Leveraging Rust Types for Program Synthesis

Jonáš Fiala, Shachar Itzhaky, Peter Müller, Nadia Polikarpova, Ilya Sergey

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ETH zürich

TECHNION Israel Institute of Technology

UC San Diego

NUS National University of Singapore

Program Synthesis for Rust with Guarantees

Rust type

+

functional spec

RusSOL

code

- well-typed
- correct

This Talk

1. A taste of RusSOL
2. Synthetic Ownership Logic (SOL)
3. Evaluation

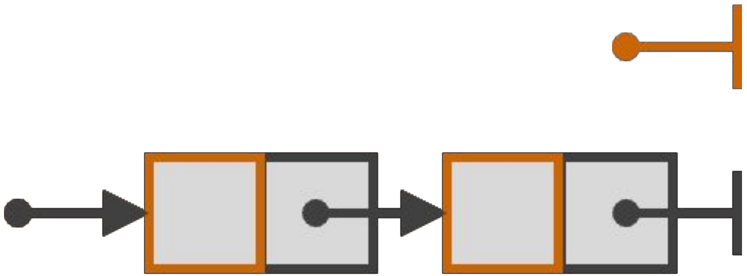
Demo

sum type

```
enum List<T> {
    Nil,
    Cons { elem: T, next: Box<List<T>> },
}
```

generic payload

pointer with ownership

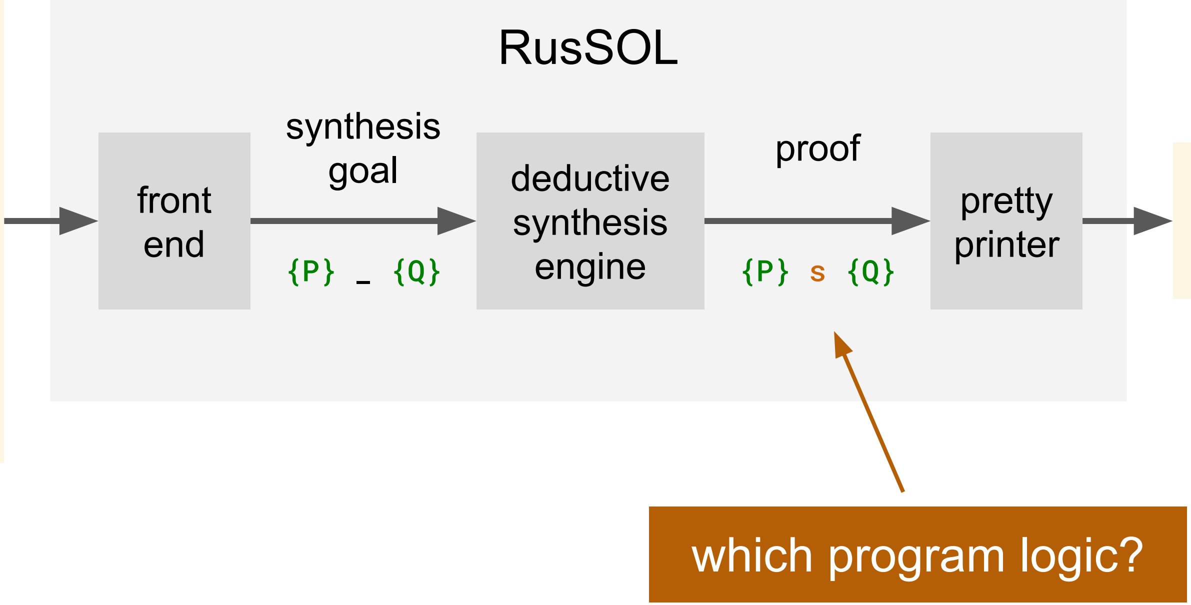


RusSOL Workflow

```
struct UserType
{ … }

#[requires(…)]
#[ensures(…)]
fn target(x: T1,…)
  -> T

#[pure]
fn f(x: T1,…) -> T
{ … }
```




```
fn target(x: T1,…)
  -> T
{ s' }
```

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Key Properties

ownership & borrowing

Aeneas [Ho & Protzenko’22]

Synthetic Ownership Logic (SOL)

program synthesis

SuSLik [Polikarpova & Sergey’19]

```
#[requires(…)]
#[ensures(…)]
fn target(x: T_1,…)
  -> T

#[pure]
fn f(x: T_1,…) -> T
{ … }
```

functional properties of safe Rust

Prusti [Astrauskas et al’19]

Creusot [Denis et al’21]

Example: Constr Rule

$$\frac{\textsc{Constr.Cons}}{\left\{\begin{array}{c} \mathsf{e}: \mathsf{T} * \\ \mathsf{n}: \mathsf{Box} \end{array}\right\} \ \textbf{let}\ \mathsf{x} = \mathsf{List::Cons}\ \{\ \mathsf{e}, \mathsf{n}\ \}\ \{\mathsf{x}: \mathsf{List}\}}$$

Example: Singleton

```
fn singleton<T>(elem: T) -> List<T> {
  // {elem: T}



  todo!();



  // {result: List}
  result
}
```

CONSTR.CONS

$$\frac{}{\left\{\begin{array}{l} \mathtt{e}\colon \mathtt{T} * \\ \mathtt{n}\colon \mathtt{Box} \end{array}\right\} \ \textbf{let}\ x = \mathtt{List::Cons}\ \{\ e, n\ \}\ \{\mathtt{x}\colon \mathtt{List}\}}$$

Example: Singleton

```
fn singleton<T>(elem: T) -> List<T> {
  // {elem: T}



  todo!();



  // {elem: T * next: Box}
  let result = List::Cons{elem, next}; // Constr.Cons
  // {result: List}
  result
}
```

CONSTR.CONS

$$\frac{}{\left\{\begin{array}{l} e\colon T \ast \\ n\colon Box \end{array}\right\} \ \textbf{let}\ x = List::Cons\,\{\, e, n \,\}\ \{x\colon List\}}$$

Example: Singleton

```
fn singleton<T>(elem: T) -> List<T> {
  // {elem: T}



  todo!();



  // {elem: T * next: Box}
  let result = List::Cons{elem, next}; // Constr.Cons
  // {result: List}
  result
}
```

CONSTR.BOX

$$\frac{}{\{l : \texttt{List}\}\ \textbf{let}\ x = \texttt{Box::new}(l)\ \{x : \texttt{Box}\}}$$

Example: Singleton

```
fn singleton<T>(elem: T) -> List<T> {
  // {elem: T}

  todo!();

  // {elem: T * list: List}
  let next = Box::new(list);            // Constr.Box
  // {elem: T * next: Box}
  let result = List::Cons{elem, next}; // Constr.Cons
  // {result: List}
  result
}
```

Constr.Box

$$\frac{}{\{\texttt{l}: \texttt{List}\}\ \textbf{let}\ \texttt{x} = \texttt{Box::new(l)}\ \{\texttt{x}: \texttt{Box}\}}$$

Example: Singleton

```
fn singleton<T>(elem: T) -> List<T> {
  // {elem: T}

  todo!();

  // {elem: T * list: List}
  let next = Box::new(list);              // Constr.Box
  // {elem: T * next: Box}
  let result = List::Cons{elem, next}; // Constr.Cons
  // {result: List}
  result
}
```

Constr.Nil

$$\frac{}{\{\mathrm{emp}\}\ \textbf{let}\ x = \texttt{List::Nil}\ \{x : \texttt{List}\}}$$

Example: Singleton

```
fn singleton<T>(elem: T) -> List<T> {
  // {elem: T}
  todo!();
  // {elem: T}
  let list = List::Nil;                 // Constr.Nil
  // {elem: T * list: List}
  let next = Box::new(list);            // Constr.Box
  // {elem: T * next: Box}
  let result = List::Cons{elem, next}; // Constr.Cons
  // {result: List}
  result
}
```

CONSTR.NIL

$$\frac{}{\{emp\}\ \textbf{let}\ x = \texttt{List::Nil}\ \{x : \texttt{List}\}}$$

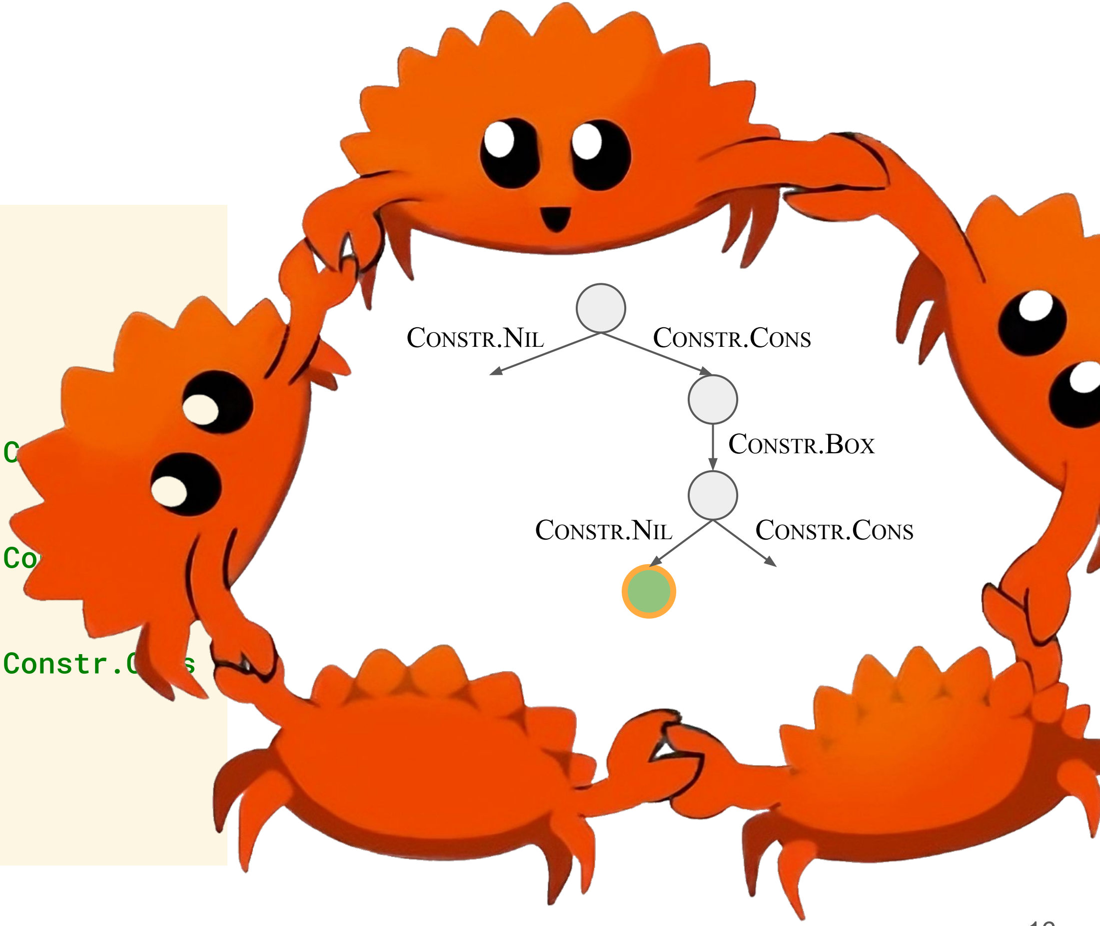
Example: Singleton

```
fn singleton<T>(elem: T) -> List<T> {
  // {elem: T}
  todo!();
  // {elem: T}
  let list = List::Nil;                     // Constr.Nil
  // {elem: T * list: List}
  let next = Box::new(list);                // Constr.Box
  // {elem: T * next: Box}
  let result = List::Cons{elem, next}; // Constr.Cons
  // {result: List}
  result
}
```

Example: Singleton

```
fn singleton<T>(elem: T) -> List<T> {
  // {elem: T}

  // {elem: T}
  let list = List::Nil;                 // C
  // {elem: T * list: List}
  let next = Box::new(list);            // Co
  // {elem: T * next: Box}
  let result = List::Cons{elem, next}; // Constr.C
  // {result: List}
  result
}
```



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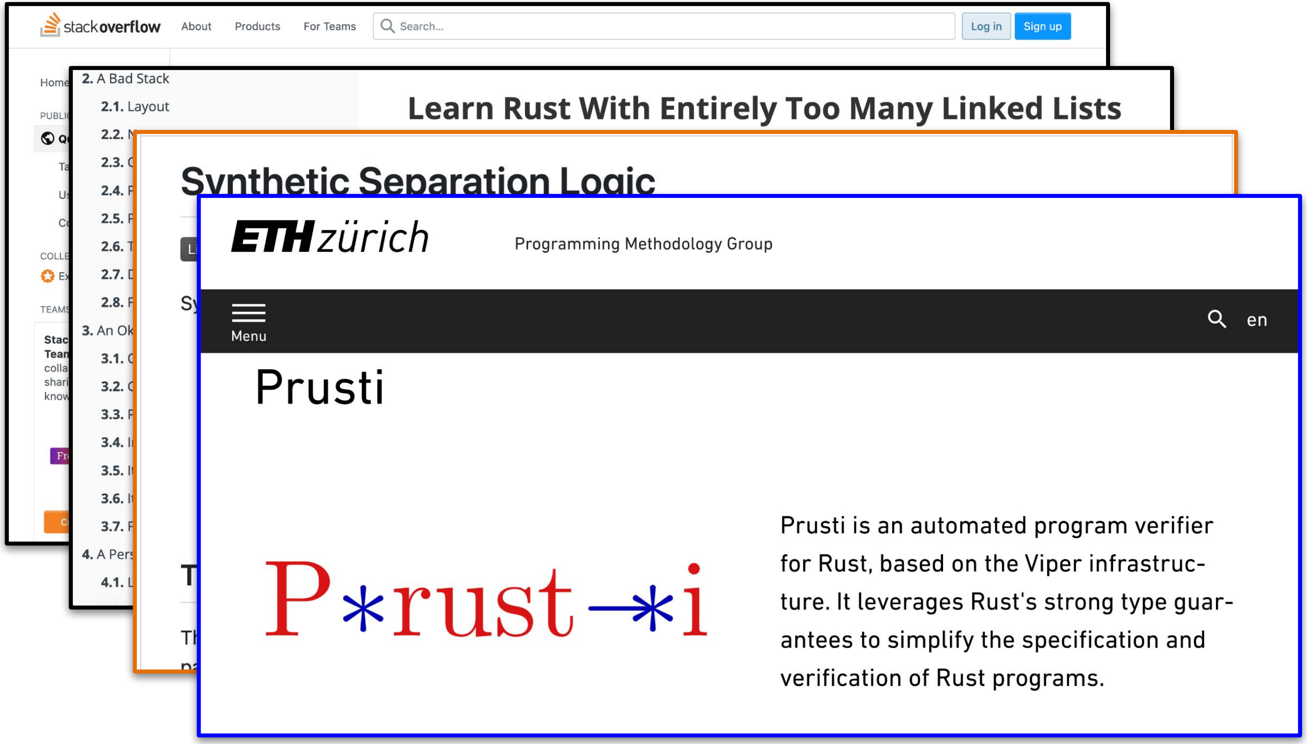
Annotated

3 sources

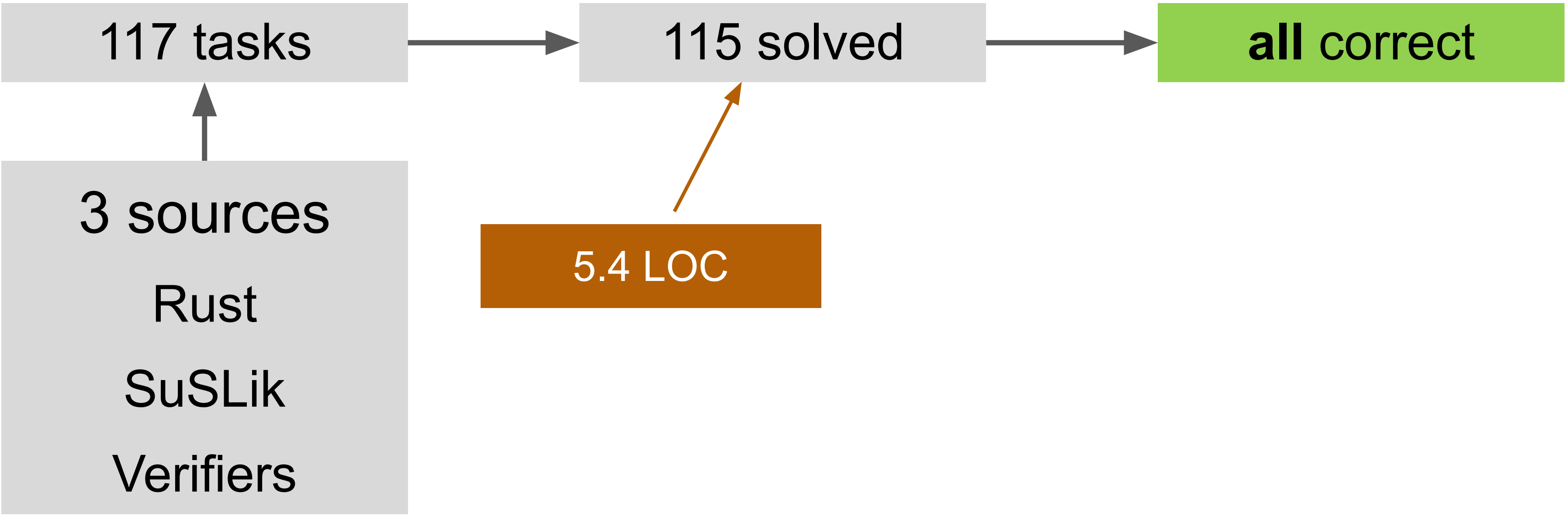
Rust

SuSLik

Verifiers



Annotated

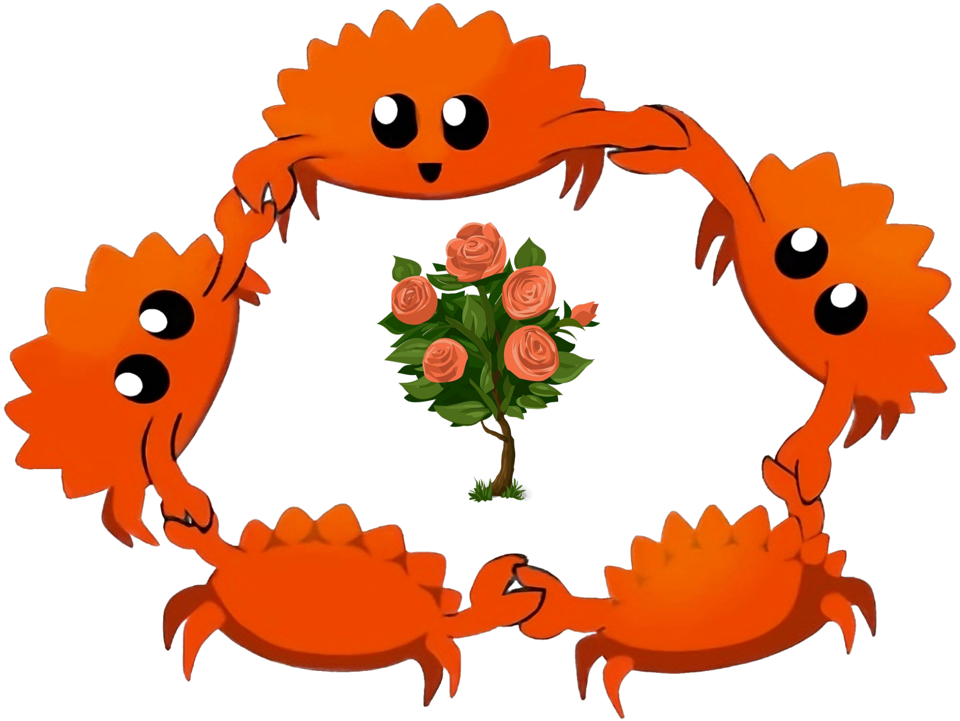

117 tasks
115 solved
all correct
3 sources
Rust
SuSLik
Verifiers
5.4 LOC

Annotated

```
enum Tree<T> { Nil, Cons { elem: T, next: List<Tree<T>> } }
enum List<T> { Nil, Cons(Box<(T, List<T>)>) }

#[ensures(result.len() == tree.size())]
fn flatten<T>(tree: Tree<T>) -> List<T> {
  match tree {
    Tree::Nil => List::Nil,
    Tree::Cons { elem, next } => flatten_3(elem, next),
  }
}
fn flatten_3<T>(elem: T, next: List<Tree<T>>) -> List<T> {
  match next {
    List::Nil => {
      let bx = (elem, List::Nil);
      let _0 = Box::new(bx);
      List::Cons(_0)
    }
    List::Cons(_0) => {
      let result = flatten(_0.0);
      flatten_14(elem, _0.1, result)
    }
  }
}
fn flatten_14<T>(elem: T, _1: List<Tree<T>>, result: List<T>) -> List<T> {
  match result {
    List::Nil => flatten_3(elem, _1),
    List::Cons(_0) => {
      let result = flatten_14(_0.0, _1, _0.1);
      let bx = (elem, result);
      let _0 = Box::new(bx);
      List::Cons(_0)
    }
  }
}
```

2 aux fns	24 LOC	10s



Unannotated

no spec

100 most downloaded packages (crates)

→

~3K LOC

all solutions well-typed

filter unsupported fns

```rust
// either/src/lib.rs:832
fn factor_first<T, L, R>
  (x: Either<(T, L), (T, R)>)
    -> (T, Either<L, R>) {
  match x {
    Either::Left(_0) => {
      let _1 = Either::Left(_0.1);
      (_0.0, _1)
    }
    Either::Right(_0) => {
      let _1 = Either::Right(_0.1);
      (_0.0, _1)
    }
  }
}
```

Conclusion

Online demo
t.ly/2-8A
Tools -> RusSOL

RusSOL

- first deductive synthesis tool for Rust
- leverages Rust types to reduce spec overhead

Synthetic Ownership Logic (SOL)

- verifies well-typed programs which satisfy spec
- leverages Rust types to prune search space
- friendly to synthesis

```rust
fn push<T>(x: &mut List<T>, elem: T) {
  let list: List<T>      =
                    std::mem::replace(x, List::Nil);
  let next: Box<List<T>> = Box::new(list);
  let extended: List<T>  = List::Cons{elem, next};
  *x = extended
}
```

&mut V → V
impossible in safe Rust

```rust
#[ensures(result == *idol)]
fn std::mem::replace<V>(idol: &mut V, bag: V) -> V {
  unsafe
}
```