# AUTOMATICALLY DETECTING LIFETIME ANNOTATION BUGS IN THE RUST LANGUAGE


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## WHY RUST?

**Efficient performance** while providing **strong memory safety, thread safety**, and **type checking**.

## SOME FEATURES OF RUST

### Ownership

Move: Transfer Ownership

a is no longer valid; accessing it gives error

```
Heap:xxxx  1. let a = String::from("Hello");
Heap:xxxx  2. let b = a;
Heap:xxxx  3. println!("{ }",a);
```

### Borrowing

b is borrowing w/o transferring ownership

a is valid; accessing it does not give error

```
Heap:xxxx  1. let a = String::from("Hello");
Heap:xxxx  2. let b = &mut a;
Heap:xxxx  3. println!("{ }",a);
```

## BORROW CHECKING AND LIFETIMES

RUST uses ***lifetimes***, a construct that assists the compiler in verifying the validity of each borrow. Both borrow variables and the borrowed values have lifetimes, as illustrated below

```
fn foo() {
  let a : String::from("Hello");
  {
    let b = &mut a;
    println!("b: { }", b);
  }
}
```

b's lifetime

a's lifetime

*The lifetime of a borrow variable cannot be longer than the lifetime of the borrowed value.*

The following code will not compile because the borrow checker will flag an error.

```
let b : &i32;
{   let a : i32 = 5;
    b = &a; // Error
} println!("{}", b);
```

b's lifetime

a's lifetime

## RAW POINTERS AND UNSAFE CODE

RUST's borrow checker can be too restrictive sometimes because its analysis is inherently conservative. So RUST provides "raw pointers" (`*const`, `*mut`) that don't have borrow checking.

**Dereferencing** raw pointers requires an `unsafe` block

```
let b : i32 = 5;
let a : const* i32 = &b;
unsafe{println!("{}", *a);}
```

## LIFETIME ANNOTATIONS

Consider a function that takes two borrows as inputs and returns one borrow.

```
fn foo(x: &i32, y: &i32) -> &i32 {/*..*/}
```

The two input borrows could have different lifetimes, in which case an appropriate lifetime must be assigned to the output borrow. It could be annotated as follows, indicating that the returned borrow refers to `x`.

```
fn foo<'a,'b>(x: &'a i32, y: &'b i32)
                -> &'a i32 {/*..*/}
```

Here 'a and 'b are lifetime annotation parameters. At compile-time, the compiler assigns **concrete scopes** to each lifetime parameter. Appropriate lifetime annotations can guide the borrow checker to ensure memory safety. Consider the following example :

```
struct Foo {
  inner: *mut String
}
impl Foo {
  fn get<'a>(&'a mut self) -> &'a String {
    unsafe{&*self.inner}
  }
}
```

```
1  let s1 = String::from("Abc");
2  let x = &s1;
3  {
4      let mut s2 = String::from("Hello");
5      let mut foo = Foo{inner: &mut s2};
6      x = foo.get();
7  }
8  println!("{:?}", x);
```

Concrete lifetime of 'a

&mut foo

foo

x

The implicit borrow to `foo` on line 6 needs to last till line 8, but the `foo` object is valid only until line 6. So this will raise a compilation error, which is good.

## BUG PATTERNS

Incorrect lifetime annotations on functions that handle raw pointers can cause memory safety violations. We consider the specific case of **structures containing raw pointers**.

Consider a function that manipulates a raw pointer inside a structure. Then there are three broad categories of manipulations that involve a borrowed value. The function could :

1. Take a borrow as input and **update** the raw pointer to point to the borrowed value.
2. **Read** from the raw pointer and return a borrow to the value that it's pointing to.
3. Take a borrow as input and **create a new structure object** with the raw pointer pointing to the borrowed value.

We define three patterns of bugs based on these three operations. A full discussion of the three patterns is beyond the scope of this poster, but we discuss the first pattern here.

```
struct Foo<'a> {
    inner: [*const|*mut] T,
    ...
}

impl<'a> Foo<'a> {
    fn foo<..>(&'b [mut] self,
               ..., inp: &'c T,
        ...) [-> ...] { ... }
}
```

Lifetime condition :

`'a != 'c`

Dataflow condition :

`inp` → `self.inner`

The function `foo` takes an input borrow `inp` with lifetime `'c`, but the lifetime of the structure object is `'a`. Further, there is a **dataflow** from `inp` to `self.inner`. This means that the structure could potentially outlive the borrowed value.

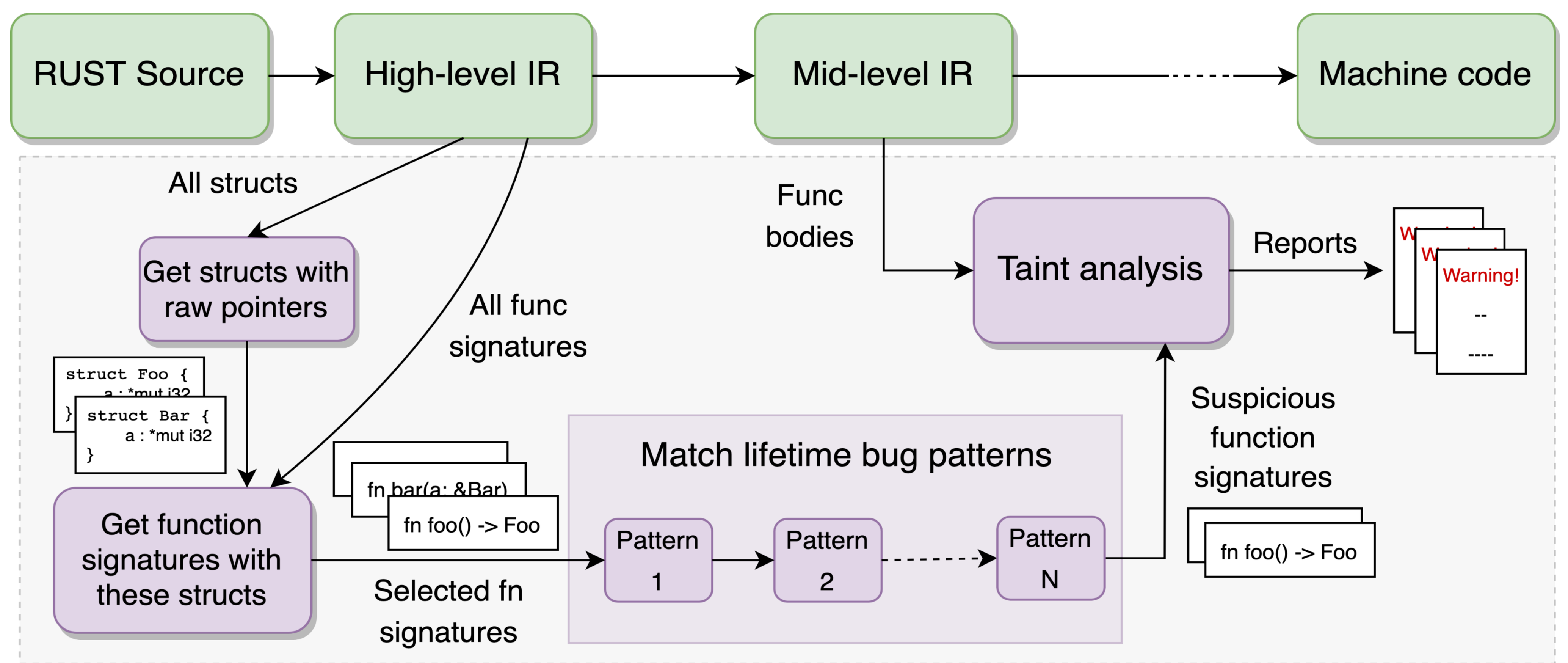
```
let i = "Hello".to_string();
let mut obj = Foo{inner: &i};
{
  let j = "ABC".to_string();
  obj.foo(&j);
}
// obj now contains an invalid pointer
```

## OUR SYSTEM

When RUST code is compiled, it goes through a High-level Intermediate Representation (HIR) and a Mid-level Intermediate Representation (MIR). We implement a **hybrid analysis** that combines information from the **HIR** and the **MIR**, as shown in the diagram alongside.

We implement our system as a subroutine within the **Rudra** [1] project.

Our code will soon be made publicly available.





[1] Bae, Yechan, et al. "RUDRA: finding memory safety bugs in Rust at the ecosystem scale." *Proceedings of the ACM SIGOPS 28th Symposium on Operating Systems Principles*. 2021.



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