**Week 4: C++ In Research (Part B)**

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# Examine current research being done with C++

“Coppelia is an end-to-end tool that given a processor design and collection of security critical requirements, can automatically generate exploit code (Zhang, Deutschbein, Huang, & Sturton, 2018).”

The authors acquired a list of 31 known vulnerabilities in two open source processors. Their goal was to reproduce these issues purely through automated discovery technics. The system detected 29 of the 31 issues and found four new issues. After finding an issue, Coppelia will generate a short exploit script to reproduce the issue. This was used to confirm no false positives were reported and provide a mechanism to validate future patches are accurate.

# How did C++ fit into the research?

The first challenge was to get the processor designs into a format which standard tools can consume and manipulate. The researches decided to accomplish this by compiling the Verilog hardware design language (HDL) into C++. This reduced the time to start collecting results as rich open source tooling already exist for C++.

After they generated the C++ code it was then compiled another level into LLVM Intermediate Representation (IR). KLEE is a general-purpose test case generator, which looks at the branches within a function and determines the argument set to gain the maximum coverage (KLEE Team, 2019). These determinations are driven by IR byte code source files.

# What were the research questions?

With the build pipeline configured the researchers could then focus on the goal of efficiently finding processor code defects. They settled on an approach where they begin at the end state of a security constraint was violated. Then they would traverse backwards through the call graph and determine what paths can eventually lead to this. If a path could not be found within a configured number of steps, that branch would be pruned from the search space and the next tried.

For example, one of the vulnerabilities was caused by an incorrect branch taken when comparing a 16bit and 32bit value. If the most significant bit was set on the 32bit value it resulted in an integer overflow. Their system was able to determine example values and the specific assembly instructions required to trigger vulnerability.

# What did the authors find?

The researchers found that they were able to find the defects however it was trivial for the search algorithm have exponential path combinations. They described how a naïve search strategy found over a million possible such paths during the first 24 hours.

To reduce the search space, they performed 10,000 iterations of breath first search (BFS) followed by 500,000 iterations of depth first search (DFS). This resulted in a very wide net that could spider in parallel. A master process recorded the progress of each search agent and would prevent them from searching sub paths that had already been explored. Using the hybrid BFS+DFS model reduced the time required to find defects from hours to minutes.

# What is some future work which could be built upon this research?

## Safer Hardware

Security vulnerabilities that are printed into hardware applications are inherently expensive. A recent example can be seen in the Intel Meltdown vulnerability which enables a user mode process to read arbitrary physical memory (Horn, et al., 2018). The issue impacts all Intel processors since 2010, which is nearly a decade of vulnerable hardware that is unlikely to be fixed.

Having systems such as Coppelia involved in the design process early on can mitigate some of these scenarios. This creates an economic incentive to expand the approach across more processors.

## More Languages

The researchers compiled Verilog source code into C++ so that they could leverage extensive open source tooling. A similar approach might be possible for other niche languages which are not as rich. This would allow them to quickly gain these specializations and identify complex vulnerabilities.

These specializations would not need to be limited to vulnerability detection but could also include modern protections that are not possible in legacy systems. For instance, the legacy application can be compiled into IR and then a mutator instrument all file I/O operations with calls to a hardware encryption device (Gossen, Beubauer, & Steffen, 2017). This approach might server as a cheap upgrade path for legacy software to become regulatory compliant.

## More Targets

The journal focused specifically on finding code defects in hardware implementations, but a similar approach might be possible for system kernels. Within a kernel is a collection of system calls and security constraints. It might be possible to augment the search and symbolic execution components to fit this similar model.

# What are some similar/contrasting works and their findings?

## Blackbox Approach

One of the challenges with the proposed approach is that it starts at the security violation and walks backwards. What happens if we do not know some or all these places? Clearly issues will be missed.

An alternative method is to start with black box fuzzing as a mechanism to select the components to focus further attention (Avgerinos, et al., 2014). Avgerinos provides an example where every binary in the /usr/bin was invoked and given a valid 16kb file path. Within 15 minutes the simple test found 59 distinct crashes.

These crashes were used to identify which developers misunderstood low-level memory management or the implementation of various API sets. In some ways this is analogous to the BFS+DFS model used by Zang, et al. as the Avgerino started all applications included in his Linux distro and quickly subset it to the areas that needed additional testing.

# References

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