Selective Symbolic Execution

Analysis of user space binaries using the S^2E platform

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Abstract

Bla blablablal

```
void autoShiftGear(unsigned &rpm,
                   unsigned &gear)
{
  if (rpm > 2500) {
    gear = gear + 1;
    rpm = rpm * 0.5;
  } else if (rpm < 1000) {
    gear = gear - 1;
    rpm = rpm * 2;
  }
}
```

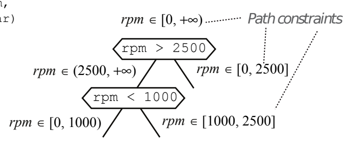

Figure 1: Execution tree with path constraints for the symbolic variable *rpm* [7]

1 Introduction

2 Selective Symbolic Execution

Symbolic execution is an advanced analysis technique particularly suited for automated software testing and malware analysis . Instead of concrete input (7, "string", ...) symbolic execution uses symbolic values (λ, β, ...) when processing code. Assignments in the program path have impacts on these symbolic values. The integer calculation $x = x - 2$, for instance, would update the symbolic expression representing the input x to $\lambda - 2$. Conditional statements (if <condition> then ... else ...) fork program execution into two new paths. Both paths are then constrained by an additional condition, the 'then' branch with the if-condition and the 'else' branch with the negated if-condition respectively.

Following this procedure results in a tree-like structure of constrained symbolic expressions. A constraint solver can now take all constraints along one execution path as input and find one concrete input (e.g., $\lambda = 5$) which would lead to the program following exactly this path. Such results greatly alleviate writing reproducible test cases [8].

On a technical level, symbolic execution engines save state information (program memory, constraint information, ...) in a custom data structure. Each conditional statement involving symbolic values results in a *fork* of the program state. The two newly created branches are completely independent and can therefore be processed in parallel.

But the exponential growth of conditionals soon reveals scaling problems of this forking strategy. Despite heavy research on optimisations mitigating this *path explosion* problem only relatively small programs ($\cong$ thousands of lines of code) can be analysed symbolically [8].

Additionally, symbolic execution faces problems when the program under analysis *interacts with its environment*. If it calls a system library like *libc*, in theory the whole system stack including invoked libraries, operating system and drivers would have to be executed symbolically. Considering the path explosion problem mentioned before, the resulting complexity makes such a profound analysis hardly feasible.

One way to solve this problem is to build abstract models of the program's environment . However,

due to the complexity of real-world systems, building a model of the entire system is both tedious and unnecessary - the user usually wants to analyse one single program and not the whole system [8].

In order to overcome typical problems of conventional symbolic execution, Chipounov et al. from the Swiss Federal Institute of Technology in Lausanne (EPFL) developed the concept of **selective symbolic execution** (S^2E) [8]. Based on a virtual execution platform S^2E gives users the illusion of running the entire system symbolically. By limiting the scope of interest (i.e. which parts of the system should be executed symbolically), users can effectively restrain the path explosion problem. Program code within this defined scope is executed symbolically, whereas out-of-scope parts, which are irrelevant to the analysis, switch to concrete execution.

Definition of the scope of interest (what to execute symbolically) is highly flexible. Users may specify whole executables, code regions, or even single variables to be executed symbolically. Everything else will be treated concretely.

But since on a technical level symbolical and concrete execution are handled very differently - concrete code may run natively while symbolic instructions need to be emulated - switching back and forth these two modes is a major challenge. Hence one of the main contributions of the EPFL team around Chipounov is the transparent and consistent management of switching between symbolic and concrete execution modes.

kill [8] [9] [10] [7]
bla bla bla

3 The S^2E Platform

Based on the concepts described in the previous chapter, Chipounov and his team implemented the S^2E platform, an open source framework for writing custom system analysis tools. S^2E employs the theoretical concepts of selective symbolic execution by running the system under analysis in a virtual machine and treating code within the scope of interest as symbolic. These symbolic parts are translated into an intermediate representation ( ), while irrelevant instructions are directly passed to the host for native execution.

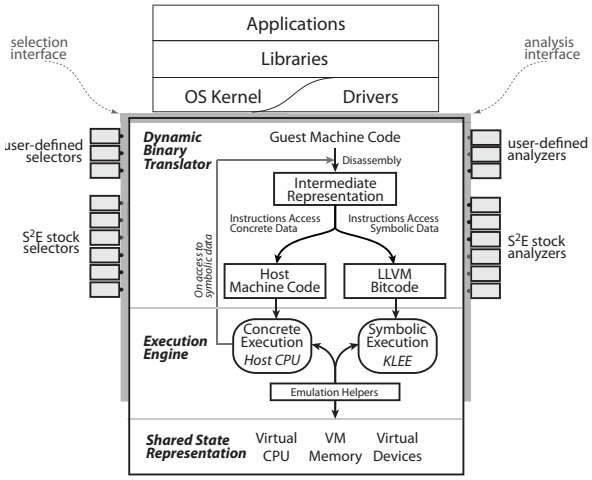

Figure 2: Architecture of the S^2E platform [10]

Technical backbone of S^2E are the virtual machine hypervisor QEMU [3, 5], the symbolic execution engine KLEE [1, 6] and the LLVM compiler infrastructure [2, 11]. Figure 2 gives an overview of how these technologies are integrated into the S^2E platform. The top of the picture depicts the software stack of the guest system (=the system under analysis), which is managed by QEMU. S^2E is not restricted to user land applications, but also allows inspection on deeper levels (e.g., operating system functions).

For easier emulation, QEMU translates machine code of the guest system into an intermediate representation, called *microoperations*. S^2E's dynamic binary translator (DBT) splits the resulting microoperations into those that need to be explored symbolically and those which may run concretely. All concrete microoperations are directly converted into host instructions. Symbolic expressions, on the other hand, are prepared for being executed on the KLEE engine. This requires microoperations to be translated into the LLVM intermediate representation, called LLVM Bitcode in figure 2.

S^2E's execution engine, which is an extension to QEMU's execution engine, now manages the operation of the platform. In an endless loop it asks the DBT for new guest code. Depending on the result, instructions can either be run straight on the host system or are fed into the KLEE symbolic execution engine.

In order to keep the mix of symbolic and concrete

execution consistent, S^{2}E stores state (VM CPU, memory, ...) centrally, by consolidating QEMU and KLEE data structures and managing them in a single machine state representation.

Users work with S^{2}E by writing selection and analysis plugins or by simply configuring S^{2}E's standard plugins according to their needs. Plugins subscribe to system-wide events (e.g., *onInstrExecution*) and can perform logging/monitoring tasks or even manipulate the system state.

Configuration usually starts with defining what parts of the system to explore symbolically. This can for example be done with S^{2}E's selection plugin *CodeSelector*, which restricts symbolic execution to a specified module or code region.

Standard analysis plugins allow users to find bugs (*WinBugCheck*), monitor memory (*MemoryChecker*), study performance characteristics (*PerformanceProfiler*) and much more (see [7], p. 50).

4 Project Idea

The practical part of this project strives to explore privacy issues in a sample binary.

In order to make life easier, many people use little freeware applications on a regular basis. But most of these programs are proprietary and have to be trusted without any knowledge of their functioning. Real malware (Trojan horses, spyware, ...) is usually detected rather quickly by anti-virus software and can often be blocked effectively. However, between unambiguous malware and thoroughly benign software many shades of grey can be found.

This work will focus on the scenario that an application (intentionally or unintentionally) leaks delicate private data without the user's consent or knowledge.

Due to the difficulty to find a real-world program which shows exactly this desired behaviour and also in general the complexity of real-world applications, the showcase described here bases on a little self-written program.

The software works as follows:

What we do not want is...

All analysis will be done using the S^{2}E platform.

5 Implementation

6 Analysis of S^{2}E Output

7 Outlook

Other cool things one could do...

Apply to real malware...

8 Related Work

Banabic et al. do bla... [4]

9 Conclusion

References

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[3] *QEMU*, http://qemu.org.

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