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Weak Muller acceptance conditions for tree automata☆

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Abstract

Over the last decades the theory of automata on infinite objects has been an important source of tools for the specification and the verification of computer programs. Trees are more suitable than words to model nondeterminism and concurrency. In the literature, there are several examples of acceptance conditions that have been proposed for automata on infinite words and then have been fruitfully extended to infinite trees. The type of acceptance condition can influence both the succinctness of the language acceptors and the computational complexity of the decision problems. Here we consider, relatively to automata on infinite trees, two acceptance conditions that are obtained by a relaxation of the Muller acceptance condition: the *Landweber* and the *Muller-Superset* conditions. We prove that Muller-Superset tree automata accept the same class of languages as Büchi tree automata. Also, we show that for such languages the minimal Muller-Superset acceptor is at least as succinct as the minimal Büchi acceptor and, in some cases, it can be exponentially more succinct. Landweber tree automata, instead, define a class of languages that is not comparable with that defined by Büchi tree automata. The main result we prove is that the emptiness problem for this class of automata is decidable in polynomial time, and thus we extend the class of automata with a tractable emptiness problem.

Keywords: Tree automata; Formal languages

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1. Introduction

Since its early days the theory of automata had an astonishing impact in computer science. Several models of automata have been extensively studied and applied to many fields. In the sixties, with their pioneering work, Büchi [2,3], McNaughton [17], and Rabin [18] enriched this theory by introducing finite automata on infinite objects. The connections between such automata and the formal theories have been fruitfully investigated and have originated automata-theoretic approaches to reduce decision problems in the field of mathematical logics to automata decision problems [9,13,21,22].

Automata on infinite words and trees turn out to be very useful for those areas of computer science where nonterminating computations are studied. They give a unifying paradigm to specify, verify, and synthesize nonterminating systems [13,22,23]. A system specification can be translated into an automaton, and thus, questions about systems and their specifications are reduced to decision problems in the automata theory. For example, the satisfiability of a specification can be reduced to checking for the nonemptiness of a language accepted by an automaton. Also, the correctness of a system with respect to a given specification can be rephrased as an instance of the language containment problem. It is thus important to study classes of automata for which nonemptiness is tractable and closure with respect to intersection holds.

In system modeling, trees are more suitable than words to model nondeterminism, which is also useful to model concurrent programs (nondeterministic interleaving of atomic processes). It is worth noticing that some concurrent programs, such as operating systems, communication protocols, and many control systems, are intrinsically nondeterministic and nonterminating. Moreover, by using trees we can express the existential path quantifier, and thus we are able to express lower bounds on nondeterminism and concurrency. This feature turns out to be greatly helpful in applications such as program synthesis [4,5].

In the literature, several acceptance conditions on infinite words have been fruitfully extended to infinite trees, such as Büchi, Muller, and Rabin conditions [21]. The kind of acceptance condition can influence the succinctness of the model, the computational complexity of the decision problems, and the closure properties of the accepted languages. While for Büchi tree automata the emptiness problem is decidable in polynomial time, for Rabin tree automata it is NP-complete. On the other hand, Büchi tree automata are not closed under language complementation, while Rabin tree automata are. Since Rabin tree automata are strictly more expressive than Büchi tree automata (in terms of the class of accepted languages), it is worth searching for new models of automata with interesting closure properties and tractable decision problems.

For automata on infinite objects, the acceptance is defined with respect to the set of states which are visited infinitely often while reading the input. For example, for a Büchi tree automaton, some of the states are accepting and acceptance is granted when on all paths of a tree at least an accepting state is visited infinitely often. For Muller tree automata, the accepting states are given as a collection of sets of states with the meaning that on each path of a tree the set of states that repeat infinitely often is exactly one of the accepting sets. In this paper, we study two new acceptance conditions for tree automata: *Landweber* and *Muller-Superset* acceptance conditions. They are obtained by relaxing the Muller condition