

Optimizing Away Security in C

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Abstract

TODO: After we have finished the paper

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1 Introduction

The C programming language is one of the most widely used programming languages in the world. It is used in a wide variety of applications, ranging from embedded systems to cryptographic libraries. However, C is also notorious for lacking security guarantees. Security-related issues in programs written in C stem from both the programmer, but also from the compiler.

The problem with security issues introduced by the compiler is especially prevalent in the context of timing attacks on cryptographic algorithms. Developers try to mitigate timing attacks by writing constant-time code – code where the execution time is independent of the input. However, the compiler may introduce timing leaks by optimizing away the constant-time code. In a recent study by Jancar et. al. [4], it was shown that the vast majority of developers of cryptographic libraries rely on constant-time code practices that in theory result in constant-time code, but may be vulnerable after compilation.

The issues related to timing vulnerabilities introduced by compilers are well-known in the community. Timing vulnerabilities have previously been linked to certain compiler optimizations [3]. They have also been compared across compiler versions [6]. However, to the best of our knowledge, no study has quantified the issue of timing attacks introduced by the compilers.

In this paper, we try to quantify the issue of timing attacks introduced by the two most popular C compilers, gcc¹ and clang². We do this by implementing a tool, OptiFuzz, that generates, analyzes and fuzzes random C programs. For simplicity, the generated programs are limited to only containing non-branching arithmetic, logical and comparison operations. Also / and % are avoided, to mitigate division-by-zero errors. We investigate what optimization flags are responsible for introducing timing leaks and compare them. Finally, we discuss how the issue of timing attacks introduced by the compiler can be mitigated by using language-based security techniques.

1.1 Related Work

The issue of timing attacks introduced by the clang C compiler across different versions has been researched by Simon et. al. [6]. Several studies have investigated potential solutions to the issue, including using constant-time branching instructions [6], using black-box testing software [5], a domain specific language [2], and notably a verified constant-time C compiler has been developed [1].

1.2 Contributions

We provide a quantitative analysis of timing vulnerabilities introduced by gcc and clang, focusing on specific troublesome optimization flags. Additionally, we provide a tool, OptiFuzz, that can be used to generate, analyze and fuzz random C programs for further investigation of the issue. Finally, we provide a discussion of how the issue of timing attacks introduced by the compiler can be mitigated by using language-based security techniques found in other literature. **TODO: Might be more when we finish the paper**

1.3 Overview

This paper is organized as follows: ... **TODO: After we have finished the rest of the paper TODO: Insert guide on how to read appendix here??**

¹<https://gcc.gnu.org/>.

²<https://clang.llvm.org/>.

2 Preliminaries

2.1 C Compiler Optimizations

2.2 Side-Channel Attacks

3 OptiFuzz

We created a tool, OptiFuzz, that can be used to generate, analyze and fuzz random C programs. The source code for OptiFuzz is available on GitHub³. The goal of OptiFuzz is to quantify the issue of timing attacks introduced by C compilers with different optimization flags enabled. The tool works as follows:

- OptiFuzz generates random C programs consisting of non-branching arithmetic, logical and comparison operations.
- OptiFuzz then compiles the generated C programs with different specified optimization flags enabled and inspects the generated assembly for conditional branching instructions introduced by the compiler. If branching is found, the program is flagged.
- OptiFuzz then fuzzes the flagged programs with various random inputs to test whether the branching instructions can be exploited to leak information about the input.
- At last, OptiFuzz reports the results of the fuzzing in the form of a PDF report.

The OptiFuzz pipeline is illustrated in Figure 1. Each of the steps in the pipeline is described in detail in the following sections.

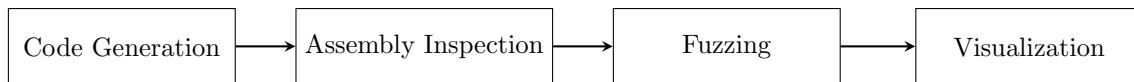


Figure 1: The OptiFuzz pipeline.

3.1 Code Generation

3.1.1 Limitations

3.2 Assembly Inspection

3.2.1 Limitations

3.3 Fuzzing

3.3.1 Limitations

3.4 Visualization

4 Experimental Results

5 Conclusion and Future Work

³<https://github.com/anbclausen/optifuzz>.

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Appendix