, 382-383, 424, 436,
518-519, 521, 523, 552, 558, 565, 647
ts, 173-176, 186
n, 362
ultiprocessing, 590, 593
ower5, 593
reading and, 590
643
9, 127, 139, 204, 343, 376, 379, 424,
473, 616, 651
391
65, 173
ements, 404
vel, 61, 374
139, 188, 556
uffer, 139, 556

class, 8, 106, 229, 423, 523, 574
block, 229, 423
classes, 74, 349, 370, 522-523, 534, 635
diagram, 534
language, 635
top level, 534
Client, 38, 54, 257, 595, 597
clients, 56, 306
Clock, 2-3, 15, 36-37, 41-43, 45, 50-52, 60,
62-63, 87, 90-91, 93, 96, 100, 102-103,
109-111, 153, 177, 179-182, 263-266, 282,
393, 395-400, 405, 531-532, 538-540, 556,
568, 588-590, 592, 614, 621-625, 629,
631-632, 641-642, 649-650
Clock frequency, 109, 177, 588, 629, 632
clock speed, 2, 15, 41-42, 45, 50, 60, 62, 538, 650
Clocking, 111, 153, 180, 185, 264-265
clocks, 100, 102, 508, 568
Cluster, 119, 121, 154, 573-575, 577, 595-599,
601-603, 619, 623-624
Clusters, 119, 121, 154, 573-577, 595-598,
601-602, 618-619, 660-661, 666
blade servers, 573, 601
computer architecture, 154, 573, 660-661, 663,
666
configurations, 573, 595-596
design requirements, 595
failure management, 598
load balancing, 598
OS design, 619
parallelizing computation, 598
passive standby, 597, 619
COBOL, 437
code, 3, 19, 38, 51, 54, 56, 61, 63, 68, 74, 76-79,
97, 162, 172-173, 175-176, 183-184, 186,
192, 200, 204, 209, 214, 222, 229, 257, 274,
283, 300, 385, 406-408, 429-433, 438,
444-445, 448-449, 475, 478-481, 491-492,
494-495, 524, 527, 531, 541-543, 563-564,
566, 581-583, 620, 622-624, 652-653,
656-657
described, 176, 229, 546
editing, 429
error-correcting, 172-173, 176, 183, 204, 214
error-detecting, 176, 183, 229
rate, 3, 19, 51, 54, 56, 61, 184, 186, 222, 229,
531, 620
Coding, 55, 182, 655
color, 440, 442
columns, 27, 167, 171, 174, 308, 370, 378, 383,
399
Command, 74-76, 86, 91-93, 111, 178-179, 195,
211, 228, 230-234, 238, 242, 246, 248, 262,
278, 424-425, 429, 472, 583
command line, 233, 238
input and output, 233
Commands, 76, 83, 223, 228-234, 236, 259, 264,
279, 583, 647
key, 223, 264, 279
programmed I/O, 223, 230-234
TYPE, 231, 236
comment, 62, 194, 233, 365, 414, 439, 444, 449,
458, 539
comments, 458, 501, 550
Commercial computers, 23
Commit, 545, 550, 567, 595
Communication devices, 226
Community, 59

Commutative law, 406
Compact disk (CD), 212
Comparison, 51, 53-54, 59, 117, 155, 172-173,
177, 182, 196, 206, 208-209, 219, 336,
344-345, 361, 423, 431, 448, 495, 538, 552,
614, 618, 665
comparison of, 51, 54, 59, 117, 177, 182, 209, 219,
336, 361, 423, 538
Compiler, 49, 51-52, 138, 272, 274, 435, 437,
448-449, 465, 473, 476, 478-479, 537, 541,
547, 549, 582-583, 589, 592, 613
complex systems, 8, 268
components, 2, 7-9, 12, 14, 28-29, 33, 35, 39-41,
61, 65-69, 84-86, 89, 93, 98, 100, 118, 142,
144, 186, 193, 195, 197, 210-211, 260-261,
404, 489, 599, 648
components, 12, 144, 195, 210-211
Compression, 55
video, 55
Computer, 1-4, 5, 7-14, 15-64, 65-111, 118, 121,
125, 148, 151-152, 154-155, 161-162, 176,
183-184, 194, 197, 201, 207, 212, 223-227,
229, 248-249, 251-254, 265, 267-275,
277-279, 284, 307-309, 321-365, 369, 405,
409-411, 413, 416-417, 430, 432, 450, 458,
471, 481, 483, 530-531, 566, 595-599, 606,
619-620, 623-624, 638, 651, 655-666
Computer languages, 2
Computer performance, 16, 53, 60, 197
benchmark programs, 53
embedded systems, 16
Computer software, 3, 271
computer systems, 37, 46, 85, 115, 188, 248, 499,
660, 665
external memory, 115, 188
instruction execution, 499
internal memory, 115
interrupts, 248
processors, 37, 248, 575, 660, 665
system bus, 87
Computer-aided design (CAD), 155
Computers, 7-8, 10, 15-17, 19, 23-25, 27-28,
31-33, 35, 38, 40, 44, 48, 54, 58-59, 63,
74, 148, 162-163, 176, 183, 215, 278, 317,
319, 324, 333, 360-361, 369, 386, 405, 408,
430, 566, 595-599, 624, 627-653, 655-663,
665-666
Computers, 417
data storage, 10, 220
function, 8, 10, 16, 19, 28, 48, 58, 74, 148, 183,
369, 386, 430, 530-531, 579, 598-599, 652
integrated circuits, 15, 28, 31
microprocessors, 16, 35, 38, 44, 48, 59, 530,
566, 577, 655-658, 662, 665-666
parts, 10, 19, 63, 598
performance, 7, 10, 15-17, 19, 23-25, 27-28,
31-33, 35, 38, 40, 44, 48, 54, 58-59, 63, 148,
176, 209, 361, 566, 574, 595-598, 627-634,
636-640, 652-653, 655-663, 665-666
vacuum tubes, 15-17
Computing systems, 659
Concatenation, 370
Concurrency, 619, 638, 660, 662
Condition, 22, 74, 119, 172, 270, 272, 279, 291,
351-352, 363, 380-381, 395, 423-424,
430-431, 436-439, 443-444, 446, 448, 450,
477, 479-481, 490-493, 510, 515-518, 522,
527, 531, 533, 562, 567, 624

Condition codes, 424, 437-439, 443-444, 448, 479,
490-493, 515-518, 531, 562
registers for, 490, 493
conditional, 22-23, 423, 430-431, 436, 438-439,
443-448, 477, 491-492, 500, 502, 504, 511-
513, 515, 525, 531-532, 534, 536, 549-550,
555, 570-571
Conditional execution, 444, 525
Conditional jump, 436, 438-439, 448
Conditions, 47, 58, 74, 119, 152, 231, 249, 284,
351-352, 359, 378, 380, 436, 444, 462, 506,
517, 529, 533, 583, 641
Configuration, 27, 67, 94, 98-99, 104-105, 169,
180, 186, 203, 243, 245, 252-253, 256,
258-259, 261, 310, 388, 548, 587, 597-599,
601, 603, 620-621, 637
Configuration, 104
Connection, 169, 251-252, 261-262, 280,
401-402, 489, 577, 595
connections, 30, 89-90, 93-94, 255, 260-262,
401-402, 404, 492, 601, 649-650
connectors, 224, 252
USB, 252
console, 35, 272
Constant, 38-39, 50-51, 102, 110, 117, 163,
190-191, 194, 213, 220, 360, 363, 399, 475
Constant linear velocity (CLV), 220
Constants, 364, 423, 458, 480
content, 4, 17, 44, 166, 360, 374, 388, 445, 587,
650, 652
Contention, 64, 90, 143-144, 270, 277, 509
Context data, 281, 283
Context switch, 127, 518, 589
Continuous-field simulation, 606
Contract, 48
contrast, 17, 33, 103, 164, 188, 198, 219, 276, 425,
437, 472, 478, 526, 542, 606
control, 7, 9-14, 17-23, 25, 27-29, 33, 46, 60-62,
66-68, 70, 76-78, 80, 82-87, 89-90, 92-93,
95-98, 100, 104, 107-108, 110, 122-125,
132, 135, 146, 156, 162-163, 177-180, 182,
191-192, 195, 224-231, 233-243, 245-246,
249-251, 259-260, 263-265, 267, 269-271,
273-275, 278-279, 281-284, 293, 297-298,
302-303, 305-307, 338, 349, 362, 397, 399,
413, 418, 421-424, 429-431, 436, 445, 462,
480, 487-496, 525-526, 528-529, 534, 551,
553-554, 558, 574-579, 587-589, 611, 613,
624, 629-630, 640-641
Control, 29, 70, 231, 413, 517
control
branch instructions, 413, 430-431, 495, 525, 554
conditional execution, 525
I/O modules, 90, 224, 226, 229, 233, 236-238,
245, 249
Label, 388, 399
microinstructions, 13
skip instructions, 431
Timer, 264, 275, 423, 643-644
transfer of, 77, 82, 228, 242-243, 249, 256, 264,
409, 421-424, 430, 445
word, 19-20, 25, 61, 70, 84, 86, 115, 122-124,
135, 179, 224, 229, 231, 234-235, 238-239,
243, 250-251, 265, 362, 413, 418, 421-424,
436, 448, 492-493, 517-518
Control and status registers, 263, 487, 492
Control bits, 122-123, 265, 293, 302-303, 306,
517-518, 520, 644

Control lines, 86, 108, 124, 225, 229-230,
241-242, 263
Control registers, 146, 230, 519, 645
Control signals, 7, 21, 29, 66-68, 84-86, 92-93,
104, 180, 226, 241, 333, 515, 561, 574
Control statements, 624
Control system, 429
Control unit (CU), 489
controllers, 87, 89, 98, 115, 140, 230, 249, 254,
261-263, 583, 641-642
conversion, 47, 50, 315-316, 327, 408, 409, 418,
422, 424, 429, 452
converting, 68, 227, 311-312, 316-317, 320, 429,
450
Copyright, 1
law, 15
Core, 2, 35, 37, 43, 45, 58, 61, 64, 94, 97, 99, 106-
107, 128, 144, 146-147, 258, 526, 628-629,
633, 638-642, 646, 649-652, 659-660, 662
Cortex-A8 processor, 560
costs, 209, 650
counters, 97, 368, 398-399, 407, 417, 521, 560,
593
CPU, 2-3, 12-14, 18, 25-27, 32-33, 35-36, 43,
45, 61, 63, 66, 68-69, 71, 84, 86, 122, 124,
245-246, 248-250, 255-256, 262, 264, 275,
294, 397-398, 489, 498-499, 503, 613, 631,
639, 641-647, 663-664
Creating, 154, 176, 258, 269, 380
Crystal, 50
CSS, 258-259
current, 7, 31, 33, 40, 44, 76-78, 96, 110, 116,
121, 127, 164-165, 189-190, 208, 215, 229,
234-235, 289-290, 306, 392-394, 399, 401,
435, 450, 491, 494-495, 509, 517, 522, 524,
527-528, 530, 533, 542, 545, 555, 597, 650
Customer, 8, 24, 31, 62, 64, 166, 215, 258,
260-261, 635
customers, 31, 64
cycle, 20-22, 25-27, 32, 50-51, 60-62, 66,
69-70, 72-74, 76-78, 80, 86, 91-92, 105,
108-111, 116-117, 180-181, 184, 232, 234,
236, 242-244, 262, 264-265, 334-335, 341,
411, 439, 458, 462, 469, 487-488, 495-496,
504-508, 515, 521, 531-532, 541, 543-545,
556-557, 560-564, 568-569, 588-593, 614,
616, 623-624, 631, 649-650, 652-653
Cycle stealing, 242, 262, 264
Cyclic redundancy check (CRC), 97
cylinders, 193, 221

D

Data, 7, 9-10, 12, 19-21, 23-25, 27-29, 31-36,
38-40, 43-45, 51, 56, 58, 60-63, 65-70,
72-74, 76, 78, 80-81, 83-87, 89-98, 100,
102-111, 116-128, 130-133, 136-137, 140-
144, 146-149, 153, 155-156, 159, 163-167,
169, 172-177, 179-182, 194-195, 197-200,
202-218, 220-222, 224-234, 238-243,
245-246, 248-253, 255-259, 262-266,
269-271, 281, 283, 288, 291, 293, 300-301,
306-307, 309, 317, 322-323, 332-333, 385,
395, 397, 409-413, 416-426, 428-430,
438-441, 443-444, 447, 449-450, 452-454,
458, 464, 469-470, 472, 478-482, 487-500,
504-508, 515-518, 524-526, 528-529,
531-533, 539-544, 548-549, 556-563, 567,
569, 582-584, 586-590, 604-609, 611-613,
617-618, 620-623, 635-638, 647, 652-653,
656, 660, 665-666
Double, 106, 109, 142, 174, 176, 180-181, 192,
203-204, 212, 218, 419-421, 435, 439, 449,
452, 491
Integer, 62, 116, 317, 319, 322-323, 419-421,
426, 428, 435, 440-441, 443, 454, 478, 517-
518, 526, 551, 556-563, 617, 649, 652-653
integrity, 587
organization and formatting, 187, 189
Single, 7, 12, 28-29, 33, 35-36, 43, 45, 56, 58,
60, 69-70, 72-73, 80, 84-85, 87, 90-91, 118,
122-123, 153, 164, 166-167, 173-174, 184,
186, 195, 197-198, 200, 202-204, 221-222,
233, 240, 252, 255-256, 259, 262, 301, 413,
418-421, 499, 516-517, 524, 549, 551, 559,
575-579, 589-590, 597-598, 608-609, 611,
620, 623, 629-630, 635-638
Data communications, 10, 656
trends, 656
Data disk, 204-205
Data fields, 192, 440
Data files, 121
data link layer, 65, 100, 105, 107
data mining, 635
Data output, 29, 264, 563
Data packet, 98
Data processing, 9-10, 12, 31, 413, 417-418,
443-444, 466, 479-481, 524, 526, 562, 606
Data registers, 229-230, 233, 248, 263, 490-491,
494-495
data sets, 575
data storage, 9-10, 118, 164, 212, 220, 222, 271
Data structures, 155, 296, 417, 419, 422, 449, 452,
560
data structures and, 419
Data transfer, 23, 62, 85, 87, 89-90, 100, 109-111,
179, 181-182, 184, 198, 202-203, 224, 226,
242, 248-249, 252-253, 259, 264-266, 409,
422-426, 438, 441, 447, 464, 489, 529, 583
user, 198, 202, 205, 252, 464, 529
Data transmission, 252
data type, 440, 472
Data types, 7, 409-410, 417, 419-421, 439-440,
452, 491, 521
Database, 31, 38, 56, 197, 207, 214, 297, 635
database design, 197
Database schemes, 197
Databases, 144, 597, 638
Date, 148, 219, 583, 585
Dates, 25
DDR2, 182
DDR3, 182, 642
Deadlock, 581, 620
mutual exclusion and, 581
debugging, 3, 518, 520, 523, 632
decimal, 17, 62, 308, 311-320, 326-327, 337, 343,
345, 347, 349, 352, 362-365, 380-382, 406,
417-420, 424, 426, 429, 438, 445-447, 454,
466, 476, 484-485
Decimal numbers, 314, 320, 343, 362, 417-418,
426, 446, 476, 485
Decimal system, 17, 312-315, 365
Decomposition, 500-501
default, 299, 357, 420, 450, 464, 477-478, 552,
599, 643
Default values, 643

8, 33, 325, 388, 526
11, 87, 177, 179, 195-197, 220-221,
391-393, 395, 398-399, 407, 504-505,
516, 532, 540-542, 549, 561-562, 564,
590, 592, 650
ion, 41, 87, 372, 398
195
184-185, 195, 374, 395, 401, 505, 532,
23, 650
82
aging, 291-292, 306-307
t, 262, 601, 658
order, 523
-8, 10, 16-17, 38, 40-45, 48, 51, 56-57,
65-66, 84, 89-90, 125-126, 141-143,
150-153, 155, 159, 167, 183, 186, 197-198,
207, 255-256, 262, 297, 322, 360-361,
401, 405-407, 409, 414-416, 438, 444-445,
471-473, 483, 486, 491, 495-496, 504, 507,
511, 565-567, 580-582, 618-619, 639, 645,
652, 658, 660-665
s, 37, 46-47, 50, 181, 194, 252, 566, 660
nt, 159
nt, 24, 37, 43-44, 48, 53, 56, 197, 212,
91, 347, 361, 432, 483, 549, 575, 603,
655, 657-658, 660-661, 663-664
ver, 104
vers, 104, 273
0, 16, 27-29, 40, 46, 48-49, 59, 68, 74,
87, 89, 91, 93-95, 97-100, 103-104, 110,
108, 204, 208, 210-212, 223-226, 228-230,
233, 240-241, 248-249, 251-252, 254-257,
261, 263-264, 266, 271, 368-369, 397,
402, 577-578, 606
s, 276
276, 324
equations, 155, 606
25, 28-29, 32, 37, 46, 49-50, 59, 164,
196, 208-209, 212-213, 215, 217-218,
222, 252, 271, 317, 319, 360, 367-408,
440, 658-659, 662
ata, 319, 369
y, 16, 25, 28, 183, 212, 252, 439, 659, 662
o, 212
era, 271
ge, 439
c, 322, 367-408, 665
atile disk (DVD), 215
51, 272, 465, 590
ss, 117, 149, 154, 248, 273
ping, 115, 128-132, 134, 138-139, 149
nory access (DMA), 83, 231, 242, 262
aling, 242, 262
emory access (DMA), 83, 231, 242, 262
42, 96, 100, 155, 180, 189, 192-193,
26, 229, 252, 264, 469, 478, 485, 513,
93, 649
298, 599
92, 298-301, 519-520, 583, 599,
05, 619
647
errupts, 77
omponents, 28-29
), 80, 83, 89, 98-99, 115, 117, 119, 121,
152, 154, 157, 159-160, 183, 187-207,
222, 223, 226-229, 251, 265, 277-278,
35-286, 294-295, 595-599, 660-661

Disk access, 159, 188, 195, 203
Disk cache, 121, 154, 157, 160
Disk controller, 83, 192, 194-195, 215, 245
disk drive, 191-194, 207, 214, 219-221, 223,
227-228, 265, 269
disk drives, 89, 188, 192, 195, 198, 202, 204-205,
209, 214
disk mirroring, 597
Disk scheduling, 197
rotational delay, 197
disk space, 201, 203, 222
Disks, 116, 121, 187-188, 192-200, 202-207, 209,
212, 214-219, 222, 252, 261, 597-598
Dispatcher, 280, 650
Displacement addressing mode, 464
Distributed interrupt controller (DIC), 644
division, 18, 24, 321, 340-343, 351-352, 354, 356,
359, 361, 363, 428, 523, 612, 662
partial remainder, 340-342
division by, 74, 428, 523
document, 25, 29, 566, 652, 658, 660
documentation, 59, 297, 451, 566, 660
documents, 4, 215, 360
external, 215
recent, 360
domain, 98, 254, 261, 302, 304-306
Domains, 306
dot operator, 370
double, 26, 106, 109, 142, 174, 176, 180-181, 183,
192, 203-204, 212, 218, 354, 415, 419-421,
435, 439, 449, 452, 465, 491, 523
hexadecimal, 449
Double precision, 26, 421, 565
downloading, 404
downstream, 105, 252
Drift, 100, 102
Driver, 103-104, 167, 209-210
Drivers, 104, 254, 273
Drives, 89, 187-188, 192, 195, 198, 202-209, 214,
216, 219, 251-252, 282, 620, 646
DROP, 37, 41, 92, 206, 357, 577
duration, 90, 109, 111, 155, 277, 401, 500-502
DVD-R, 212, 220
DVD-RAM, 119
DVD-ROM, 212, 216, 220
DVDs, 46, 216
Dynamic allocation, 641
Dynamic memory, 165
Dynamic random-access memory (DRAM), 38
dynamic storage, 148
Dynamics, 47, 188

E
EBCDIC, 418, 429
editing, 206-207, 252, 429
Effective, 8, 41, 43, 51, 62, 100, 152-153, 182,
202, 204, 265, 279, 285, 291-292, 420, 450,
457-461, 463-466, 478, 483-485, 501,
540-541, 581, 583, 598-599, 602, 605, 611,
622, 624, 631-632, 636
effects, 141, 159, 249, 277, 365, 502, 561-562
Levels, 141
electrical signals, 163
Electrically erasable programmable read-only
memory (EEPROM), 166
electronics, 2-3, 20, 25, 28, 46, 215, 227, 276, 324,
655, 662

terms, 25, 276, 324
Element, 40, 50, 58, 68, 115, 141, 162, 195, 252,
257, 309, 332, 383, 415, 436, 439, 453,
461-462, 465, 489-490, 577, 606, 610, 612,
615-616, 618, 641
elements, 28-30, 35, 47, 65-66, 69, 89-90,
114-115, 125-127, 148, 164, 167, 260-261,
283, 322, 332, 362, 369, 377, 392, 397, 404,
407, 409-411, 442, 445, 462, 472, 477, 516,
526, 550-551, 582, 607-613, 616, 618, 623,
625, 640
form, 29, 69, 115, 258, 362, 377, 392, 407, 607
else, 232, 234, 242-243, 447, 450, 454, 509, 513,
533
E-mail, 207
Embedded DRAM, 649
Embedded systems, 3, 15-16, 44-47, 261
embedding, 59
empty space, 292
encapsulation, 254
encoding, 100, 102-103, 253, 347, 417, 478-479
differential, 100, 102-103
scrambling, 102
encryption, 219
End systems, 195
servers, 195
Engineering, 2-3, 16, 38, 59, 181, 215, 297, 369,
374, 445, 530, 566, 606, 632, 651, 656-658,
661
ENIAC, 16-17, 62
Entity, 97, 279, 358, 452, 588
Environment, 9-10, 12, 47, 56, 197, 202-205,
225-227, 422, 459, 510, 534, 603, 636, 645,
666
environments, 30, 93, 297, 477, 534, 657
Erasable programmable read-only memory
(EPROM), 166
Erasable Programmable ROM (EPROM), 183
Ergonomics, 640
Error, 69, 74, 93, 96-97, 104, 107-108, 161-162,
172-176, 182-183, 186, 194, 204, 210-212,
214, 228-229, 249, 257, 270, 272, 274-275,
283, 351, 354, 364-365, 430, 511, 519-524,
656
Error control, 93, 96-97, 108, 162, 182
Error correction, 161, 172, 174, 183, 186, 210
Hamming code, 183, 186
hard failure, 172, 183
semiconductor memory, 172, 183
soft error, 172, 183
Error detection, 174, 211, 228, 418
Error-correcting code, 172-173, 176, 204, 214
errors, 97, 102, 106-107, 162, 172-173, 176, 186,
190, 204, 229, 231, 364-365, 520
establishing, 401, 404
Ethernet, 40, 89, 98-99, 260-262, 601, 662
Even parity, 229, 418, 438, 531
Event, 35-36, 47, 92, 104, 153, 172, 203-204,
207, 236, 274, 283, 340, 502, 521-522, 529,
581, 590-591, 596
events, 90-91, 97, 234-235, 273, 283, 338, 393,
496, 502, 522, 524, 585, 646
Exception, 351, 358-359, 370, 475, 517-518,
521-523, 526-530, 534, 557, 613
exceptions, 19, 116, 411, 518-519, 522-523, 526,
529-530, 545, 563, 613
program execution, 545
Exchanges, 66, 68, 83-84, 177, 180, 257

Execute cycle, 60, 70, 72, 77, 108, 498
computer instructions, 108
Execute stage, 500, 503, 513, 515, 529, 542, 545,
568-570, 590
Execution, 7, 22-23, 25, 32, 39, 41-42, 45, 51-58,
62-64, 67-72, 74, 76-80, 108-109, 119,
138, 141, 143-146, 148, 154-156, 202-203,
210, 234-236, 263, 265, 268-269, 271-275,
277-284, 286, 308-309, 410-412, 415-416,
423, 430, 432-433, 436, 448-449, 459-460,
463, 471, 488, 490, 492, 494, 499-501,
503-506, 518, 520-522, 524-526, 529-530,
532-533, 542-546, 549-552, 556-557, 560-
561, 567-569, 588-590, 616, 620, 622-624,
629-630, 640, 649, 653, 655
execution, 39, 269, 492, 588
Execution
instruction rate, 54
multithreading, 574, 588-590, 592, 622,
629-630, 633, 665
execution:
of program, 39, 588
Execution
out-of-order, 144-145, 535, 543-546, 551, 556,
567-569, 649
taxonomy of, 575
EXISTS, 7, 119, 259, 280, 382, 392, 554, 641
Exponent, 322, 343-356, 359-362, 364, 421, 448,
522, 534, 610
Exponent field, 345
Exponent value, 344, 351
exponents, 347-349, 352-356, 534
negative, 349
exposure, 166
Expressions, 370-371, 377, 380-381, 401-402,
406, 662
logical not, 370
external data bus, 109
External memory, 115-116, 121, 144, 187-222,
309, 515, 525, 647
magnetic disks, 116, 188, 192, 214-215,
218-219
magnetic tape, 188, 218-220
extracting, 231

F
Failures, 66, 96, 172, 186, 206-207, 598-599, 643
Family concept, 32
Fanout, 261-262
Fast Ethernet, 89
fault tolerance, 207, 595
Faults, 308, 523, 526, 613
Feature size, 36-37, 633
Features, 24, 32, 44, 49, 100, 109, 218, 253, 266,
275, 277, 309, 345, 548, 574, 579-581, 649,
661
Feedback, 392
Fetch cycle, 22, 60, 70, 77-78, 108, 469, 496,
498, 515
Fetch stage, 500, 509, 512-513, 515, 549, 570
Fibre Channel, 261
Fields, 8, 106-107, 109, 126, 129, 135, 149-150,
192, 214, 298, 411-412, 416, 427, 448, 451,
456, 470, 478, 493, 521, 524, 528, 556, 616
File, 155, 196-197, 207, 209-211, 221-222,
230, 269, 275, 525-526, 541, 546, 552, 554,
562-563, 577, 599, 630, 665

sequential, 196-197, 552
file access, 197
File directories, 599
File system, 209-210
files, 10, 37, 121, 203, 211, 215, 269, 282, 452
and arrays, 452
records, 121
streams, 588
FireWire, 88-89
firmware, 97, 210
First-in-first-out (FIFO), 139
Five-state process model, 280
Fixed-head disk, 220, 227
Fixed-size partitions, 286
flag, 74, 109, 266, 322-323, 332, 423, 435-436,
438, 444, 447, 459, 480, 518-520, 522-523,
527, 562
Flags, 322-323, 424, 436, 438, 443-444, 447-448,
480-481, 489, 491, 493-495, 515-517,
519-520, 524, 527-529, 531, 552, 554, 557
Flash drives, 209
Flash memory, 163, 166, 182-183, 187, 208-211,
219-220
SSDs, 208-209, 211
Floating-point, 45, 49, 52, 54, 57, 321-322, 343-
347, 349-352, 354-358, 360-362, 364-365,
417, 419-421, 425-426, 436, 465, 472, 490,
517-518, 520-523, 534, 535-537, 556-558,
564-565, 574, 606, 608-610, 617, 649, 653,
655, 658-659, 662, 664-665
floating-point notation, 346, 362
biased representation, 362
guard bits, 362
overflow, 346, 362
representation, 346, 362
rounding, 362
significand, 346, 362
underflow, 346
Floppy disk, 40, 189, 220
Flow control, 95-97, 100, 107-108, 254
Flowchart, 22, 232, 293, 335, 341, 352, 354,
511-512
Form, 17-19, 23, 29, 38, 40-42, 72, 76, 83, 93,
96, 115, 118, 133, 153, 162, 171, 203, 226,
229-230, 232, 238, 256, 258, 294-296, 315,
329-330, 339-340, 343-345, 357, 359, 362,
365, 373-377, 392, 399, 401, 406-407,
412-413, 431, 465-466, 482, 532-533,
605-607, 615
design a, 407
Designer, 118, 401, 424, 652
formats, 19-20, 94, 98, 217, 224, 230, 263, 267,
298-299, 303-304, 310, 345, 347-349,
415-416, 421, 451, 455-486, 658
formatting, 187, 189, 191
Forms, 10, 84, 115, 121, 175, 177, 226, 297, 317,
384, 432, 488, 498, 642
FORTRAN, 54, 155, 274, 413, 437, 607, 614, 624
Forwarding, 563
frames, 58, 260-261, 289-290, 300, 308, 437, 441,
478-479
background, 261
Frequency, 7, 39, 42, 50-51, 63, 93, 109, 118-119,
155, 177, 182, 264, 542, 588, 632, 650
fundamental, 7, 42, 50
Function, 6, 8-10, 14, 18-19, 28-29, 46, 48,
58, 64, 65-111, 120, 129, 138, 142, 148,
157-159, 165, 172, 183, 194-195, 204, 210,

221, 223-230, 240-242, 248-249, 270, 280,
308, 369-370, 372-378, 386, 388, 391-393,
395-396, 404, 406, 424, 447, 487-534,
560-562, 578-579
computation of, 404, 515
description, 8, 69, 108-109, 229, 424, 488, 492,
523, 529, 562
Functions, 96, 556, 599
components and, 68
execute cycle, 108
fetch cycle, 108, 469
in, 9-10, 12, 14, 28-29, 67-68, 93, 96-97,
108, 165, 177, 224, 228, 233, 242-243, 256,
263, 268-273, 293, 309, 352, 369, 372-374,
378, 388, 392, 397, 401-402, 404, 410-441,
443-454, 469, 490, 493, 504-505, 550
instruction cycle, 74, 108, 243, 411, 504-505
interrupt-driven I/O, 224, 230, 242
I/O channels, 224, 230, 309
point of view, 270, 273, 410
Return statement, 433
Fuses, 402

G
games, 46, 48, 215, 636
Gap, 189-194, 220, 359-360
Gate, 28-30, 164, 208, 368-369, 372-374, 376,
384-385, 391-393, 395, 401-402, 405-407
Gates, 28-29, 41, 127, 368-369, 372-376, 382,
384-385, 388, 390, 392-393, 395, 401-402,
405-407
General-purpose register, 415, 465, 471, 490, 533
General-purpose registers, 36, 415, 443,
459-460, 462, 465, 467, 471-473, 475,
486, 490-491, 516, 527
Generator, 178, 561
Generic types, 89
Geometric mean, 55, 60, 63-64
Gigabit Ethernet, 40, 98-99
Global history buffer (GHB), 560
global variables, 465
Gradual underflow, 360, 365
Granularity, 299-300, 470, 603, 636
hybrid threading, 636
Graph, 42, 308, 631, 656
Graphics, 40, 43, 45, 49, 60, 87, 89, 252-253,
439-440, 605, 637
Graphics workstation, 89
Gray, 79, 407, 439
Grouping, 380, 382
Guard bits, 322, 355-357, 361-362
guidelines, 3, 445
guides, 48

H
Handle, 38, 40, 56, 195, 238, 249, 256, 263, 278,
359, 475, 504, 529, 601, 605-606, 616, 622,
645
Handles, 269, 274, 465, 565, 590, 643, 647
handling, 40, 104, 235-236, 242, 278, 294, 296,
423, 437, 449, 524, 529-530, 534, 557, 606,
616, 628, 644, 655
handshaking, 241-242
Handshaking lines, 242
hard disk, 40, 121, 188, 191-192, 194, 207, 220,
262, 601
Hard disks, 195

es, 252
re, 172, 183
7, 24-25, 31, 33, 41, 45-46, 48-49,
7, 59, 67-68, 74, 76, 90, 108, 125-126,
140, 154, 194, 235, 237-238, 255,
258, 260, 268-272, 275, 277, 289-290,
296-298, 332-334, 361-362, 402, 454,
473, 475, 491-492, 501, 508-509, 525-
537-539, 547-550, 556, 573-574, 577,
583, 589-590, 592, 598-599, 618-619,
629, 635-636, 642-644, 665-666
consumption, 49, 628
mean, 54, 60, 63
e, 292-293
292-293
ble, 292-293
06-508, 561, 563-564, 566, 661
-195, 203, 214, 218-222, 226-227
3, 106
50
7, 62, 188, 454
, 50
nal digits, 72
mal notation, 70, 130, 312, 319-320, 533
9, 39, 51-52, 56, 66, 85, 87, 114-115,
121, 125, 149, 156, 166, 219, 226, 599
of, 39, 115, 599
l language (HLL), 270
l languages, 2, 419, 463, 483
l programming languages, 25
ed LANs, 89
n, 277
157
nel adapter (HCA), 261
4, 445, 658, 661
8, 664
reading, 636-637
reading, 593
outer, 17-19, 21, 27, 38, 61
3-25, 27-28, 31-33, 37-38, 44, 59-60,
3, 121, 128, 143, 176-177, 220, 223,
258-261, 309, 346-347, 360-361, 364,
428, 450, 469, 478, 503, 509, 593,
616, 618-619, 621, 628-629, 648-649,
659-661, 663-666
tion, 195, 237, 518, 599
50, 148, 182-183, 220, 276, 319,
322, 324, 347-350, 355, 357-361, 364,
405, 419, 421, 448, 483, 530-531, 558,
567, 619, 655-666
mputer Society, 361, 530, 619
nt, 448
ccessing, 37, 443
40, 442
e addressing, 455, 458, 466, 473,
484
tation, 2, 13, 25, 45, 49, 51-52, 55, 96,
135, 139, 206, 292, 305, 334, 347-348,
358-360, 368-369, 373-377, 382,
385, 388, 390-391, 395-396, 398-399,
416, 448-449, 492, 519, 535-536, 539,
566, 601, 612, 622, 651, 658
ts, 28, 99, 309, 514, 552, 559-560,
641, 643, 649

IMPLIED, 346, 348-349, 354-355, 363-364, 415,
431, 463
IN, 2-4, 7-10, 12-14, 15-25, 27-33, 35-36,
38-64, 66-74, 76-80, 83-94, 96-98, 100,
102-111, 115-136, 138-144, 146-157, 159,
162-167, 169, 171-177, 179-184, 186,
188-198, 200-219, 221-222, 224-243,
245-246, 248-266, 268-298, 300-303,
305-310, 322-347, 349, 351-352, 354-355,
357-365, 369-374, 376-386, 388, 390-393,
397-402, 404-408, 410-441, 443-454, 456,
458-473, 475-486, 498-513, 515-534,
536-571, 577-593, 595-599, 601-606,
608-625, 655-666
Increments, 70, 246, 595, 643
Index registers, 308, 461, 472, 494-495
Indexing, 461-462, 465-467, 470, 472-473, 478,
483, 485
Indices, 608
Indirect addressing, 3, 455, 459-460, 462, 465,
471-472, 483-485, 496, 498
Indirection, 20, 459, 462, 473, 497
InfiniBand, 223-224, 250, 252, 255-258, 260-262,
658, 660
infinite, 316
Information:, 242, 282, 399
Initialization, 97
INPUT, 2, 10, 14, 17, 19, 21, 28-29, 60, 68-69,
80, 84-85, 102, 109, 169-171, 173, 175,
179, 186, 209, 223-266, 272-273, 277, 363,
371-372, 374-376, 384-386, 388-393,
395-397, 401, 403-404, 406, 409, 412, 417,
426, 435, 440, 471, 481-482, 556-557, 609,
612-613, 646
Input variables, 371, 385
Input/output (I/O), 429
programmed, 429
Insert, 111, 177, 185, 264, 522
Insertion, 153, 165
installation, 309-310
Instance, 258, 410, 480, 588, 636
Instances, 154, 330, 511, 539, 542-543
Instruction cycle, 20, 27, 60-62, 66, 69-70, 72-74,
76-77, 80, 86, 108, 111, 234, 236, 243-244,
411, 458, 462, 495-496, 499-500, 504-505,
531-532
data flow, 496, 499
indirect cycle, 495-496
interrupt cycle, 77, 80
interrupts and, 76, 80
multiple interrupts, 80, 108, 236
state diagrams, 532
Instruction execution, 23, 32, 41-42, 51-52, 54,
69, 74, 108, 143, 265, 410, 412, 430, 444,
479, 492, 499-500, 542, 545, 550
execute stage, 500, 542, 545, 590
fetch stage, 500
Instruction formats, 263, 415-416, 455-456,
470-471, 473, 475, 477, 479, 483
assembly language, 456, 483
variable-length, 455, 473, 483
Instruction pointer, 437, 494-495, 517, 524,
552-553
Instruction register, 60, 69-72, 109, 386, 412, 496,
498, 525, 558
Instruction register (IR), 60, 70-71, 412, 496
instruction set, 2, 7-8, 17, 19, 23, 27, 32, 36,
44-45, 49, 51, 53, 60, 248, 409-411, 416,

419, 423-424, 437, 440-441, 449, 460, 462-
463, 472-473, 475-476, 479-480, 485-486,
490-491, 517, 524, 529, 616, 651, 655, 661
Instruction-level parallelism, 535-571, 588-589,
592-593, 629, 631
antidependency, 539, 546, 567
branch prediction, 535, 549-550, 552-553, 555,
557-558, 560, 567, 570-571, 589
instruction issue policy, 535, 542-543
Intel Pentium 4 processor, 566
output dependency, 539, 563, 567
procedural dependency, 539-543, 567
register renaming, 535, 546-549, 552-553, 556,
567, 589
resource conflict, 540-541, 543, 567, 569
integer division, 343, 363
Integers, 61, 311-312, 314-316, 319, 323-327,
330, 332-336, 340-346, 354, 362-363, 407,
419, 421, 438, 447-448, 451, 454, 656
fixed-point, 343, 346, 363
negation, 325, 330, 362
operations on, 344
sign magnitude, 324-325, 327, 330, 362
signed integers, 419, 421, 438, 448
unsigned, 323, 325, 330, 332-336, 340-344,
362-363, 417, 421, 438, 447-448
zero and, 323, 438
Integrated circuits, 15, 28-29, 31, 118, 401
Integration, 3, 25, 29, 33, 89, 155, 401, 613
Intel processors, 643
intensity, 213, 215, 222, 440
Interaction, 83, 227, 530, 637
Interconnect, 39, 65-66, 88, 90, 93-95, 98, 108,
255, 261-262, 269, 402, 404, 601, 603-604,
642-643, 661
Interconnections, 7, 29-30, 388, 401, 630
Interfaces, 7, 47, 85, 87, 223-224, 248, 250-252,
270, 579
Intel 82C55A programmable peripheral, 223
List, 85
multipoint, 223, 251-252
operating system, 270
parallel I/O, 251
point-to-point, 85, 223, 251
serial I/O, 251
Interference, 190, 638
Interleaved memory, 161, 171
Interleaved multithreading, 591-592, 622
Interleaving, 279, 578, 589
Internal memory, 115-116, 121, 154, 161-186,
488-489
chips, 162, 166-167, 170-171, 180-181, 184,
186
electrically erasable programmable read-only
memory (EEPROM), 166
erasable programmable read-only memory
(EPROM), 166
error correction, 161, 172, 174, 183, 186
flash memory, 163, 166, 182-183
interleaved, 161, 171
random-access memory (RAM), 163
read-only memory (ROM), 163, 165, 183
Internet, 1, 4, 215, 362
Internet and, 4, 215
Internet Protocol (IP), 362
Interpreter, 67-68, 273
Interrecord gaps, 218
Interrupt, 3, 74-85, 87, 108-109, 111, 223-224,

230-232, 234-244, 256, 262-264, 266, 273,
275, 278, 282-284, 306, 423, 436, 487,
495-499, 502-503, 518-524, 526-530, 532,
545, 567, 628, 643-647, 652
Interrupt handler, 75, 77-78, 80, 82, 108, 236,
282-284
Interrupt service routine (ISR), 108, 264
Interrupt-driven I/O, 223-224, 230-232, 234, 240,
242, 262, 264, 266
drawbacks of, 223, 242, 266
programmed I/O and, 224, 240
interrupts, 65-66, 74-80, 82-83, 104, 108, 231,
234, 236, 238, 240, 248, 264, 268, 277, 493,
518, 520, 522-524, 641, 643-646
distributed interrupt controller (DIC), 644
exceptions and, 523
handler routine, 78, 80
instruction cycle and, 66, 74
request, 74, 76, 80, 104, 236, 275, 641,
645-646
request signal, 76, 80
stage, 74, 495, 502, 545
vectored, 238, 493
Intersection, 383, 401-402
Intranet, 207
Intranets, 215
Introduction, 2, 5-14, 25, 28, 33, 36, 43, 45, 108,
128, 219, 249, 252, 405, 439-440, 557, 651,
659, 666
history, 33, 656
I/O modules, 90, 140, 224, 226, 229, 232-233,
236-238, 245, 249, 262
iPhone, 48
iPod, 48
Isolated I/O, 233-234, 262-264
Isolation, 636
Item, 58, 118, 127, 231, 274, 292, 418-419, 425,
435, 452-453, 525, 586
Iteration, 155-156, 510, 563-564, 606, 614-616,
652-653
J
J2EE, 636
Java, 54, 635-636
Java Virtual Machine, 54, 635
Job, 238, 246, 272-280, 284, 286, 292, 306-307,
310, 479, 577, 599, 620
Job control language (JCL), 306
Join, 607-608, 635
K
Kernel, 271, 282, 306, 309, 454, 589
keyboard, 40, 109, 111, 223, 227, 233, 241-242,
251, 264, 272
keyboard input, 227, 233
L
L1 cache, 122, 132, 141-143, 146, 149, 152,
558, 580, 587, 604, 621, 638-639, 644, 647,
649
L2 cache, 122, 141-144, 149, 160, 551-554,
558, 561-563, 580, 587, 594, 603-604, 621,
629-630, 638-642, 647, 649-650, 652
L3 cache, 122, 143-144, 149, 580, 621, 629,
638-639, 641-642, 649-650

Languages, 2-3, 25, 60, 155, 417, 432, 437-438,
483, 566-567, 574, 659-662, 664-665
Laptops, 37, 252, 641
Lasers, 216
Latency, 41, 93, 117, 179, 194-195, 202-203, 209,
221, 254, 542, 551, 562, 590-591, 622, 642,
650-651, 666
layers, 9, 94-95, 97, 99-100, 108, 253-254, 257
Layout, 50, 174, 180, 190-191, 198, 201-202,
218, 240, 260, 273, 374, 383, 401, 403,
449-450, 452
gate, 374, 401
layouts, 449, 452
Leading, 33, 91, 180, 582-583
Leading edge, 91
Leakage, 57
Libraries, 25, 269-270, 273
shared, 270
LIKE, 25, 28, 36, 53, 61, 118, 127, 146, 157,
165-166, 179, 196, 215, 249, 271, 274, 308,
324-325, 382, 391, 402, 456, 461, 498, 534,
537, 605-606, 618
Line:, 44, 646
Link layer, 65, 95-97, 100, 102, 105, 107, 257
Linking, 272, 473
loading and, 272
links, 4, 16, 93-96, 99, 224-225, 251, 255,
258-259, 261, 265, 306, 643
Links, InfiniBand, 258, 261
Linux, 25, 49, 589
List, 4, 14, 16, 44, 61, 71, 85, 108, 139, 149-150,
186, 263-264, 282, 284, 289, 307, 362, 377,
417, 430, 461-462, 467, 479, 492, 531, 567,
637-638, 646, 651-652
Lists, 2, 17, 53, 74, 89, 125, 127, 174, 192, 357,
370, 399, 401, 435, 437-438, 440, 491,
529-530, 550, 595, 598-599, 635, 637, 643
numbered, 174
Literal, 475-476
Little endian, 410, 445-446, 450-451, 453-454
Load balancing, 202, 598-599, 605
Loading, 20, 51, 258, 290-291, 385, 586, 612
local data, 109
Local variable, 465
Local variables, 434, 465, 479, 582
Locality of reference, 122
locations, 19-20, 23, 39, 68, 70, 72, 86, 117,
139, 152, 156, 186, 222, 233, 246, 281, 307,
322, 413-415, 420, 429, 431, 436, 443, 445,
459-462, 464, 468, 471, 486, 489, 608-609,
611, 614, 617, 638-639
Locking, 104, 598, 638
Locks, 104
Logic (Boolean) instructions, 413
Logic level, 96
Logical address, 126, 289-290, 296-297, 301,
306, 309, 420
Logical shift, 397, 440, 445, 466
logical view, 558
Long-term scheduling, 267, 279, 306
Lookup, 298, 303, 404, 406, 435, 513-514
Lookup table, 404, 406
Loop, 119, 152, 155-156, 216, 233, 263, 379,
430-431, 477, 492, 509-511, 513, 533-534,
624, 636
loops, 119, 162, 180, 215, 233, 379, 436, 510, 524,
555, 612, 624, 636
Lotus, 635

M

machine, 3, 24, 31-33, 44, 46, 48, 51, 53-55,
61-64, 69-71, 109, 126, 150, 225-226, 233,
258, 265, 270, 308, 341, 409-413, 416-417,
424, 430, 433, 435, 452, 454, 456, 463, 466,
470-471, 481-482, 490-492, 511-512, 519,
521, 535-536, 540-543, 548-549, 551-552,
555-556, 565, 578, 592, 595-596, 612,
623-624, 652-653, 655
Machine cycle, 265, 624
Machine cycles, 265
Machine instructions, 17, 32, 51, 126, 146, 233,
410-413, 417, 456, 481, 491-492, 498, 652
BRANCH, 51, 233, 413, 491-492, 552
instruction set design, 491
I/O, 17, 32, 146, 233, 410-411, 413, 417, 498,
652
LOAD, 51, 233, 412-413, 481
logic (Boolean), 413
ROTATE, 481
STORE, 51, 233, 411-413, 417, 481, 574
symbolic representation, 412
test, 233, 413, 492
Machine language, 51, 61, 270, 410, 412-413,
419, 435, 481-482
Machine languages, 417
Machine parallelism, 535, 541-543, 548, 567
Magnetic disks, 116, 188, 192, 214-215, 218-219
heads, 188, 192, 218
write mechanisms, 188
Magnetic tape, 119, 188, 218-220, 265
Mail server, 54
Main memory, 12-14, 18, 21, 25, 27, 32, 35,
38-42, 52, 58, 61-62, 64, 68-69, 87-89,
94, 98, 103, 115-117, 121-124, 126-136,
139-140, 143-144, 146-154, 157, 159,
161-162, 165, 171-172, 176-177, 222,
228-229, 231, 237, 245, 248-250, 263-265,
269, 271-275, 278-279, 282, 285-292,
294-295, 298, 300-303, 307-310, 432, 456,
458-461, 468-469, 484-485, 496, 506-507,
511, 577-580, 582-584, 586-588, 602-604,
609, 613-614, 620, 623-624, 641-642, 645,
649-650
cache memory and, 87, 146
segmentation, 295, 298, 307, 309, 461
mantissa, 344, 361, 521
Manufacturing, 28, 42, 46, 172, 384, 499
failures, 172
Map, 103-104, 129-130, 132, 136, 151, 201,
292-293, 369, 377-378, 380, 401, 406
mapping, 97, 102, 114-115, 122, 126-136,
138-139, 149, 202, 254, 302, 309, 450-452,
458, 521
value, 97, 102, 450-451, 458
Maps, 102, 128-129, 134, 200, 256, 292, 376-381,
383, 400-401, 452
Mask, 179, 240, 247-248, 402, 441, 519-520,
615-616, 618
masks, 163, 428
Mass storage, 121, 251, 274
math, 4, 29, 45, 346, 520
Matrices, 606
Matrix, 24, 29, 51, 125, 140, 383, 439, 607
square, 29, 383
Mauchly, John, 16
Maximum, 32, 57, 86, 109-111, 148, 184, 191,

264-266, 292, 297, 313, 348, 364,
419, 505, 543, 592-593, 620, 640
value, 313, 398, 505
-55, 60, 63-64, 186, 206, 276-277,
548, 589, 595, 636
63-64
4, 47, 657
188, 222, 257
9
n scheduling, 267, 280, 306
55
31, 200, 205, 219, 598
7, 12-14, 17-44, 47, 49, 51-52, 56,
52, 64, 66-74, 76, 83-94, 98-99,
113-160, 161-186, 187-222,
5, 228-229, 231-234, 237, 242-246,
0, 253, 255-260, 262-266, 267-310,
3, 392-393, 404, 406, 410-413, 415-
9-425, 428-438, 443-444, 447-454,
3, 475, 477-478, 484-486, 498-502,
5-512, 514-515, 523-526, 529-530,
4, 540-542, 550-551, 556-557, 561-
3-588, 597, 599, 601-605, 609-611,
6, 618-625, 636, 638-639, 641-642,
7-653, 656-663, 665-666
148, 206, 271, 289, 297, 309, 469,
6, 605, 638, 645, 656-657
Migratory lines, 647
MIMD, 575-577
Minimum, 109, 203, 215-216, 222, 235, 277, 280,
348, 351, 384, 469, 475, 558, 561-562, 620,
624, 653
Mirror disk, 203
MMX, 45, 145, 419, 439-443, 449, 521-522, 551,
557, 663
Mnemonics, 412, 425
Mod, 477-478
Mode, 146, 177, 179, 182, 185-186, 204, 214,
231, 240-241, 246, 248, 255, 263-265, 273,
278, 357, 386, 416, 424-425, 450, 454,
457-458, 460, 462-465, 468, 470, 475-476,
478-479, 484-486, 491-494, 515-520,
526-530, 624
Modeling, 37, 530, 658, 661
Models, 7-8, 31, 33, 47, 62, 146, 275, 530, 555,
657
interaction, 530
subsystem, 8, 146
Modem, 40, 88, 251
Modes, 146, 233, 239-240, 246, 248, 416, 454,
455-486, 487, 515, 524, 526-528
kernel, 454, 526
Modifiers, 471
Module, 27, 35, 57, 68-70, 73, 76, 78, 83-87,
90-94, 109-110, 115-116, 139, 161, 170-171,
180, 182, 184, 223-232, 238-240, 242-243,
245, 248-251, 260, 262-264, 411, 424-425,
488, 579
Modules, 33, 66, 74, 84, 86-87, 90, 116, 140, 171,
223-224, 228-229, 232-233, 236-238, 243,
245, 249, 262, 264, 309, 579, 601
Monitor, 139, 223, 227, 270, 273-276, 285, 307,
519-520, 582, 637
Monitors, 46, 140, 252, 637, 640-641, 647
Most significant bit, 324-325, 330, 342, 345, 352,
391-392, 451, 454
Motherboard, 255
motion, 47, 192-193, 202, 218-219
Motorola, 153, 448, 451-452, 494, 510, 533, 665

Messages, 103, 105, 578, 596
response, 103
Metal, 24, 28, 41, 217
Metallization, 29
Method, 68, 90, 255, 288, 343, 357-358, 363,
380-383, 406, 461, 466, 536, 547, 549,
596-598
Add, 68, 357, 382, 448, 461
Clear, 288
Close, 357
Exists, 382
methods, 10, 90, 191, 224, 242, 360-362, 376,
467, 511, 661
get, 10, 360
Metrics, 54-55, 198
product, 55
Microinstructions, 13, 471
control memory, 13
Microprocessor, 15, 35-38, 44-45, 48, 59, 61, 150,
153, 186, 263-264, 296, 309, 445-446, 448,
494-495, 530-532, 566, 577, 629, 632, 649,
651, 655-657, 662-665
Microprocessors, 16, 35-38, 44, 48, 59, 110,
143, 262, 266, 445, 494, 566, 577, 655-658,
664-666
register organizations, 494
Migratory lines, 647
MIMD, 575-577
Minimum, 109, 203, 215-216, 222, 235, 277, 280,
348, 351, 384, 469, 475, 558, 561-562, 620,
624, 653
Mirror disk, 203
MMX, 45, 145, 419, 439-443, 449, 521-522, 551,
557, 663
Mnemonics, 412, 425
Mod, 477-478
Mode, 146, 177, 179, 182, 185-186, 204, 214,
231, 240-241, 246, 248, 255, 263-265, 273,
278, 357, 386, 416, 424-425, 450, 454,
457-458, 460, 462-465, 468, 470, 475-476,
478-479, 484-486, 491-494, 515-520,
526-530, 624
Modeling, 37, 530, 658, 661
Models, 7-8, 31, 33, 47, 62, 146, 275, 530, 555,
657
interaction, 530
subsystem, 8, 146
Modem, 40, 88, 251
Modes, 146, 233, 239-240, 246, 248, 416, 454,
455-486, 487, 515, 524, 526-528
kernel, 454, 526
Modifiers, 471
Module, 27, 35, 57, 68-70, 73, 76, 78, 83-87,
90-94, 109-110, 115-116, 139, 161, 170-171,
180, 182, 184, 223-232, 238-240, 242-243,
245, 248-251, 260, 262-264, 411, 424-425,
488, 579
Modules, 33, 66, 74, 84, 86-87, 90, 116, 140, 171,
223-224, 228-229, 232-233, 236-238, 243,
245, 249, 262, 264, 309, 579, 601
Monitor, 139, 223, 227, 270, 273-276, 285, 307,
519-520, 582, 637
Monitors, 46, 140, 252, 637, 640-641, 647
Most significant bit, 324-325, 330, 342, 345, 352,
391-392, 451, 454
Motherboard, 255
motion, 47, 192-193, 202, 218-219
Motorola, 153, 448, 451-452, 494, 510, 533, 665

Mouse, 40
Movable-head disk, 220
move, 10, 16, 21, 25, 29, 32, 45, 94, 144-145, 155,
190, 195, 198, 222, 227, 242, 248, 285, 398,
414-415, 425, 435-436, 441, 446, 448-449,
454, 476, 481, 568, 593, 629, 651
instruction, 21, 25, 32, 45, 144-145, 231,
248, 414-415, 423, 425, 435-436, 441,
446, 448-449, 454, 476, 481, 568, 593,
629, 651
Movements, 221
movies, 215
MP3, 208-209
Multicast, 256
Multicore computers, 58, 627-653
hardware performance, 629
Intel Core Duo, 628, 638-641, 651
Intel Core i7, 628, 638-642
software performance, 629, 633
threading, 635-637
Multimedia, 37, 45, 179, 251, 419, 663
image, 37, 439
multimedia devices, 251
Multiple, 3, 12, 38-40, 42-45, 47, 50-51, 55-56,
58-59, 62, 65-66, 70, 73, 80-85, 87, 90, 93,
96, 98-99, 108, 122, 134, 139, 143, 149,
153, 166-167, 179, 184, 191-192, 197-198,
201-204, 206-207, 211-213, 220, 222,
236-238, 243, 248-250, 252, 262, 265, 278,
295-296, 384, 386, 390-391, 404, 414-416,
439-441, 454, 458, 467-470, 479, 491, 497,
499, 531-532, 536-537, 542-543, 549-550,
573-579, 581-584, 588-592, 596-599,
601-603, 611-612, 629-638, 641, 655,
664-665
Multiple registers, 416, 470, 491, 499
Multiple-platter disks, 192
Multiplexing, 90, 253
Multiplexor, 27, 61, 249-250, 261-262, 265
Multiplication, 18, 23, 140, 316, 321, 333-340,
351-352, 354-355, 361-363, 428, 435, 439,
447, 607, 616
unsigned integers, 333, 335-336, 362
Multipoint interfaces, 252
Multiprogramming, 148, 197, 272, 276-280, 283,
285, 291-292, 306, 429, 581, 606, 655
time-sharing systems, 278
multitasking, 44, 276, 307, 519
Multithreading, 573-574, 588-593, 595, 618-619,
622, 629-630, 633, 636, 639, 651, 665
parallel processing, 573-574, 588-593, 595,
618-619, 622
multiuser, 270
Mutual exclusion, 581

N
named, 166, 188, 265, 360
names, 460
NaN, 350-351, 358-359, 518, 522
NAND, 208-209, 211, 370-373, 376, 384,
406-407
NAND gates, 373, 384, 407
nanoseconds, 152
navigation, 558
Negation, 165, 321, 328-331, 362, 372, 401
Nested, 82, 239, 432, 434, 437, 518-519
nesting, 156, 433, 446

Network, 84, 87-89, 93-94, 98, 194, 252-253,
255-258, 261-262, 575-576, 579, 584, 597,
599, 603-604, 658, 664
Network adapter, 253
network layer, 257-258
Networking, 599
networking, 49, 255, 269, 599, 603
networks, 38, 89, 93, 599
Nodes, 255, 596, 598, 603
levels, 605
Noise, 97, 640
thermal, 640
Nonuniform memory access (NUMA), 574, 576,
602, 619
organizations, 574, 576
uniform memory access (UMA), 619
NOR, 208-209, 308, 343, 370-374, 376, 383-384,
392-395, 406-407, 526
Normal, 19, 74, 77, 272, 344-345, 348-350,
360-361, 443, 498, 526, 528-529
Normalization, 55, 354
Normalized form, 365
NOT gate, 401
Notation, 19, 70, 130, 133, 311-312, 314-320,
322, 327, 329, 335, 339, 343, 346, 362-363,
370, 427-428, 445-447, 449, 476, 481, 533,
608
scientific, 343
Number systems, 311-320
Numbers, 322, 325, 363
floating-point, 322
Numeric data, 413, 417, 421

O
Object, 51, 272, 274, 637
objects, 637
Odd parity, 229, 418, 438
Offsets, 151, 478
OLTP, 635
One-dimensional array, 73
one-dimensional arrays, 606
One-to-one relationship, 232
OPEN, 49, 118, 141, 164-165, 217, 219-220, 230,
345, 636, 663
Operand, 73-74, 81, 109, 111, 153, 233, 244,
323, 352, 354-355, 358, 370, 410-412,
414-417, 423-426, 429-430, 435-436, 438,
445, 447-448, 451, 456-460, 462, 464, 468,
470, 472-473, 475, 477-480, 482, 484-486,
490-491, 493, 496-498, 501, 512, 517, 532,
546-547, 609-610, 614
Operands, 20, 73, 81, 110-111, 300, 322, 343,
347, 351-352, 370, 409-412, 414-415, 419,
423-426, 429-430, 437-440, 443-445, 447-
448, 466, 468-470, 475, 478, 486, 496-497,
500-501, 516, 524, 531-532, 556-557, 609,
613-615, 618
logical data, 409, 417, 419, 426
packed decimal representation, 445
Operating system, 3, 32, 74, 77-78, 154, 194,
197-198, 209-211, 222, 235, 254, 267-310,
429, 438, 454, 490-494, 526-527, 573,
577-578, 581-582, 588-589, 605, 612, 616,
645
Operating system (OS), 307
time-sharing, 307
operating system software, 210, 271

operating systems, 2, 49, 60, 148, 197, 254, 267-
268, 272-273, 276, 278, 296-297, 306, 309,
520, 557, 566-567, 589, 613, 635, 655-657,
659-662, 664-665
execution of, 268, 272, 278, 520, 589, 613
serial processing, 273
Operations, 10-11, 18, 20, 22, 25, 38, 41, 43, 45,
47, 50-52, 57, 67-69, 73-74, 79, 85-87,
91-92, 104, 119, 144, 146, 148, 162, 169,
209, 211, 225, 236, 257-258, 307, 325-326,
330, 336, 339, 359, 369-370, 409, 413-419,
422-431, 435-439, 446-447, 460-462,
468-469, 471-473, 475-476, 480, 490-495,
508, 517-518, 520-522, 524, 534, 556-557,
562, 592, 616, 623, 625, 661-662
Optical fiber, 255, 257
single-mode, 255
optimization, 46, 530, 539, 547, 647, 658, 660
OR function, 86, 204
Orders, 229
Orthogonality, 472-473
Oscilloscopes, 28
Out-of-order execution, 145, 535, 545, 551, 556,
568
OUTPUT, 2, 10, 14, 17, 19, 21, 28-29, 60, 68-69,
84-85, 87, 102, 109, 169-170, 177, 179, 184,
186, 223-266, 277, 363, 371-372, 374-376,
384-386, 388-389, 391-393, 395-401,
403-404, 407, 409, 417, 424, 426, 429, 435,
440, 450, 508, 526, 547, 549, 563, 567, 609
Output buffer, 69
Overflow, 61, 74, 270, 292-293, 322, 325, 330-
333, 335, 345-346, 349, 351-356, 361-363,
390, 417, 428, 430, 436, 438-440, 443-444,
447, 493, 518, 523, 527, 531
Overflows, 440
Overlap, 26, 85, 305, 307, 500, 612, 637, 652

P
Packed decimal representation, 406, 418, 445
Packet, 89, 95, 97-98, 100, 102-103, 105-107,
253-254, 256-257
packets, 58, 93, 95, 100, 102-103, 105, 107-108,
254, 256-258
Padding, 337
page, 147, 154, 179, 209, 211, 289-295, 298-310,
418, 459, 463, 471, 493, 519-521, 523, 605,
613
Page fault, 294, 308, 459, 511, 520, 523
Page numbers, 308
Page tables, 292, 294, 298, 300-301, 308
inverted, 292
pages, 4, 154, 211, 289-293, 298, 300-309, 471,
520-521, 605
first, 211, 292, 298, 302, 304, 307-308, 521, 605
last, 154, 289, 309, 520
Paging, 154, 267-268, 286, 289-292, 294-298,
306-307, 309, 463, 519-520
demand, 291-292, 306-307
page replacement, 291, 294, 581
page size, 298, 307, 309, 519
page tables, 292, 294, 298
Palm OS, 49
paper, 24, 57, 148, 198, 206, 219, 227, 229,
333-334, 360, 369, 445, 530, 659-660, 662
paragraphs, 43, 107, 555
Parallel organization, 7, 574

cache coherence, 574
nonuniform memory access (NUMA), 574
vector computation, 574
Parallel processing, 56, 573-625
parallelism, 41-42, 179, 535-571, 578, 581,
588-589, 592-593, 605-606, 628-629, 631,
651-652, 659-660, 665
instruction-level, 535-571, 588-589, 592-593,
629, 631, 660, 665
machine, 535-536, 538, 540-543, 548-549,
551-552, 555-556, 565, 567, 578, 592, 652,
665
Parameter, 2, 51, 157, 228, 310, 348, 424, 434
Parameters, 49, 74, 89, 117, 124-125, 148,
151-152, 157, 187, 194, 219, 270, 300, 305,
348, 429, 433-435, 599, 622, 652
Parity, 74, 173, 176, 180, 184, 198, 201, 203-207,
218, 229, 265, 438-439, 521, 531
Parity bit, 173, 176, 184, 204, 218, 229, 265, 418
Parity bits, 173, 203, 205
Partial remainder, 340-342
Partitioning, 219, 267-268, 286-288, 290,
307-308
fixed, 286-287, 308
Pascal, 155, 410, 437
Passing, 2, 116, 189, 424, 434, 645
Path, 30, 32, 44, 61, 86, 95, 195, 242-243,
249-250, 254, 259, 492, 511, 649, 652, 658
paths, 20, 29, 33, 39, 84-85, 97, 141, 259, 322,
332-333, 404, 489-490, 575, 577, 616, 618
Pattern, 29, 102, 138, 143, 165, 167, 192, 206,
330, 341, 345-346, 359, 364, 402, 504,
570-571, 584
patterns, 40, 117, 188, 202, 227-228, 330, 349,
399, 571
Pentium, 37, 41, 45, 59, 62, 98, 114, 128, 143-144,
180, 262, 267, 292, 296-301, 436, 445, 494,
518, 530, 549, 551-556, 570, 582, 584, 593,
659-660
Pentium 4 Processor, 146, 566, 660
Perfect, 207
performance, 1-2, 5, 7, 10, 15-64, 86-90, 93,
98-99, 108-109, 113-118, 120-121, 124-125,
127, 138-139, 141-143, 146-149, 152-154,
159-160, 176-177, 182, 194, 197-198, 200,
205-206, 208-209, 211, 219-220, 222, 234,
249, 252-253, 259, 270, 286, 309-310, 361,
419, 473, 480, 499-500, 502, 504-505, 509,
514, 519, 521, 530-532, 535-538, 547-549,
565-566, 592-593, 595-598, 605-607,
612-613, 616, 618-621, 627-634, 636-640,
655-666
Peripherals, 7, 12, 25, 27, 40, 89, 224, 228, 231,
251-252, 429
Permanent storage, 550
Personal computer, 44, 98, 192, 629
Phase, 215, 352, 354, 383, 507, 618
Phase change, 215
Physical layer, 65, 94-97, 100, 102, 253, 257
pipelines, 42, 507, 509, 530, 536, 542-543, 550,
561-562, 565, 569, 588-589, 618, 629-632,
651, 655
pipelining, 38, 42, 44, 51, 143, 146, 487-488,
499-500, 502, 504, 506, 508, 530, 532, 534,
541, 574, 611, 629-632, 651
branches and, 502, 530
bubble, 506
cycle time, 51, 500, 504

34, 536-537, 547-549, 551-553, 555,
58, 563-565, 567-571, 574-578, 580-
595-599, 611-616, 618-625, 629-636,
643, 658-661, 664-666
25, 27, 34, 54, 62, 64, 70, 73, 86, 106,
123, 129, 134-136, 140-141, 147-153,
162-163, 167, 169-171, 185, 243, 265,
299, 330, 419-420, 440-441, 443,
477, 466, 470-471, 473, 482, 486, 488,
3
y of, 118-119
106, 429
1, 38, 89, 98, 128, 580, 599-600, 629
II, 16
Web, 54
Web (WWW), 54

Worm, 219
wrapping, 378

WRITE, 10, 28-29, 36, 58, 61, 67-68, 72-76,
83-85, 87, 90-93, 100, 102-104, 114,
116-117, 121, 126, 139-140, 142, 146-149,
153, 162-167, 171, 179, 181, 185, 187-190,
192-195, 203-209, 211-212, 214-215, 218-
219, 226-228, 230-233, 239-240, 242-243,
246-248, 251, 255, 265-266, 297, 299-302,
305-306, 309, 315, 378, 393, 398, 406, 412,
424, 443, 450, 501, 503, 507-508, 519-520,
543-546, 558-559, 582-587, 620-622, 644,
646

Write operation, 74, 91, 93, 111, 117, 162,
164-166, 193, 195, 204-205, 219, 248, 265,
300-301, 508

writing, 4, 35, 61, 139, 162-163, 166-167, 185,
189, 196, 209, 214, 218, 222, 252, 397,
436-437, 443, 446, 451, 488, 515, 523, 543,
584, 614, 641

Y

Yield, 44, 68, 138, 159, 439, 548, 577, 620

Z

Zero, 35, 74, 96, 141-142, 198, 208, 246, 305,
308, 323, 325, 345-346, 349-352, 357-358,
360, 415, 430-431, 436, 438-439, 442-444,
446-448, 454, 468, 471, 473, 477, 481,
491-493, 523, 527, 531, 533

Zone, 191, 640-641



NINTH EDITION

COMPUTER ORGANIZATION AND ARCHITECTURE

DESIGNING FOR PERFORMANCE

WILLIAM STALLINGS

For these special editions, the editorial team at Pearson has collaborated with educators across the world to address a wide range of subjects and requirements, equipping students with the best possible learning tools.

This international edition preserves the cutting-edge approach and pedagogy of the original, but may also feature alterations, customization and adaptation from the United States version.

This edition is manufactured in India and is authorized for sale only in India, Bangladesh, Bhutan, Pakistan, Nepal, Sri Lanka and the Maldives.

   /PearsonIN

ISBN 978-93-325-1870-4



9 789332 518704

www.pearson.co.in

Cover Image: Shutterstock.com