Alternation Elimination by Complementation* (Extended Abstract)**

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Abstract. In this paper, we revisit constructions from the literature that translate alternating automata into language-equivalent nondeterministic automata. Such constructions are of practical interest in finite-state model checking, since formulas of widely used linear-time temporal logics with future and past operators can directly be translated into alternating automata. We present a construction scheme that can be instantiated for different automata classes to translate alternating automata into language-equivalent nondeterministic automata. The scheme emphasizes the core ingredient of previously proposed alternation-elimination constructions, namely, a reduction to the problem of complementing nondeterministic automata. Furthermore, we clarify and improve previously proposed constructions for different classes of alternating automata by recasting them as instances of our construction scheme. Finally, we present new complementation constructions for 2-way nondeterministic automata from which we then obtain novel alternation-elimination constructions.

1 Introduction

Alternating automata are a powerful tool in finite-state model checking. Here, they serve as a glue between declarative specification languages like LTL [26] and PSL [1] and simple graph-like structures such as nondeterministic Büchi automata, which are well suited for algorithmic treatment, see e.g., [31]. By establishing translations from alternating automata to nondeterministic Büchi automata, one reduces the model checking problem for finite-state systems to a reachability problem on simple graph-like structures, see e.g., [13]. Similarly, such translations can be used to solve the satisfiability problem for declarative specification languages like LTL and PSL.

Translations of declarative specification languages into alternating automata are usually rather direct and easy to establish due to the rich combinatorial structure of alternating automata. Translating an alternating automaton into a nondeterministic Büchi automaton is a purely combinatorial problem. Hence, using alternating automata as an intermediate step is a mathematically elegant way to formalize such translations and to establish their correctness. Another

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** Due to space limitations, some proofs have been omitted. These can be found in an extended version of the paper, which is available from the authors’ webpages.
more practical advantage of such translations is that several automata-based
techniques are applicable to optimize the outcome of such translations, e.g.,
simulation-based reduction techniques [9, 10].

Different classes of alternating automata are used for these kinds of trans-
lations depending on the expressive power of the specification language. For
instance, for LTL, a restricted class of alternating automata suffices, namely
the so-called very-weak alternating Büchi automaton [21, 27]. These restrictions
have been exploited to obtain efficient translators from LTL to nondeterministic
Büchi automata, see [11]. For more expressive languages like the linear-time μ-
calculus μLTL [2, 28], one uses alternating parity automata, and for fragments
of the standardized property specification language PSL [1], one uses alternating
Büchi automata [5]. If the temporal specification language has future and past
operators, one uses 2-way alternating automata instead of 1-way alternating
automata, see, e.g., [12, 15, 30]. Due to the immediate practical relevance in
finite-state model checking, different constructions have been developed and
implemented for translating a given alternating automaton into a language-
equivalent nondeterministic automaton like the ones mentioned above.

In this paper, we present a general construction scheme for translating al-
ternating automata into language-equivalent nondeterministic automata. In a
nutshell, the general construction scheme shows that the problem of translating
an alternating automaton into a language-equivalent nondeterministic automa-
ton reduces to the problem of complementing a nondeterministic automaton. We
also show that the nondeterministic automaton that needs to be complemented
inherits structural and semantic properties of the given alternating automaton.
We exploit these inherited properties to optimize the complementation construc-
tions for special classes of alternating automata.

Furthermore, we instantiate the construction scheme to different classes of al-
ternating automata. Some of the constructions that we obtain share similar tech-
nical details with previously proposed constructions as, e.g., the ones described
in [11, 17, 22]. Some of them even produce the same nondeterministic Büchi
automata modulo minor technical details. However, recasting these known con-
structions in such a way that they become instances of the construction scheme
increases their accessibility. In particular, correctness proofs become modular
and less involved. Another benefit of utilizing the construction scheme is that
differences and similarities between the translations for the different classes of
alternating automata become apparent.

We also present novel alternation-elimination constructions. These construc-
tions are instances of our construction scheme and utilize a new complementation
construction for so-called loop-free 2-way nondeterministic co-Büchi automata.
In particular, we obtain an alternation-elimination construction that translates
a loop-free 2-way alternating Büchi automaton with \( n \) states into a language-
equivalent nondeterministic Büchi automaton with at most \( O(2^{4n}) \) states. This
construction has potential applications for translating formulas from fragments
of PSL extended with temporal past operators into nondeterministic Büchi au-
tomata. To the best of our knowledge, the best known construction for this class