INDEX

A

absolute (direct) addressing, 169, 172
accumulators, 104–105, 110
  bit shifts, 143
  defined, 186
addition circuits, 62
  carry look-ahead adder circuits, 68–69
  full adder circuits, 66–67
  half adder circuits, 63–65
  ripple carry adder circuits, 67–68
ADD mnemonic, 163, 166, 192
address assignment, 89–91
address bus, 92, 96–97, 99
addressing modes, 165, 168
  absolute addressing, 169, 172
  effective addressing, 169
  indirect addressing, 170–171, 174
  relative addressing, 173
address modification, 174–175
address pointers, 91, 92
address references, 167
address registers, 108
address space (memory space)
  control of, 90, 119–120
  external devices, 121
  size of, 96–97
ALUs (arithmetic logic units), 22–24
  74S181 example, 177
  and binary arithmetic, 47
  and bus width, 95
AND gate (logic intersection gate), 51–55
applications, 198
arithmetic operations, 15,
  in binary, 44–47
  as instructions, 142–144, 179–180
arithmetic shifts, 149–151
arithmetic unit, 16–19, 22–24
assembly languages, 193, 198
  characteristics of, 194, 196–197
  smaller-scale software development, 198
asynchronous counters, 82
ATMs, 25–26, 113–114

B

base 2 system. *See* binary number (base 2) system
base 10 (decimal number) system, 38–41
base registers, 175, 186
Basic Input/Output System (BIOS), 120, 208
billion floating-point operations per second (GFLOPS), 138
binary number (base 2) system
  addition and subtraction in, 44–47
  vs. decimal, 38–41
  sign bits, 147–148
BIOS (Basic Input/Output System), 120, 208
bits, 39, 97
bit shifts, 143
  arithmetic shifts, 149–151
  circular shifts, 152
  left shifting, 146
  logical shifts, 145–146, 149
  overflow, 150–151
  right shifting, 145–146
block, 133
borrow flag, 187
branches, 113
branch instructions, 155–157
  conditional jumps, 161
  in programs, 200–203
bundled signal pathways, 94–95
buses
  address bus, 92, 96–97, 99
  bundled signal pathways, 94–95
  bus width, 95–97
  control bus, 99
  data bus, 92, 95, 99
  external bus, 92–93, 96
  internal data bus, 92–93
bytes, 97

C

CAD (computer-aided design) programs, 85
carry flag (C-flag), 160, 187
carry input and output, 67
carry look-ahead adder circuits, 68–69
central processing units. *See* CPUs (central processing units)
C-flag (carry flag), 160, 187
circular shifts (rotating shifts), 152
CISC (complex instruction set computer) architecture, 239
clock frequency, 133–134
clock generators, 134–135, 208
clocks, 78–80, 133
  degree of accuracy, 134
  frequency of, 133–134
clock speed, 133–134
command input, 24
compiling, 197, 198
complements
  in binary arithmetic, 44–47, 147–148
  in logic operations, 60–61
  and relative addressing, 173
complex instruction set computer (CISC) architecture, 239
compression, 32–33

computer-aided design (CAD) programs, 85
computers
components of, 16
information processing, 11–13
operations of, 14–15
condensers, 134
conditional branches, 161
conditional jumps, 161, 202
conditional skips, 161
condition evaluation, 113
branch instructions and, 161, 200–203
status flags, 158–160, 187–188
continuous output, 31
control (instruction) flow, 16, 21
control bus, 99
control signals
I/O signals, 100
R/W signals, 98–99
control unit, 16, 19–21
counters
asynchronous counters, 82
program counter, 107–108, 112–114, 187
synchronous counters, 82
C++ programming language, 198
C programming language, 197, 198
CPUs (central processing units)
accumulators, 104–105
addresses, 89–91
address space, 90, 96–97, 119–121
ALUs, 22–24
architecture, 106–107
arithmetic unit, 16–19
buses, 92–97
clock, 133–135
compression, 33
control signals, 98–100
control unit, 16, 20–21
current technologies, 238–239
decision making, 25–27
information processing, 11–13
instruction processing cycle, 107–114
interaction with other components, 16
interrupts, 122–129, 135–137
I/O ports, 132–133
memory classifications, 132
memory devices, 115–118
memory system. *See* memory system
vs. microcontrollers, 216–217
operands and opcodes, 102–103
operation processing, 14–15, 18–19, 25–27
performance of, 138
pre-execution process, 208–209
program counter, 107–108, 112–114
registers, 103–105
reset signals, 136–137
stack and stack pointer, 126–127
crystal oscillators, 134

D

data bus, 92, 95, 99
data flow, 16, 21
data transfer operations, 153
decimal number (base 10) system, 38–41
De Morgan's laws, 60–61
destination operand, 164
D flip-flops, 78–80
digital information and operations, 12–13, 204. *See also* addition circuits; logic operations; memory circuits
addition and subtraction in binary, 44–47
vs. analog, 31–33
binary vs. decimal system, 38–41
fixed- and floating-point numbers, 42–43
mobile phones, 224
reciprocal states, 37–38
direct (absolute) addressing, 169, 172
discrete output, 31
DSPs (digital signal processors), 222–224

E

effective addressing, 169
electron vacuum tubes, 220
embedded controllers, 215. *See also* microcontrollers
ENIAC computer, 220
exclusive logic union gate (XOR gate), 57, 59
exponents, 42
external bus, 92–93, 96
external devices
address space, 121
external bus, 93
I/O ports and signals, 100, 121, 132–133, 154
microcontrollers and, 219
synchronization, 124

F

facial-recognition software, 204
falling edge, 79
fast Fourier transforms (FFTs), 224
fetching, 111
field-programmable gate arrays (FPGAs), 85, 225
fixed-point numbers, 42–43
flip-flop circuits, 74–75
D flip-flops, 78–80
RS flip-flops, 76–77
T flip-flops, 81–83
floating-point numbers, 42–43, 137–138, 151, 224
FLOPS (floating-point operations per second), 137–138
FPGAs (field-programmable gate arrays), 85, 225
FPUs (floating point units), 15
frequency dividers, 135
full adder circuits, 66–67

G

GFLOPS (billion floating-point operations per second), 138
GPUs (graphics processing units), 133
ground, 37
GT flag, 187

H

half adder circuits, 63–65
hard disk drives (HDDs), 115–118
hardware description language (HDL), 85
high-level languages, 193
  characteristics of, 194–197
  large-scale software development, 198

I

ICs (integrated circuits), 48–50. *See also* microcontrollers
  addition circuits, 62–69
  architecture, 178
  De Morgan's laws, 60–61
  DSPs, 222–224
  function table, 179
  logic gates, 50–59
  memory circuits, 70–83
  modern circuit design, 85
  pins, 49–50, 177
immediate value processing, 166
index registers, 175, 186
indirect addressing, 170–171, 174
information, 30–31. *See also* digital information and operations
  analog, 31–33
  compression of, 32–33
  processing of, 11–13
  signal-to-noise ratio, 30
  transmission of, 31, 185
information technology (IT), 30
input devices, 16–17
input/output (I/O) instructions, 154
input/output (I/O) ports, 100, 121, 132–133
input/output (I/O) signals, 100
input/output (I/O) space, 117, 121
instruction (control) flow, 16, 21
instruction decoders, 109, 186
instruction registers, 105, 109, 186
instructions. *See* operations and instructions
integrated circuits. *See* ICs (integrated circuits); microcontrollers
internal data bus, 92–93
interrupt flag, 188
interrupt masks, 128, 187
interrupts, 122–125
  non-maskable, 129
  priority of, 128–129
  resets, 209
  stack and stack pointer, 126–127
  timer, 129, 135–136
interrupt signals, 136
interrupt vector table (IVT), 209
I/O (input/output) instructions, 154
I/O (input/output) ports, 100, 121, 132–133
I/O (input/output) signals, 100
I/O (input/output) space, 117, 121
IT (information technology), 30
IVT (interrupt vector table), 209

J

Java, 198
jump instructions, 155–157, 161

L

large-scale software development, 198
latching, 74, 77
LDA mnemonic, 167, 192
left shifting, 146
load/store (L/S) signals, 98–99
logical shifts, 145–146, 149
logic gates, 50–51
  addition circuits, 62–69
  AND, 51–55
  De Morgan's laws, 60–61
  NAND, 57–58
  NOR, 57–59
  NOT, 51, 53, 56
  OR, 51–52, 55
  XOR, 57, 59
logic intersection complement gate (NAND gate), 57–58
logic intersection gate (AND gate), 51–55
logic negation gate (NOT gate), 51, 53, 56
logic operations, 15, 33, 179, 181. *See also* logic gates
  De Morgan's laws, 60–61
  instructions for, 143
  integrated circuits, 48–50
logic union complement gate (NOR gate), 57–59
logic union gate (OR gate), 51–52, 55
loops, 113
lossless compression, 33
lossy compression, 33
L/S (load/store) signals, 98–99
LT flag, 187

M

machine code monitors, 208
machine language, 142, 194
memory circuits
  flip-flop circuits, 74–83
  importance of, 71–73
  registers, 70–71, 103–105
memory management units (MMUs), 114
memory space. *See* address space
memory system
  addresses, 89–91
  classifications of memory, 132
  hard disk drives, 115–118
  I/O space, 121
  primary memory, 16, 18–19, 70, 115, 116–118
  RAM space, 119–121
  ROM space, 119–121
  secondary memory, 16, 18, 115
  solid state drives, 118

MFLOPS (million floating-point operations per second), 138
microcontrollers, 213
  architecture of, 220
  vs. CPUs, 216–217
  DSPs, 222–224
  function of, 214–215
  history of, 220–221
  in industrial machines, 224–225
million floating-point operations per second (MFLOPS), 138
MIPS (million instructions per second), 137
MMUs (memory management units), 114
mnemonics, 163, 192, 196–198
mode pin, 177, 179
modification registers, 175, 186
motherboards, 120
multiplexers (MUX), 93
multiplier-accumulate operation circuits, 222, 224

N

NAND gate (logic intersection complement gate), 57–58
negative flag (N-flag), 187
noise (information), 30, 33
non-maskable interrupts (NMI), 129
non-volatile memory, 132, 208
NOR gate (logic union complement gate), 57–59
NOT gate (logic negation gate), 51, 53, 56
number systems, 38–41

O

object code, 199
ODD flag, 187
on-board programming, 208
opcodes, 102–103, 110, 142, 162–163, 180
operands, 102–103, 110, 142
  addressing modes, 165, 168–174
  address modification, 174–175
  address references, 167
  immediate value processing, 166
  number of, 163–164
  types of, 162–165
operation execution speed, 137
operations and instructions, 14. *See also* arithmetic operations; bit shifts; digital information and operations; logic operations
  ALUs and, 22–24
  branch instructions, 155–157, 161, 200–203
  data transfer operations, 153
  I/O instructions, 154
  jump instructions, 155–157, 161
  memory and, 18–19, 70–71, 89–90, 103–105
  processing and decision making, 25–27
  programs and, 19
  skip instructions, 157
  SLEEP instruction, 188
  types of, 15
OR gate (logic union gate), 51–52, 55
output devices, 16–17
overflow, 45, 150–151
overflow flag (overflow bit; OV-flag), 151, 187

P

parallel transmission, 185
PC (program counter), 107–108, 112–114, 187
personal computers (PCs), 220
pins, 49–50
pipelining, 238
prefetch instructions, 238
primary memory, 16, 18–19, 70, 115, 116–118
primitives, 32
processing speed, 118
program counter (PC), 107–108, 112–114, 187
programs, 19, 101, 192, 199
  assembly languages, 192–194, 196–197
  with conditions and jumps, 200–203
  control unit and, 20–21
  high-level languages, 194–197
  large-scale software development, 198
  machine language, 194
  pre-execution process, 208–209
  vs. source code, 199
  storage of, 208
propagation delay, 68
Python, 198

R

RAM (random access memory), 119–121, 132, 208
read-only memory (ROM), 119–121, 132, 208
read/write (R/W) signals, 98–99
read-write memory (RWM), 132
reduced instruction set computer (RISC) architecture, 238–239
registers, 70–71, 83, 103–104
  accumulators, 104–105, 110, 143, 186
  address registers, 108
  base registers, 175, 186
  index registers, 175, 186
  instruction decoders, 109, 186
  instruction registers, 105, 109, 186
  program counter, 107–108, 112–114, 187
  shift registers, 185
  stack pointer, 126–127, 187
  status registers, 160, 186
  temp registers, 186
relative addressing, 173
repeating processes, 202
resets, 128–129
reset signals, 136–137

reset vector, 208–209
right shifting, 145–146
ripple carry adder circuits, 67–68
RISC (reduced instruction set computer) architecture, 238–239
rising edge, 79
ROM (read-only memory), 119–121, 132, 208
rotating shifts (circular shifts), 152
RS flip-flops, 76–77
R/W (read/write) signals, 98–99
RWM (read-write memory), 132

S

SAM (sequential access memory), 132
scientific notation (standard form), 42
SD cards, 220
secondary memory, 16, 18, 115
select pins, 177, 179
semiconductors, 220
sequential access memory (SAM), 132
serial transmission, 185
S-flag (sign flag), 160, 187
shift registers, 185
signal (information), 30
signals (I/O), 56
signal-to-noise ratio, 30
sign bits, 147–148
sign flag (S-flag), 160, 187
skip instructions, 157
SLEEP instruction, 188
solid state drives (SSDs), 118
source code, 198–199
source operand, 164
stack, 126–127
stack pointer (SP), 126–127, 187
STA mnemonic, 167, 192
standard form (scientific notation), 42
state, 71, 74
status flags, 159–160, 187–188, 201
status output, 24–26
status registers, 160, 186
synchronization, 124
synchronous counters, 82

T

temp registers, 186
T flip-flops, 81–83
TFLOPS (trillion floating-point operations per second), 138
thermometers, 31–32
timer interrupts, 129, 135–136
transistors, 220
trigger conditions, 74
trillion floating-point operations per second (TFLOPS), 138
truth tables, 53–56, 58–59
two's complement
  in binary arithmetic, 44–47
  expressing negative numbers in binary, 147–148
  and relative addressing, 173

U

underflow, 151

V

variables, 195
Venn diagrams, 54–56, 58–59
virtual memory, 114
vocoders, 224
volatile memory, 132
voltage, 31
  as binary states, 37–38
  and reset process, 136–137
  and turning on CPU, 208

X

XOR gate (exclusive logic union gate), 57, 59
xx-register relative addresses, 173

Z

zero flag (Z-flag), 187