RustSan: Retrofitting AddressSanitizer for Efficient Sanitization of Rust

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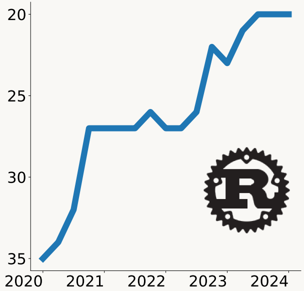
Rust: The Safe Programming Language

- Rust is safer alternative to C/C++ in system programming with its language-level safety guarantees
- Rust is seeing widespread adoption



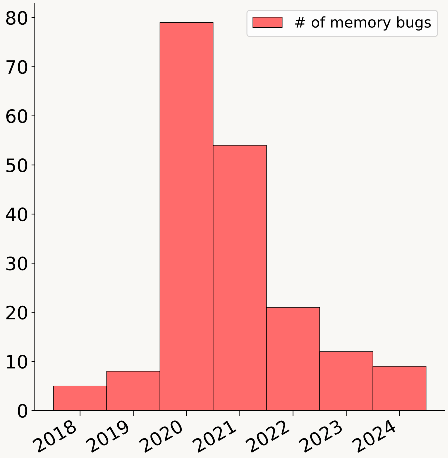
Github, Top 50 Programming Languages Globally

Rust: The (*Mostly*) Safe Programming Language

- Rust's safety guarantees are not free
  - Programmers are forced to participate in Rust concepts and semantics such as ownership.
- `unsafe` Rust allows programmers to temporarily trade safety for flexibility
  - Raw pointer access
  - Override ownership rules
  - Invoke unsafe foreign functions (e.g., C/C++)
  - Etc..

Rust: The (*Mostly*) Safe Programming Language

- Rust is certainly not infallible to memory bugs
- Study shows 99%(184/185) all reported memory bugs stem from `unsafe` use[1]



[1] Hui Xu et al. *"Memory-Safety Challenge Considered Solved? An In-Depth Study with All Rust CVEs."*, ACM Trans. SW. Eng. Methodol. (Sept. 2021).

Rust: The (*Mostly*) Safe Programming Language

- Rust has built-in option for compiling with **ASan** since 2017 [1]
  - E.g., `rustc -Zsanitizer=address ..`
- Many Rust developers have been using ASan for testing to have found numerous memory errors across many crates

[1] https://github.com/rust-lang/rust/pull/38699

Our Observation

Sanitizers for unsafe languages assume memory error anywhere in program, while most of Rust program code retains safety even with `unsafe`.

- But.. bugs reside in `unsafe` in fact can have cascading effect on safe code.
- Accurately identifying *true-safe* code and *false-safe* code is not trivial

Safety of Rust

```
fn unsafe_func<T>(...) -> &'static mut T {
...
    let refer: &'static mut T = unsafe { ptr + 0xdeadbeef as & _ };
    return refer;
}
...
    let from_unsafe = unsafe_func(..);
    let refer:&'a mut T = *from_unsafe ;
...
    refer.push(other_val);
```

: *False-Safe* : Unsafe

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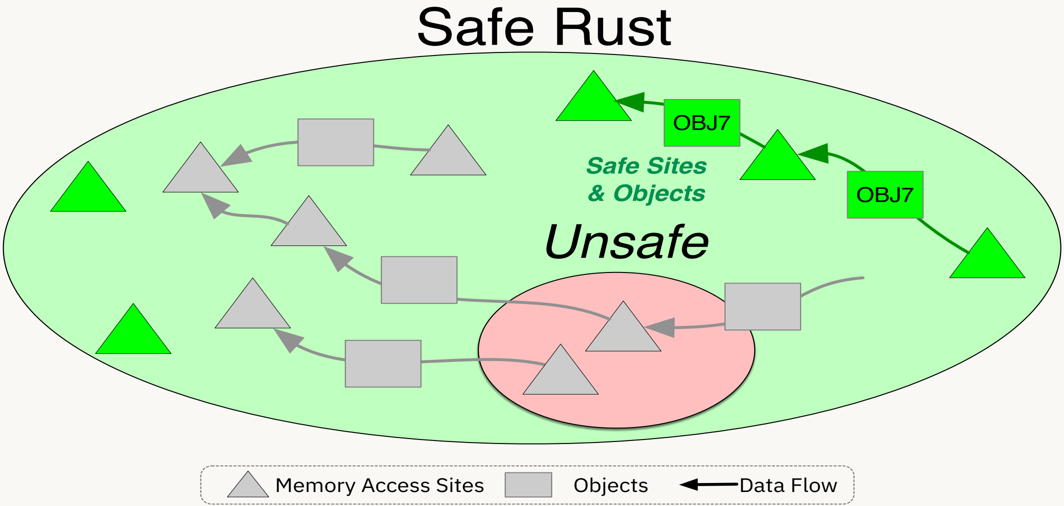
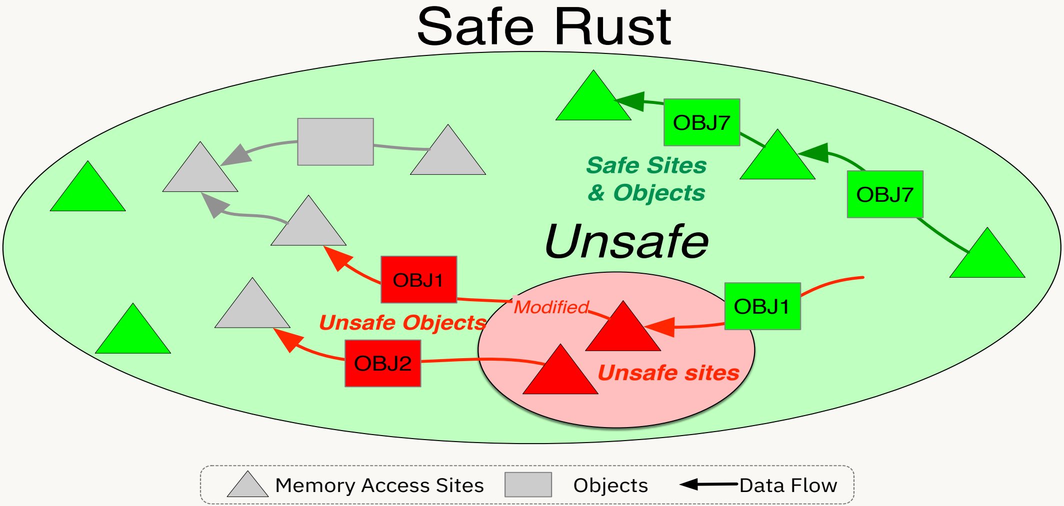
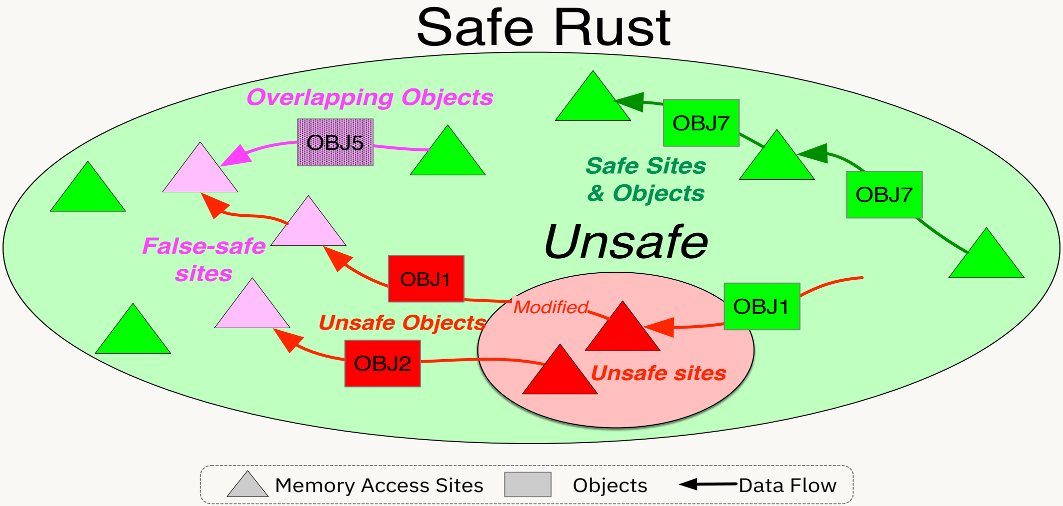
RUSTSAN Terminology



RustSan Terminology



RustSan Terminology

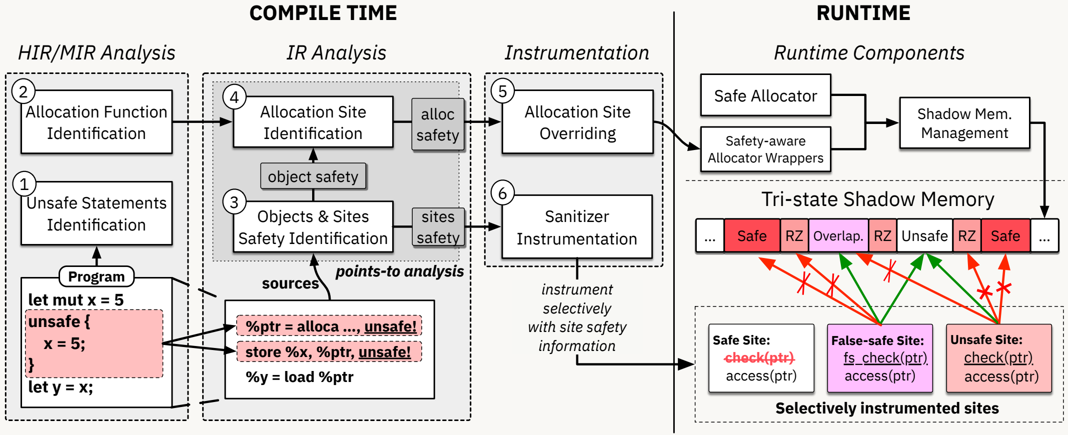


RustSan Research Statement

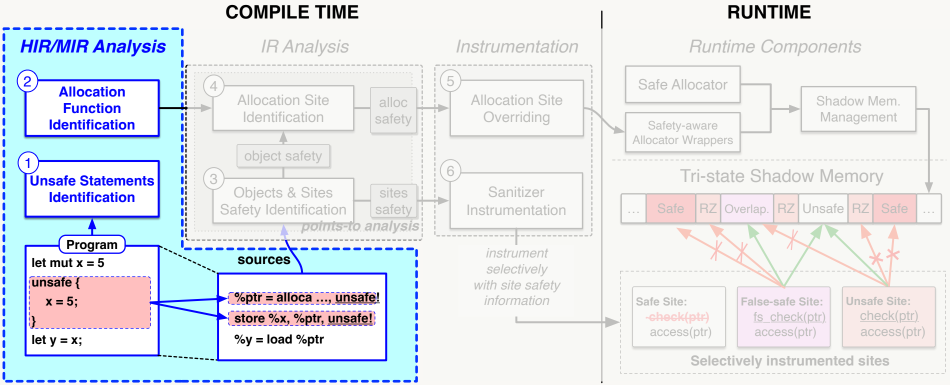
RustSan retrofits ASan to pinpoint unsafe and potentially unsafe memory access sites while lifting costly shadow memory checks on safe sites.

- Bridging Rust semantics and LLVM-based sanitizer with **Cross-IR analysis**
- Non-binary memory access validation model with **Tri-state shadow memory**

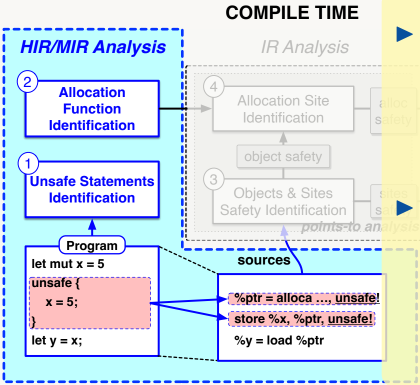
RustSan: Overall Design



RustSan: Rust HIR/MIR-level

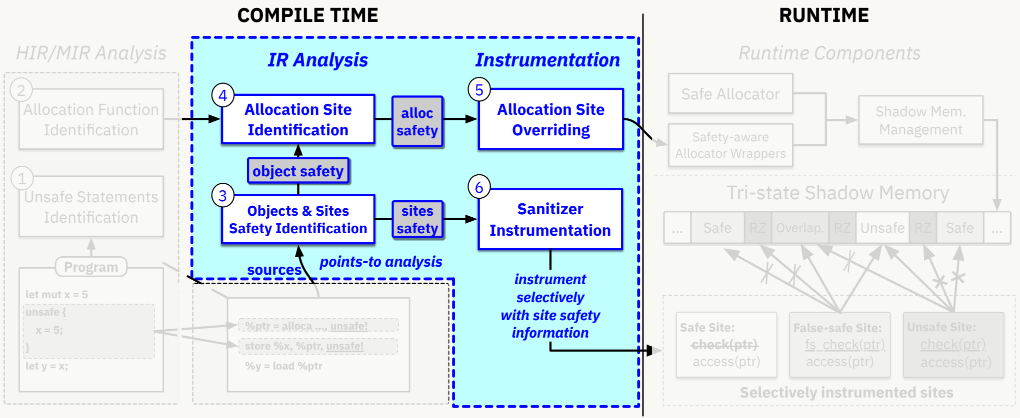


RustSan: Rust HIR/MIR-level

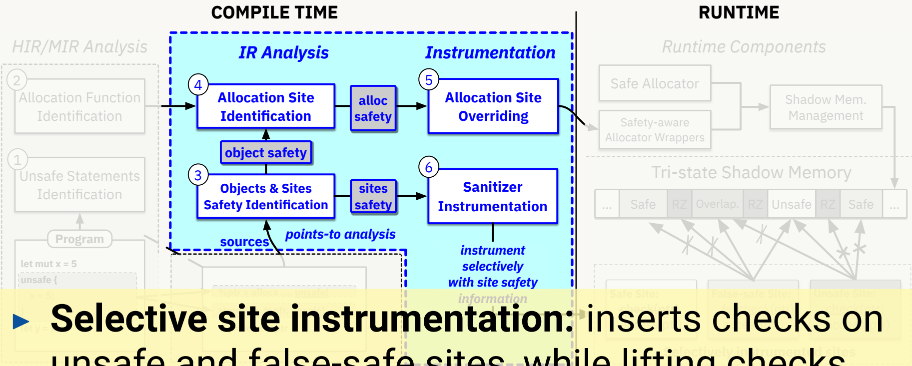


- **`unsafe` analysis** Rust HIR/MIR semantics such as `unsafe` are lost during translation to LLVM IR
- **Bridging two IR forms** Our analysis identifies variable modifications within `unsafe`, and propagates to LLVM IR stage

RustSan: LLVM IR-level



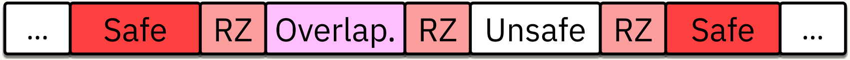
RustSan: LLVM IR-level



- **Selective site instrumentation:** inserts checks on unsafe and false-safe sites, while lifting checks checks on *safe* sites
- **Object safety coloring**: Intercept and instrument object allocations and color objects according to object safety

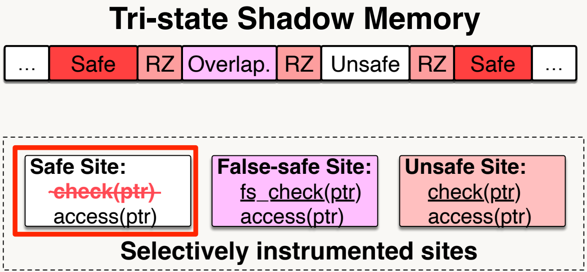
Safety-aware Object Allocation

Tri-state Shadow Memory



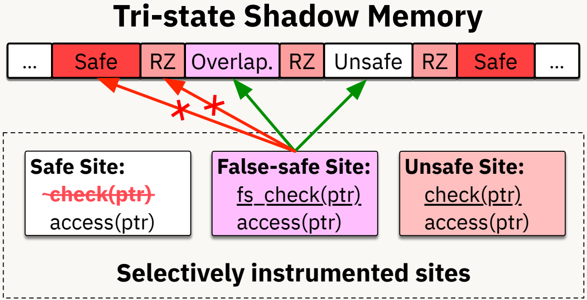
- Heap objects are allocated with different colors according to object safety identified during analysis

Tri-state Shadow Memory Enforcement



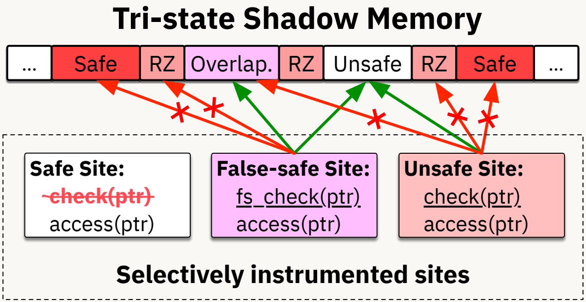
- Checks are *eliminated* on safe sites

Tri-state Shadow Memory Enforcement



- Checks are *eliminated* on safe sites
- False-safe can access unsafe/overlapping object

Tri-state Shadow Memory Enforcement



- Checks are *eliminated* on safe sites
- False-safe can access unsafe/overlapping object
- Unsafe can only access unsafe object

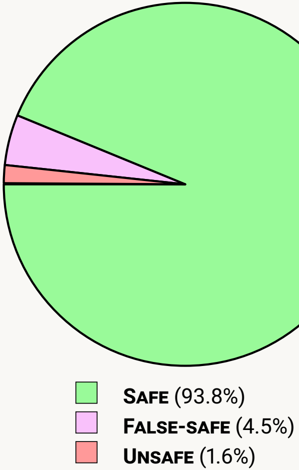
Evaluation

- Detection Capability Evaluation
  - Collect 31 CVEs that ASan can detect and reproduce with RustSan
- Performance Evaluation
  - 20 real-world applications from `Crate.io`

Evaluation: Site Safety Statistics

- Average site safety distribution In 33 applications:

RUSTSAN eliminates 93.8% of ASan checks!

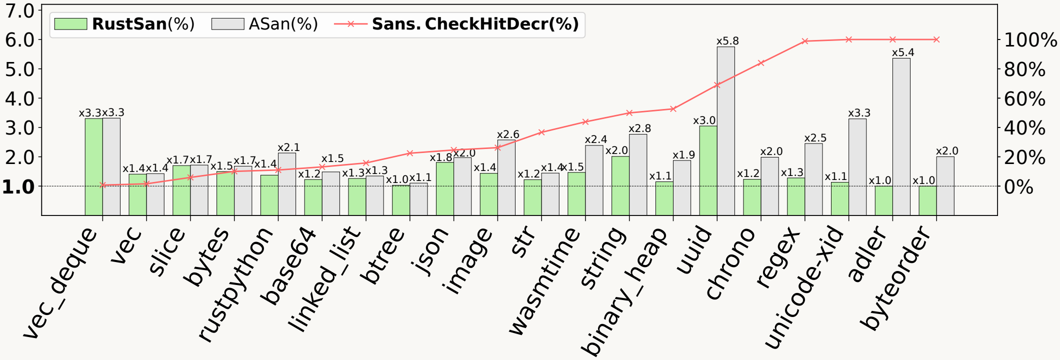


Evaluation: Detection Capability

CVE	Vuln. Class	Detected	*FS/U*	CVE	Vuln. Class	Detected	*FS/U*
CVE-2020-36465	UAF	✓	FS	CVE-2021-45694	Heap Ovf.	✓	FS
CVE-2018-20991	UAF	✓	FS	CVE-2021-26954	UAF	✓	FS
CVE-2019-15551	UAF	✓	FS	CVE-2021-28028	UAF	✓	FS
CVE-2019-25009	UAF	✓	FS	CVE-2021-29933	UAF	✓	FS
CVE-2020-25574	UAF	✓	FS	CVE-2020-35891	UAF	✓	FS
CVE-2020-35858	Stack Ovf.	✓	FS	CVE-2017-1000430	Heap Ovf.	✓	U
CVE-2020-25792	Stack Ovf.	✓	FS	CVE-2020-35861	Heap Ovf.	✓	U
CVE-2020-25791	Stack Ovf.	✓	FS	CVE-2021-25900	Heap Ovf.	✓	U
CVE-2020-25795	UAF	✓	FS	CVE-2020-35906	UAF	✓	U
CVE-2021-45713	UAF	✓	FS	CVE-2021-45720	UAF	✓	U
CVE-2019-16882	UAF	✓	FS	CVE-2020-36464	UAF	✓	U
CVE-2018-21000	Heap Ovf.	✓	FS	CVE-2020-36434	UAF	✓	U
CVE-2019-16140	UAF	✓	FS	CVE-2020-35860	UAF	✓	U
CVE-2021-30455	UAF	✓	FS	CVE-2020-35892	Heap Ovf.	✓	U
CVE-2021-30457	UAF	✓	FS	CVE-2020-35893	Heap Ovf.	✓	U
CVE-2021-28031	UAF	✓	FS				

- RustSan reproduced all detected cases with ASan in memory errors in the `Advisory-DB`
- 67% of bugs(21/31) were detected in a false-site site

Evaluation: Performance



- 62% performance advantage over ASan on average
- 43% less shadow memory check encounter during runtime

More details

- **Implementation details**
  - HIR/MIR analysis improvements over previous works
  - SVF framework extensions for Rust
  - Shadow memory encoding
- **Experiment data omitted in this talk**
  - Ratio of sites and objects of varying safety classification for 33 crates.
  - Real-world performance gains in fuzz testing scenario
- **Thorough analysis of threats to validity**

👉 For more details, please check out our paper!

Thank you

Q&A time!!