CS380S: Project Update

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One common misuse of cryptography is the misuse of entropy. Without proper random inputs, many cryptographic algorithms are vulnerable to basic forms of cryptanalysis. Some cryptographic schemes, such as DSA, can even disclose long-term secrets like the signing key when the random per-message input is low entropy, made public, or nonunique.

Given two versions P_1, P_2 of the same program P, we propose a relational verification for the entropy of the cryptographic values in the program. By introducing the concept of "differential taint analysis", we hope to produce a product program $P_1 \times P_2$ that is semantically equivalent to the sequential composition $P_1; P_2$, but such that we can prove useful safety properties of $P_1 \times P_2$ that would be difficult to prove with standard techniques on P_1, P_2, or $P_1; P_2$. The safety property we are the most interested in proving is that cryptographic values rely on sufficiently many bits of entropy when they are used.

1 Example

Consider the following two programs P_1 and P_2 that are equivalent from a cryptographic point of view, but might have small feature changes.

```
function P1
    s ← entropy
    ⋮
    if p then
        c ← AES(s)
    end if
    ⋮
end function

function P2
    s ← entropy
    ⋮
    if p then
        c ← AES(s)
    end if
    ⋮
end function
```

where p is some complex predicate that is difficult to reason about, but does not change between P_1 and P_2 (and no values that p depends on change, either). Then, a safety property about the entropy of the cryptographic values in c would hold in both programs or in neither program.

2 Existing Techniques, DTA Motivation

Static code analysis has a history of identifying security vulnerabilities at a source code level. Some examples include SQL injection, cross-site scripting exploits, and buffer overflow attacks. However, there has not been any attempt in the literature to statically analyze source code for cryptographic vulnerabilities stemming from entropy misuse, which we seek to do. We claim that standard static code analysis techniques developed thus far are insufficient for the analysis we would like to perform.

The sources of entropy can be tainted standard taint analysis techniques can be used to approximate how the taint propagates. But this approximation may be too coarse to provide useful information to the user. Even with a sufficiently precise taint analysis, it is unclear how to determine the "correct" set of sources a cryptographic value should rely on at any point in the program.

Verification modulo versions can be leveraged, the static analyzer is treated as opaque in an effort to cut down the number of alarms by inferring assumptions made by the original program (assumed to be correct). This is especially appealing in the security software development cycle because there are documented cases of entropy bugs being introduced in new versions of programs (for example, OpenSSL and FreeBSD). This would involve under-approximating the taint of one ver-

sion of the program and over-approximating the taint of another version of the program. Current tooling does not widely support under-approximating taint analysis.

Another existing technique is relational verification, in which relational properties between two programs are used to prove k-safety properties. In our case, we would want to show the equivalence of entropy assignment and the equivalence of the entropy propagation. Relational verification would proceed with the construction of a product program between versions of the program that captures the semantics of executing them sequentially, but that lends itself to standard verification techniques.

3 Our Approach

Given the two programs in the example, we propose generating a product program similar to the following:

function $P_1 \times P_2$
  $S_1 \leftarrow$ entropy
  $S_2 \leftarrow$ entropy
  $\vdots$
  if f() **then**
    $c_1 \leftarrow \text{AES}(s_1)$
    $c_2 \leftarrow \text{AES}(s_2)$
  end if
  $\vdots$
end function

Note that, during the construction of the product program, we need to be able to merge the if statements in the two programs.

We would like to demonstrate set equality between the taint for s_1, s_2 when they are used in the if statement, which amounts to demonstrating the equivalence of the taint propagation through the program. We would also like to demonstrate that we assign the output of a sufficiently entropic value to a variable in P_1 if and only if we also assign it that sufficiently entropic value in P_2.

Proving these two properties (set-equality and equivalence of assignments) allows us to claim that P_1 has the safety property if and only if P_2 has the safety property.

4 Real World Applications

A verification tool like this could be especially useful for a maintainer of a project that relies on cryptographic values. For example, if she audits her code once to confirm that it uses entropy properly, she can use differential taint analysis on future commits to confirm that the new code does not introduce this class of bugs.

How our analysis framework would be able to identify real world bugs. What are the benchmarks we compare against (OpenSSL, FreeBSD, etc.). What are the projects we will evaluate the tool on.

5 Research Hypotheses

These are the principal hypotheses we would like to test:

1. An automated tool can detect entropy bugs in real-world programs.
2. Entropy is insufficiently propagated in programs that rely on cryptography.
3. Multiple versions of the same program can make static analysis for this domain more effective

6 Links

1. Debian/OpenSSL Bug
   (a) `https://www.schneier.com/blog/archives/2008/05/random_number_b.html`
   (b) `https://research.swtch.com/openssl`
   (c) `https://freedom-to-tinker.com/2013/09/20/software-transparency-debian-openssl-bug/`
   (d) `https://www.cs.umd.edu/class/fall2017/cmsc818O/papers/private-keys-public.pdf`
2. Data flow
   (a) `https://en.wikipedia.org/wiki/Data-flow_analysis`
   (b) `https://www.seas.harvard.edu/courses/cs252/2011sp/slides/Lec02-Dataflow.pdf`
3. Static Program Analysis
   (a) `https://cs.au.dk/~amoeller/spa/spa.pdf`
   (b) `https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6859783`
4. Relational Verification:
   (a) `https://dl.acm.org/citation.cfm?id=2021319`
   (b) `https://ac.els-cdn.com/S235222081630044X/1-s2.0-S235222081630044X-main.pdf?_tid=076a0492-9cee-4995-9710-bcb3c64b98e0&acdnat=1539815890_178849b4f14af3751e9acb03b238db4d`

(c) https://www.microsoft.com/en-us/research/publication/differential-assertion-checking/

(d) https://www.microsoft.com/en-us/research/wp-content/uploads/2014/06/paper-1.pdf

(e) https://www.cs.utexas.edu/~isil/pldi16-chl.pdf

5. Projects to analyze

   (a) OpenPGP

   (b) BouncyCastle

   (c) OpenSSL

   (d) GnuPGP

   (e) F# SSL project with proof of correctness

   (f) NQSBTLS

   (g) Amazon's s2n (signal to noise)