
Contents

1	Introduction	1
1.1	Formal Verification	1
1.2	Model Checking of Infinite State Space Systems	4
1.3	Goals and Contributions of the Thesis	6
1.4	Structure of the Thesis	7
2	Regular Model Checking	9
2.1	Finite Automata and Transducers	10
2.2	Regular Model Checking	11
2.2.1	Example: Token Passing	11
2.2.2	Acceleration techniques	12
2.3	Abstract Regular Model Checking	15
2.3.1	Abstraction Based on Automata State Equivalence	15
2.3.2	Configuration-Oriented Abstractions	17
2.3.3	Use of ARMC in Verification	18
2.4	Summary of RMC	18
3	Regular Tree Model Checking	21
3.1	Regular Tree Languages and Transducers	22
3.2	Basics of Regular Tree Model Checking	24
3.2.1	Example: Tree Token Passing	25
3.2.2	Acceleration Techniques	25
3.3	Abstract Regular Tree Model Checking	27
3.3.1	Abstraction Based on Automata State Equivalence	28
3.3.2	Abstraction Based on Languages of Finite Height	28
3.3.3	Abstraction Based on Predicate Languages	28
3.4	Implementation and Experimental Results	30
3.4.1	Algorithmic Decomposition of Bottom-up Tree Transducers	30
3.4.2	Verified protocols	31
3.5	Summary of RTMC	33

4	Abstract Regular Tree Model Checking of Complex Dynamic Data Structures	35
4.1	Existing Alternative Approaches	36
4.1.1	Techniques Based on Logics	37
4.1.2	Automata-Based Techniques	40
4.1.3	Other Techniques	42
4.2	ARTMC of Programs with Recursive Data Structures: The Basic Framework	44
4.2.1	The Considered Programs	45
4.2.2	The Considered Properties	46
4.2.3	The Verification Problem	47
4.3	Logic of Bad Memory Patterns	47
4.3.1	Syntax of LBMP	47
4.3.2	Semantics of LBMP	48
4.3.3	An Example: Doubly-Linked Lists	49
4.3.4	Evaluating LBMP Specifications	49
4.4	Tree Automata Encoding of Pointer Manipulating Programs	50
4.4.1	Encoding of Sets of Memory Configurations	50
4.4.2	Tree Memory Configurations in Mona	53
4.4.3	Encoding Program Statements as Tree Transducers	54
4.4.4	Verification of Programs with Pointers using ARTMC	56
4.5	Implementation and Experimental Results	58
4.5.1	An ARTMC Tool for Tree Automata Memory Encodings	58
4.5.2	Case Studies	59
4.5.3	Experimental Results	64
4.6	Implementation Details	64
4.6.1	Mona	65
4.6.2	Transduction	67
4.6.3	Encoding Memory Configuration in Binary	67
4.6.4	Correctness of Tree Memory Encoding After an Abstraction	69
4.6.5	Implementation of the Finite-Height Abstraction	71
4.6.6	Implementation of Predicate-Based Abstraction	72
4.6.7	Implementation of Routing Expressions	74
4.7	Garbage Checking	76
4.8	Summary of ARTMC for Dynamic Data Structures	77
5	Proving Termination of Tree Manipulating Programs	79
5.1	Existing Approaches	81
5.2	The Notions Used	83
5.3	Programs with Trees	85
5.3.1	Program Preprocessing	87
5.4	The Termination Analysis Loop	89
5.5	Using ARTMC in the Proposed Framework	91

5.6	Abstraction of Programs with Trees into Counter Automata ..	94
5.6.1	Abstract Control Flow Graphs	95
5.6.2	Translation to Counter Automata	96
5.7	Checking Spuriousness of Counterexamples	99
5.7.1	Deciding Spuriousness of Lassos without Destructive Updates	102
5.7.2	Checking Spuriousness of Lassos with Destructive Updates	104
5.8	Abstraction Refinement	105
5.9	Implementation and Experimental Results	108
5.9.1	Necessity of Refinement	110
5.10	A Support for the Insert and Delete Statements	111
5.11	Summary of Termination for Tree Manipulating Programs	113
6	Conclusions and Future Directions	115
	References	119
	Proofs	129
A.1	Proof of Lemma 1	129
A.2	Proof of Theorem 2	129
A.3	Proof of Theorem 4	130
A.4	Proof of Theorem 5	131
A.5	Proof of Corollary 1	133