## Contents

List of Figures			xiii
P	reface	2	xvii
A	bout	the Authors	xxiii
A	cknov	wledgments	xxv
1	Con	npilation	1
	1.1	Compilers	
		1.1.1 Programming Languages	
		1.1.2 Machine Languages	
	1.2	Why Should We Study Compilers?	
	1.3	How Does a Compiler Work? The Phases of Compilation	
		1.3.1 Front End	
		1.3.2 Back End	
		1.3.3 "Middle End"	
		1.3.4 Advantages to Decomposition	
		1.3.5 Compiling to a Virtual Machine: New Boundaries	
		1.3.6 Compiling JVM Code to a Register Architecture	
	1.4	An Overview of the <i>j</i> to JVM Compiler	
		1.4.1 <i>j</i> Compiler Organization	
		1.4.2 Scanner	
		1.4.3 Parser	
		1.4.4 AST	_
		1.4.5 Types	
		1.4.6 Symbol Table	
		1.4.7 preAnalyze() and analyze()	
		1.4.8 Stack Frames	
		1.4.9 codegen()	
	1.5	j Compiler Source Tree	
	1.6	Organization of This Book	
	1.7	Further Readings	
	1.8	Exercises	. 24
<b>2</b>	Lex	ical Analysis	29
	2.1	Introduction	. 29
	2.2	Scanning Tokens	
	2.3	Regular Expressions	
	2.4	Finite State Automata	
	2.5	Non-Deterministic Finite-State Automata (NFA) versus Deterministic	c
		Finite-State Automata (DFA)	. 40

viii Contents

	2.6	Regular Expressions to NFA
	2.7	NFA to DFA 40
	2.8	Minimal DFA 4
	2.9	IavaCC: Tool for Generating Scanners         5-
		Further Readings
	2.11	Exercises $\dots \dots \dots$
3	Pars	ng 5
	3.1	ntroduction
	3.2	Context-Free Grammars and Languages
		3.2.1 Backus–Naur Form (BNF) and Its Extensions 6
		3.2.2 Grammar and the Language It Describes
		3.2.3 Ambiguous Grammars and Unambiguous Grammars 60
	3.3	Fop-Down Deterministic Parsing
	0.0	3.3.1 Parsing by Recursive Descent
		3.3.2 LL(1) Parsing
	3.4	Bottom-Up Deterministic Parsing
	0.1	3.4.1 Shift-Reduce Parsing Algorithm
		3.4.2 LR(1) Parsing
		3.4.3 LALR(1) Parsing
		8.4.4 LL or LR?
	3.5	Parser Generation Using JavaCC
	3.6	Further Readings
	3.7	Exercises
	0.,	220101300
4	Тур	Checking 12'
		ntroduction
	4.2	Types
		1.2.1 Introduction to $j$ Types
		1.2.2 Type Representation Problem
		2.2.3 Type Representation and Class Objects
	4.3	Symbol Tables
		1.3.1 Contexts and Idefns: Declaring and Looking Up Types and Local
		Variables
		1.3.2 Finding Method and Field Names in Type Objects
	4.4	Pre-Analysis of $j$ Programs
		4.4.1 An Introduction to Pre-Analysis
		4.4.2 JCompilationUnit.preAnalyze() 13
		4.4.3 JClassDeclaration.preAnalyze()
		4.4.4 JMethodDeclaration.preAnalyze()
		4.5 JFieldDeclaration.preAnalyze() 13
		4.4.6 Symbol Table Built by preAnalyze() 139
	4.5	Analysis of $j$ Programs
	-	4.5.1 Top of the AST
		4.5.2 Declaring Formal Parameters and Local Variables
		4.5.3 Simple Variables
		4.5.4 Field Selection and Message Expressions
		4.5.5 Typing Expressions and Enforcing the Type Rules
		4.5.6 Analyzing Cast Operations
		4.5.7 Java's Definite Assignment Rule
	4.6	Visitor Pattern and the AST Traversal Mechanism

Contents	ix
0 0	

	4.7			162
	4.8			163
			1	163
				166
			*	167
	4.9		ĕ	168
	4.10	Exercise	es	168
5	JVN	I Code	Generation	171
	5.1	Introdu	ction	171
	5.2	Generat	ing Code for Classes and Their Members	175
		5.2.1	Class Declarations	176
		5.2.2	Method Declarations	177
				177
				178
	5.3			178
				178
				180
				181
	5.4		ing Code for Message Expressions, Field Selection, and Array Access	101
	0.1			181
		-		181
			<u> </u>	183
				184
	5.5			184
	5.5		• • •	184
				186
				188
	T 6			
	5.6			189
	5.7		e e e e e e e e e e e e e e e e e e e	190
	5.8		ĕ	191
	5.9	Exercise	es	191
6		_		205
	6.1	Introdu		205
			11	205
				206
			1	207
	6.2			209
		6.2.1	MIPS Organization	209
		6.2.2	Memory Organization	210
		6.2.3	Registers	211
		6.2.4	Routine Call and Return Convention	212
		6.2.5 ]	Input and Output	212
	6.3			213
				213
			9	214
				221
				227
			- · · · · · · · · · · · · · · · · · · ·	229

x Contents

		6.3.7 Peephole Optimization of the SPIM Code				
	6.4	Further Readings				
	6.5	Exercises				
7	Register Allocation 245					
'	7.1	Introduction				
	7.2	Naïve Register Allocation				
	7.3	Local Register Allocation				
	7.4	Global Register Allocation				
	1.1	7.4.1 Computing Liveness Intervals				
		7.4.2 Linear Scan Register Allocation				
		7.4.3 Register Allocation by Graph Coloring				
	7.5	Further Readings				
	7.6	Exercises				
	7.0	Exercises				
8	Cele	ebrity Compilers 27				
	8.1	Introduction				
	8.2	Java HotSpot Compiler				
	8.3	Eclipse Compiler for Java (ECJ)				
	8.4	GNU Java Compiler (GCJ)				
		8.4.1 Overview				
		8.4.2 GCJ in Detail				
	8.5	Microsoft C# Compiler for .NET Framework				
		8.5.1 Introduction to .NET Framework				
		8.5.2 Microsoft C# Compiler				
		8.5.3 Classic Just-in-Time Compilation in the CLR				
	8.6	Further Readings				
		l' A C.u.' II ID ' '				
ΑĮ		dix A Setting Up and Running j  Introduction				
		Obtaining <i>j</i>				
	A.3	What Is in the Distribution?				
		A.3.1 Scripts				
		A.3.2 Ant Targets				
	A.4	8-13				
	A.5	Setting Up $j$ in Eclipse				
	A.6	Running/Debugging the Compiler				
		Testing Extensions to $j$				
	A.8	Further Readings				
Αı	open	dix B j Language 299				
•	B.1	Introduction				
	B.2	j Program and Its Class Declarations				
	B.3	<i>j</i> Types				
	B.4	j Expressions and Operators				
	B.5	j Statements and Declarations				
	B.6	Syntax				
	ט.ט	B.6.1 Lexical Grammar				
		B.6.2 Syntactic Grammar				
		B 6.3 Relationship of i-to Java				

Contents	X1

Appen	dix C Java Syntax	307
C.1	Introduction	307
C.2	Syntax	307
	C.2.1 Lexical Grammar	307
	C.2.2 Syntactic Grammar	
C.3	Further Readings	313
	dix D JVM, Class Files, and the CLEmitter	315
	Introduction	
D.2	Java Virtual Machine (JVM)	
	D.2.1 pc Register	
	D.2.2 JVM Stacks and Stack Frames	
	D.2.3 Heap	
	D.2.4 Method Area	
	D.2.5 Run-Time Constant Pool	318
	D.2.6 Abrupt Method Invocation Completion	319
D.3	Class File	319
	D.3.1 Structure of a Class File	319
	D.3.2 Names and Descriptors	321
D.4	CLEmitter	322
	D.4.1 CLEmitter Operation	322
	D.4.2 CLEmitter Interface	323
D.5	JVM Instruction Set	327
	D.5.1 Object Instructions	328
	D.5.2 Field Instructions	328
	D.5.3 Method Instructions	329
	D.5.4 Array Instructions	330
	D.5.5 Arithmetic Instructions	331
	D.5.6 Bit Instructions	332
	D.5.7 Comparison Instructions	332
	D.5.8 Conversion Instructions	
	D.5.9 Flow Control Instructions	
	D.5.10 Load Store Instructions	
	D.5.11 Stack Instructions	
	D.5.12 Other Instructions	
D.6	Further Readings	
		-
Appen	dix E MIPS and the SPIM Simulator	341
E.1	Introduction	341
E.2	Obtaining and Running SPIM	341
E.3	Compiling <i>j</i> Programs to SPIM Code	341
E.4	Extending the JVM-to-SPIM Translator	343
E.5	Further Readings	344
Bibliog	raphy	345
	~~~~~~	
$\mathbf{Index}$		351