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Regular Methods for Operator Precedence Languages

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Abstract: The operator precedence languages (OPLs) represent the largest known subclass of the context-free languages which enjoys all desirable closure and decidability properties. This includes the decidability of language inclusion, which is the ultimate verification problem. Operator precedence grammars, automata, and logics have been investigated and used, for example, to verify programs with arithmetic expressions and exceptions (both of which are deterministic pushdown but lie outside the scope of the visibly pushdown languages). In this paper, we complete the picture and give, for the first time, an algebraic characterization of the class of OPLs in the form of a syntactic congruence that has finitely many equivalence classes exactly for the operator precedence languages. This is a generalization of the celebrated Myhill-Nerode theorem for the regular languages to OPLs. As one of the consequences, we show that universality and language inclusion for nondeterministic operator precedence automata can be solved by an antichain algorithm. Antichain algorithms avoid determinization and complementation through an explicit subset construction, by leveraging a quasi-order on words, which allows the pruning of the search space for counterexample words without sacrificing completeness. Antichain algorithms can be implemented symbolically, and these implementations are today the best-performing algorithms in practice for the inclusion of finite automata. We give a generic construction of the quasi-order needed for antichain algorithms from a finite syntactic congruence. This yields the first antichain algorithm for OPLs, an algorithm that solves the ExpTime-hard language inclusion problem for OPLs in exponential time.

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