Fine-Grained Complexity of Program Analysis

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Abstract

There is a well-known "cubic bottleneck" in program analysis and language theory: many program analysis problems can be solved in time cubic in the size of the input but, despite years of effort, there are no known sub-cubic algorithms. For example, context-free reachability (whether there is a path in a labeled graph that is labeled with a word from a context-free language), the emptiness problem for pushdown automata, and the recognition problem for two-way nondeterministic pushdown automata all belong to the cubic class. We survey the status of these problems through the lens of fine-grained complexity.

We study the related *certification* task: given an instance of any of these problems, are there small and efficiently checkable certificates for the existence and for the non-existence of a path? We show that, in both scenarios, there exist succinct certificates ($O(n^2)$ in the size of the problem) and these certificates can be checked in subcubic (matrix multiplication) time. Thus, all these problems lie in nondeterministic and co-nondeterministic *subcubic* time.

We also study a hierarchy of program analysis problems above the cubic bottleneck. A representative problem here is the recognition problem for two-way nondeterministic pushdown automata with k heads. We show fine-grained hardness results for this hierarchy.

We also discuss purely language-theoretic consequences of these results: for example, we obtain hardest languages accepted by two-way nondeterministic multihead pushdown automata, as well as separations between language classes.

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