Mitigating Bugs in the Linux eBPF Verifier using Rust- or PREVAIL-based Layered Verification

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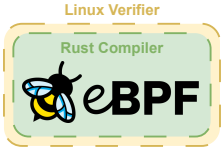
Motivation and Overview

- Kernel verifier is bug-prone
- Existing solutions introduce runtime overheads or are not exhaustive
- Layered-security approach
  - Verify program-safety twice
  - Bugs in one algorithm are *"caught by the other verifier?"*
- Case study with Rust Compiler and PREVAIL
  - Exploitable? *Yes, but sometimes tedious*



Layered Verification

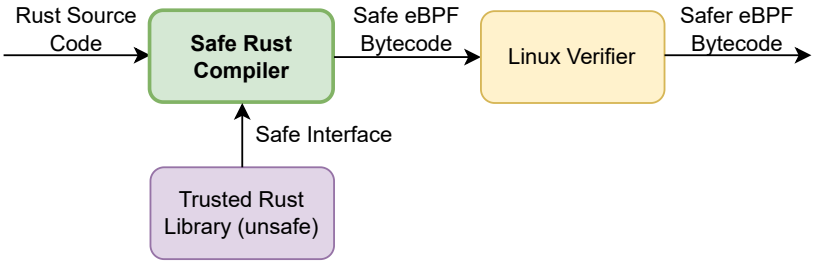
- Two verifiers
  - Implementations should be as different as possible
  - Must be unlikely to share the same bug
- Potential benefits
  - No runtime overheads
  - Reuse exiting tools

Case-Studies

- Safe Rust Compiler:
  - All unsafe features disabled
  - Generates BPF object files
- PREVAIL:

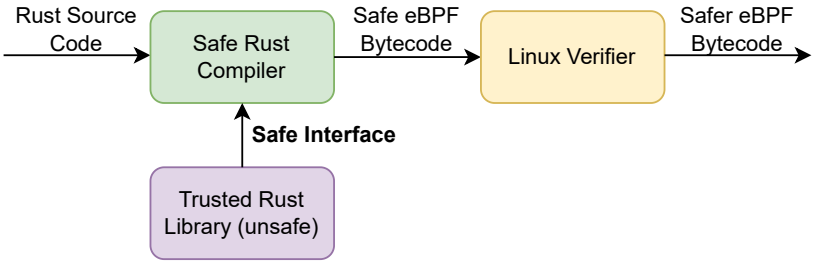
- *Changes Required? Bugs? Exploitable?*

Adaptions for a Safe Rust Compiler



- Disable unsafe and bug-prone features (e.g., `proc_macro`)
- Termination checks

Adaptions for a Safe Rust Library Interface



- Extend `aya-rs`
- Guarantee non-static destructors

Scope of Rust Compiler Bugs

- All compiler bugs: 3979 to 9906
- Arbitrary-code-execution bugs: 0 to 104
  - None *reported so far*
  - 104 compiler crashes reported (`SIGSEGV` etc.)
  - Potential for further hardening exists
- Relevant unsoundness bugs: 34 to 94
  - Exploitable if there are only unsoundness bugs?

Exploit for Rust-based Layered Verification

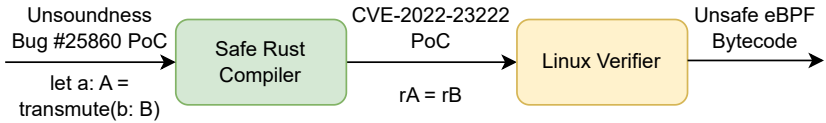
- Rust Unsoundness Bug #25860[1]
  - *“Implied bounds on nested references + variance = soundness hole”*
  - Open since 2015, to be fixed by work-in-progress design changes
- Linux Verifier CVE-2022-23222
  - Pointer-arithmetic tracked incorrectly

[1] `https://github.com/rust-lang/rust/issues/25860`

Rust Unsoundness Bug #25860: Unsafe Transmute Primitive

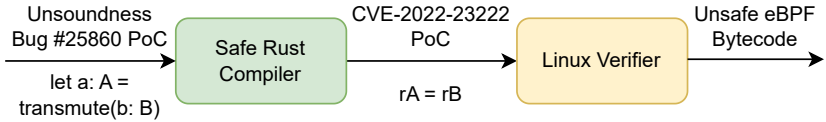
```
pub fn transmute<A, B>(obj: A)
  -> B {
  enum DummyEnum<A, B> {
    A(Result<
      A, Option<Blank<A, B>>>),
    ...
  }
  ...
  core::mem::replace(
    ref_to_b, Err(None)
  ).ok().unwrap()
}
```

Exploit for Rust-based Layered Verification: Approach



1. Use Rust unsoundness bug for type-unsafety
2. Create OOBs pointer
3. Find Rust program that generates unsafe bytecode missed by Linux Verifier

Exploit for Rust-based Layered Verification: Techniques



- Use `transmute()` to construct OOB pointer
  - Optimizations remove complexity
  - Compiles to register assignment `rA = rB`
- Prevent unwanted optimizations using data-dependencies
- Tedios: Get register-usage as needed
  - e.g., `ptr += scalar` vs. `scalar += ptr`

PREVAIL-based Layered Verification

- Does not reuse kernel code → Bugs likely different
- 37 issues open (1 potentially relevant bug)
- Assume there exists bytecode F( ) which is incorrectly abstracted
- Exploitable?

Exploit for PREVAIL-based Layered Verification: Idea

- Incorrectly abstracted functions
  - F1( ): Linux eBPF Verifier (e.g., CVE-2017-16995)
  - F2( ): PREVAIL (assumed)
- Approach for layered-verification exploit
  - Combine result of F1( ) and F2( )
  - “Hide” OOB read/write

Exploit for PREVAIL-based Layered Verification: Code

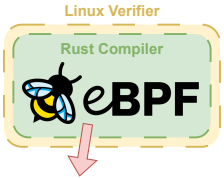
```
r1 = F1()      # actual: 1  Linux: 0  PREVAIL: 1
r2 = F2()      # actual: 1  Linux: 1  PREVAIL: 0
r3 = r1 & r2   # actual: 1  Linux: 0  PREVAIL: 0

r3 *= OOB_OFF
r4 = PTR_TO_MAP_ELEM()
r4 += r3       # actual: r4+OOB_OFF  Linux/PREVAIL: r4
*r4 = ...      # OOB write
```

Summary

- Layered verification has limited potential
  - Exploits can be combined
  - Roughly **doubles exploitation effort**
  - Bugs in the runtime (e.g., helpers) not covered
- Effort for exploit

  Rust Tedious (because of indirection)

  PREVAIL Easy
- `https://github.com/luisgerhorst/sust`



Appendix

The following slides were not presented during the talk.

Rust Compiler Bug References

- 34 unsoundness bugs relevant to eBPF:
  https://github.com/rust-lang/rust/issues?q=is%3Aissue%20state%3Aopen%20label%3AI-unsound%20AND%20(%20label%3AT-compiler%20OR%20label%3AT-lang%20)%20AND%20(-label%3AO-Arm%20-label%3AO-wasm%20-label%3AO-PowerPC%20-label%3AO-windows%20-label%3AO-AArch64%20-label%3AO-SPARC%20-label%3AO-x86_64%20-label%3AO-MIPS%20-label%3AO-windows-msvc%20-label%3AO-AVR%20-label%3AO-x86_32%20-label%3AA-inline-assembly%20-label%3AF-extern_types%20-label%3AF-type_alias_impl_trait%20-label%3Afixed-by-next-solver%20-label%3AF-thread_local%20-label%3AF-simd_ffi)%20&page=1

Rust Compiler Bug References

- 94 unsoundness bugs: https://github.com/rust-lang/rust/issues?q=is%3Aissue%20state%3Aopen%20label%3AI-unsound%20
- 104 compiler craches: https://github.com/rust-lang/rust/issues?q=is%3Aissue%20state%3Aopen%20label%3AT-compiler%20label%3AI-crash
- Rust unsoundness bug exploited: https://github.com/luisgerhorst/sust/blob/10a103f8dad718c54813bf715dad69da3399fba5/ebpf/cgroup-skb-egress-ringbuf/cgroup-skb-egress-ebpf/src/main.rs#L42

Safe Rust Compiler

- Other Rust compiler features that might be bug-prone or unsafe: feature(specialization), panics, unions, trait objects, projections, async/await, self-referential types