

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Motivation	2
1.1.1	Code Generation	2
1.1.2	System Abstractions	3
1.2	Our Approach: Certifying Translations	5
1.3	Contributions	7
1.3.1	General Methodology	7
1.3.2	Certifying Code Generation	7
1.3.3	Certifying System Abstractions	8
1.3.4	Evaluation	9
1.3.5	Restrictions	9
1.4	Overview of the Thesis	9
<b>2</b>	<b>Related Work</b>	<b>11</b>
2.1	Work on Behavioral Equivalence	11
2.2	Work on Compiler Correctness	11
2.2.1	Work Related to the Certifying Translations Approach	12
2.2.2	Work Related to Certified Compilers	14
2.3	Work on Correct System Abstractions	15
<b>3</b>	<b>Prerequisites</b>	<b>17</b>
3.1	Basic Mathematical Notions	17
3.2	Transition Systems and Simulation	17
3.3	A Brief Introduction to Isabelle/HOL	24
3.4	A Brief Introduction to Coq	27
<b>4</b>	<b>A Framework for Certifying Translations</b>	<b>31</b>
4.1	Our Semantic Framework	32
4.1.1	Framework Specification	32
4.1.2	Derived Correctness Criteria	41
4.1.3	Applying the <i>Generic Correctness Criteria</i> to Verification Scenarios	43
4.2	Embedding System Descriptions into the Framework - Shallow and Deep Embedding	43
4.3	Working with the <i>Generic Correctness Criteria</i> Family	45
4.3.1	Partial Orders of Correctness Criteria, State Correspondence and Simulation Relations	45
4.3.2	Handling Inputs and Non-Determinism	48

4.3.3	Combining Correctness Criteria . . . . .	48
4.4	Our Correctness Criteria and their Relation to Other Formalisms . . . . .	50
4.4.1	Final Value Semantics . . . . .	51
4.4.2	Explicit Trace Representations in Transition Systems . . . . .	51
4.4.3	Coalgebraic Trace Representations . . . . .	52
4.4.4	Explicit vs. Implicit Trace Representation . . . . .	54
4.5	Discussion: Formalizing the Framework in a Theorem Prover . . . . .	55
<b>5</b>	<b>Certifying Code Generation</b>	<b>57</b>
5.1	Syntax and Semantics of an Intermediate Language . . . . .	58
5.2	Syntax and Semantics of MIPS code . . . . .	64
5.3	The Code Generation Algorithm . . . . .	67
5.4	Correct Code Generation . . . . .	68
5.4.1	Adapting the <i>Generic Correctness Criterion</i> . . . . .	69
5.4.2	Proof Sketch on Proving Code Generation Runs Correct . . . . .	72
5.4.3	Analyzing Proving Effort . . . . .	74
5.4.4	Setting up the Proof: Establishing the Simulation Relation . . . . .	74
5.4.5	Proving the Prerequisites . . . . .	76
5.4.6	Proving the Steps Correct . . . . .	78
5.4.7	Putting it All Together . . . . .	86
5.5	Generating and Handling of the Certificates . . . . .	86
5.5.1	Program Representation Generation . . . . .	87
5.5.2	Certificate Generation Algorithm . . . . .	88
5.5.3	Preparing for the Theorem Prover . . . . .	91
5.6	Using Checker Predicates to Optimize the Proof Process . . . . .	92
5.6.1	The Nature of Checker Predicates . . . . .	92
5.6.2	A Fast Injectivity Proof . . . . .	93
5.7	A Checker Predicate for Semantical Equivalence . . . . .	94
5.7.1	Our Checker Intermediate Language Semantics . . . . .	95
5.7.2	Our Checker MIPS Semantics . . . . .	99
5.7.3	Verifying Steps using the Checker Semantics . . . . .	102
5.7.4	A Checker Predicate Implementation for Fast Step Correctness Checking . . . . .	105
5.7.5	Checker Predicate Correctness . . . . .	107
<b>6</b>	<b>Verifying System Abstractions</b>	<b>113</b>
6.1	SAS Transition Systems . . . . .	115
6.2	Correctness of Abstractions . . . . .	117
6.2.1	Formalizing Properties . . . . .	117
6.2.2	Property Preservation via Simulation . . . . .	119
6.3	Proving Abstractions Correct . . . . .	124
<b>7</b>	<b>Evaluation</b>	<b>127</b>
7.1	Our Certifying Compilers . . . . .	127

7.2	Verification of System Abstractions . . . . .	128
7.3	Certificate Checking with Isabelle and Coq . . . . .	129
7.3.1	Look-up Operations . . . . .	129
7.3.2	Other Performance Effecting Formalization Choices . . . . .	132
7.3.3	Certificate Checking for Code Generation . . . . .	132
7.3.4	Speedup using Checkers and Explicit Proof Terms . . . . .	134
7.3.5	Proof Checking for System Abstractions . . . . .	135
7.4	Framework Evaluation . . . . .	136
7.5	Some Concluding Remarks . . . . .	136
<b>8</b>	<b>Conclusion</b>	<b>137</b>
	<b>Bibliography</b>	<b>141</b>
<b>A</b>	<b>Coq Formalization of Intermediate and MIPS language</b>	<b>151</b>
A.1	Intermediate Language . . . . .	151
A.2	MIPS language . . . . .	155
<b>B</b>	<b>Correctness Formalization in Coq</b>	<b>161</b>
<b>C</b>	<b>Generation of Code Generation Certificates</b>	<b>163</b>
C.1	Variable-Assignment Rules . . . . .	163
C.2	Array-Assignment Rule 1 . . . . .	170
C.3	Branch-Statement Rules . . . . .	170
C.4	Procedure Call and Return Rules . . . . .	171
C.5	Print-Statement Rules . . . . .	173