Electrolysis

Verifying Rust Programs via Functional Purification

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Why Rust? (What is Rust?)

Rust is a new systems programming language sponsored by Mozilla Research

- multi-paradigm with an ML-like syntax
- pursues "the trifecta: safety, concurrency, and speed"
  - speed through zero-cost abstractions and manual memory management
  - memory safety through tracking reference lifetimes in the type system
  - safe concurrency through forbidding shared mutable references

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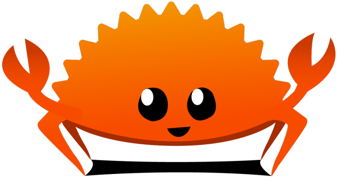

Why Rust: Because It's Almost Pure Already

- turn destructive updates into functional ones

```
p.x += 1;                  let p = Point { x = p.x + 1, ..p };
```

- references: save value instead of pointer, write back at end of lifetime

```
let x = f(&mut p);    let (x, p) = f(p);
```

Simple Verification via Purification

1. make Rust program purely functional
2. transpile it into expression language of a theorem prover (Lean)
3. prove correctness of the Lean definition

Simple Verification via Purification

1. make Rust program purely functional
2. transpile it into expression language of a theorem prover (Lean)
   - run `rustc` up to CFG generation
   - sort definitions topologically by dependencies
   - extract loops from CFG and put them into loop combinator
   - resolve static/dynamic trait calls

   Things Rust fortunately does not have:

   - exceptions
   - subtyping
3. prove correctness of the Lean definition

Verifying std::[T]::binary_search: Input

```
fn binary_search_by<F>(&self, mut f: F) -> Result<usize, usize> where
    F: FnMut(&T) -> Ordering
{
    let mut base = 0usize;
    let mut s = self;

    loop {
        let (head, tail) = s.split_at(s.len() >> 1);
        if tail.is_empty() {
            return Err(base)
        }
        match f(&tail[0]) {
            Less => {
                base += head.len() + 1;
                s = &tail[1..];
            }
            Greater => s = head,
            Equal => return Ok(base + head.len()),
        }
    }
}

fn binary_search(&self, x: &T) -> Result<usize, usize> where T: Ord {
    self.binary_search_by(|p| p.cmp(x))
}
```

- high-level implementation working with subslices instead of explicit indicing
- transitively uses
  - 5 traits
  - 6 structs and enums
  - 7 functions

Verifying std::[T]::binary_search: Output

```
section
  parameters {T : Type} {F : Type}
  parameters [ops_FnMut__T__F : ops.FnMut (T) F (cmp.Ordering)]
  parameters (self : (slice T)) (f : F)

  definition slice._T_.slice_SliceExt.binary_search_by.loop_4 state__ :=
  match state__ with (f, base, s) :=
  ...

  definition slice._T_.slice_SliceExt.binary_search_by :=
  let self ← self;
  let f ← f;
  let base ← (0 : nat);
  let t1 ← self;
  let s ← t1;
  loop' (slice._T_.slice_SliceExt.binary_search_by.loop_4) (f, base, s)
end

...

structure cmp.Ord [class] (Self : Type) extends cmp.Eq Self, cmp.PartialOrd Self Self :=
(cmp : Self → Self → option ((cmp.Ordering)))

definition slice._T_.slice_SliceExt.binary_search {T : Type} [cmp_Ord_T : cmp.Ord T] (self : (slice T)) (x : T) :=
...
```

Verifying std::[T]::binary_search: Proof

```
parameter {T : Type}
parameter [Ord' T]
parameter self : slice T
parameter needle : T

hypothesis Hsorted : sorted le self

inductive binary_search_res : Result usize usize → Prop :=
| found     : Πi, nth self i = some needle → binary_search_res (Result.Ok i)
| not_found : Πi, needle ∉ self → sorted le (insert_at self i needle) →
  binary_search_res (Result.Err i)

section loop_4
  variable s : slice T
  variable base : usize

  structure loop_4_invar :=
  (s_in_self  : s ⊑ₚ dropn base self)
  (insert_pos : sorted.insert_pos self needle ∈ '[base, base + length s])
  (needle_mem : needle ∈ self → needle ∈ s)

  inductive loop_4_step : loop_4.state → Prop :=
  mk : Πbase' s', loop_4_invar s' base' → length s' < length s → loop_4_step (f, base', s')

  ...
end

...

theorem binary_search.sem : option.any binary_search_res (binary_search self needle) :=
begin
  rewrite [↑binary_search, bind_some_eq_id, funext (λx, bind_some_eq_id)],
  apply binary_search_by.sem,
end
```

Conclusion and Future Work

- a tool for verifying real-world Rust code
- correctness proof of a central stdlib algorithm

- next step: find a new algorithm to verify!
- possible enhancement: different monad stacks for e.g. complexity analysis, global side effects, ...
- maybe allow some restricted forms of unsafe code

`github.com/Kha/electrolysis`