

Yulei Sui

# Practicing the Art of Static Analysis

December 27, 2022

Springer Nature

# Contents

## Part I Aim & Scope

<b>1</b>	<b>Introduction to Static Analysis</b>	<b>1</b>
1.1	Program Analysis and Static Analysis	1
1.2	Applications of Static Analysis	2
1.2.1	Compiler Optimizations	2
1.2.2	Vulnerability Detection	4
1.2.3	Code Embedding	6
1.2.4	Many Other Program Analyses	6
<b>2</b>	<b>Introduction to Intermediate Representation</b>	<b>7</b>
2.1	LLVM	7
2.1.1	LLVM Compiler	7
2.1.2	LLVM Intermediate Representation (IR)	8
2.1.3	A Compilation Example	9
2.2	SVF	10
2.2.1	SVF Architecture	13
2.2.2	SVF IR and Code Graphs	15
<b>3</b>	<b>Control and Data Dependence</b>	<b>19</b>
3.1	Control Dependence	20
3.1.1	ICFG	21
3.1.2	Control-Flow Reachability	21
3.1.3	Context-Sensitive Control-Flow Reachability	27
3.2	Data Dependence	28
3.2.1	Pointer Analysis	29
3.2.2	Andersen's Inclusion-based Analysis	32
3.2.3	Information Flow Tracking	41

<b>4 Static Value-Flows</b>	47
4.1 Value-Flows	47
4.2 Memory SSA Form	47
4.2.1 Intraprocedural and Interprocedural Memory SSA Forms	47
4.2.2 Interprocedural Side-Effect Analysis	48
4.2.3 Memory Region Generation	49
4.3 Sparse Value-Flows	51
4.4 Value-Flows for Multithreaded Programs	53
4.4.1 Static Thread Model	53
4.4.2 Computing Thread-Oblivious Def-Use Chains	55
4.4.3 Computing Thread-Aware Def-Use Chains	56
4.4.3.1 Interleaving Analysis	56
4.4.3.2 Value-Flow Analysis	58
4.4.3.3 Lock Analysis	58
4.4.4 Sparse Analysis	59
<b>5 Pointer Alias Analysis</b>	61
5.1 Field- and Array-Sensitive Pointer Analysis	62
5.2 Flow-Sensitive Pointer Analysis	66
5.3 Context-Sensitive Pointer Analysis	70
5.4 Points-to Data Structures	75
5.4.1 Compacting Points-To Sets	75
5.4.1.1 Representing Points-To Sets as Bit-Vectors	78
5.4.1.2 Contiguous and Sparse Bit-Vectors	78
5.4.1.3 Core Bit-Vector	81
5.4.1.4 Compacting Points-To Sets	82
5.4.1.5 Integer Programming Formulation	83
5.4.1.6 Hierarchical Clustering	85
5.4.1.7 Linkage Criteria	86
5.4.1.8 Clustering Objects	88
5.4.1.9 More Efficient Region-Based Clustering	89
5.4.1.10 Word-Aligned Identifier Mapping	91
5.4.2 Hash Consed Points-To Sets	93
5.4.2.1 Introduction	93
5.4.2.2 Motivating Examples	96
<b>6 Context-Free Language Reachability</b>	99
6.1 Edge-Labeled Graphs and Context-Free Grammars	99
6.2 All-Pair Analysis and Demand-Driven Analysis	99
6.3 Graph Compaction and Transitive Redundancy	99
<b>7 Software Verification and Symbolic Execution</b>	101
7.1 Code Verification	101
7.2 Predicate Logic	108
7.3 Software Verification Using Theorem Prover	115

<b>Contents</b>	<b>xix</b>
<b>7.4 Assertion-based Verification Using Symbolic Execution . . . . .</b>	<b>124</b>
<b>8 Abstract Interpretation . . . . .</b>	<b>131</b>
<b>8.1 Concrete and Abstract Domains . . . . .</b>	<b>131</b>
<b>8.1.1 Non-Relational Abstract Domains . . . . .</b>	<b>136</b>
<b>8.1.2 Relational Abstract Domains . . . . .</b>	<b>138</b>
<b>8.2 Abstract State and Abstract Execution . . . . .</b>	<b>138</b>
<b>8.2.1 Abstract Execution over Multiple Domains . . . . .</b>	<b>143</b>
<b>8.2.2 Abstract Execution over Memory Address and Interval Domains . . . . .</b>	<b>149</b>
<b>8.3 Sparse Abstract Execution . . . . .</b>	<b>162</b>
<b>8.4 Weak Topological Ordering . . . . .</b>	<b>163</b>
<b>8.5 Data-Flow Analysis . . . . .</b>	<b>164</b>
<b>8.5.1 Maximal Fix Point (MFP) . . . . .</b>	<b>164</b>
<b>8.5.2 Meet Over Feasible Paths . . . . .</b>	<b>164</b>
<b>8.5.3 Meet Over All Paths (MoP) . . . . .</b>	<b>164</b>
<b>8.6 Typestate Analysis . . . . .</b>	<b>164</b>
<b>9 Machine Learning for Static Analysis . . . . .</b>	<b>165</b>
<b>9.1 Learning-Based Static Analysis . . . . .</b>	<b>165</b>
<b>9.2 Vulnerability Detection using Deep Graph Neural Networks . . . . .</b>	<b>165</b>
<b>10 Static Analysis for Machine Learning . . . . .</b>	<b>167</b>
<b>10.1 Deep Neural Networks . . . . .</b>	<b>168</b>
<b>10.2 DNN Robustness Issues . . . . .</b>	<b>169</b>
<b>10.3 Verification for Deep Neural Networks . . . . .</b>	<b>170</b>
<b>10.4 SOTA Tools . . . . .</b>	<b>181</b>
<b>Appendix . . . . .</b>	<b>183</b>
<b>A.1 Online Materials . . . . .</b>	<b>183</b>
<b>A.1.1 Open Courses . . . . .</b>	<b>183</b>
<b>Glossary . . . . .</b>	<b>185</b>
<b>Solutions . . . . .</b>	<b>187</b>
<b>Index . . . . .</b>	<b>189</b>
<b>References . . . . .</b>	<b>190</b>