INDEX

Symbols	В
& (AND operator), 242–243	background (NES), 177, 187-189
~ (complement operator), 244	Backus–Naur form (BNF), 28–32
« (left-shift operator), 239–240	bank switching (NES), 144, 148-149
- (minus sign), 79	BASIC, 21–59
(OR operator), 240–242	dialects of, 22–23
>> (right-shift operator), 240	history of, 22-23
:= (walrus operator), 77	variables in, 25
^ (XOR operator), 130, 243–244	BCC instruction (6502), 163
	BCS instruction (6502), 163
A	BEQ instruction (6502), 163
abstraction, 23	big-endian order, 81–82
abstract syntax tree, 9, 32–33, 39, 42–48	binary
layers of, 117	operations, 239–244
ADC instruction (6502), 163	review of, 237–239
addressing modes (6502), 153-154, 170-172	binary-coded decimal (BCD), 121
ahead-of-time compilation, 17	BIT instruction (6502), 163
algorithms	bit planes, 179–180
dithering, 67–72	bits, 179, 238
hill climbing, 105	per pixel, 181
KNN, 207–218, 222–224	bitwise operations, 237–244
accuracy, 218	BMI instruction (6502), 164
machine learning, 206–218	BNE instruction (6502), 164
performance of, 211	BNF (Backus-Naur form), 28-32
stochastic optimization, 111	Boolean expressions in BASIC, 26, 31
stochastic painting, 89-95	parsing in NanoBASIC, 46
Allen, Paul, 22–23, 201	boolean_expr production rule, 32
Allison, Dennis, 30, 42	BPL instruction (6502), 164
AND operator (&), 242–243	Brainfuck, 3–19
animated GIFs, 64, 86	description of, 4
APU (audio processing unit), 143, 145	example programs, 6–9
ArgumentParser, 11–12, 33, 66, 95–96, 146	history of, 3–4
artificial intelligence (AI), 206	implementation of, 10-14
ASL instruction (6502), 163	testing the interpreter, 15–16
AST (abstract syntax tree), 9, 32–33, 39, 42–48	BRK instruction (6502), 164
Atkinson, Bill, 67, 86	Brofeldt, Pekka, 212
Atkinson dithering, 67–72, 86	buffer overflow protection, 112
attribute tables (NES), 180–183	bytecode, 17, 116, 139
audio on NES, 143	bytes, 238–239

C	CPX instruction (6502), 165
C (programming language), 6	CPY instruction (6502), 165
cartridges (NES), 144, 148–152	cross validation, 218
characters in terminals and non-	CRT televisions, 147, 185
terminals, 29	CSV files, 210, 212–213, 215
CHIP-8, 115–140	
description of, 115–117	D
history of, 116–117	data fork, 80
implementation of, 122–136	DataPoint class, 209-211
instructions, 119–122	data points, 209–211
memory and registers, 117–119	DEC instruction (6502), 165
playing games on, 137–138	declaration vs. imperative
testing the virtual machine,	languages, 23
136–137	DEFLATE algorithm, 86
CHR RAM (NES), 149, 177-178	DEX instruction (6502), 165
CHR ROM (NES), 149, 177–178	DEY instruction (6502), 165
classification	digital art, 85
of digits, 215–217	Digit class, 215-216
of fish, 212–214	digits classification of, 215-217
with KNN, 205–219	handwritten, 215–217, 224–228
CLC instruction (6502), 164	regression on, 224–228
CLD instruction (6502), 164	Dijkstra, Edsger, 27, 48
CLI instruction (6502), 165	dithering, 63–87
CLR (Common Language Runtime),	algorithms for, 67–72
139–140	Atkinson dithering, 67–72, 86
CLV instruction (6502), 165	explanation of, 64–65
CMP instruction (6502), 165	Floyd-Steinberg dithering,
collision detection (NES), 191	67–69, 86
color dithering algorithms 63–72	DMA (direct memory access), 156, 174
in MacPaint, 180–182	domain-specific languages (DSLs), 57
in NES, 183-184	drawing
in stochastic painting algorithm,	backgrounds (NES), 187–189
90-95	using CHIP-8, 128–130
Common Language Runtime (CLR),	using Pygame, 224–228
139–140	dynamic recompilation, 132
compilation, 17, 57	E
compilers, 17	-
complement (~) operator, 244	EOR instruction (6502), 165
computational art, 63–112	error-diffusion dithering, 67–69
creating abstract impressions,	error handling
89–112	in BASIC interpreter, 40–41
consume() function, 42	in CHIP-8 VM, 126
COSMAC VIP, 117	esoteric programming languages, 3, 10
Counter (Python), 211	Euclidean distance, 206, 209, 211, 218
CPM instruction (6502), 165	F
CPU (central processing unit) in NES,	_
143, 152–176	Fayzullin, Marat, 149
	Fibonacci sequence, 27–28, 135

C1 C	
file formats	I
iNES, 149	IBM PC, 23, 200
MacBaint 79, 87	IF statement (BASIC), 26
MacPaint, 72–87	parsing in NanoBASIC, 43-44
finite state machine, 152	IfStatement node, 36–37
Fish class, 213–214	IFTHEN statements, 26
fish classification, 212–214	image processing, 63–87
fish weight prediction, 224	imperative vs. declarative languages, 23
flags register (6502), 155–176	impressionism, 90
flipping sprites (NES), 190–191	INC instruction (6502), 165
Floyd-Steinberg dithering, 67–69, 86	index register, 118
font set (CHIP-8), 126–127	iNES file format, 149
forks (Mac OS), 80–82	inheritance, 37–39
FPS (frames per second), 185, 199–200	InterpreterError class, 40-41
frames (NES), 185	interpreters, 3–59
functional programming, 23–24, 52	Brainfuck, 3–19
•	components of, 9, 32–33
G	implementing, 10–14
games	NanoBASIC, 21–59
BrickBreaker, 178, 181, 198	overview of, 17–18
Chase, 198	parser, 9, 41–48
Lan Master, 199	structure of, 9
Thwaite, 182	runtime, 9, 49–53
Gates, Bill, 22–23, 201	tokenizer, 9, 33–36
getattr() function, 224	INX instruction (6502), 166
getcolors() method (Pillow), 100	INY instruction (6502), 166
getpixel() method (Pillow), 71	
GIFs, 64, 86, 96, 107, 227–228	J
GOSUB statement (BASIC), 24, 26	Java, 17, 18, 116, 117, 139
GOTO statement (BASIC), 24, 26–27	JIT (just-in-time) compilation,
grammar	17, 140
for BASIC, 28–32	JMP instruction (6502), 166
context-free, 30	Joypad class, 154, 173–174
formal definition of, 28-32	JSR instruction (6502), 166
graphics	jump tables, 131–132, 157–161
on CHIP-8, 128–130	just-in-time (JIT) compilation, 17, 140
on NES, 176–185	Just in time (J11) compliation, 17, 110
in retro image processing, 63-87	K
in stochastic painting algorithm,	k-d tree, 218
89–112	Kemeny, John, 22, 55
grayscale, 64–66, 215	k-means clustering, 235
	KNN (k-nearest neighbors), 205–229
Н	algorithm explanation, 207–209
halftone, 64	classification with, 205–219
Hamming distance, 209, 218	history of, 205
hblank (NES), 147, 185	implementing, 209–212
hill climbing, 105–106	regression with, 221–229
homebrew games, 143	16g16551011 with, 221–229
y	

Kopec, Danny, 55	Microsoft, 22–23, 140, 201
Kurtz, Thomas, 22, 55	minus sign (-), 79
	mirroring (NES), 172-174, 180-181
L	MOS 6502, 200
LDA instruction (6502), 166	Müller, Urban, 3–4, 6, 10
LDX instruction (6502), 166	
LDY instruction (6502), 166	N
left-shift (<<) operator, 239–240	nametables (NES), 180-181
LET statement (BASIC), 25, 45	NanoBASIC, 21–59
parsing in NanoBASIC, 45	description of, 22–24
LetStatement node, 39	example programs, 27–28
libraries	formal grammar, 28–32
Pillow, 66-67, 71-72, 82-84,	implementation of, 32–53
99-102	parser, 41–48
Pygame, 123-124, 126, 146-147,	running a program, 53
216, 224–228	style and syntax, 24–27
line numbering (BASIC), 24	testing, 53–57
lines (stochastic painting), 93-95	tokenizer, 33–36
LineStatement node, 39	nearest() method, 211
Lisp, 17	NES (Nintendo Entertainment System),
little-endian order, 82	141–201
LLMs (large language models), 206	background drawing, 187–189
logic programming, 23	cartridges, 148–152
Logo (programming language), 56	colors, 183–184
LSR instruction (6502), 166	CPU emulation, 152–176
	description of, 142–144
M	emulator structure, 145
MacBinary, 80–83	frames and timing, 185
machine learning, 205–229	hardware, 143–144
history of, 206	history of, 142–143
KNN algorithm, 207–218	instruction execution,
regression with KNN, 221–229	130–136
Macintosh, 63-65, 80-82, 201	main loop, 145–148
Mac OS, 80–82	memory access, 170–175
MacPaint, 63-87	PPU emulation, 176–195
file format, 72–87	software, 144–145
run-length encoding, 73–79	sprite drawing, 189–191
mappers (NES), 149, 201	testing the emulator,
match statement, 12, 48, 132, 151	194–197
MemMode enum, 153–154, 170–172	NesDev, 142–143, 183, 234–235
memory access modes (6502), 153–154,	neural networks, 206, 228, 235
170–172	nibble, 119
memory in CHIP-8, 117–119	non-terminal, 28
memory-mapped registers, 143,	NOP instruction (6502), 166
172–173	NROM mapper, 149
memory page, 154	NumPy, 123, 146, 189, 216, 223–224
microprocessor, 143, 152–153	Nystrom, Robert, 234

0	program counter, 118
object-oriented programming	programming languages
(OOP), 23	BASIC, 21–59
OCR (optical character recognition), 215	Brainfuck, 3–19
one-time pad, 244	C, 6
opcodes	creating your own, 234
CHIP-8, 119–122	Logo, 56
6502, 152–169	NanoBASIC, 21–59
OR () operator, 240–242	paradigms of, 23–24
ORA instruction (6502), 166	Turing-complete, 4–5
overfitting, 218	<pre>putpixel() method (Pillow), 71</pre>
, 410	Pygame, 123–124, 126, 146–147, 216,
P	224–228
PackBits algorithm, 75–77	Python
palettes (NES), 180–184	Counter, 211
Panic Playdate, 64, 86	match statement, 12, 48, 132, 151
ParserError class, 40–41	performance, 199-200
parsers, 9, 41–48	Protocol, 209-210
recursive descent, 41–48	struct module, 150
pattern tables (NES), 178–180	type hints, 12, 35
PHA instruction (6502), 167	walrus operator, 77
PHP instruction (6502), 167	•
picture processing unit. See PPU	Q
Pillow library, 66–67, 71–72, 82–84,	QR codes, 238
99–102	_
pixels	R
in CHIP-8, 128–130	RAM
in dithering, 63–87	in CHIP-8, 117–119
in NES, 176–195	in NES, 143, 148–149, 151
in stochastic painting, 89–112	RAM size, 143, 151
PLA instruction (6502), 167	random() function, 103
play_sound property, 125	recursion, 52
PLP instruction (6502), 167	recursive descent parsing, 41-48
PPU (picture processing unit), 143, 145,	registers
176–195	in CHIP-8, 117–119
accessing memory, 193–194	in 6502, 155–156
accessing registers, 191–193	regression
description of, 176–185	of digits, 224–228
drawing backgrounds, 187–189	with KNN, 221-229
drawing sprites, 189–191	predicting fish weights, 224
implementation of, 185–194	resolution
PRG RAM (NES), 148–149, 151	of CHIP-8 games, 128
PRG ROM (NES), 148–149, 151	of MacPaint, 72
PRINT statement (BASIC), 25–26	of NES, 180
parsing in NanoBASIC, 44	resource fork, 80
PrintStatement node, 39	retro computing, 63-87
production rules, 28–32	Retro Dither, 85
P. 5 3 3 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	

RETURN statement (BASIC), 26	implementation of, 99–107
ReturnStatement node, 39	results of, 107–110
RETURN_T token, 45	strings, escaping, 58
right-shift (>>) operator, 240	struct module, 150
RLE (run-length encoding), 73–79	STX instruction (6502), 168
ROL instruction (6502), 167	STY instruction (6502), 168
ROM files, 122, 144–145, 149–152	SVG (Scalable Vector Graphics),
ROR instruction (6502), 167	97–98
RTI instruction (6502), 167–168	switch statement, 131
RTS instruction (6502), 168	System 1 (Mac OS), 84
run-length encoding (RLE), 73–79	T
S	
	take_same() function, 76–77
SBC instruction (6502), 168	TAX instruction (6502), 168
scanlines, 147, 185	TAY instruction (6502), 169
scrolling (NES), 201	terminal, 29
SeaTurtle, 56, 234	testing
SEC instruction (6502), 168	Brainfuck interpreter, 15–16
SED instruction (6502), 168	CHIP-8 VM, 136–137
SEI instruction (6502), 168	dithering, 78–79
setZN() method, 175	NanoBASIC interpreter, 53–57
shunting yard algorithm, 48	NES emulator, 194–197
6502 microprocessor, 143, 152–176	OCR with KNN, 216–217
addressing modes, 153–154,	text processing, 229
170–172	Thwaite (game), 182
CPU emulation, 152–176	tiles (NES), 178–180
registers, 155–156	timers
sound	in CHIP-8, 118, 125
on CHIP-8, 125	in NES, 185
on NES, 143, 201	tokenizer, 9, 33–36
speed	Torvalds, Linus, 22
of NES emulator, 199–200	transpiler, 18
of stochastic painting, 95	TSX instruction (6502), 169
sprites	TXA instruction (6502), 169
on CHIP-8, 129–130	TXS instruction (6502), 169
on NES, 177, 189–191	TYA instruction (6502), 169
stack, 155, 175	type hints, 12, 35
stack pointer, 156	
STA instruction (6502), 168	U
standard library, 11, 71	under-fitting, 218
Statement node, 37	unit tests, 15–16, 78–79, 194–197,
static type checking, 12	213–217, 224
status register (6502), 156, 175–176	unpack() function, 150
step() method, 132, 169, 187	V
stochastic optimization, 111	V
stochastic painting, 89–112	variables in BASIC, 25
algorithm explanation, 98–99	variable table, 49–51

vblank (NES), 147, 185
vector graphics, 94, 97–98
virtual machines (VMs), 115–140
CHIP-8, 115–140
emulators, compared to, 116
history of, 116–117
Java, 116
runtime environments, 139–140

W

walrus operator (:=), 77 Weisbecker, Joseph, 116 write_memory() method, 174–175

X

XML, 97 XOR (^) operator, 130, 243–244